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WP2: Developing a system-dynamic understanding of mechanisms, lock-ins and levers in the broader food system

D2.2: System Dynamic Model to ENFASYS sustainable EU farming system

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List of abbreviations

CAP – Common Agricultural Policy

CLD – Casual Loop Diagram

CSCs - Case Study Coordinators

CS – Case Study

EC – European Commission

EU – European Union

GA – Grant Agreement

SDM – System Dynamics Model

SFD – Stock and Flow Diagram

WP – Work Package

LIA – Low-input Agriculture

LE – Livestock Extensification

SCDS – Sustainable Consumption and Direct Selling

1 Introduction

Deliverable 2.2 of the ENFASYS project is centred on the development of thematic Stock and Flow Diagrams (SFDs) to support the transition towards sustainable farming systems across Europe. This output seeks to construct diagrams that are not confined to an EU-level perspective but instead reflect specific transformation pathways that consider local perspectives. By integrating the diverse dynamics observed in CSs with EU-level policy frameworks, Deliverable 2.2 bridges local insights and systemic strategies, providing a robust foundation for sustainable agricultural transitions.

The primary goal of this output is to utilize the insights gained from the Causal Loop Diagrams (CLDs) developed in D2.1 to design thematic Stock and Flow Diagrams (SFD) that address key transformation pathways. These pathways - such as the conversion to low-input farming, the extensification of livestock systems, and the promotion of consumer branding and direct selling - represent critical areas where systemic interventions can drive meaningful change. By focusing on these pathways, the SFDs will identify leverage points and lock-ins, providing evidence-based support for EU-level policy development.

The goal of the creation of SFDs is to produce a System Dynamic Model, which will be the basis of ENFASYS D5.3, “User guide web-based tool to simulate the impact of interventions on the EU food system”. The goal of this deliverable is the creation of a practical Web Tool for analysing how thematic interventions can drive sustainable progress in agri-food systems. The objectives are structured around three main goals: (i) providing targeted insights into thematic policy impacts, (ii) identifying leverage points and systemic barriers, and (iii) supporting scenario-based decision-making tailored to specific pathways. The thematic SDMs will simulate changes within the EU agricultural system under different pathways, illustrating the potential impacts of different interventions on areas such as production practices, biodiversity, and market dynamics-. While the CSs provide the foundational dynamics and relationships for these models, the thematic focus ensures alignment with EU-level policies and initiatives. This dual approach enables both broad systemic analysis and case-specific insights, allowing for tailored strategies that address unique regional and thematic challenges. Identifying leverage points and systemic barriers (lock-ins) is central to the SDM’s value. The model will analyse feedback loops and variable interconnections to pinpoint areas where targeted interventions can produce significant, system-wide effects. For example, leverage points might include shifts toward reduced pesticide use or the improvement of animal welfare standards. Similarly, identifying lock-ins, such as market or regulatory barriers, will help design strategies to overcome these challenges, enabling effective implementation of sustainable practices across different EU contexts.

Coherently with the workflow envisioned for project activities, the output of this deliverable are models based on previously developed project deliverables (namely Home et al 2023, Ottaviani Aalmo et al 2024, and Roglic et al, 2025), which helped to ground the structure of the models in realistic and relevant notions, tailored to project’s case studies. The deliverables in question have undergone varying levels of stakeholder engagement for validation purposes, therefore a first validation stage was achieved through the use of already validated results. Further validation will be seeked for the implementation of project Task 5.4, which, building on the model outputs of this deliverable, will consist of a Web Tool for scenarios and policy analysis. Therefore, after the methodological basis posed in the current deliverable, several inputs will be included in the Web Tool, including models’ results as well results of experimental tasks 5.2 and 5.3 and the outcome of several rounds of validation with relevant stakeholders. More information concerning other project tasks and workflow can be found in the dedicated chapter of this document, number 3.

Another objective of this deliverable is scenario-based decision-making. Indeed, the thematic SDMs will enable users to explore potential outcomes of diverse strategies within each pathway. Policymakers and businesses can test interventions, assess their impacts on sustainability metrics, and refine their approaches based on anticipated results. This functionality ensures that decisions are informed by robust, data-driven projections, fostering adaptive strategies that are both effective and resilient.

Stakeholder engagement is pivotal to the success of Task 2.3. Coordinators of the CSs play a critical role in providing input on the local dynamics and ensuring that the thematic models accurately reflect the realities on the ground. Collaboration with EU-level experts, including representatives from European policy experts, further ensures that the models are aligned with current policy dialogues and scientific evidence. This iterative process of validation and calibration enhances the credibility and practical relevance of the models.

Lastly, these models will be foundational inputs for the web-based tool to be developed in Task 5.4, ensuring its capacity to simulate scenarios and inform decision-making for a wide range of stakeholders.
The problem statement for the D2.2 SFD is aligned with the overarching goal of the ENFASYS project, which is **encouraging the implementation of sustainable practices through EU specific transition pathways in the European food system.**

Given the complexity of this process, three distinct problem statements have been considered for the purpose of building three SFDs, each based on three thematic pathways identified by the European Institutions as key strategies for the transition to sustainable agricultural systems in Europe. These will be the basis for building three distinct SDMs, which will underpin D5.3, the Web Tool for scenario analysis.

The construction of thematic SDMs begins with an initial analysis of the problem statement for each case study. This analysis serves to determine how each case study fits into existing specific transformation pathways identified, such as low-input farming, or livestock extensification. Once the pathways have been defined, the salient components of the CLD for each case study are extracted and integrated, enabling the identification of archetypes and recurrent relationships. This process ensures that the models capture the most critical dynamics for each transformation pathway, while preserving the unique context of each case study. In this way the thematic SDMs will represent shared challenges and opportunities, while simultaneously safeguarding the localized insights that are essential for a robust systems analysis.

The present report should be taken as a preliminary step in the iterative development of a robust System Dynamics Model (SDM) rather than a final and stabilized version. As (Sterman, 2003) stated, SDMs require continuous refinement through testing, simulation, and validation to ensure that they capture complexity as accurately as possible. At this stage, the models outlined in this report represent an initial structured framework that will evolve over time, incorporating further empirical insights and adjustments. A key limitation of this work is that the models have not yet undergone full-scale simulation or testing under different policy and market conditions. Their refinement will depend on a combination of scientific literature, which provides the theoretical foundations for modelling systemic interactions, and European policy reports and databases, which ensure alignment with real-world agricultural and environmental dynamics. Additionally, behavioural experiments conducted in T5.2 and T5.3 will play a critical role in providing insights into farmer decision-making, policy responses, and the adaptation of different market actors to sustainability transitions. The results of these experiments will serve as an essential input for calibrating the models, allowing for a progressive adjustment of their assumptions and parameterization. Given these considerations, this report should be regarded as a starting point that establishes both a methodological foundation and a first structured version of the three Stock and Flow Diagrams (SFDs), which will later be expanded into fully operational SDMs. The refinement of these models will require iterative engagement with stakeholders at multiple levels to ensure their relevance and applicability. As outlined in T5.4, this process will include progressive validation at the European level, integrating the perspectives of project partners and policymakers. The final outcome will be a refined, empirically validated, and policy-relevant tool, capable of simulating different intervention scenarios and providing valuable insights for decision-making in the transition towards sustainable food system.

2 State of the art

System Dynamics modelling is particularly fruitful considering the complexity and increasing level of unpredictability of changes in the contemporary era; highlighting causal links and creating tools for future scenario prediction, in fact, allows to identify the sections of a system where interventions might prove most effective, allowing for a resilience analysis (Rocha et al., 2019).

Systems thinking, as a foundational approach, aims to understand the interrelations among system components rather than isolating individual elements (Sterman, 2000). Moreover, within the domain of systems thinking, various modelling paradigms have emerged to address specific phenomena and diverse stakeholder needs. Agent-based models, for instance, simulate individual behaviours and their collective outcomes, proving valuable for understanding policy implications at the societal level (Savin et al., 2023). System dynamics modelling, in contrast, is designed to capture non-linear interactions and explore the long-term dynamics of complex systems. Crielaard et al., (2022) (Dentoni et al., 2022) emphasize that systems thinking provides a robust framework for engaging with complex socio-ecological challenges, enabling stakeholders to collaboratively map systemic dynamics and design interventions tailored to diverse contexts.

As a matter of fact, system dynamics approaches are particularly advantageous in projects like ENFASYS, where they serve as comparative frameworks for integrating insights from multiple CSs. This kind of modelling allows for the translation of qualitative narratives into quantitative simulations, supporting scenario analysis and policy development (Rocha et al., 2019).. Another possible application is the transfer of qualitative knowledge into models that can be used as the bases for computational models (Crielaard et al., 2022). In particular, multilevel models have been highlighted in recent research as a needed tool for the purpose of identifying emergent trends and to provide effective information at the policy level (Vermeulen et al., 2020).

As stated previously, the field of system dynamics is designed to help us learn about the structure and dynamics of the complex systems in which we are embedded, design high-leverage policies for sustained improvement, and catalyse successful implementation and change (Sterman, 2020). More specifically, SDMs aim to portray the dynamics of complex systems through a representation that allows to analyse the impact of potential changes over time. SDMs can reveal how variables interact by expressing the causal links between them using difference equations. Specifically, system dynamics modelling is used to understand and simulate a complex system's non-linear behaviour in different scenarios (Crielaard et al., 2020).

The representation of a system through a dynamic model is subordinated to the first step of creating a Causal Loop Diagram (CLD), a graphical tool used to represent the causal relationships between the different variables included in a complex system. A CLD combines information gathered through various sources in a diagram, which narratively outlines the proposed dynamic interplay and feedback loops between all different factors that altogether shape the phenomenon of interest (Crielaard et al., 2022). In fact, factors and relationships form a series of close sequences of cause-and-effect relationships, referred to as ‘feedback loops’ (Crabolu et al., 2023). These feedback loops can be positive or negative, therefore reinforcing or balancing a certain set of causal relations; furthermore, they can constitute leverage points, places within a complex system “where a small shift in one thing can produce big changes in everything."(Meadows, 1999.).Variables are connected by arrows denoting causal influence. A link is positive if a change in the origin variable produces a change in the same direction on the response variable, whereas a negative link denotes a relationship characterized by the opposite direction (J. C. Rocha et al., 2019). While CLDs highlight effectively the interrelatedness of variables and therefore give an overview of the possible effects of variables among one another, it cannot show what the effect would be if a system part were changed and what the exact impact on the whole system would be. As stated previously, system thinking aims at identifying leverage points in complex systems, which is crucial in order to achieve systemic change (Meadows, 1999). For this reason, to develop effectively a Web Tool that is consultable and usable by policy makers, the thematic pathway CLDs will ultimately be transformed into SDMs for the purpose of ENFASYS project.

The conversion of a Causal Loop Diagram into a System Dynamic Model entails several intermediate passages. The first of these passages is the quantification of the relations between the variables, which results in the transformation of a CLD in a Stock and Flow Diagram. A SFD is a type of representation used to assess which variables part of a system can be considered stocks and which flows, by highlighting the magnitude of the causal relations between the different variables. More specifically, stocks are quantities at each point in time, while flows are the change in quantity from one point in time to the next (Spiller et al., n.d.).

Asking case study coordinators (CSCs) to provide this kind of data has been established as the most effective strategy, considering the necessity to validate the ability of said data to be representative of the case study in question; asking CSCs to provide the data through a data collection template will create the possibility of speeding up the data collection process. (Liu et al., 2011)

In the process of developing the System Dynamic Model, Rocha's and Ostrom's frameworks will be employed. Rocha's framework, based on Social-ecological systems (SESs), allows to diagnose problems, identify complex interactions, and solutions tailored to each SES, and can also be upscaled to specific contexts where the availability of data is scarce but decision-making needs to be facilitated using such tools (J. Rocha et al., 2020). Ostrom's framework, conversely, is used to analyze the sustainability of SESs, and has been therefore increasingly used to characterize systems in recent years (Del Mar Delgado-Serrano & Ramos, 2015).

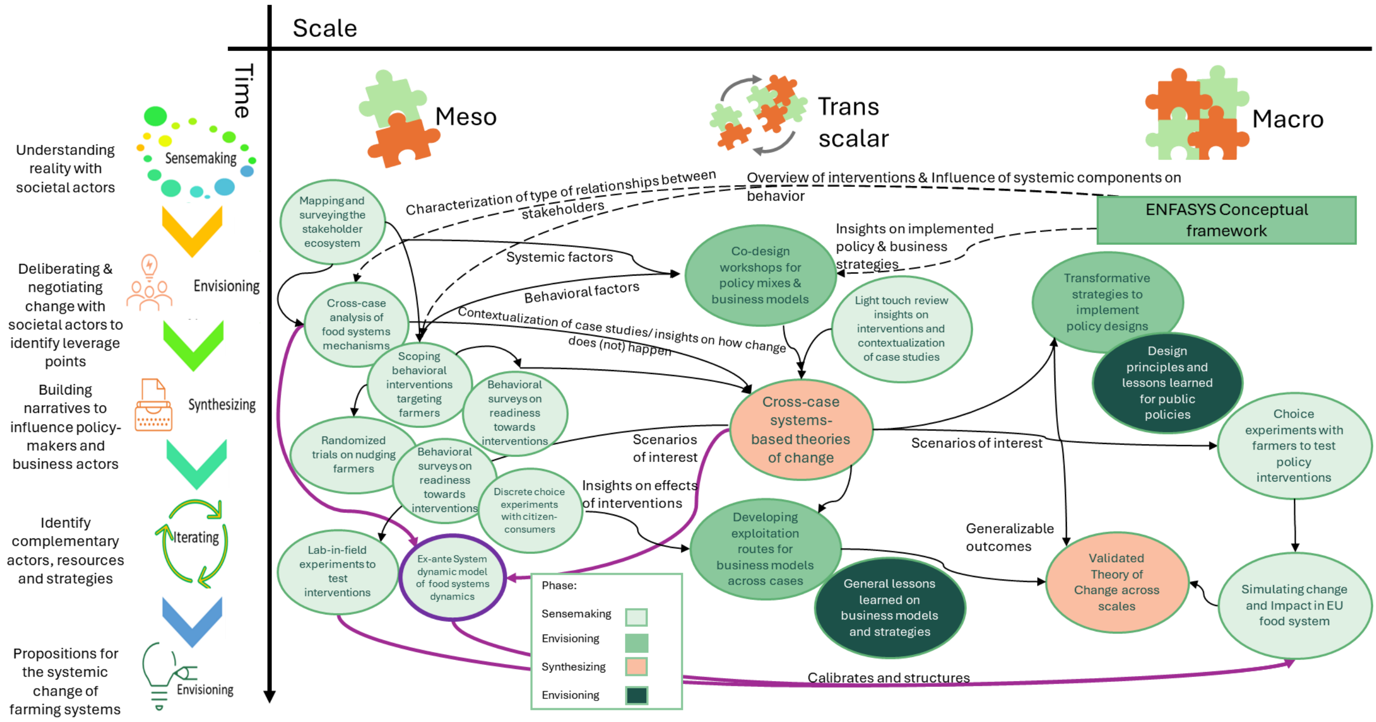
(Dentoni et al., 2022) highlighted the importance of experts and stakeholder engagement to refine food system change models, emphasizing that input from stakeholders adds relevance to models when applied to real-world scenarios. The report "Confidence in Models and Simulations: A Multi-Stakeholder Analysis"(Chaudhari et al., 2022) discusses this challenge, underscoring the need for multi-disciplinary collaboration to enhance the usefulness of models. The participatory approach in validation processes helps bridge the gap between model developers and end-users, allowing for iterative feedback and adjustments that make models more accessible and useful. Salter et al. (2010) also underscored the need for participatory integrated assessment methods, where stakeholder workshops allow experts from various domains to contribute to refining the model structure and assumptions, enhancing both scientific rigor and user confidence. Engaging experts and stakeholders in extended consultations enables end-users to understand and apply the models effectively in decision-making processes, which is especially critical in multi-dimensional fields like sustainable food system transitions.

The implementation of web-based and digital tools has become increasingly critical for advancing sustainable agricultural practices. Several recollections (Burns et al., 2022) do offer a comprehensive assessment of digital tools supporting agroecological transitions, such as FarmBetter and Cool Farm Tool, which provide agro-advisory services - like recommendations for climate resilience and footprint assessments - and performance assessments across environmental dimensions like water usage, emissions, and biodiversity. While these tools are valuable for delivering actionable insights at the farm level, they are often tailored to local or regional applications, focusing primarily on productivity improvements and environmental benchmarking

3 Connection with other ENFASYS' project tasks

The present work is closely connected to various tasks within the ENFASYS project, both in terms of its foundational basis and its future applications. This deliverable builds upon previous research while also serving as a critical input for upcoming tasks that will refine and expand upon its results. Figure 1 depicts in detail the embeddedness of the different project tasks, as well as portraying the varying perspectives and levels of analysis that will concur to the development of project results, and the defined aims for each task.

Figure 1 - System Mapping for Sustainable Transition in ENFASYS project



The basis of this report is D2.1 – "Cross-case identified lock-ins and potential levers from a food systems perspective", which provided the analytical foundation for the present deliverable. Without the extensive work carried out in D2.1, it would not have been possible to construct this systemic dynamic modelling framework. The strong correlation between these two tasks is evident in the methodological section, where the lock-ins and leverage points identified in D2.1 are structurally embedded in the modelling approach of this deliverable.

Furthermore, this deliverable (D2.2) is not only a stand-alone output but also a key component of T2.3, where the transition from a qualitative aggregated CLD to a quantitative System Dynamic Model (SDM) was first initiated. The results derived here will serve as the basis for iterative calibration, ensuring that the model aligns with empirical insights and stakeholder validation.

This model will be tested in T5.2 and T5.3, where the scenarios developed in D4.2 and the outputs of this model will be examined under experimental conditions. Specifically:

- T5.2 will assess the impact of behavioural interventions, testing how farmers respond to different policy and incentive scenarios based on the Theory of Change identified in D4.2.
- T5.3 will implement lab-in-the-field experiments to corroborate model assumptions and further investigate systemic dynamics that emerge from the model simulations.

This experimental validation process is essential, as the transition from qualitative system mapping to quantitative modelling requires a progressive calibration mechanism. Since the assignment of case studies to thematic pathways is a key component of this deliverable, the feedback loop between T5.2, T5.3, and the model itself will refine its predictive accuracy. A major goal is to stabilize the model through counter-validation by case study coordinators, ensuring that each case study is correctly mapped to its thematic pathway following the structured approach outlined in this report. By testing scenarios and strategies through behavioural intervention tasks (T5.2 and T5.3), the model will be iteratively refined, benefiting from empirical insights derived from experimental interventions.

The final version of the model, incorporating adjustments based on intervention results and stakeholder validation, will be the foundation for T5.4. This task will focus on the creation of a web-based visualization tool, serving as the final output of both T2.3 and T5.4.

- T5.4 will translate the SDM into an interactive web tool, allowing policymakers, researchers, and stakeholders to explore different policy and business strategy scenarios.
- The final calibrated model, expected as an outcome of D5.3, will integrate scientific literature, European databases, and primary data from experimental interventions, ensuring a robust and policy-relevant simulation framework.

By combining literature-based parameterization, empirical case study validation, and real-world testing, the final web tool will provide a calibrated, scenario-based approach to inform policy decisions and sustainable business strategies. This integrated workflow—linking theoretical insights, empirical validation, and digital implementation—ensures that the ENFASYS model remains grounded in both scientific rigor and practical relevance.

4 Identification of the scope of the ENFASYS's System Dynamic Model (T2.3 and T5.4)

The ENFASYS System Dynamics Model (SDM) serves as a crucial tool for exploring thematic pathways that support sustainable agricultural transitions within the European Union (EU). As part of Task 2.3 and as a foundation for T5.4, the model aims to develop multiple thematic SDMs aligned with the EU's Farm to Fork Strategy, Biodiversity Strategy, and Common Agricultural Policy (CAP). These thematic models will capture the systemic interactions and dynamics observed within the ENFASYS CSs (CSs) and offer insights tailored to specific transformation pathways, such as low-input farming, or sustainable consumer branding. The focus on thematic models ensures relevance to EU-level policy while retaining the specificity required to address regional and contextual challenges.

The scope of the SDM includes defining its primary objectives, identifying central variables derived from the CSs' Causal Loop Diagrams (CLDs) as outlined in (Ottaviani Aalmo et al, 2024), and establishing its application for scenario-based decision-making and web-based tools under T5.4. By aligning with thematic pathways, the SDM aims to provide actionable insights for policymakers, agricultural practitioners, researchers, and NGOs, ensuring its utility across diverse contexts.

The thematic SDMs will simulate changes within the EU agricultural system under different pathways, illustrating potential impacts on areas such as production practices, biodiversity, and market dynamics. While the CSs provide the foundational dynamics and relationships for these models, the thematic focus ensures alignment with EU-level policies and initiatives. This dual approach enables both broad systemic analysis and case-specific insights, allowing for tailored strategies that address unique regional and thematic challenges.

Identifying leverage points and systemic barriers (lock-ins) is central to the SDM's value. The model will analyze feedback loops and variable interconnections to pinpoint areas where targeted interventions can produce significant, system-wide effects. For example, leverage points might include shifts toward reduced pesticide use or the adoption of biodiversity-friendly practices. Similarly, identifying lock-ins, such as market or regulatory barriers, will help design strategies to overcome these challenges, enabling effective implementation of sustainable practices across different EU contexts.

Scenario-based decision-making is another key objective. The thematic SDMs will enable users to explore potential outcomes of diverse strategies within each pathway. Policymakers and businesses can test interventions, assess their impacts on sustainability metrics, and refine their approaches based on anticipated results. This functionality ensures that decisions are informed by robust, data-driven projections, fostering adaptive strategies that are both effective and resilient.

5 Conceptual Framework and Methodology

The methodological framework employed for the purposes of this document have been defined over the course of several consultations rounds with project partners as well as several rounds of literature review and refinements. The list of the methodological steps employed is listed below, as well as described in further detail in the following paragraphs.

Methodological steps:

- **First section: from ten case study CLDs to three thematic CLDs**
- Matching each CLD to one of the three Pathways
- Mapping recurring relationships and central variables within case study CLDs
- Identification of variables influence level on the system and recurring systemic patterns (archetypes)
- Matching identified systemic dynamics to thematic pathways
- Aggregating Harmonized CLDs and relevant systemic elements

- **Second section: conversion of CLDs into Stock-and-Flow Diagrams (SFDs)**
- Diagrams Identifying Stocks, Flows, and Auxiliary Variables
- Establishing Mathematical Relationships and translating systemic variables into formal relationships
- Validation and Refinement of SDMs
- Analysing relevant insights from simulations

5.1 From ten case study CLDs to three thematic CLDs

Matching each CLD to one of the three Pathways

The first step of the SFD development begins with a critical alignment process, where thematic pathways—rooted in European Commission policies such as low-input farming, biodiversity conservation, and climate resilience—are matched to relevant ENFASYS case studies (CSs). This step ensures that the thematic models are not only evidence-based but also directly address the specific challenges identified within the causal loop diagrams (CLDs) of each case study.

To achieve this, a structured methodology is employed. First, a comprehensive literature review is undertaken, drawing upon key European Union policy documents such as the European Green Deal, the Farm to Fork Strategy, and the Biodiversity Strategy for 2030. This review identifies critical focus areas, including pesticide reduction, low-input agriculture, and soil health, which will guide the thematic pathways.

Next, an in-depth analysis of the case study focus is conducted. Insights from the light-touch review by Home et al. (2023) are leveraged to cross-reference each case study's primary themes and recurring relationships with the identified thematic pathways. By doing so, the most relevant case studies for each pathway are established, ensuring that their core dynamics are well-represented in the model. Furthermore, the association between Pathways and Case Studies is further corroborated by considering single case studies goals and objectives to reach in order to achieve sustainable transition in each specific context.

Mapping recurring relationships and central variables within case study CLDs

A crucial step in this process involves mapping recurring relationships within the CLDs, as developed by Ottaviani Aalmo et al. (2024). These relationships are prioritized through a rigorous multi-step analysis. First, key variables and connections that frequently appear in feedback loops are systematically identified using an adjacency matrix. The frequency, strength, and systemic role of these relationships are evaluated to determine their significance. Subsequently, their alignment with thematic pathways is validated, ensuring they contribute to overarching EU policy goals. This validation process incorporates evidence from Home et al. (2023), ensuring that the mapped relationships align with strategic objectives such as those outlined in the Farm to Fork Strategy and the Biodiversity Strategy.

The objective of the following phase is to systematically identify the most relevant portions of case study CLDs that align with thematic pathways, as well as the central variable for each CLD. The central variables serve as anchors for integrating systemic archetypes into thematic pathway models, ensuring that the models are grounded in critical system dynamics. A variable is considered central when it meets specific criteria that highlight its systemic importance. It must demonstrate high out-degree centrality ((J. Rocha et al., 2020), (Forrester, 1961) meaning it has numerous direct connections to other variables within the system; additionally, central variables actively participate in feedback loops, reinforcing system behaviour and connecting multiple dynamics. Finally, they serve as drivers or critical components in systemic patterns developed by Ottaviani Aalmo et al. (2024), further underscoring their relevance in shaping system behaviour. This involves focusing on key variables, feedback loops, and systemic dynamics—such as lock-ins and leverage points—that correspond with policy objectives and thematic priorities.

Variables are prioritized in accordance with their specific relevance and impact with the single Case Studies goals, as will be detailed in the following steps. It is important to consider at all times that all variables included in the modelling process are behaviour-based, as the final model itself is behaviour based, rather than resource based. This means that all variables depict possible behaviours and behaviours effects, rather than material changes in resource accumulation flows.

Identification of variables influence level on the system and recurring systemic patterns (archetypes)

Following this, a preliminary quantitative analysis is conducted, leveraging cosine similarity and structural equivalence scores previously validated in Ottaviani Aalmo et al. (2024). These measures help identify associations between variables and systemic dynamics, such as feedback loops, as well as assessing variables for their connectivity and systemic significance, allowing to identify central variables.

Central variables identified in the previous phases are systematically compared to detect overlaps, similarities, or equivalences. This comparison relies on cosine similarity, a method already used in Ottaviani Aalmo et al. (2024), which serves as the primary quantitative tool for assessing the directional alignment between variables (Newman, 2010).

Variables and relationships exhibiting high similarity or equivalence scores across multiple CLDs are given special attention, as they indicate strong thematic alignment. Also central variables are addressed, prioritizing the top 25% of variables based on degree centrality, ensuring that those with the most significant influence on system behaviour are identified.

Central variables are also hierarchically structured to clarify their systemic roles, following the framework proposed by(J. C. Rocha et al., 2019) This structuring is crucial for distinguishing between variables with global influence and those with more localized effects, in alignment with (Meadows, 2009) principles on leverage points. The hierarchy consists of top, intermediate and base tier, depending on their level of influence. The hierarchical structuring follows the Rocha et al. (2019) and Meadows (2008) framework, ensuring that variables are classified according to their systemic influence:

- Top Tier → Primary drivers of systemic change, directly shaping financial incentives, knowledge dissemination, and cultural acceptance.
- Intermediate Tier → Reinforcing systemic dynamics, acting as amplifiers or moderators of the transition.
- Base Tier → Localized influence, supporting broader system dynamics but not directly governing systemic behaviour.

Matching identified systemic dynamics to thematic pathways

Building on these findings, the next step involves mapping dynamics to thematic pathways. By applying predefined thresholds—such as cosine similarity values greater than 0.7 and structural equivalence scores of 1—variables and dynamics that exhibit strong alignment with thematic goals are identified.

The process then proceeds with the identification of recurring systemic patterns across CLDs, leveraging the systemic dynamics outlined in Ottaviani Aalmo et al. (2024). These include feedback loops, lock-ins, and leverage points that have already been systematically analysed. To ensure that variables and dynamics with aligned systemic roles are effectively grouped, cosine similarity—previously validated in Ottaviani Aalmo et al. (2024)—is applied. This methodological approach, grounded in the work of Rocha et al. (2020) helps harmonize variables with similar systemic roles while avoiding duplication, ensuring a robust alignment of systemic behaviours across multiple case studies.

Once recurring patterns have been identified, the next step is to define the archetypes ("*Causal network representations of the system's structure and functions*", Rocha et al., 2019). These archetypes are constructed by grouping the aligned variables and patterns identified through cosine similarity and systemic validation. Each archetype is designed to synthesize systemic behaviours across multiple CLDs.

To further refine and validate these archetypes, a cross-referencing process is conducted. Harmonized variables are compared against thematic pathway objectives and relevant literature, including Home et al. (2023) and key European policy documents. This step ensures that the constructed archetypes align with both empirical systemic dynamics, as validated in Ottaviani Aalmo et al. (2024), and overarching thematic goals. Additionally, project deliverables, including Home et al. (2023), provide further empirical and contextual refinement to enhance the applicability of the archetypes.

The objective of this following phase is to align and integrate the central variables identified across case study CLDs within the same thematic pathway, as well as integrating harmonized Causal Loop Diagrams (CLDs) and systemic archetypes into unified thematic SFDs for each pathway. By ensuring consistency and coherence, this process lays the foundation for the construction of systemic archetypes that accurately reflect the underlying dynamics of each pathway for a comprehensive representation of system dynamics.

Following this, harmonization is achieved through categorization. Variables that exhibit overlapping or equivalent roles, as determined through cosine similarity analysis, are grouped under unified categories to create a consistent and structured framework. For example, if one case study refers to "Pesticide Reduction" while another refers to "Synthetic Input Reduction," these may be consolidated under the broader category of "Reduction of Chemical Inputs." However, if certain variables have distinct systemic roles or impacts, they are retained as separate entities, as justified by their quantitative differentiation. The final validation step in the procedure will ensure that these distinctions are empirically sound and contextually appropriate. The categorized variables are then cross-referenced with thematic pathway objectives and relevant literature, such as Home et al. (2023) and key European policy documents.

This leads to obtaining a harmonized set of central variables across relevant CLDs, with similar variables grouped into unified categories where appropriate.

Aggregating Harmonized CLDs and relevant systemic elements

The following step in this integration involves aggregating the harmonized CLDs associated with the same thematic pathway into a single, unified representation. By doing so, all relevant systemic elements—including feedback loops, lock-ins, and leverage points—identified in Ottaviani Aalmo et al. (2024) are accurately incorporated.

Once the harmonized CLDs are consolidated, the systemic archetypes developed in the previous phase are incorporated to provide structural organization to the thematic model. These archetypes serve as essential frameworks for capturing recurring systemic patterns and behaviours. For example, the archetype of *Sustainable Input Management* may encapsulate systemic dynamics related to pesticide reduction and soil quality improvement. By synthesizing these recurring feedback loops, systemic barriers, and leverage points across multiple case studies, the thematic models effectively capture the essence of shared systemic behaviours, following the principles outlined by (Meadows, n.d.) and (J. C. Rocha et al., 2019)

5.2 Conversion of CLDs into Stock-and-Flow Diagrams (SFDs)

Identifying Stocks, Flows, and Auxiliary Variables

Building upon the unified thematic models derived from CLDs, the next step involves translating these models into Stock-and-Flow Diagrams (SFDs) using the software Vensim, available at https://vensim.com/. This transition is critical for refining core causal assumptions, particularly those related to dynamic relationships such as feedback loops. By defining variables as either stocks or flows and establishing their mathematical interconnections, this process facilitates quantitative modelling and ensures systemic consistency. Additionally, it helps identify the specific data requirements from case studies (CSs) needed to construct realistic and calibrated models.

The structure of each SDM follows a standard stock-and-flow architecture, where variables have been assigned the following functional roles:

- **Stocks** represent key accumulations within the system, capturing the dynamic state of critical resources, capacities, or conditions over time.
- **Flows** represent the rates of change that increase or decrease the level of stocks, modelling the processes of accumulation or depletion.
- **Auxiliary variables** serve as bridging elements between the CLDs and the quantitative model, making explicit the causal relationships and feedbacks identified in the qualitative phase. They allow the preservation of the original systemic logic while enabling the quantitative formulation of intermediate processes.

The weights assigned to auxiliary variables, the parameters defining their lookup functions, and the relative importance of variables within each flow were calibrated using empirical evidence and expert feedback. Specifically, this process was informed by Deliverable D4.2, which identified cross-cutting systemic drivers from the case studies' Theories of Change. These drivers were mapped onto the model structure and used to prioritise variable influence and feedback intensities. Methodological input from MBS further supported this process by guiding the initial weighting criteria, particularly in contexts with limited quantitative data, and by helping define the slope and sensitivity of the lookup functions associated with auxiliary variables. These assumptions represent a preliminary calibration step and will be subject to validation and refinement during the subsequent tasks (T5.2–T5.4), which will involve both internal and external stakeholders in an iterative participatory process, the evidence gathered by Roglic (2025).

The initial values of stocks are determined using a combination of relevant scientific literature and major European databases, including the Farm Accountancy Data Network (FADN) and EUROSTAT, where applicable. To facilitate the handling of different units of measurement and to focus on the behavioural dynamics rather than the absolute quantities of resource flows, all variables in the models are normalized between 0 and 1. This normalization supports the comparative interpretation of results and aligns with the behavioural focus of the models, which aim to capture systemic transition dynamics rather than physical resource accounting.

Establishing Mathematical Relationships and translating systemic variables into formal relationships

At the heart of systemic modelling lies the precise definition of mathematical relationships between stock and flow variables.

By defining these relationships upfront, the integration of case study data becomes more straightforward. The stock-and-flow structure inherently embeds the feedback dynamics from Ottaviani Aalmo et al. (2024), ensuring a rigorous and systemic representation of real-world interactions.

With the necessary data in place, the translation of CLDs into SFDs is carried out using Vensim. This process involves mapping systemic relationships, assigning each variable as either a stock or a flow, and defining the mathematical equations governing their interactions.

- Variables representing accumulations, such as *Soil Fertility* or *Water Reserves*, are categorized as stocks.
- Variables denoting rates of change, such as *Nutrient Inputs* or *Crop Harvesting Rate*, are designated as flows.
- Stocks are formulated as integrals of inflows minus outflows, ensuring they evolve dynamically over time. Flows are expressed as functions of external inputs, feedback loops, and systemic interactions (Sterman, 2000).

For instance, *Soil Fertility* may be modelled as the integral of *Nutrient Inputs* minus *Nutrient Depletion*, where *Nutrient Inputs* is influenced by *Fertilizer Application Rate* and external factors such as subsidies or market prices (Meadows, 2008). These mathematical formulations capture the dynamic nature of systemic interactions, ensuring consistency with empirical observations and policy-driven influences.

For each variable, the simulated dynamic is discussed in relation to theoretical expectations (Home et al., 2023), empirical evidence from the cross-case analysis (Roglic, 2025), and the systemic archetypes associated with the pathway. The resulting analysis enables the identification of critical patterns, systemic delays, leverage activation points, and potential risks of stagnation, providing a comprehensive understanding of the system's transition dynamics. Importantly, the model does not rely on predefined external shocks or exogenous scenario assumptions to produce change. Rather, system behaviour emerges endogenously from the internal structure of stocks, flows, and auxiliary variables. The model is "set in motion" through internal feedback mechanisms: changes in key variables—such as market demand, adoption rates, or environmental performance—are not externally imposed, but arise from the interactions between components within the system itself. This endogenous behaviour is driven by the feedback loops that structure the system—not abstractly imposed but directly derived from the transformation of the Causal Loop Diagrams (CLDs) into System Dynamics Models (SDMs). In this process, reinforcing and balancing loops identified during the qualitative phase were translated into formal relationships between stocks, flows, and auxiliary variables. These loops provide the causal architecture that governs how the system evolves over time and reacts to internal shifts. Each variable in the model is defined based on its systemic role as described in the Causal Loop Diagrams. Stocks represent the accumulations in the system—variables with memory that change over time under the influence of other elements. These are typically the outcome variables in the CLDs that are themselves influenced by other drivers. For each stock, we define two corresponding flows: an inflow ("increase of [stock]") and an outflow ("decrease of [stock]"), which determine the rate at which the stock accumulates or decumulates.

The influence of one stock on another is not modelled through direct connections between flows, but rather through auxiliary variables. These variables serve as bridges: if stock A influences stock B (positively or negatively), that influence is implemented through an auxiliary variable that modulates the inflow or outflow of stock B accordingly. Whether the influence acts on the inflow or outflow is determined by the polarity and position of the connection in the original CLDs. The intensity of this influence—that is, how strongly the auxiliary variable modulates the flow—is based on the empirical insights provided in Deliverable D4.2, and further refined through feedback from MBS.

Where appropriate, auxiliary variables include lookup functions to model non-linear relationships such as threshold effects, saturation points, or delayed impacts. These lookup functions were constructed to reflect the behavioural nature of the dynamics being modelled, often inspired by the multi-level perspective on socio-technical transitions (Geels, 2002). In many cases, the variables involved represent niche-level dynamics interacting with more dominant regime structures, and the slope of the lookup curve—which determines how quickly influence intensifies—was calibrated with input from MBS to reflect plausible behavioural responses.

It is also important to clarify that the models developed are behavioural models, not models of physical resource exchange. This distinction justifies a key structural decision: flows are not directly connected to one another. In physical systems, it is common for the outflow of one stock to become the inflow of another. However, in behavioural systems this would imply a direct transfer of state—e.g., a decrease in awareness leading mechanically to an increase in trust—which would misrepresent how change actually occurs in complex social systems. Instead, we model causal influence among flows indirectly, via auxiliary variables, preserving the qualitative logic of the CLDs while allowing for nuanced, asymmetric, and time-dependent effects.

Analysing relevant insights from simulations

The simulations of the thematic models were interpreted as exploratory tools to investigate systemic dynamics within the identified transition pathways. Each core variable was analysed against theoretical expectations, empirical evidence, and system archetypes, allowing for the identification of strengths, vulnerabilities, and potential leverage points. This interpretive process enabled the recognition of recurring patterns and enabling conditions for transition consolidation. Furthermore, sensitivity analysis supported the identification of key driver variables capable of triggering resilient and self-reinforcing systemic change.

Analysing relevant insights with new EC Vision point of view

For the purpose of the present work, the main inputs gathered from the new EC Vision for agriculture and food systems are incorporated into this analysis as theoretical inputs, in order to perform the analysis of the results of the models' simulations. This allows to provide relevant insights from the simulations that are aligned with the new policy priorities of the Commission. Performing this additional analysis step will allow to provide coherent, up to date, and relevant insights, extracting them from simulation results in accordance with the main inputs from the Vision. This strategy will allow to achieve relevant results for future policy making purposes, while building the core of the work on the thematic pathways, ensuring continuity between policy landscapes and paradigms.

Some of the main inputs that will be employed as transversal lenses for simulation analysis are detailed below.

Competitiveness: as previously detailed, the new Vision for agriculture and food marks a major turning point in the priorities envisioned for the European agricultural and food system for the next years. Overall, a major shift towards competitiveness across all priority areas can be detected: attention is paid to the necessity of building circumstances that can help stability through economic means. For this reason, a transversal lens that will be used in the course of the entire analysis will be based on the concept of competitiveness, with specific connotations changing in each different model, and ranging according to the specific policies and strategies associated with the overarching theme of competitiveness.

Resilience and future-proofing: another major input that can be extracted from the themes envisioned for the future of the EU is the necessity of putting in place mechanisms that can ensure resilience in the current fast changing global environment, from the environmental, economic and social point of view. For this reason, results from the simulations that might portray dynamics related to shocks and abrupt changes will be particularly highlighted in order to allow for policy proposal in terms of resilience and flexibility.

Reduction of dependencies: as previously showed in detail, one of the key transversal elements that the Commission highlighted as crucial for the future of food systems in Europe is connected to the gradual but steady reduction of dependence on external imports. This applies to raw materials, resources, agricultural inputs, and all other possible resources being imported from outside the EU, as much as possible without disruptions of the economic landscape. The aim of such a strategy is to reduce the exposure of Member States to the economic volatility that can create instability and possible ripple effects contributing to furthering instabilities. This kind of strategy is particularly crucial in this historical time, due to the global political landscape's instability and possibility of future shocks to the economy as well as to people's livelihoods.

6 EU Thematic Pathways selected

The transformation of European food systems towards sustainability is a key priority within the European Green Deal and is reinforced by strategic frameworks such as the Farm to Fork Strategy, the EU Biodiversity Strategy for 2030, Common Agricultural Policy (CAP) (European Commission, 2020) and Food 2030 (European Commission, 2023). As food production faces increasing environmental, economic, and social challenges, it has become evident that a systemic transformation is needed to support resilient and sustainable food systems.

Within this context, in this report we identified three thematic pathways that serve as key strategies to guide this transformation and aligned with CS's goals. These pathways provide a structured approach to tackling systemic barriers and leveraging transition enablers, integrating policy insights, scientific research, and empirical data (Home et al, 2023) Each of these pathways is designed to address specific sustainability challenges while aligning with EU priorities and existing food policy strategies. The three thematic pathways explored in this deliverable include:

1. *Low-input Agriculture*, which focuses on reducing synthetic inputs, improving biodiversity and soil health, and mitigating greenhouse gas emissions.

2. *Extensification of Livestock Systems*, emphasizing animal welfare and reducing methane, nitrogen and phosphorusemissions through less intensive farming practices.

3. *Sustainable Consumption and Branding*, which aims to strengthen consumer engagement through sustainability certifications, direct selling models, and food system transparency.

These thematic pathways are supported by a robust body of literature and policy reports, including the Food 2030 Strategy and CAP strategic plans, which highlight the necessity of fostering sustainable agricultural practices through a combination of regulatory incentives, market mechanisms, and behavioural shifts (European Commission, 2023).

- **Low-input Agriculture: Reducing Chemical Inputs and Enhancing Soil Health**

One of the major challenges of the current agricultural system is its heavy reliance on synthetic inputs, such as chemical fertilizers and pesticides, which contribute to soil degradation, biodiversity loss, and water contamination. The Farm to Fork Strategy directly addresses these concerns by setting ambitious targets, including a 50% reduction in pesticide use by 2030 and an increase in organic farming to cover at least 25% of total agricultural land (European Commission, 2020).

Transitioning towards low-input agricultural systems presents multiple obstacles. Many conventional farming models remain financially and structurally dependent on synthetic inputs, making a shift towards more sustainable methods difficult without economic support (Altieri & Nicholls, 2017). Furthermore, knowledge gaps persist, as many farmers lack adequate advisory services and training in alternative practices, leading to uncertainty about the effectiveness and profitability of these systems (Home et al., 2023).

To overcome these barriers, policy frameworks have increasingly promoted subsidy realignment through the CAP's agri-environmental measures (AEMs), which provide financial support for sustainable agricultural practices (European Commission, 2023). Additionally, investments in soil health programs, biodiversity-friendly practices, and peer-learning networks can accelerate the adoption of low-input farming techniques. Studies show that reduction of mineral fertilizers and synthetic pesticides, the reduction of animal numbers, ecological compensation areas not only enhance soil health but also contribute to climate resilience and farm profitability (Lal, 2015). Furthermore, expanding the use of agroforestry systems, integrating perennial crops, and strengthening performance-based incentives for biodiversity conservation have been identified as key strategies to overcome these barriers (Home et al., 2023).

- **Extensification of livestock systems: reducing methane emissions and prioritizing animal welfare**

Livestock production is a significant contributor to environmental degradation, with intensive farming practices driving deforestation, greenhouse gas emissions, eutrophication and land degradation. The European Green Deal has highlighted the necessity of transforming the livestock sector by promoting climate-friendly animal farming, reducing nitrogen, phosphorus and methane emissions, and encouraging extensive pasture-based systems (European Commission, 2020).

Despite its environmental benefits, extensification presents notable economic and logistical challenges. Pasture-based systems require larger land areas and increased labour investment, making them less financially competitive than intensive livestock production (Home et al, 2023). Additionally, farmers face market volatility due to fluctuating consumer demand and high production costs, which limit incentives for transitioning to more sustainable livestock systems (Home et al, 2023).

To facilitate this transition, policies should focus on enhancing regional feed autonomy, reducing dependency on imported soy-based protein feeds, and increasing incentives for methane reduction technologies in ruminant farming (Hristov et al., 2015). Strengthening certification schemes for animal welfare and carbon footprint labelling can also help create market-driven incentives for sustainable livestock products (Home et al., 2023).

- **Sustainable consumption and branding: driving market transformation**

Consumer behaviour plays a fundamental role in shaping food system sustainability, as demand for certified and responsibly produced food can incentivize agricultural transitions. The Food 2030 Strategy highlights the need for consumer engagement, sustainability certifications, and transparent labelling as core strategies for accelerating change (European Commission, 2023).

Despite this potential, economic constraints and weak regulatory enforcement continue to limit consumer-driven sustainability. Many consumers prioritize low-cost food options, making sustainably produced goods less competitive in the marketplace (Sonnino & Marsden, 2006). Additionally, power imbalances in retail markets limit direct access for small-scale producers, reducing the viability of local food networks (Vermeulen et al., 2020).

Expanding food labelling regulations, improving certification standards, and strengthening regional market access can enhance consumer trust in sustainable food systems (Home et al., 2023). Digital traceability systems, direct selling models, and short food supply chains also present opportunities to promote more transparent and resilient food systems.

7 Results

This chapter presents the results of the structured analysis of the System Dynamics identified through the methodology explained in Cap. 5, organized into three main sections. The methodological flow begins with a detailed analysis of CSs' CLDS validated by Ottaviani Aalmo et al, 2024 aiming to highlight systemic dynamics relevant to a specific thematic pathway, subsequently converging the findings into three thematic pathways' CLDs and, lastly, converting the causal relationships of the thematic pathways CLDs into thematic pathways' Stock and Flow Diagrams (SFDs).

The first section (**7.1 Case Study Systemic Profiles: Analysing CLDs for Thematic SFD Transition**) focuses on the analysis of Causal Loop Diagrams (CLDs) developed for each case study. At this stage, the examination remains rooted in specific case contexts, identifying key systemic drivers, relevant reinforcing and balancing feedback loops, and structural challenges that shape sustainability transitions in diverse agricultural settings and systemic dynamics relevant for the thematic pathways assigned to each Case Study.

The second section (**7.2 Thematic Pathways CLDs**) builds upon these insights by transitioning from individual case study CLDs to thematic pathways' CLDs. In this phase, the focus is no longer on specific CSs but on identifying common systemic behaviours, such as Thematic Pathways’ systemic archetypes, harmonizable variables across case studies and common systemic dynamics that define sustainability transitions within thematic pathways. This section consolidates systemic insights from the ten case studies, synthesizing intra-case dynamics into broader system archetypes that highlight shared challenges and leverage points on which thematic pathways CLDs are built.

The third section (**7.3 Thematic Pathways SDMs**) advances the analysis by translating the causal relationships identified in the thematic CLDs into SFDs. This transition from qualitative causal mapping to quantitative system modelling allows for a structured representation of systemic relationships using linear equations.

7.1 Case Study Systemic Profiles: Analysing CLDs for Thematic SFD Transition

7.1.1 CS1 – France and Belgium: Facilitating Uptake of Agri-Environment Climate Measures (AECMs)

1. Introduction to the Case Study

The adoption of Agri-Environment Climate Measures (AECMs) is essential for promoting low-input agriculture in France and Belgium. This case study examines systemic factors influencing AECM uptake, focusing on financial incentives, compliance costs, advisory services, and cultural factors.

Following the ENFASYS T2.3 System Dynamic Model (SDM) framework, a Causal Loop Diagram (CLD) systemic analysis was conducted to identify feedback loops and systemic constraints affecting the implementation of AECMs.

By analysing reinforcing and balancing loops, this study provides insights into how AECM adoption can be enhanced, addressing barriers and systemic lock-ins that limit implementation.

2. Systemic Challenges

Several structural barriers hinder the adoption of AECMs in France and Belgium:

- *Economic Dependency*: Farmers rely heavily on subsidies, making AECM adoption uncertain if financial support is reduced.
- *Regulatory Barriers:* Complex compliance requirements increase transaction costs, limiting participation in sustainability programs.

- *Cultural Resistance:* Farmers accustomed to high-yield, conventional practices may be reluctant to transition to AECMs.
- *Technological Lock-ins:* Inadequate advisory services and knowledge gaps create barriers to adopting non-chemical-dependent farming methods.

These systemic lock-ins reinforce reliance on conventional, high-input farming, slowing the transition toward low-input agriculture.

3. Systemic Analysis

Using Causal Loop Diagram (CLD) systemic analysis, key reinforcing and balancing feedback loops were identified, illustrating the interactions between financial incentives, compliance mechanisms, and advisory services.

Central Variable: Rate of AECM Adoption (RAA)

Following systemic analysis and adjacency matrix assessments, RAA was identified as the most influential variable due to its systemic impact on financial incentives, compliance burdens, and knowledge transfer.

Rationale for Identifying RAA as the Central Variable

- High Systemic Connectivity → RAA appears in multiple reinforcing loops (R1, R2, R3) and a balancing loop (B1).
- Direct Impact on Key Dynamics → RAA influences subsidy allocation, regulatory complexity, and training service demand.
- Out-Degree Centrality Indicators → RAA influences key systemic variables, including Subsidies (SF), Compliance Costs (CC), Advisory Services (EAS), and Cultural Factors (CO).

This central role makes RAA the primary driver that can help foster the adoption of practices related to Low-input Agriculture.

4. Alignment with Low-Input Agriculture

5. Feedback Loops

R1 - Advisory and Awareness Reinforcing Loop (Reinforcing)

- Pathway: Training & Education (TE) → Effectiveness of Advisory Services (EAS) → Access to Knowledge & Expertise (AKE) → Environmental Awareness (EAC) → Rate of AECM Adoption (RAA) → (Feedback) TE
- Relevance to Low-input Agriculture: Strengthened advisory services facilitate the adoption of low-input agricultural practices, ensuring farmers have the necessary support in acquiring technical expertise.

R2 - Cultural-Environment Reinforcing Loop (Reinforcing)

- Pathway: Cultural Openness (CO) → Environmental Awareness (EAC) → Rate of AECM Adoption (RAA) → (Feedback) CO
- Relevance to Low-input Agriculture: A self-reinforcing mechanism in which increased understanding of environmental benefits supports long-term adoption of sustainable farming practices.

B1 - Compliance Burden and Farmer Participation Loop (Balancing)

- Pathway: Compliance Costs (CC) & Administrative Burden (AB) → Rate of AECM Adoption (RAA) → (Feedback) CC
- Relevance to Low-input Agriculture: If compliance costs and bureaucratic complexity rise, fewer farmers participate in AECMs, balancing adoption rates.

6. Identified Variables

The identification of key systemic variables follows the (J. C. Rocha et al., 2019) and (Meadows, 2009) framework, prioritizing high-impact systemic variables over localized supporting factors (see Table 1).

Table 1 - Identified Key Variables CS1

Variable	Acronym	Systemic Role
Rate of AECM Adoption	RAA	The primary driver of systemic change, influencing financial incentives, regulatory burdens, and advisory services.
Subsidies Available for Farmers	SF	Determines the financial feasibility of adopting sustainable practices.
Compliance Costs for Adoption	CC	Represents a financial and administrative barrier to transitioning towards low-input farming.
Effectiveness of Advisory Services	EAS	Ensures farmers have the technical capacity to implement sustainable agricultural practices.
Environmental Awareness	EAC	Drives behaviour towards the adoption of environmentally sustainable farming.
Cultural Openness	CO	Facilitates the shift from conventional to agroecological farming models.
Farmer Administrative Burden	AB	Bureaucratic complexity can act as a deterrent to participation in sustainability schemes.
Training & Education	TE	Supports the development of technical expertise necessary for sustainable farming.
Access to Knowledge and Expertise	AKE	Reduces knowledge gaps that can prevent the adoption of low-input agricultural practices.
Total Allocated Budget for AECM	TABA	Determines whether funding is sufficient to sustain agroecological transitions.
Penalties related to AECM Contracts	PEN	Compliance measures that can either incentivize or deter engagement in sustainable practices.

7. Hierarchical Structure of Variables and Their Systemic Role

To facilitate systemic archetype analysis, variables were categorized into hierarchical tiers based on their role in feedback loops and systemic influence (see Table 2).

Table 2 - Hierarchical Structure of Variables and Respective Systemic Role CS1

Tier	Variable	Systemic Role
Top Tier (Primary Driver of Systemic Change)	**Rate of AECM Adoption (RAA)**	The primary driver of systemic change, directly influencing financial incentives, regulatory requirements, and advisory services.
Intermediate Tier (Reinforcing Systemic Dynamics)	**Compliance Costs (CC)**	A financial and administrative barrier that can limit the feasibility of transitioning to sustainable farming practices.
	Effectiveness of Advisory Services (EAS)	Ensures that farmers possess the technical knowledge and resources necessary for AECM implementation.
	Environmental Awareness (EAC)	Drives behavioural shifts toward the adoption of environmentally sustainable practices.
	Cultural Openness (CO)	Facilitates the shift from conventional to agroecological farming models.
Base Tier (Constraints and Supporting Factors)	**Biodiversity (B)**	A direct outcome of AECM adoption, reflecting the ecological benefits of sustainable farming practices.
	Soil Health (SH)	A key indicator of long-term sustainability, directly linked to AECM adoption.

Tier	Variable	Systemic Role
	CO_2 Emissions (CO2)	Reduction in CO_2 emissions is a key objective of the Low-input Agriculture pathway.

Case Study 1 Profile Highlights

Central Variable: Rate of AECM Adoption (RAA)
Thematic Pathway: Low-Input Agriculture
Other Thematic Pathway possible alignment: None

Low-Input Agriculture Pathway – Rationale:
This case study is centred on increasing the uptake of Agri-Environment Climate Measures (AECMs), which are key instruments to reduce synthetic inputs and support agroecological transitions. The objective is to overcome structural barriers—such as economic dependency on subsidies, high compliance costs, and cultural resistance—to enable more farmers to adopt low-input practices.

7.1.2 CS2 – Serbia: CAP-proofing Serbian Agriculture

1. Introduction to the Case Study

The CAP-proofing Serbian Agriculture initiative aims to foster the adoption of Regenerative Agriculture (RA) to enhance soil health, economic resilience, and environmental sustainability. Through financial incentives, advisory services, and technical knowledge transfer, this case study explores the systemic barriers and enablers affecting the uptake of regenerative farming practices in Serbia.

2. Systemic Challenges

Several systemic lock-ins, identified through structural equivalence analysis and adjacency matrix assessments (Ottaviani Aalmo et al., 2024), hinder the adoption and scalability of regenerative agriculture:

- *Economic Dependency on Subsidies:* Farmers rely on government incentives, making sustainable transitions financially unviable if support is reduced.
- *Regulatory Barriers*: Compliance burdens and administrative complexity discourage participation in sustainability programs.
- *Cultural Resistance to Low-Input Farming:* Many farmers are reluctant to shift from high-yield conventional methods to RA, limiting adoption rates.
- *Technological Lock-ins:* High equipment costs and limited advisory services slow the transition to RA.
- *Market Constraints:* Limited market access for RA-produced goods weakens the financial incentive for sustainable practices.

These systemic challenges reinforce reliance on conventional high-input farming, limiting the transition to regenerative models.

3. Systemic Analysis

Through Causal Loop Diagram (CLD) analysis, RA adoption dynamics were examined to identify reinforcing and balancing feedback loops that shape adoption and sustainability transitions. The Rate of Adoption of RA (RAA) (Ottaviani Aalmo et al., 2024) was identified as the central systemic variable, directly shaping economic feasibility, knowledge diffusion, and cultural acceptance of sustainable farming.

The study highlights three reinforcing loops (knowledge diffusion, financial incentives, and soil improvement) that facilitate adoption, alongside a balancing loop (economic and technical constraints) that regulates adoption rates.

By understanding these systemic interactions, this case study provides a framework for improving policy design, technical advisory services, and financial support mechanisms for RA adoption.

Central Variable: Rate of Adoption of RA (RAA)

The structural analysis of the CLD (Ottaviani et al., 2024), combined with out-degree centrality metrics (Rocha et al., 2020), identified Rate of Adoption of RA (RAA) as the most influential variable in the system.

Rationale for identifying RAA as the central variable

- High Systemic Connectivity → RAA appears in multiple feedback loops, both reinforcing (R1, R2, R4) and balancing (R3).
- Direct Impact on Key Dynamics → RAA determines financial viability (via subsidies), technical knowledge transfer (via advisory services), and cultural acceptance of RA.
- Out-Degree Centrality Indicators → RAA has the highest number of outgoing connections, influencing key variables such as Subsidy Allocation, Knowledge Supply, Profitability, and Market Demand for RA Products.

This central positioning makes RAA the primary driver of Serbia's transition toward Low-input Agriculture.

4. Alignment with the low-input agriculture pathway

5. Feedback Loops

The systemic analysis confirms that the adoption of regenerative agriculture practices aligns with sustainability transitions through interlinked social, economic, and technical feedback loops.

- **The Knowledge and Adoption Loop (R1)** emphasizes how the increase in knowledge and expertise on regenerative agriculture (RA) stimulates its adoption. As farmers adopt RA practices, demand for knowledge rises, reinforcing a continuous cycle of learning and uptake.
- **The Economic Incentives Loop (R2)** illustrates how financial subsidies lower economic barriers, enabling adoption of RA. This adoption leads to environmental and economic benefits, which could justify continued or increased subsidies, provided adaptive policies are in place.
- **The Financial and Technical Constraints Loop (B1)** acts as a balancing mechanism where high machinery and input costs reduce profitability and adoption rates. As adoption slows, demand for specialized equipment diminishes, stabilizing the system and highlighting the role of affordability and scale.
- **The Cultural Resistance Loop (R3)** reveals that low social acceptance initially limits adoption. However, as RA benefits become visible, cultural attitudes shift, fostering broader acceptance and reinforcing future adoption. This loop requires time and consistent exposure to success stories to be effective

6. Identified Variables

The table below presents the key identified variables, along with their systemic role within the Low-input Agriculture pathway:

Table 3 - Identified Key Variables CS2

Variable	Acronym	Systemic Role
Rate of Adoption of RA	**RAA**	Measures the transition pace toward low-input farming.
Youth Interest in Farming	**YIF**	Drives new entrants into farming, increasing RA adoption potential.

Variable	Acronym	Systemic Role
Supply of Knowledge and Expertise	**SKE**	Supports farmers' ability to transition to regenerative practices.
Capacity of Public Extension & Advisory Services	**CPEAS**	Ensures farmers receive technical guidance on sustainable practices.
Consultation Fee of Private Advisors	**CFPA**	Affects affordability of technical advice, influencing RA adoption.
Social & Cultural Acceptance	**SA/CA**	Determines willingness to adopt RA based on community values.
Total Input Cost	**TIC**	Higher costs for inputs can drive farmers toward low-input farming.
Profitability	**P**	Economic feasibility influences long-term sustainability of RA.
Yield	**Y**	Improved soil health enhances productivity, promoting RA expansion.
Soil Quality	**SQ**	A key indicator of long-term sustainability, directly linked to RA.
Plant Diversity	**PD**	Enhances soil resilience and reduces chemical dependency.
Chemical Input Use	**CIE**	Declining use supports the Low-input Agriculture transition.
Organic Fertilizer Use	**OFU**	Improves soil structure, contributing to long-term sustainability.
Demand for Machinery	**DM**	High equipment costs can discourage adoption of sustainable methods.
Demand for Labor	**DL**	Affects the economic feasibility of RA adoption.
Demand for Seeds	**DS**	Availability and cost influence ease of transition to regenerative practices.
Supply & Availability of RA Machinery	**SAMRA**	Determines ease of transitioning to RA practices.
Available Financial Subsidies	**AFS**	A major enabler in offsetting costs associated with RA adoption.
Market Access for RA Products	**MA**	Ensures long-term economic viability of sustainable farming.
Community Engagement & Education	**CEE**	Strengthens knowledge diffusion and acceptance of RA.

7. Hierarchical structure of variables and their systemic role

Table 4 - Hierarchical Structure of Variables and Respective Systemic Role CS2

Tier	Variable	Systemic Role
Top Tier	Rate of Adoption of RA (**RAA**)	The **primary driver of systemic change**, influencing financial incentives, knowledge dissemination, and cultural acceptance.
Intermediate Tier	Supply of Knowledge & Expertise (**SKE**)	Supports farmers' ability to transition to regenerative practices, reinforcing systemic adoption (R1).
	Available Financial Subsidies (**AFS**)	Provides economic support, facilitating adoption and improving environmental and economic sustainability (R2).
	Farmer Motivation (**FM**)	Key driver for adoption, influenced by profitability and sustainability awareness (R1, R2).
	Market Demand for RA Products (**MA**)	Ensures long-term economic viability of sustainable farming (R2).
	Soil Quality (**SQ**)	A key indicator of long-term sustainability, directly linked to RA (R2).

Tier	Variable	Systemic Role
	Plant Diversity (**PD**)	Enhances soil resilience and reduces chemical dependency (R2).
	Cultural & Social Acceptance (**SA/CA**)	Determines willingness to adopt RA based on community values, reinforcing social and economic feasibility (R4).
	Capacity of Public Extension & Advisory Services (**CPEAS**)	Ensures farmers receive technical guidance on sustainable practices (R1).
	Economic Returns (**ER**)	Reinforces financial feasibility, driving sustained adoption of RA (R2).
Base Tier	Consultation Fee of Private Advisors (**CFPA**)	Affects affordability of technical advice, influencing RA adoption.
	Total Input Cost (**TIC**)	Higher costs for inputs can drive farmers toward low-input farming.
	Profitability (**P**)	Economic feasibility influences long-term sustainability of RA.
	Yield (**Y**)	Improved soil health enhances productivity, promoting RA expansion.
	Chemical Input Use (**CIE**)	Declining use supports the Low-input Agriculture transition.
	Organic Fertilizer Use (**OFU**)	Improves soil structure, contributing to long-term sustainability.
	Demand for Machinery (**DM**)	High equipment costs can discourage adoption of sustainable methods (R3 - Balancing).
	Demand for Labor (**DL**)	Affects the economic feasibility of RA adoption.
	Supply & Availability of RA Machinery (**SAMRA**)	Determines ease of transitioning to RA practices.
	Community Engagement & Education (**CEE**)	Strengthens knowledge diffusion and acceptance of RA.
	Agricultural Cooperatives (**C**)	Facilitates peer learning and collaborative resource use.

CS2 – Serbia: CAP-proofing Serbian Agriculture Highlights

Central Variable: Rate of Adoption of Regenerative Agriculture (RAA)
Thematic Pathway: Low-Input Agriculture
Other Thematic Pathway possible alignment: None

Low-Input Agriculture Pathway – Rationale:
This case study aims to accelerate the adoption of regenerative agriculture (RA) in Serbia, with the goal of enhancing soil health, economic resilience, and long-term sustainability. The focus is on supporting systemic change by addressing key barriers such as farmers' dependency on subsidies, high input and equipment costs, and limited advisory capacity.

7.1.3 CS3 – Switzerland: Biodiversity Promotion Using Locally Adapted Practices

1. Introduction to the Case Study

The promotion of biodiversity-friendly farming practices in Switzerland is a key strategy to enhance ecosystem health, resilience, and agricultural sustainability. Through financial incentives, advisory services, and stakeholder collaboration, this case study examines the systemic barriers and enablers influencing the uptake of biodiversity measures by farmers (UBMF).

2. Systemic Challenges

Several systemic lock-ins, identified through structural equivalence analysis and adjacency matrix assessments (Ottaviani Aalmo et al., 2024), limit the adoption and long-term sustainability of biodiversity measures:

- *Economic Dependency on Incentives*: Farmers depend on subsidies to sustain biodiversity practices, making them vulnerable to funding fluctuations
- *Regulatory Barriers*: Standardized biodiversity policies fail to account for regional ecological differences, limiting effectiveness
- *Cultural Resistance*: Biodiversity-friendly farming is often perceived as less productive, reducing acceptance among farmers
- *Knowledge Gaps*: Limited training in biodiversity management slows adoption rates.

These constraints reinforce reliance on conventional intensive farming models, making it difficult to scale biodiversity conservation practices.

3. Systemic Analysis

Through Causal Loop Diagram (CLD) analysis, biodiversity measure adoption dynamics were examined to identify reinforcing and balancing feedback loops that shape long-term adoption and sustainability transitions. The Uptake of Biodiversity Measures by Farmers (UBMF) (Ottaviani Aalmo et al., 2024) was identified as the central systemic variable, directly shaping financial feasibility, policy support, and biodiversity quality on farmland.

The study highlights three reinforcing loops (financial incentives, knowledge transfer, and stakeholder collaboration) that facilitate adoption, alongside a balancing loop (economic constraints and knowledge barriers) that regulates adoption rates.

By understanding these systemic interactions, this case study provides a framework for improving policy alignment, farmer education, and financial support mechanisms to enhance biodiversity promotion.

Central Variable: Uptake of Biodiversity Measures by Farmers (UBMF)

The structural analysis of the CLD (Ottaviani et al., 2024), combined with out-degree centrality metrics (J. Rocha et al., 2020) identified Uptake of locally adapted Biodiversity Measures by Farmers (UBMF) as the most influential variable in the system.

Rationale for Identifying UBMF as the Central Variable

- High Systemic Connectivity → UBMF appears in multiple feedback loops, both reinforcing (R1, R2, R3) and balancing (B1).

- Direct Impact on Key Dynamics → UBMF influences biodiversity quality (BQF), policy adjustments (BFPA), and financial incentives (FI).

- Out-Degree Centrality Indicators → UBMF has the highest number of outgoing connections, shaping farmer knowledge, economic viability, and stakeholder collaboration.

This central positioning makes UBMF the primary driver of Switzerland’s transition toward Biodiversity Conservation and Restoration.

4.Alignment with the Low-Input Agriculture Pathway

5.Feedback Loops

- The Policy and Incentive Reinforcement Loop (R1) highlights how financial and policy support mechanisms reinforce biodiversity adoption, demonstrating the role of regulatory alignment and economic viability.
- The Farmer Awareness and Knowledge Sharing Loop (R2) underscores the importance of advisory services and training, ensuring that farmers have the capacity to implement biodiversity measures.
- The Biodiversity and Ecosystem Services Loop (R3) illustrates how biodiversity gains improve ecosystem resilience, reinforcing sustainability practices on farms.

By linking policy adjustments, farmer education, and financial support, this study validates biodiversity promotion as a key strategy for agricultural sustainability.

6. Identified Variables

The selection of variables follows the Rocha et al. (2019) and Meadows (2008) framework, ensuring a clear distinction between globally influential variables and those with more localized effects.

Table 5 - Identified Key Variables CS3

Variable	Acronym	Systemic Role
Knowledge & Skills in Biodiversity Management	KSBM	Enhances farmer capacity to implement biodiversity measures effectively.
Advisory Services	AS	Provides guidance and technical support for biodiversity conservation.
Uptake of locally adapted Biodiversity Measures by Farmers	UBMF	Measures the integration of biodiversity-friendly farming practices.
Biodiversity Quality on Farmland	BQF	A core indicator of ecosystem health and resilience.
Financial Incentives	FI	Supports the economic feasibility of biodiversity-friendly farming.
Stakeholder Collaboration	SC	Strengthens cross-sectoral cooperation for biodiversity conservation.
Biodiversity-Friendly Policy Adjustments	BFPA	Ensures policies are aligned with biodiversity enhancement objectives.
Food & Feed Production	FFP	Balances biodiversity conservation with agricultural productivity.
Other Environmental Benefits	OEB	Measures additional ecosystem services such as CO_2 reduction.

7. Hierarchical Structure of Variables and Their Systemic Role

Table 6 - Hierarchical Structure of Variables and Respective Systemic Role CS3

Tier	Variable	Systemic Role
Top Tier	Uptake of Biodiversity Measures by Farmers (**UBMF**)	The **primary driver of systemic change**, directly influencing biodiversity quality, policy support, and financial incentives.
Intermediate Tier	Knowledge & Skills in Biodiversity Management (**KSBM**)	Enhances farmer capacity to implement biodiversity measures effectively (R1, R3).
	Financial Incentives (**FI**)	Supports the economic feasibility of biodiversity-friendly farming, ensuring long-term adoption (R2).
	Biodiversity Quality on Farmland (**BQF**)	A core indicator of ecosystem health and resilience, reinforcing sustainability efforts (R1, R2).
	Advisory Services (**AS**)	Provides guidance and technical support for biodiversity conservation (R1).
	Policy Adjustments (**BFPA**)	Ensures policies are aligned with biodiversity enhancement objectives, reinforcing systemic stability (R1, R2).
	Stakeholder Collaboration (**SC**)	Strengthens cross-sectoral cooperation for biodiversity conservation, accelerating systemic knowledge transfer (R3).
Base Tier	Food & Feed Production (**FFP**)	Balances biodiversity conservation with agricultural productivity.
	Other Environmental Benefits (**OEB**)	Measures additional ecosystem services such as CO_2 reduction.

CS3 – Switzerland: Biodiversity Promotion Using Locally Adapted Practices Highlights

Central Variable: Uptake of Biodiversity Measures by Farmers (UBMF)
Thematic Pathway: Low-Input Agriculture
Other Thematic Pathway possible alignment: None

Low-Input Agriculture Pathway – Rationale:
This case study focuses on increasing the adoption of biodiversity-friendly practices through a locally adapted approach that enhances ecological resilience while reducing input dependency. Systemic dynamics reveal three key reinforcing loops: (1) policy and financial incentives encourage uptake, which in turn justifies further support; (2) advisory services and training build farmer capacity, sustaining adoption; (3) biodiversity improvements generate ecological benefits that reinforce sustainable practices. These are counterbalanced by barriers such as cultural resistance, insufficient localized policy design, and knowledge gaps.

7.1.4 CS4 – France: Promoting Protein Autonomy in French Livestock Farms

1. Introduction of Case Study

The transition towards protein autonomy in French livestock farms is a critical step in reducing reliance on imported protein sources, improving economic resilience, and promoting sustainable livestock systems. By fostering the use of local feed sources (LFS) and supporting pasture-based livestock management, this case study explores the systemic enablers and barriers to achieving protein self-sufficiency.

2. Systemic Challenges

Several systemic lock-ins, identified through structural equivalence analysis and adjacency matrix assessments (Ottaviani Aalmo et al., 2024), hinder the adoption and long-term sustainability of protein autonomy in livestock systems. The pivotal lock-ins for CS4 are:

- *Economic Dependency on Imported Protein Sources*: the cost-effectiveness of imported soy compared to locally grown protein crops limits shifts toward self-sufficiency.
- *Regulatory barriers*: inconsistent national protein strategies and policy frameworks fail to provide long-term stability for local feed production
- *Cultural resistance:* large-scale feed processors maintain control over supply chains, limiting farmer autonomy in protein crop selection.
- *Technological lock-ins:* the lack of local feed processing and storage infrastructure makes imported feed more economically viable.
- *Knowledge Gaps:* farmers lack training in pasture-based feeding strategies and protein crop rotations, reducing adoption rates.

These challenges reinforce reliance on external feed sources, making it difficult to achieve full protein autonomy.

Central Variable: Local Feed Source

3. *Rationale for identifying LFS as the Central Variable*

Through Causal Loop Diagram (CLD) analysis, the transition to local protein autonomy was mapped by identifying reinforcing feedback loops that shape adoption and sustainability. The Local Feed Sources (LFS) (Ottaviani Aalmo et al., 2024) was identified as the central systemic variable, directly influencing economic viability, policy incentives, and pasture management. The study highlights six reinforcing loops (feed autonomy, economic incentives, market stability, infrastructure development, policy support, and community engagement) that facilitate adoption. By understanding these systemic interactions, this case study provides a framework for improving policy alignment, farmer education, and infrastructure investment to enhance protein self-sufficiency in livestock farming.

4. Alignment with Livestock Extensification pathway

5. Feedbacks Loops

Following the ENFASYS T2.3 SDM protocol, the systemic analysis of protein autonomy in livestock systems identified six reinforcing loops (R1-R5, R7) as the primary mechanisms influencing adoption dynamics:

FL-R1 - Local Feed Sources Loop (Reinforcing)

- Pathway: Local Feed Sources (LFS) → Enhanced Pasture Management (EPM) → Market Dependency Reduction (MDR) → (Feedback) LFS
- Systemic Role: Increasing the use of local feed improves pasture management, reducing reliance on imported protein sources and stabilizing self-sufficiency in feed production.

FL-R2 - Economic Incentives Loop (Reinforcing)

- Pathway: Economic Incentives (EI) → Local Feed Sources (LFS) → Enhanced Pasture Management (EPM) → Market Dependency Reduction (MDR) → (Feedback) EI
- Systemic Role: Financial support accelerates the transition to sustainable, local feed production, ensuring that profitability and stability reinforce long-term adoption.

FL-R3 - Market Stabilization Tools Loop (Reinforcing)

- Pathway: Market Stabilization Tools (MST) → Local Feed Sources (LFS) → Economic Incentives (EI) → (Feedback) MST
- Systemic Role: Market stabilization tools provide income predictability, ensuring that livestock farmers can adopt and maintain pasture-based feeding systems.

FL-R4 - Infrastructure Development Loop (Reinforcing)

- Pathway: Infrastructure Development (ID) → Local Feed Sources (LFS) → Sustainable Agriculture Policies (SAP) → (Feedback) ID
- Systemic Role: Investments in storage and processing facilities enhance feed autonomy by facilitating on-farm production and reducing reliance on external inputs.

FL-R5 - Sustainable Agriculture Policies Loop (Reinforcing)

- Pathway: Sustainable Agriculture Policies (SAP) → Enhanced Pasture Management (EPM) → Local Feed Sources (LFS) → (Feedback) SAP
- Systemic Role: Regulatory frameworks encourage pasture-based feeding, ensuring alignment between policy objectives and low-input livestock systems.

FL-R7 - Community Engagement Loop (Reinforcing)

- Pathway: Education & Community Engagement (ECE) → Local Feed Sources (LFS) → Extension Services (ES) → (Feedback) ECE
- Systemic Role: Strengthening farmer education and community involvement fosters knowledge-sharing and long-term adoption of local feed sources.

These feedback loops illustrate the systemic interplay between economic, regulatory, and social factors, ensuring protein autonomy can be sustained within livestock farming.

6. Identified Variables

The selection of variables follows the (J. C. Rocha et al., 2019) and (Meadows, 2009) framework, ensuring a clear distinction between globally influential variables and those with more localized effects.

Table 7 - Identified Key Variables CS4

Variable	Acronym	Systemic Role
Local Feed Sources	**LFS**	A core driver of protein autonomy, reducing reliance on imported soy.
Economic Incentives	**EI**	Supports the transition by mitigating financial risks.
Market Stabilization Tools	**MST**	Ensures stable income and encourages sustainable practices.
Infrastructure Development	**ID**	Improves logistics for local feed processing and storage.
Sustainable Agriculture Policies	**SAP**	Establishes regulatory support for sustainable feed production.
Enhanced Pasture Management	**EPM**	Improves soil health and reduces feed dependency.
Market Dependency Reduction	**MDR**	Decreases reliance on volatile global feed markets.
Indicator-Based Monitoring	**IBM**	Tracks the effectiveness of extensification policies over time.
Extension Services	**ES**	Facilitates farmer education on sustainable feed practices.
Skills Enhancement for Legume Cultivation	**SELC**	Improves technical knowledge required for growing protein crops.
Education & Community Engagement	**ECE**	Strengthens awareness and farmer participation in sustainable transitions.
Resilience Building	**RB**	Enhances system adaptability through diversified production models.

7. Hierarchical Structure of Variables and Their Systemic Role

The variables have been hierarchized into three levels following the (J. C. Rocha et al., 2019) and (Meadows, 2009) framework.

Table 8 - Hierarchical Structure of Variables and Respective Systemic Role CS4

Tier	Variable	Systemic Role
Top Tier	Local Feed Sources (**LFS**)	Core driver of protein autonomy, reducing reliance on imported soy, and a key factor in feedback loops (R1, R2, R3).
Intermediate Tier	Economic Incentives (**EI**)	Supports financial sustainability by mitigating transition risks.
	Market Stabilization Tools (**MST**)	Ensures stable income and encourages sustainable practices.
	Infrastructure Development (**ID**)	Improves logistics for local feed processing and storage.
	Sustainable Agriculture Policies (**SAP**)	Provides regulatory support to sustain protein autonomy efforts.
	Enhanced Pasture Management (**EPM**)	Improves soil health, reinforcing system sustainability (R1, R5).
	Market Dependency Reduction (**MDR**)	Decreases reliance on volatile global feed markets, ensuring long-term stability.
	Indicator-Based Monitoring (**IBM**)	Tracks the effectiveness of extensification policies over time.
	Extension Services (**ES**)	Strengthens farmer education on sustainable feed practices.
Base Tier	Skills Enhancement for Legume Cultivation (**SELC**)	Improves technical knowledge for transitioning to protein autonomy.
	Education & Community Engagement (**ECE**)	Increases farmer participation in sustainable transitions.
	Resilience Building (**RB**)	Enhances system adaptability through diversified production models.

CS4 – France: Promoting Protein Autonomy in French Livestock Farms Highlights

Central Variable: Local Feed Sources (LFS)
Thematic Pathway: Livestock System Extensification
Other Thematic Pathway possible alignment: Low-Input Agriculture – The case also contributes to the Low-Input Agriculture pathway by promoting pasture-based systems and legume cultivation, which reduce dependence on external synthetic inputs.

Livestock Extensification Pathway – Rationale:
This case study aims to reduce dependency on imported soy by promoting protein autonomy through the adoption of local feed sources and pasture-based management. The systemic dynamics are structured around six reinforcing feedback loops that link financial incentives, infrastructure development, market stability, policy alignment, and community engagement. These loops interact to create enabling conditions for extensification, such as improved pasture quality, reduced market dependency, and increased knowledge among farmers.

7.1.5 CS5 – Germany: Creating Regional Production-Consumption Cycles / Sustainable Pig Farming

1. Introduction to the Case Study

Sustainable pig farming in Germany is increasingly driven by regional production-consumption cycles, which aim to enhance environmental sustainability, improve animal welfare, and strengthen economic resilience. A critical challenge in this transition is ensuring that farmers adopt sustainable practices, while maintaining market competitiveness and supply chain stability.

2. Systemic Challenges

Several systemic lock-ins, identified through structural equivalence analysis and adjacency matrix assessments (Ottaviani Aalmo et al., 2024), limit the transition toward regional, extensified pig farming models:

- *Economic Dependencies:* Farmers rely on high-input, conventional systems that ensure profitability and financial stability.
- *Regulatory Barriers:* Strict certification requirements create financial and administrative burdens, slowing adoption.
- *Cultural Resistance:* Large agribusiness and supply chain actors influence farmer decision making limiting transition to sustainable practices.
- *Technological Lock-ins:* Existing infrastructure and equipment are optimized for intensive production, making transitions costly.
- *Market conditions:* External price fluctuations and inconsistent consumer demand for sustainable pork affect financial viability.
- *Knowledge Gaps:* Limited training and advisory services slow farmer understanding and adoption of sustainable practices.

These constraints reinforce reliance on intensive production models, delaying system-wide adoption of extensified pig farming practices.

3. Systemic Analysis

Through Causal Loop Diagram (CLD) analysis, the transition to regionalized, sustainable pig farming was mapped by identifying reinforcing and balancing feedback loops shaping adoption and sustainability.

The Farmer Proposals and Adoption Practices (FP+ARSP) (Ottaviani Aalmo et al., 2024) was identified as the central systemic variable, directly influencing regional feed production, animal welfare, profitability, and value chain development.

This study highlights two reinforcing loops (certification & value chains, sustainable practices & profitability) that support adoption, along with one balancing loop (market adjustments & external pressures).

By understanding these systemic interactions, this case study provides a framework for improving regulatory adaptability, market incentives, and infrastructure investment to support the transition toward extensified, regionally integrated pig farming.

Central Variable: Farmer Proposals and Adoption Practices (FP+ARSP)

Rationale for Identifying FP+ARSP as the Central Variable

- High Systemic Connectivity → FP+ARSP appears in multiple feedback loops, both reinforcing (R1, R2) and balancing (B1), confirming its critical role in shaping the transition toward sustainable pig farming.

- Direct Impact on Key Dynamics → FP+ARSP determines the extent of farmer engagement in sustainable practices, directly influencing regional feed autonomy (RFP), financial viability (via Profitability P), and consumer demand (via CWTP).
- Out-Degree Centrality Indicators → FP+ARSP has the highest number of outgoing connections

4. Alignment to Livestock System Extensification Pathway

5. Feedback Loops

Following the ENFASYS T2.3 SDM protocol, the systemic analysis identified two reinforcing loops (R1-R2) and one balancing loop (B1) as the primary mechanisms influencing adoption dynamics:

FL-R1 - Certification and Value Chain Enhancement Loop (Reinforcing)

- Pathway: FP+ARSP → Animal Husbandry System (AHS) → Animal Welfare Systems (AWS) → Certification (CERT) → Regional Quality Label (RQL) → Value Chain Development (VCD) → Actor Influence (AI) → (Feedback) FP+ARSP

- Systemic Role: Strengthening certification and quality labelling mechanisms promotes regionalized, ethical pig production, ensuring that sustainable farming practices become profitable and widely adopted.

FL-R2 - Integrated Sustainable Practices and Profitability Loop (Reinforcing)

- Pathway: FP+ARSP → Arable Production System (APS) → Regional Feed Production (RFP) → AHS → AWS → CERT → RQL → Consumer Willingness to Pay (CWTP) → Profit (P) → (Feedback) FP+ARSP

- Systemic Role: A shift to sustainably produced feed and livestock management enhances market value, ensuring that profitability reinforces further sustainability investments.

FL-B1 - Market Adjustment Loop (Balancing)

- Pathway: External Market Factors (EMF) → Value Chain Development (VCD) → Actor Influence (AI) → FP+ARSP → Profit (P) → (Feedback) EMF

- Systemic Role: External economic pressures moderate the pace of adoption, necessitating market stabilization strategies to ensure sustainability investments remain viable.

6. Identified Variables

The selection of variables follows the(J. C. Rocha et al., 2019) and (Meadows, 2009) framework, ensuring a clear distinction between globally influential variables and those with more localized effects.

Table 9 - Identified Key Variables CS5

Variable	Acronym	Systemic Role
Farmer Proposals and Adoption Practices	**FP+ARSP**	Reflects farmer-led transitions to sustainable practices.
Regional Feed Production	**RFP**	Reduces dependency on imported feed, supporting extensification.
Animal Welfare Systems	**AWS**	Enhances sustainability and aligns with consumer expectations.
Value Chain Development	**VCD**	Strengthens the economic viability of regionalized pig farming systems.
Actor Influence	**AI**	Determines the role of stakeholders in shaping sustainable transitions.
External Market Factors	**EMF**	Captures external economic pressures affecting sustainability.

Variable	Acronym	Systemic Role
Consumer Willingness to Pay	**CWTP**	Drives demand for sustainably produced pork, influencing profitability.
Government Funding Support	**GFS**	Provides financial incentives for farmers adopting sustainability measures.
Environmental Impact	**EI**	Measures the ecological benefits of transitioning to sustainable pig farming.
Profitability	**P**	Economic feasibility influences farmer participation in sustainability.
Arable Production System	**APS**	Supports regional feed autonomy for pig production.
Animal Husbandry System	**AHS**	Implements sustainable livestock management practices.
Certification	**CERT**	Provides market recognition for sustainably produced pork.
Perceived Regulatory Risk	**PRR**	Determines farmer willingness to comply with new sustainability standards.
Regional Quality Label	**RQL**	Market tool for distinguishing sustainable products and increasing profitability.

7. Hierarchical Structure of Variables and Their Systemic Role

The variables have been hierarchized into three levels following the (J. C. Rocha et al., 2019)and (Meadows, 2009) framework.

Table 10 - Hierarchical Structure of Variables and Respective Systemic Role CS5

Tier	Variable	Systemic Role
Top Tier	Farmer Proposals and Adoption Practices (**FP+ARSP**)	The central variable, driving systemic change by influencing sustainability transitions in pig farming.
Intermediate Tier	Animal Husbandry System (**AHS**)	Implements sustainable livestock management practices (R1, R2).
	Animal Welfare Systems (**AWS**)	Enhances sustainability and aligns with consumer expectations (R1, R2).
	Arable Production System (**APS**)	Supports regional feed autonomy for pig production (R2).
	Certification (**CERT**)	Provides market recognition for sustainably produced pork (R1, R2).
	Consumer Willingness to Pay (**CWTP**)	Drives demand for sustainably produced pork, influencing profitability (R2).
	External Market Factors (**EMF**)	Captures external economic pressures affecting sustainability (B1).
	Profitability (**P**)	Economic feasibility influences farmer participation in sustainability (R2, B1).
	Regional Feed Production (**RFP**)	Reduces dependency on imported feed, supporting extensification (R2).
	Regional Quality Label (**RQL**)	Market tool for distinguishing sustainable products and increasing profitability (R1, R2).
	Value Chain Development (**VCD**)	Strengthens the economic viability of regionalized pig farming systems (R1, B1).
	Actor Influence (**AI**)	Determines the role of stakeholders in shaping sustainable transitions (R1, B1).
Base Tier	Policy Requirements (**PR**)	Establishes regulatory conditions that influence farmer decision-making.
	Government Funding Support (**GFS**)	Provides financial incentives for farmers adopting sustainability measures.
	Environmental Impact (**EI**)	Measures the ecological benefits of transitioning to sustainable pig farming.

Tier	Variable	Systemic Role
	System Trust (**ST**)	Strengthens farmer confidence in long-term sustainability transitions.
	Policy Dialogue (**PD**)	Facilitates regulatory negotiations for sustainable farming.
	Perceived Regulatory Risk (**PRR**)	Determines farmer willingness to comply with new sustainability standards.
	Constantly Changing Regulations (**CCR**)	Regulatory instability affects farmer investment in sustainability.

This hierarchical structuring ensures that the most influential variables are emphasized, supporting thematic CLD development and further systemic modelling.

CS5 – Germany: Creating Regional Production-Consumption Cycles Highlights

Central Variable: Farmer Proposals and Adoption Practices (FP+ARSP)
Thematic Pathway: Livestock System Extensification
Other Thematic Pathway – possible alignment: Low-Input Agriculture – The shift toward regional feed autonomy and reduced reliance on imported soy aligns with low-input principles, as it reduces external inputs in pig farming systems.

Livestock Extensification Pathway – Rationale:
This case study focuses on transitioning pig farming from intensive models toward more sustainable, regionally integrated systems that prioritize animal welfare, environmental impact reduction, and supply chain resilience. Systemic dynamics are organized around two reinforcing loops: (1) certification and regional quality labels strengthen value chains and profitability; (2) integration of sustainable feed and welfare practices increases market value and reinforces adoption. A balancing loop highlights the moderating effect of market volatility and actor influence.

7.1.6 CS6 – Greece: Influence of consumer branding and selling strategies on the expansion of organic products

1. Introduction to the Case Study

The transition to sustainable agricultural practices requires systemic transformations in market access, consumer engagement, and producer cooperation. This case study examines how consumer branding and selling strategies influence the expansion of organic products across the EU, with a focus on Greece. By mapping feedback mechanisms, this study identifies key systemic lock-ins, reinforcing loops, and balancing dynamics that shape market expansion for sustainable consumer goods.

2. Systemic Challenges

Several systemic constraints hinder the expansion of organic and sustainable consumer products in Greece:

- *Fragmented Transportation and Logistics:* High logistics costs and weak distribution networks limit the availability of organic products.
- *Limited Access to Digital Technologies:* Small producers struggle with investment in digital marketing and traceability tools.
- *Consumer Mistrust and Lack of Awareness:* Consumers often do not recognize the added value of sustainable products, reducing demand.

- *High Market-Related Barriers:* Certification costs, regulatory complexity, and market entry constraints slow adoption.
- *Insufficient Cooperative Efforts:* Weak producer collaboration reduces economies of scale, making organic markets less competitive.

These structural lock-ins reinforce reliance on conventional products and limit the transition to sustainable branding.

3. Systemic Analysis

Using Causal Loop Diagram (CLD) analysis, the study identified key reinforcing and balancing feedback loops shaping market access and consumer engagement in sustainable agriculture.

Central Variable: Market Access for Organic Products (MAOP)

Following structural equivalence analysis and adjacency matrix assessments, MAOP was identified as the most influential variable due to its direct influence on key consumer and producer dynamics.

Rationale for Identifying MAOP as the Central Variable

- High Systemic Connectivity → MAOP appears in multiple feedback loops (R1, R2, R3) and balancing constraints (B1).
- Direct Impact on Key Dynamics → MAOP shapes consumer demand, producer cooperation, and distribution logistics.
- Out-Degree Centrality Indicators → MAOP has the highest number of outgoing connections, influencing variables such as Consumer Education (CE), Distribution of Organic Products (DOP), and Market-Related Barriers (MRB).

4. Alignment to Sustainable Consumer Branding and Selling pathway.

5. Feedback Loops

R1 - Consumer Demand Loop (Reinforcing)

- Pathway: Consumer Education (CE) → Willingness to Pay (WTP) → Market Access for Organic Products (MAOP) → (Feedback) CE
- Relevance to Sustainable Consumer Branding and Selling: Raising awareness increases demand, reinforcing product availability and continued consumer engagement.

R2 - Market Access Loop (Reinforcing)

- Pathway: Market Access for Organic Products (MAOP) → Distribution of Organic Products (DOP) → Entry of Organic Products (EOP) → Cooperation Among Small Producers (CSP) → (Feedback) MAOP
- Relevance to Sustainable Consumer Branding and Selling: Expanding market access improves distribution, encourages producer participation, and sustains organic market growth.

R3 - Knowledge and Training Loop (Reinforcing)

- Pathway: Knowledge and Training in Sustainable Practices (KTSP) → Investment in Digital Agriculture Technologies (IDAT) → (Feedback) KTSP
- Relevance to Sustainable Consumer Branding and Selling: Strengthening knowledge transfer increases digital investment, market efficiency, and product traceability.

R4 - Sustainable Practices Loop (Reinforcing)

- Pathway: Practices to Reduce Fertilizers (PRF) → Market Stability (MS) → (Feedback) PRF
- Relevance to Sustainable Consumer Branding and Selling: Reducing fertilizer use enhances environmental branding, ensuring long-term market sustainability.

R5 - Logistics and Cooperation Loop (Reinforcing)

- Pathway: Transportation and Logistics Challenges (TLC) → Cooperation Among Small Producers (CSP) → (Feedback) TLC
- Relevance to Sustainable Consumer Branding and Selling: Addressing logistics inefficiencies improves supply chain collaboration, increasing organic market penetration.

6. Identified Variables

The identification of central variables follows the Rocha et al. (2019) and Meadows (2009) framework, ensuring that systemic influences are prioritized. The selection was based on:

The table below presents the key identified variables and their systemic roles:

Table 11 - Identified Key Variables CS6

Variable	Acronym	Systemic Role
Market Access for Organic Products	MAOP	Key determinant of the scalability of sustainable consumer goods.
Consumer Education	CE	Drives demand through awareness campaigns.
Willingness to Pay	WTP	Indicates consumer readiness to support sustainable agriculture financially.
Distribution of Organic Products	DOP	Ensures effective logistics for organic product penetration.
Entry of Organic Products	EOP	Measures the expansion of sustainable product availability.
Transportation and Logistics Challenges	TLC	Addressing bottlenecks improves organic product distribution.
Cooperation Among Small Producers	CSP	Strengthens producer networks for efficient supply chains.
Investment in Digital Agriculture Technologies	IDAT	Improves market efficiency and traceability.
Practices to Reduce Fertilizers	PRF	Enhances environmental branding and stability.
Market Stability	MS	Ensures stable supply and demand for sustainable products.
Market-Related Barriers	MRB	Identifies obstacles to expanding sustainable product markets.
Knowledge and Training in Sustainable Practices	KTSP	Enhances adoption of sustainable techniques and branding opportunities.

7. Hierarchical Structure of Variables and Their Systemic Role

To facilitate systemic archetype analysis, variables were categorized based on their systemic influence, following the Rocha et al. (2019) and Meadows (2008) framework.

Table 12 - Hierarchical Structure of Variables and Respective Systemic Role CS6

Tier	Variable	Systemic Role
Top Tier (Primary Driver of Systemic Change)	**Market Access for Organic Products (MAOP)**	The key determinant of sustainable consumer goods scalability, present in multiple reinforcing loops (R2 & R3).

Tier	Variable	Systemic Role
Intermediate Tier (Reinforcing Systemic Dynamics)	**Practices to Reduce Fertilizers (PRF)**	Reducing chemical inputs enhances the environmental branding of products.
	Market Stability (MS)	Ensures stable supply and demand for sustainable products.
	Transportation and Logistics Challenges (TLC)	Addressing logistics bottlenecks improves organic product distribution.
	Cooperation Among Small Producers (CSP)	Strengthens producer networks for efficient supply chains.
	Investment in Digital Agriculture Technologies (IDAT)	Improves market efficiency and traceability for organic products.
	Knowledge and Training in Sustainable Practices (KTSP)	Enhances adoption of sustainable techniques and branding opportunities.
	Consumer Education (CE)	Drives demand for sustainable products through awareness campaigns.
	Willingness to Pay (WTP)	Indicates consumer readiness to support sustainable agriculture financially.
	Entry of Organic/Biological Products (EOP)	Measures the expansion of sustainable product availability.
	Distribution of Organic/Biological Products (DOP)	Ensures effective logistics for organic product penetration.
Base Tier (Constraints and Supporting Factors)	**Market-Related Barriers (MRB)**	Identifies obstacles to expanding organic and sustainable product markets.

CS6 – Greece: Influence of Consumer Branding and Selling Strategies on the Expansion of Organic Products

Central Variable: Market Access for Organic Products (MAOP)
Thematic Pathway: Sustainable Consumer Branding and Selling
Low-Input Agriculture – While not the primary focus, this case touches on low-input dynamics by incentivizing reduced fertilizer use through consumer preferences and branding strategies that reward environmentally friendly practices.

Sustainable Consumer Branding and Selling Pathway – Rationale:
This case study addresses the systemic conditions enabling the expansion of sustainable consumer markets by focusing on organic product branding, distribution, and consumer engagement in Greece. It maps five reinforcing feedback loops, including mechanisms linking consumer education to willingness to pay, market access to producer cooperation, and digital innovation to market efficiency. These dynamics are key to scaling organic production through improved traceability, collaboration among small producers, and effective logistics

7.1.7 CS7- Slovenia: direct selling models adoption

1. Introduction to the Case Study

The adoption of direct selling models in Slovenian agriculture represents a key strategy for strengthening short supply chains, increasing economic resilience for small farmers, and enhancing consumer-producer relationships. This case study examines the systemic factors influencing direct selling adoption, focusing on market access, consumer trust, and policy support.

Through the analysis of reinforcing and balancing loops, this study provides insights into how direct selling can be expanded in Slovenia, addressing barriers and systemic lock-ins that limit its growth.

2. Systemic Challenges

Several structural barriers hinder the widespread adoption of direct selling models among Slovenian farmers:

- *Economic Dependencies:* Farmers require continuous reinvestment in infrastructure, limiting flexibility in adopting direct sales models.
- *Regulatory Barriers:* Strict compliance requirements hinder market entry for small-scale direct sellers.
- *Cultural Resistance:* Traditional farming communities remain hesitant to embrace digital marketing and direct selling approaches.
- *Technological Lock-ins:* Many small farms lack access to digital tools for optimizing direct sales.
- Market Conditions: Logistical and distribution challenges create financial barriers for scaling direct sales.
- Knowledge Gaps: Many farmers lack training in business development, consumer engagement, and direct selling strategies.

These systemic lock-ins reinforce conventional retail distribution channels, slowing down the transition to direct selling models.

3. Systemic Analysis

Using Causal Loop Diagram (CLD) analysis, key reinforcing and balancing feedback loops were identified, illustrating the interactions between direct selling adoption, consumer trust, and policy incentives.

Central Variable: Rate of Adoption of Farmers Practicing Direct Selling (RAFDS)

Following structural equivalence analysis and adjacency matrix assessments, RAFDS was identified as the most influential variable due to its systemic impact on market demand, revenue stability, and institutional support.

Rationale for Identifying RAFDS as the Central Variable

- High Systemic Connectivity → RAFDS appears in multiple reinforcing loops (R1, R2, R3) and balancing loops (B1).

- Direct Impact on Key Dynamics → RAFDS drives farmer participation, revenue generation, and consumer engagement in direct sales networks.

- Out-Degree Centrality Indicators → RAFDS influences key systemic variables, including Farmers' Revenue from Direct Selling (FRDS), Market Demand for Locally-Sourced and Organic Products (MDLSOP), and Policy Support for Direct Sales (PSDS).

4. Alignment to Sustainable Consumer Branding and Selling.

5. Feedback Loops

R1 – Training and Digital Tool Application Loop (Reinforcing)

> Pathway:
> Farmer Training and Capacity Building → Number of Farmers Using Digital Marketing Tools → Consumer Demand for Locally-Sourced and Organic Products → Farmers' Revenue from Direct Selling → Rate of Adoption of Farmers Practicing Direct Selling → Farmer Training and Capacity Building

Relevance to Sustainable Consumer Branding and Selling:
This loop emphasizes the importance of capacity building as a key driver of digital engagement and market reach. Improved training increases the use of digital marketing tools, which boosts consumer demand for local products. This, in turn, raises revenues and accelerates the adoption of direct selling models, completing the reinforcing cycle.

R2 – Direct Selling and Infrastructure Loop (Reinforcing)

Pathway:
Farmer's Profit → Investment in Direct Selling Infrastructure → Technical Support and Quality Assurance → Farmers' Revenue from Direct Selling → Farmer's Profit

Relevance to Sustainable Consumer Branding and Selling:
This loop reflects the economic backbone of direct selling systems. Higher farmer profits lead to greater investment in infrastructure and support services, improving product quality and sales. This further increases revenue and profitability, reinforcing the attractiveness and viability of direct selling practices.

B1 – Local and Organic Direct Selling Loop (Balancing)

Pathway:
Consumer Demand for Locally-Sourced and Organic Products → Farmers' Revenue from Direct Selling → Investment in Direct Selling Infrastructure → Technical Support and Quality Assurance → Consumer Demand

Relevance to Sustainable Consumer Branding and Selling:
This balancing loop ensures the system does not exceed its sustainable capacity. While demand drives revenue and investment, improved infrastructure and support may eventually stabilize or saturate consumer interest, moderating further expansion and helping maintain systemic equilibrium.

B2 – Market Equilibrium Feedback Loop (Balancing)

Pathway:
Rate of Adoption of Farmers Practicing Direct Selling → Consumer Demand for Locally-Sourced and Organic Products → Farmers' Revenue from Direct Selling → Rate of Adoption of Farmers Practicing Direct Selling

Relevance to Sustainable Consumer Branding and Selling:
This loop functions as a natural market regulator. As adoption increases, demand and revenues may reach a threshold where market saturation begins to reduce returns, slowing further growth. This feedback helps prevent over-expansion and promotes long-term stability.

6. Identified Variables

The identification of key systemic variables follows the Rocha et al. (2019) and Meadows (2008) framework, prioritizing high-impact systemic variables over localized supporting factors.

Table 13 - Identified Key Variables CS7

Variable	Acronym	Systemic Role
Rate of Adoption of Farmers Practicing Direct Selling	RAFDS	Measures the expansion of direct selling models.
Farmers' Revenue from Direct Selling	FRDS	Core indicator of economic success from direct selling.
Investment in Direct Selling Infrastructure	IDS	Facilitates logistics and market expansion for direct selling.
Farmer Training and Capacity Building	FTCB	Enhances farmers' skills in sales, marketing, and consumer engagement.

Variable	Acronym	Systemic Role
Short Supply Chain Development and Local Economy Enhancement	SSCD	Strengthens local markets and consumer relationships.
Number of Farmers Using Digital Marketing Tools	DFMT	Expands direct sales reach and market penetration.
Consumer Demand for Locally-Sourced and Organic Products	CDLSOP	Drives direct sales growth by increasing market demand.
Cost of Production and Distribution	CPD	Determines profitability and financial feasibility of direct selling.
Market Prices of Directly Sold Products	MPDSP	Higher prices improve the viability of direct selling.
Market Accessibility	MA	Improves the reach of farmers selling directly to consumers.
Consumer Engagement	CE	Builds trust and brand loyalty for direct sales.
Consumer Awareness and Trust Levels	CATL	Encourages consumer preference for direct-selling models.
Policy and Regulatory Support with Chamber Advocacy	PRCA	Strengthens institutional support for direct selling.

7. Hierarchical Structure of Variables and Their Systemic Role

To facilitate systemic archetype analysis, variables were categorized into hierarchical tiers based on their role in feedback loops and systemic influence.

Table 14 - Hierarchical Structure of Variables and Respective Systemic Role CS7

Tier	Variable	Systemic Role
Top Tier (Primary Driver of Systemic Change)	**Rate of Adoption of Farmers Practicing Direct Selling (RAFDS)**	Measures the expansion of direct selling models, present in multiple reinforcing loops (R1, R2, R3).
Intermediate Tier (Reinforcing Systemic Dynamics)	**Farmers' Revenue from Direct Selling (FRDS)**	Core economic driver of direct selling.
	Investment in Direct Selling Infrastructure (IDS)	Facilitates logistics and market expansion.
	Farmer Training and Capacity Building (FTCB)	Enhances marketing and consumer engagement skills.
	Consumer Demand for Locally-Sourced and Organic Products (CDLSOP)	Increases direct sales market viability.
Base Tier (Constraints and Supporting Factors)	**Market Prices of Directly Sold Products (MPDSP)**	Determines economic feasibility of direct selling.
	Consumer Engagement (CE)	Strengthens brand trust.
	Policy and Regulatory Support with Chamber Advocacy (PRCA)	Ensures institutional support for direct selling.

CS7 – Slovenia: Direct Selling Models Adoption Highlights

Central Variable: Rate of Adoption of Farmers Practicing Direct Selling (RAFDS)
Thematic Pathway: Sustainable Consumer Branding and Selling
Other Thematic Pathway possible alignment: None

Sustainable Consumer Branding and Selling Pathway – Rationale:
This case study focuses on enabling the transition toward short food supply chains and direct farmer-to-consumer models in Slovenia. The systemic dynamics include two reinforcing feedback loops: (1) training and digitalization that expand consumer demand and drive adoption; (2) profitability that feeds investment in infrastructure and quality, sustaining market performance. Two balancing loops reveal systemic saturation points: consumer demand and market equilibrium naturally moderate overexpansion.

7.1.8 CS8 – Italy – Community Supported Agriculture (CSA)

1. Introduction to the Case Study

The Community-Supported Agriculture (CSA) model in Italy, represented by Arvaia in Emilia-Romagna, exemplifies a sustainable agricultural approach centered on environmental stewardship, social equity, and economic viability. Functioning as a non-hierarchical, solidarity-based cooperative, Arvaia promotes community engagement, where consumers and growers share responsibilities and benefits.

2. Systemic Challenges

Several systemic lock-ins hindered by Ottaviani Aalmo et. Al (2024) influence Arvaia's stability and expansion:

- Economic dependency on membership fees and municipal land leases, limiting investment capacity.
- Regulatory barriers due to short-term land leases, restricting long-term infrastructure planning.
- Volunteer engagement fluctuations, impacting labour availability and operational efficiency.
- Unstable market demand for organic products, affecting financial sustainability.

3. Systemic Analysis

Through Causal Loop Diagram (CLD) analysis, Arvaia's operational model has been mapped to identify key reinforcing and balancing feedback loops that influence its sustainability. The Rate of CSA Adoption (RCSAA) (Ottaviani Aalmo et al., 2024) has been identified as the central systemic variable, directly shaping financial viability, community engagement, and land-use dynamics. The study highlights reinforcing loops (volunteer engagement, worker training, and organic market demand) that support CSA expansion, alongside balancing loops (land rent costs and certification constraints) that regulate growth.

By understanding these systemic dynamics, Arvaia's cooperative model serves as a blueprint for resilient, community-driven food systems, demonstrating how collective engagement and sustainable agricultural practices can contribute to long-term food security and environmental preservation.

Central Variable: Rate of CSA Adoption (RCSAA)

The structural analysis of the CLD (Ottaviani et al., 2024), combined with out-degree centrality (Rocha et al., 2020), has identified Rate of CSA Adoption (RCSAA) as the most influential variable in the system.

Rationale for Identifying RCSAA as the central variable

- High systemic connectivity: RCSAA appears in multiple feedback loops, both reinforcing (R1, R3) and balancing (B1).

- Direct impact on key dynamics: It determines financial stability (via membership fees), community engagement, and CSA operational sustainability.
- Out-degree centrality indicators: RCSAA has the highest number of outgoing connections in the systemic network, influencing other key variables such as Total Annual Revenue from Membership Fees (TARMF), Market Demand for Organic Products (MDOP), and Volunteer Engagement Rate (VER).

4. Alignment with Sustainable Consumer Branding and Selling Pathway

5. Feedback Loops

The identification of systemic dynamics and key feedback loops within the CSA model in Italy was conducted following the structured methodology outlined in the ENFASYS T2.3 System Dynamic Model (SDM) protocol. This approach ensured that the systemic relationships were rigorously validated and aligned with the Sustainable Consumer Branding and Selling pathway.

The key feedback loops, in the context of sustainable consumer branding and selling, identified are:

FL-R1 - Community Engagement and Volunteer Participation (Reinforcing)

- Pathway: NCE → PRCE → VER → TNVSH → RCSAA → (positive feedback) NCE
- Systemic Role: Higher engagement strengthens operational sustainability.

FL-R2 - Training and Economic Stability (Reinforcing)

- Pathway: WTL → TNVSH → (positive feedback) WTL
- Systemic Role: Increased training enhances productivity and economic resilience.

FL-R3 - Organic Market Demand and CSA Growth (Reinforcing)

- Pathway: RCSAA → PEFS → WTL → PBD → MDOP → RCSAA
- Systemic Role: Organic product demand sustains CSA growth.

FL-B1 - Balancing Land Cost and Membership Fees Revenue (Balancing)

- Pathway: ALRC → TARMF → RCSAA → CLA → (negative feedback) ALRC
- Systemic Role: The system self-regulates to avoid financial imbalances.

6. Identified Variables

Table 15 - Identified Key Variables CS8

Variable	Acronym	Systemic Role
Rate of CSA Adoption	RCSAA	Core indicator of CSA stability and long-term growth
Cultivated Land Area	CLA	Determines production scale and financial sustainability
Annual Land Rent Cost	ALRC	Influences financial planning and membership fee structuring
Organic Certification Status	OCS	Enhances CSA appeal and supports sustainable branding
Production and Biodiversity Index	PBI	Measures crop diversity and ecological health of CSA
Total Number of Volunteers and Staff Hours	TNVSH	Determines CSA labor availability and efficiency
Worker Training Levels	WTL	Improves operational skills and productivity
Availability of Training Courses	ATC	Expands capacity-building opportunities for CSA workers

Variable	Acronym	Systemic Role
Volunteer Engagement Rate	VER	Ensures sufficient community participation in CSA operations
Number of Community Events	NCE	Strengthens social cohesion and CSA engagement
Participation Rate in Community Events	PRCE	Measures community involvement and engagement
Membership Fees	MF	Core revenue stream influencing CSA financial stability
Total Annual Revenue from Membership Fees	TARMF	Determines CSA financial sustainability
Market Demand for Organic Products	MDOP	External market influence on CSA membership and demand
Policy and External Funding Support	PEFS	Supports financial and operational stability of the CSA

7. Hierarchical Structure of Variables and Their Systemic Role

The variables have been hierarchized into three levels following the (J. C. Rocha et al., 2019) and (Meadows, 2009) framework, based on out-degree centrality, presence in feedback loops, and systemic impact validated by Ottaviani et al. (2024).

Table 16 - Hierarchical Structure of Variables and Respective Systemic Role CS8

Tier	Variable	Systemic Role
Top tier	Rate of CSA Adoption (**RCSAA**)	Core indicator of CSA stability and growth, present in key feedback loops (R1, R3).
Intermediate tier	Number of Community Events (**NCE**)	Strengthens social cohesion and CSA engagement.
	Participation Rate in Community Events (**PRCE**)	Determines active engagement levels within the CSA.
	Volunteer Engagement Rate (**VER**)	Directly impacts operational capacity and labor availability.
	Total Number of Volunteers and Staff Hours (**TNVSH**)	Measures human capital available for CSA operations.
	Worker Training Levels (**WTL**)	Enhances workforce skills and productivity.
	Policy and External Funding Support (**PEFS**)	Ensures long-term stability by providing access to external resources.
	Availability of Training Courses (**ATC**)	Expands training and professional development opportunities.
	Production & Biodiversity Diversity (**PBD**)	Measures crop diversity and environmental impacts.
	Annual Land Rent Cost (**ALRC**)	Critical factor for the CSA’s financial sustainability.
	Market Demand for Organic Products (**MDOP**)	Determines CSA membership growth potential.
	Total Annual Revenue from Membership Fees (**TARMF**)	Primary financial sustainability measure, linked to B1 loop.
Base tier	Cultivated Land Area (**CLA**)	Defines production capacity and agricultural sustainability.
	Membership Fees (**MF**)	Core revenue stream for CSA sustainability.
	Environmental Impact Score (**EIS**)	Assesses CSA’s environmental benefits and performance.

CS8 – Italy: Community Supported Agriculture (CSA) Highlights

Central Variable: Rate of CSA Adoption (RCSAA)
Thematic Pathway: Sustainable Consumer Branding and Selling
Other Thematic Pathway – possible alignment: Low-Input Agriculture – The CSA model promotes agroecological practices such as crop diversification, soil health, and reduced input use, aligning with the goals of low-input farming.

Sustainable Consumer Branding and Selling Pathway – Rationale:
This case study explores how a solidarity-based CSA model can drive sustainable food systems by reinforcing direct relationships between producers and consumers, community engagement, and local food access. The system is structured around three reinforcing loops: community participation and volunteerism support operations (R1), training improves efficiency and resilience (R2), and market demand sustains growth (R3). A balancing loop (B1) highlights the tension between land rent costs and membership revenue.

7.1.9 CS9 – Ireland: Organic dairy farming

1. Introduction to the Case Study

The transition to organic dairy farming in Ireland is a key strategy to enhance economic viability, environmental sustainability, and policy alignment. This case study examines systemic factors influencing organic dairy expansion, focusing on conversion practices, policy support, and market demand.

By analysing reinforcing and balancing loops, this study provides insights into how organic dairy farming can be expanded in Ireland, addressing barriers and systemic lock-ins that limit its growth.

2. Systemic Challenges

Several structural barriers hinder the widespread adoption of organic dairy farming in Ireland:

- *Economic Dependencies:* Conventional dairy remains more profitable, discouraging organic conversion.
- *Regulatory Barriers:* Inconsistent policy incentives make long-term organic transition planning difficult.
- *Cultural Resistance:* Farmers accustomed to high-yield dairy production hesitate to transition to organic practices.
- *Technological Lock-ins:* Limited organic dairy processing infrastructure reduces scalability.
- *Market Conditions:* Organic dairy demand fluctuates, increasing financial risk for transitioning farmers.
- *Knowledge Gaps:* Farmers lack training in soil conservation, organic compliance, and long-term sustainability strategies.

These systemic lock-ins reinforce conventional dairy models, slowing the transition toward organic practices.

3. Systemic Analysis

Using Causal Loop Diagram (CLD) analysis, key reinforcing and balancing feedback loops were identified, illustrating the interactions between policy support, economic incentives, and farmer motivation.

Central Variable: Conversion Practices (CP)

Following structural equivalence analysis and adjacency matrix assessments, CP was identified as the most influential variable due to its systemic impact on economic returns, policy incentives, and environmental impact.

Rationale for Identifying CP as the Central Variable

- High Systemic Connectivity → CP appears in multiple reinforcing loops (R1, R2, R3, R4, R5) and a balancing loop (B1).
- Direct Impact on Key Dynamics → CP determines farmer motivation, environmental outcomes, and policy engagement.
- Out-Degree Centrality Indicators → CP influences key systemic variables, including Economic Returns (ER), Policy Support (PS), and Market Demand (MD).

4. Alignment to Low-input Agriculture Pathway

5. Feedback Loops

R1 - Economic Return Loop (Reinforcing)

- Pathway: Market Demand (MD) → Economic Returns (ER) → Farmer Motivation (FM) → Conversion Practices (CP) → (Feedback) MD

- Relevance to Low-input Agriculture: Higher organic dairy demand increases financial viability, encouraging more farmers to transition to organic dairy.

R2 - Policy Support Loop (Reinforcing)

- Pathway: Policy Support (PS) → Economic Returns (ER) → Farmer Motivation (FM) → Conversion Practices (CP) → (Feedback) PS

- Relevance to Low-input Agriculture: Government incentives accelerate organic conversion, reinforcing the environmental and economic benefits.

R3 - Training and Advisory Services Loop (Reinforcing)

- Pathway: Training and Advisory Services (TAS) → Conversion Practices (CP) → Organic Certification (OC) → Farmer Motivation (FM) → (Feedback) TAS

- Relevance to Low-input Agriculture: Knowledge dissemination increases certification rates, further driving conversion adoption.

R4 - Environmental Impact Loop (Reinforcing)

- Pathway: Conversion Practices (CP) → Environmental Impact (EI) → Policy Support (PS) → (Feedback) CP

- Relevance to Low-input Agriculture: Improved soil health and biodiversity justify increased policy support for organic systems.

R5 - Organic Certification and Conversion Loop (Reinforcing)

- Pathway: Organic Certification (OC) → Farmer Conversion Practices (CP) → Environmental Impact Reduction (EIR) → (Feedback) OC

- Relevance to Low-input Agriculture: Strengthens certification-adoption relationships, reinforcing organic transitions.

B1 - Environmental Policy Balancing Loop (Balancing)

- Pathway: Environmental Impact (EI) → Policy Support (PS) → Conversion Practices (CP) → (Feedback) EI
- Relevance to Low-input Agriculture: If environmental impact becomes too positive, policy urgency may decrease, balancing the loop.

6. Identified Variables

The identification of key systemic variables follows the (J. C. Rocha et al., 2019) and (Meadows, 2009) framework, prioritizing high-impact systemic variables over localized supporting factors.

Table 17 - Identified Key Variables CS9

Variable	Acronym	Systemic Role
Conversion Practices	CP	Directly influences adoption of organic farming methods, reducing chemical inputs.
Market Demand for Organic Dairy	MD	Encourages long-term investment in organic farming.
Economic Returns	ER	Determines financial feasibility of transitioning to organic production.
Farmer Motivation	FM	Key driver for adoption, influenced by profitability and sustainability awareness.
Policy Support	PS	Reduces conversion barriers through subsidies and regulatory incentives.
Training and Advisory Services	TAS	Enhances farmer knowledge on organic practices and soil conservation.
Organic Certification	OC	Encourages adherence to organic standards and ensures compliance with sustainability goals.
Environmental Impact	EI	Measures the positive ecological effects of organic farming (soil health, biodiversity).
Infrastructure and Processing Facilities	IPF	Supports logistics and market access for organic dairy.
Supply Chain Efficiency	SCE	Reduces logistical costs and ensures organic dairy remains competitive.

7. Hierarchical Structure of Variables and Their Systemic Role

To facilitate systemic archetype analysis, variables were categorized into hierarchical tiers based on their role in feedback loops and systemic influence.

Table 18 - Hierarchical Structure of Variables and Respective Systemic Role CS9

Tier	Variable	Systemic Role
Top Tier (Primary Driver of Systemic Change)	**Conversion Practices (CP)**	Directly influences the adoption of organic farming methods, present in multiple reinforcing loops (R1, R2, R3, R4, R5).
Intermediate Tier (Reinforcing Systemic Dynamics)	**Market Demand for Organic Dairy (MD)**	Encourages long-term investment in organic farming.
	Economic Returns (ER)	Determines financial feasibility of transitioning to organic production.
	Farmer Motivation (FM)	Key driver for adoption, influenced by profitability and sustainability awareness.

Tier	Variable	Systemic Role
	Policy Support (PS)	Reduces conversion barriers through subsidies and regulatory incentives.
	Training and Advisory Services (TAS)	Enhances farmer knowledge on organic practices and soil conservation.
	Organic Certification (OC)	Encourages adherence to organic standards and ensures compliance with sustainability goals.
Base Tier (Constraints and Supporting Factors)	**Environmental Impact (EI)**	Measures the positive ecological effects of organic farming (soil health, biodiversity).
	Infrastructure and Processing Facilities (IPF)	Supports logistics and market access for organic dairy.
	Supply Chain Efficiency (SCE)	Reduces logistical costs and ensures organic dairy remains competitive.

CS9 – Ireland: Organic Dairy Farming Highlights

Central Variable: Conversion Practices (CP)
Thematic Pathway: Low-Input Agriculture
Other Thematic Pathway –possible alignment: Livestock Extensification – Organic dairy systems rely on pasture-based, lower-intensity methods that align with extensification goals such as improved animal welfare and reduced environmental impacts.

Low-Input Agriculture Pathway – Rationale:
This case study addresses the expansion of organic dairy farming in Ireland as a strategy to reduce chemical inputs, improve soil health, and enhance long-term sustainability. The system is structured around five reinforcing loops that connect policy support, market demand, training and advisory services, environmental performance, and certification processes—all reinforcing farmers' conversion to organic practices. A balancing loop accounts for the potential reduction in policy urgency as environmental impact improves.

7.1.10 CS10 – Belgium: Organic Vegetable Farming

1. Introduction to the Case Study

The transition to organic vegetable farming in Belgium is shaped by governance structures, economic feasibility, and environmental sustainability. This case study explores systemic factors influencing the expansion of organic-certified vegetable production, focusing on policy incentives, economic drivers, and environmental impacts. By analysing reinforcing and balancing loops, this study provides insights into how organic vegetable farming can be expanded in Belgium, addressing barriers and systemic lock-ins that limit its growth.

2. Systemic Challenges

Several structural barriers hinder the expansion of organic vegetable farming in Belgium:

- *Farming System Lock-ins:* Organic farming requires systemic changes in farm management, input use, and cultivation techniques.
- *Value Chain Lock-ins:* Weak organic retail and processing infrastructure limit farm expansion and market penetration.
- *Governance Lock-ins:* Lack of long-term policy incentives and regulatory clarity slows organic conversion rates.

- *Economic and Financial Lock-ins:* High land prices and certification costs discourage farmers from transitioning.
- *Knowledge Gaps:* Farmers lack access to technical training, financial planning, and market integration strategies.

These systemic lock-ins reinforce reliance on conventional agriculture, slowing the transition to organic vegetable farming.

3. Systemic Analysis

Using Causal Loop Diagram (CLD) analysis, key reinforcing and balancing feedback loops were identified, illustrating the interactions between policy support, economic feasibility, and farming practices.

Central Variable: Governance (G)

Following structural equivalence analysis and adjacency matrix assessments, G was identified as the most influential variable due to its systemic impact on market demand, economic viability, and environmental sustainability.

Rationale for Identifying G as the Central Variable

- High Systemic Connectivity → G appears in multiple reinforcing loops (R3, R4) and a balancing loop (B1).
- Direct Impact on Key Dynamics → G regulates organic expansion, financial incentives, and sustainability standards.
- Out-Degree Centrality Indicators → G influences key systemic variables, including Market Demand (MD), Environmental Impact (EI), and Economic Factors (EF).

Alignment to Low-Input Agriculture.

4. Feedback Loops

R1 - Market Demand Loop (Reinforcing)

- Pathway: Market Demand (MD) → Organic Farming Area (OFA) → (Feedback) MD
- Relevance to Low-input Agriculture: Higher consumer demand leads to farm expansion, further reinforcing organic supply.

R2 - Environmental Impact Loop (Reinforcing)

- Pathway: Environmental Impact (EI) → Farming Practices (FP) → (Feedback) EI
- Relevance to Low-input Agriculture: Adoption of low-input farming techniques improves biodiversity and soil quality, further reinforcing sustainable farming.

R3 - Governance and Economic Factors Loop (Reinforcing)

- Pathway: Governance (G) → Economic Factors (EF) → (Feedback) G
- Relevance to Low-input Agriculture: Stronger policies create economic incentives, improving long-term profitability and reinforcing governance support.

R4 - AKIS, Farming Practices, and Governance Loop (Reinforcing)

- Pathway: AKIS → Farming Practices (FP) → Governance (G) → Value Chain (VC) → (Feedback) AKIS

- Relevance to Low-input Agriculture: Knowledge dissemination accelerates sustainable farming adoption, leading to policy improvements and stronger market linkages.

B1 - Governance and Environmental Impact Balancing Loop (Balancing)

- Pathway: Environmental Impact (EI) → Governance (G) → (Feedback) EI
- Relevance to Low-input Agriculture: Negative environmental outcomes trigger policy interventions, eventually stabilizing sustainability efforts.

5. Identified Variables

The identification of key systemic variables follows the (J. C. Rocha et al., 2019) and (Meadows, n.d.) framework, prioritizing high-impact systemic variables over localized supporting factors.

Table 19 - Identified key Variables CS10

Variable	Acronym	Systemic Role
Governance	G	Policy incentives and regulations influence organic farming adoption.
Market Demand	MD	Consumer preference for organic vegetables influences farm expansion.
Environmental Impact	EI	Captures the benefits of organic practices, such as biodiversity and soil health.
Farming Practices	FP	Adoption of sustainable techniques directly affects environmental quality.
Economic Factors	EF	Determines financial feasibility of organic farming conversion.
AKIS (Agricultural Knowledge & Innovation Systems)	AKIS	Disseminates knowledge and advisory services supporting sustainable transitions.
Value Chain	VC	Logistics, processing, and retail integration impact organic farm profitability.
Organic Farming Area	OFA	Expansion of organic farming increases environmental sustainability.

6. Hierarchical Structure of Variables and Their Systemic Role

To facilitate systemic archetype analysis, variables were categorized into hierarchical tiers based on their role in feedback loops and systemic influence.

Table 20 - Hierarchical Structure of Variables and Respective Systemic Role CS10

Tier	Variable	Systemic Role
Top Tier (Primary Driver of Systemic Change)	**Governance (G)**	Policy incentives and regulations influence organic farming adoption, present in multiple feedback loops (R3, R4, B1).
Intermediate Tier (Reinforcing Systemic Dynamics)	**Market Demand (MD)**	Consumer preference for organic vegetables influences farm expansion.
	Environmental Impact (EI)	Captures the benefits of organic practices, such as biodiversity and soil health.
	Farming Practices (FP)	Adoption of sustainable techniques directly affects environmental quality.
	Economic Factors (EF)	Determines financial feasibility of organic farming conversion.

Tier	Variable	Systemic Role
	AKIS (Agricultural Knowledge & Innovation Systems)	Disseminates knowledge and advisory services supporting sustainable transitions.
	Value Chain (VC)	Logistics, processing, and retail integration impact organic farm profitability.
Base Tier (Constraints and Supporting Factors)	**Organic Farming Area (OFA)**	Expansion of organic farming increases environmental sustainability.

CS10 – Belgium: Organic Vegetable Farming Highlights

Central Variable: Governance (G)
Thematic Pathway: Low-Input Agriculture
Other Thematic Pathway – possible alignment: Sustainable Consumer Branding and Selling – Governance and market incentives interact with consumer demand and value chain development, supporting visibility and expansion of organic produce.

Low-Input Agriculture Pathway – Rationale:
This case study addresses the transition to organic vegetable production in Belgium by focusing on systemic enablers such as governance, knowledge diffusion, and economic viability. Reinforcing loops link improved policy incentives to better economic returns and sustainable farming practices. Additional dynamics highlight how consumer demand and the expansion of organic farming area reinforce each other, while the AKIS system supports knowledge transfer and institutional feedback. A balancing loop shows how governance responds to environmental performance, creating regulatory stability.

7.2 Thematic pathways Causal Loop Diagrams (CLDs)

7.2.1 Low-Input Agriculture Casual Loop Diagram

The transition to **Low-Input Agriculture** requires a profound reconfiguration of current farming systems, as it entails not only a reduction in chemical inputs and environmental externalities, but also a rebalancing of economic, knowledge-based, and social drivers of change. The systemic nature of this transformation demands a dynamic and integrative approach capable of capturing the multiple feedback mechanisms that sustain or hinder adoption. The **Causal Loop Diagram (CLD)** developed for this thematic pathway builds upon an extensive analysis of four case studies and reflects both the **common dynamics and unique structural patterns** observed across different European contexts.

This section introduces the CLD for Low-Input Agriculture as the outcome of a multi-step process that included the identification of **systemic archetypes**, the **harmonization of key variables**, and the translation of case-specific dynamics into a **unified thematic model**. The CLD does not aim to reproduce in detail each individual case, but rather to synthesize the most prominent mechanisms—such as reinforcing loops around financial incentives or knowledge access, and balancing loops related to compliance costs or market instability—into a coherent framework. These mechanisms are not theoretical abstractions, but derive from the empirical analysis of **feedback loops, lock-ins, and leverage points**, previously validated through qualitative modelling work (Ottaviani Aalmo et al., 2024).

The CLD provides a **conceptual backbone** for understanding how adoption of low-input practices can be supported or constrained by systemic factors. It also lays the groundwork for subsequent phases of the project, in which this causal structure will be further formalized into **Stock and Flow Diagrams (SFDs)** and subjected to **quantitative simulation**. As such, this diagram should be interpreted as a **strategic representation of system behaviour**, useful for guiding policy design and scenario exploration. It highlights the need for **multi-level interventions**—ranging from financial and regulatory support to knowledge systems and social engagement—and points toward key leverage areas where systemic transformation can be effectively activated.

The transition to *Low-Input Agriculture* represents a systemic shift that requires overcoming structural barriers while leveraging economic, social, and environmental incentives. Through the comparative analysis of Causal Loop Diagrams (CLDs) across case studies CS1 (France-Belgium), CS2 (Serbia), CS3 (Switzerland) CS9 (Ireland), and CS10 (Belgium), four systemic archetypes were identified, each capturing key constraints and enabling mechanisms shaping sustainable farming adoption.

This analysis builds upon validated systemic dynamics outlined in Ottaviani Aalmo et al. (2024), leveraging structural assessments of feedback loops, lock-ins, and leverage points to construct a coherent thematic representation. The approach follows the framework of Rocha et al. (2020), which emphasizes using systemic archetypes to generalize transition patterns across multiple socio-economic and policy contexts.

The key objectives of this section are to:

1. Identify **recurring systemic archetypes** that influence the adoption of *Low-Input Agriculture*.
2. Analyse **structural constraints (lock-ins)** and **reinforcing and balancing feedback loops** that sustain or hinder the transition.
3. Highlight **leverage points** that can inform policy interventions and systemic modelling.

The identified systemic archetypes serve as the foundation for harmonizing case study variables and developing a **unified thematic CLD** for *Low-Input Agriculture*, which will later be transformed into **Stock-and-Flow Diagrams (SFDs)** for scenario-based modelling.

Financial & Economic Dependencies (CS1, CS2, CS3, CS9, CS10)

Financial incentives play a central role in enabling the transition to Low-Input Agriculture, yet they also create systemic dependencies. While subsidies help offset initial costs (R1 – CS1, R2 – CS2), complex regulations (R3 – CS10) and weak markets (R1 – CS9) can limit autonomy and sustainability. Key lock-ins include financial dependency, regulatory barriers, and underdeveloped value chains. Leverage points include stable long-term subsidies, infrastructure financing (CS9), and support for market development (CS2, CS10)

Knowledge & Advisory Systems (CS1, CS2, CS3, CS9, CS10)

Access to knowledge and technical support is essential for adoption. Reinforcing loops show that advisory services and training (R2 – CS1, R1 – CS2) enhance awareness and capacity, but fragmented systems (R3 – CS9, R4 – CS10) and technological lock-ins limit impact. Barriers include limited extension services, knowledge gaps, and outdated infrastructure. Leverage lies in expanding training programs, advisory tools, and peer-learning networks.

Cultural & Social Dynamics (CS1, CS2, CS9)

Social norms and generational traditions strongly influence adoption. While environmental awareness can support behavioural change (R3 – CS1), cultural resistance and identity lock-ins (R4 – CS2) often prevail. Economic insecurity also affects social cohesion and openness to change (B2 – CS10). Addressing these dynamics requires cultural awareness campaigns, demonstration farms, and farmer-led knowledge exchange to build trust and legitimacy.

Environmental & Regulatory Influences (CS3, CS9, CS10)

Environmental policies can drive change (R4 – CS9), but misaligned or burdensome regulations often hinder uptake (B1 – CS10, R2 – CS10). Regulatory lock-ins include high compliance costs, top-down governance, and rigid frameworks unsuited to local contexts. Leverage points include adapting organic support policies (CS9), simplifying certification, and fostering participatory and integrated governance structures.

Table 21 - Systemic Archetypes, Feedback Loops, Lock-ins and Leverage Points of Low Input Agriculture CLD

	Feedback Loops	Lock-ins	Leverage Points
Financial & Economic Dependencies	['R1 -(CS1)', 'R2 - (CS2)', 'R1 - (CS9)', 'R3 - (CS10)', 'R2' - (CS3)]	['Economic Dependency (CS1, CS2, CS3, CS9)', 'Regulatory Barriers (CS1, CS2, CS9, CS10)', 'Market Constraints (CS2, CS9, CS10)']	['Stable Long-Term Subsidies (CS2, CS9, CS10)', 'Financial Incentives for Sustainable Infrastructure (CS9)', 'Market Development Initiatives (CS2, CS10)']
Knowledge & Advisory Systems	['R2 (CS1)', 'R1 - (CS2)', 'R3 - (CS9)', 'R4 - AKIS, (CS10)', 'R1 - (CS3), 'R3' - (CS3)]	['Technological Lock-ins (CS1, CS2, CS9)', 'Knowledge Gaps (CS9, CS10)']	['Expansion of Advisory Services (CS1, CS2, CS9, CS10)', 'Training and Education Programs (CS1, CS2, CS3, CS9, CS10)']
Cultural & Social Dynamics	['R3 - (CS1)', 'R4 - (CS2)']	['Cultural Resistance (CS1, CS2, CS9)']	['Cultural Awareness Initiatives (CS1)', 'Peer-learning Programs (CS1, CS2)', 'Coomunity Engagement' (CS3)]
Environmental & Regulatory Influences	['R4 - (CS9)', 'R2 - (CS10)', 'B1 - (CS10)']	['Governance Lock-ins (CS10)', 'Farming System Lock-ins (CS10)', 'Regulatory Barriers' (CS3)]	['Policy Adaptation for Organic Support (CS9)', 'Strengthening Governance Support for Environmental Policies (CS10)', 'Policy Interventions' (CS3), 'Financial Incentives' (CS3)]

The process of harmonizing variables across case studies ensures that the systemic dynamics of *Low-Input Agriculture* are represented in a coherent and structured manner. This integration does not aim to erase or distort the specificities of individual case studies but rather to reduce redundancy in the variables while maintaining the integrity of the underlying systemic behaviours. By aligning variables with similar systemic roles, the harmonization process facilitates a unified representation that captures the most prominent feedback loops, lock-ins, and leverage points shaping the transition towards *Low-Input Agriculture*.

In the case of Knowledge and Expertise Access, variables referring to different aspects of **knowledge dissemination, technical support, and capacity-building programs** were harmonized to create a structured category that reflects the role of advisory mechanisms in enabling change. The harmonized category, therefore, retains the nuances of these differences while providing a consolidated view of how advisory mechanisms interact with farmers' decision-making processes.

Economic viability emerged as another key thematic component, integrating variables that describe how financial factors shape adoption choices. By harmonizing variables related to financial situation under **Economic Viability for Farmers**, the thematic model ensures that economic incentives, whether enablers or constraints, are systematically incorporated into the unified CLD. This approach preserves the systemic interplay between financial mechanisms and adoption rates while eliminating redundancies in how these dynamics are represented.

Regulatory and governance influences were similarly aligned to ensure that the role of **institutional frameworks, policy adaptation, and compliance mechanisms** is systematically reflected in the thematic CLD. Harmonization process integrates policy and governance variables related into a broader category that encapsulates the **institutional dimensions of transition pathways**, ensuring that governance-related interventions are clearly delineated within the systemic model.

This approach to harmonization allows the thematic CLD to integrate the **most prominent systemic interactions** without forcing artificial uniformity across case studies. Each case study retains its unique contributions to the systemic model, while common structural patterns—those that are essential for understanding the broader transition to *Low-Input Agriculture*—are synthesized into a unified representation, as represented in Table 22. In this way, harmonization enhances the analytical clarity of the model, allowing it to effectively capture shared dynamics without compromising the distinctiveness of individual case studies.

Table 22 - Harmonization of Variables of Low Input Agriculture CLD

Harmonized Variable	Final Variable in CLD	Case Study
Economic Viability for Farmers	Economic Returns	CS9
	Profitability	CS2
	Economic Factors	CS10
Environmental Impact Factors	Environmental Impact	CS9
	Plant Diversity	CS2
	Biodiversity	CS2
	Soil Quality	CS2
	Ecosystem Services	CS2
	Other Environmental Benefits	CS3
	Biodiversity Quality on Farmland	CS3
	CO2 Emissions	CS2
Knowledge and Expertise Access	Effectiveness of Advisory Services	CS1
	Training & Education	CS1
	Capacity of Public Extension & Advisory Services	CS2
	Training and Advisory Services	CS9
	Access to Knowledge and Expertise	CS1
	Community Engagement & Education	CS2
	AKIS (Agricultural Knowledge & Innovation Systems)	CS10
	Advisory Services	CS3
	Knowledge and Skills in Biodiversity Management (KSBM)	CS3
	Supply of Knowledge and Expertise	CS2
	Market Access for RA Products	CS2
Market Demand and Value Chain Efficiency	Market Demand	CS10
	Supply Chain Efficiency	CS9
	Value Chain	CS10
	Market Demand for Organic Dairy	CS9
Policy and Governance for Sustainability	Total Allocated Budget for AECM	CS1
	Available Financial Subsidies	CS2
	Financial Incentives	CS3
	Subsidies Available for Farmers	CS1
	EU Budget Allocation for AECM	CS1
	Policy Adjustments	CS3
	Member State Budget Allocation for AECM	CS1
	Policy Support	CS9
	Governance	CS10
Sustainable Agricultural Adoption Rate	Rate of AECM Adoption	CS1
	Rate of Adoption of RA	CS2
	Farming Practices	CS10
	Conversion Practices	CS9

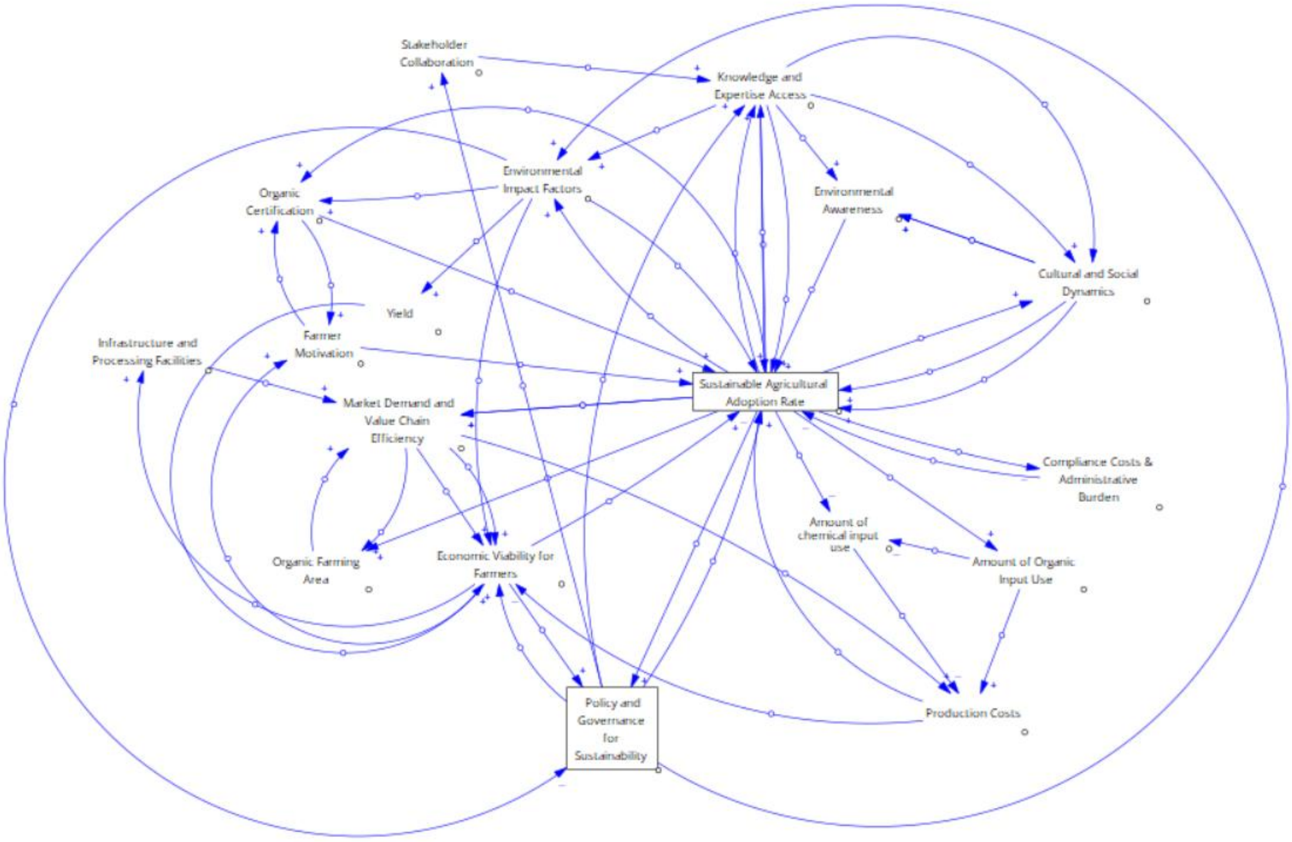
Harmonized Variable	Final Variable in CLD	Case Study
	Uptake of biodiversity measures by farmers	CS3
	Food & Feed Production	CS3
Total Production Cost	Compliance Costs for Adoption	CS1
	Demand for Machinery	CS2
	Demand for Labor	CS2
	Demand for Seeds	CS2
	Total Input Cost	CS2
Cultural and Social Dynamics	Cultural Openness	CS1
	Social & Cultural Acceptance	CS2
	Youth Interest in Farming	CS2
	Social Dynamics	CS2
	Demographics	CS2
	Farmer Motivation	CS9
	Stakeholder Collaboration	CS3
	Organic Certification	CS9
	Infrastructure and Processing Facilities	CS9
	Organic Farming Area	CS10
	Yield	CS2
	Chemical Input Use	CS2
	Organic Fertilizer Use	CS2
	Environmental Awareness	CS1

The Causal Loop Diagram (CLD) for Low-Input Agriculture (Figure 1) is the culmination of all previous analytical phases, integrating the systemic interactions identified across multiple case studies into a structured representation. The harmonization process ensured that key feedback loops, structural constraints, and leverage points were retained while reducing redundancy in variable representation. Although specific case study variables are not individually distinguishable due to this process, their systemic behaviours remain fully embedded within the model.

The construction of this CLD was not a mere aggregation of variables but rather a systematic integration of systemic archetypes and harmonized structures. The systemic archetypes identified in earlier analyses provided the foundational structure, ensuring that key transition dynamics, constraints, and enabling mechanisms were captured in a way that reflects both the empirical evidence from case studies and broader theoretical frameworks.

While not all system dynamics could be explicitly represented due to complexity constraints, the core systemic behaviours are embedded within the model. The next phase—quantitative simulation and scenario analysis—will further explore the effectiveness of different policy and economic interventions in driving sustainable agricultural transitions.

Figure 2 - Low Input Agriculture Pathway Causal Loop Diagram



This CLD, therefore, functions as a policy-relevant, system-wide representation of the transition to *Low-Input Agriculture*, capturing shared systemic behaviours while remaining empirically grounded in the realities of agricultural change While is needed a stakeholder consultation to refine and validate the structure and consequential SFD phase.

7.2.2 Sustainable Consumption and Direct Selling Pathway Casual Loop Diagram

The transition towards Sustainable Consumer Branding and Direct Selling represents a reconfiguration of existing agri-food value chains, placing greater emphasis on direct relationships between producers and consumers, trust-building, and systemic enablers that reinforce both supply and demand sides. This transformation moves beyond conventional marketing or short supply chains, embedding social, technical, and institutional dynamics into the design and adoption of sustainable selling models. The Causal Loop Diagram (CLD) developed for this thematic pathway integrates feedback mechanisms derived from case studies in Greece (CS6), Slovenia (CS7), and Italy (CS8), capturing recurring dynamics and context-specific constraints.

This section introduces the CLD for Sustainable Consumer Branding and Direct Selling as the result of a multi-stage modelling process. This included the identification of systemic archetypes across cases, the harmonization of variables, and the abstraction of feedback loops into a unified thematic framework. The diagram does not aim to reproduce individual CLDs in full detail but rather to synthesise dominant mechanisms—such as trust-demand amplification, financial viability constraints, or infrastructure-policy loops—into an integrated system view. Each loop is grounded in empirical observations and validated through qualitative analysis of leverage points, lock-ins, and transition dynamics (Ottaviani Aalmo et al., 2024).

The CLD provides a strategic representation of how sustainable direct selling models can emerge and consolidate through mutually reinforcing actions across actors and system levels. It highlights how demand-side education and awareness can activate trust and willingness to pay, how infrastructure and cooperation among producers foster accessibility and logistical viability, and how continuous knowledge diffusion underpins innovation and resilience. As with other CLDs in this report, this thematic model serves as a foundation for the development of quantitative Stock and Flow Diagrams (SFDs) and simulation-based exploration of policy scenarios. It offers a tool to navigate complex transformation pathways, illuminating where and how leverage can be applied for sustainable change.

Five systemic archetypes were identified from the comparative analysis of case studies CS6, CS7, and CS8, each illustrating key enablers, constraints, and leverage points within the consumer-facing transformation of agri-food systems:

Trust and Demand Amplification (R1 – CS6, B1 – CS7, R3 – CS8)

This archetype reinforces the consumer-facing side of the system. Higher levels of consumer trust and awareness (triggered by education and branding) increase willingness to pay, which stabilises farm revenue and sustains farmer engagement. Systemic lock-ins include consumer mistrust (CS6), cultural resistance (CS7), and low community participation (CS8). Leverage points lie in awareness campaigns, education on sustainable products, and trust-building tools.

Infrastructure & Policy-Enabling Loop (R5 – CS6, R2 – CS7, R3 – CS8)

This dynamic reflects how investments in infrastructure, policy frameworks, and technical support systems enable system scalability. Lock-ins include infrastructural and technological barriers across all three cases. Effective leverage requires targeted public and private investments, infrastructural subsidies, and inclusive technical training programs.

Producer Cooperation & Market Access (R2 – CS6, R2 – CS7, R1 – CS8)

Systemic fragmentation among producers (CS6, CS7) and weak social capital (CS8) hinder coordinated market access and value chain integration. Cooperation platforms, logistics sharing, and peer learning help overcome these constraints and build resilience, especially in rural or marginalised areas.

Financial Viability under Pressure (B2 – CS7, B1 – CS8, R5 – CS6)

High fixed costs and unstable returns pose a major challenge to the long-term viability of sustainable selling models. This archetype shows how economic stress can undermine adoption unless addressed through adaptive pricing schemes, financial reforms, and collaborative cost-sharing tools.

Knowledge Diffusion and Self-Reinforcement (R2 – CS8, R1 – CS7, R3 – CS6)

This archetype acts as a foundation for both innovation and continuity. It emphasizes how uneven access to training, advisory systems, and innovations limits the uptake of sustainable practices. The enabling dynamic lies in inclusive, decentralised knowledge systems that reinforce behavioural and operational shifts over time.

Systemic Archetype	Feedback Loops	Systemic Lock-ins	Leverage Points
Trust and Demand Amplification	R1 (CS6), B1 (CS7), R3 (CS8)	Consumer mistrust (CS6), cultural resistance (CS7), low community participation (CS8)	Awareness campaigns, trust-building tools, education on sustainable products
Infrastructure & Policy-Enabling Loop	R5 (CS6), R2 (CS7), R3 (CS8)	Technological and infrastructural barriers across all CSs	Targeted investments, infrastructural subsidies, technical training
Producer Cooperation & Market Access	R2 (CS6), R2 (CS7), R1 (CS8)	Fragmented producer networks (CS6–7), low social capital (CS8)	Cooperative logistics, community trust initiatives, peer learning

Systemic Archetype	Feedback Loops	Systemic Lock-ins	Leverage Points
Financial Viability under Pressure	B2 (CS7), B1 (CS8), R5 (CS6)	Financial strain from high costs, unstable returns	Cost-sharing platforms, pricing reforms, adaptive financial tools
Knowledge Diffusion and Self-Reinforcement	R2 (CS8),R1 (CS7), R3 (CS6)	Uneven access to knowledge and limited uptake of innovations	Continuous and inclusive training models, advisory systems

The process of harmonizing variables across case studies ensures that the systemic dynamics of Sustainable Consumer Branding and Direct Selling are captured in a unified yet nuanced way. This integration does not erase the specificity of individual case studies but reduces redundancy while preserving key feedback structures and leverage areas.

For example, variables related to *consumer education*, *environmental awareness*, and *willingness to pay* were harmonized under "Consumer Demand and Willingness to Pay," reflecting the trust-demand amplification loop. Similarly, infrastructural constraints and investment mechanisms across the three case studies were aggregated into the category "Infrastructure & Logistics Capacity," enabling cross-case analysis of enabling conditions.

Knowledge-related variables—such as technical support programs, community-based advisory services, and training schemes—were consolidated under "Training and Knowledge Support." Though contexts varied, the systemic role of knowledge as a behavioural enabler and institutional bridge remained constant.

Market access and producer networks were harmonized under "Market Access and Reach," integrating both spatial and relational dimensions of value chain participation. Finally, adoption behaviours were aligned under "Adoption Rate of Sustainable Selling Models," which functions as an outcome variable linked to multiple reinforcing and balancing loops across the model.

This harmonization supports analytical clarity and interoperability with the Stock and Flow Diagrams that will follow. It allows the CLD to retain the empirical richness of case-specific feedback structures while enabling structured simulation and policy testing at the thematic level.

Table 23 - Sustainable Consumption and Direct Selling Pathway harmonized variables

Harmonized Variable	Variable in CSs CLDs	Case Study Source
Consumer Demand and Willingness to Pay	Willingness to Pay	CS6
	Consumer Demand for Locally-Sourced and Organic Products	CS7
	Market Demand for Organic Products	CS8
Market Access and Reach	Market Access for Organic Products	CS6
	Market Accessibility	CS7
	Market Stability	CS6
Adoption Rate of Sustainable Selling Models	Rate of Adoption of Farmers Practicing Direct Selling	CS7
	Rate of CSA Adoption	CS8
Policy and Investment Support	Policy and Regulatory Support with Chamber Advocacy	CS7
	Policy and External Funding Support	CS8
Infrastructure & Logistics Capacity	Distribution of Organic Products	CS6
	Entry of Organic Products	CS6
	Transportation and Logistics Challenges	CS6
	Investment in Direct Selling Infrastructure	CS7
	Short Supply Chain Development and Local Economy Enhancement	CS7
	Number of Farmers Using Digital Marketing Tools	CS7

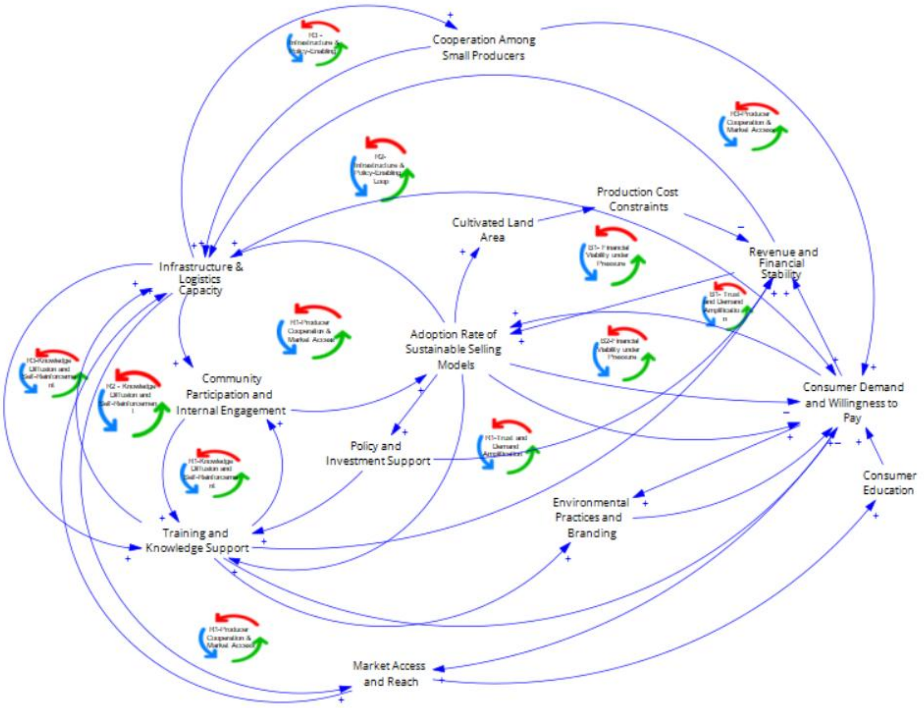
Harmonized Variable	Variable in CSs CLDs	Case Study Source
Training and Knowledge Support	Knowledge and Training in Sustainable Practices	CS6
	Farmer Training and Capacity Building	CS7
	Worker Training Levels	CS8
	Availability of Training Courses	CS8
Consumer Engagement and Trust	Consumer Engagement	CS7
	Consumer Awareness and Trust Levels	CS7
Community Participation and Internal Engagement	Volunteer Engagement Rate	CS8
	Participation Rate in Community Events	CS8
	Number of Community Events	CS8
Revenue and Financial Stability	Farmers' Revenue from Direct Selling	CS7
	Total Annual Revenue from Membership Fees	CS8
	Membership Fees	CS8
	Farmer's Profit	CS7
Production Cost Constraints	Cost of Production and Distribution	CS7
	Annual Land Rent Cost	CS8
Environmental Practices and Branding	Practices to Reduce Fertilizers	CS6
	Production & Biodiversity Diversity	CS8
	Organic Certification Status	CS8
	Cultivated Land Area	CS8
	Consumer Education	CS6
	Cooperation Among Small Producers	CS6
	Investment in Digital Agriculture Technologies	CS6
	Market Prices of Directly Sold Products	CS7
	Market-Related Barriers	CS6
	Total Number of Volunteers and Staff Hours	CS8

The Causal Loop Diagram (CLD) for Sustainable Consumption and Direct Selling (Figure 2) is the culmination of all previous analytical phases, integrating the systemic interactions identified across multiple case studies into a structured representation. The harmonization process ensured that key feedback loops, structural constraints, and leverage points were retained while reducing redundancy in variable representation. Although specific case study variables are not individually distinguishable due to this process, their systemic behaviours remain fully embedded within the model.

The construction of this CLD was not a mere aggregation of variables but rather a systematic integration of systemic archetypes and harmonized structures. The systemic archetypes identified in earlier analyses provided the foundational structure, ensuring that key transition dynamics, constraints, and enabling mechanisms were captured in a way that reflects both the empirical evidence from case studies and broader theoretical frameworks.

While not all system dynamics could be explicitly represented due to complexity constraints, the core systemic behaviours are embedded within the model. The next phase—quantitative simulation and scenario analysis—will further explore the effectiveness of different policy and economic interventions in driving sustainable agricultural transitions.

Figure 3 - Sustainable Consumption and Direct Selling Pathway Casual Loop Diagram



7.2.3 Extensification of livestock systems Thematic Causal Loop Diagram

The transition to more extensive livestock systems entails a structural transformation away from high-input, intensive production models towards more sustainable and regionally embedded practices. This process involves significant shifts in production methods, feed autonomy, certification and labelling mechanisms, and institutional support structures. The Causal Loop Diagram (CLD) developed for this pathway is based on insights from two case studies—CS4 (France) and CS5 (Germany)—and identifies critical feedback mechanisms and leverage points shaping the extensification transition.

This section presents the CLD for Extensification of Livestock Systems as the result of a structured modelling process. The process included the identification of recurring systemic archetypes across cases, the harmonization of key variables, and the construction of a unified system model. The CLD does not replicate each case in full detail but synthesizes the most influential dynamics—such as trust-based certification, sustainability-related incentives, and external market pressures—into a consolidated systemic framework. All feedback structures are grounded in empirical case study modelling and validated through comparative thematic analysis (Ottaviani Aalmo et al., 2024).

The CLD acts as a conceptual map for navigating the transition toward more extensive systems, highlighting how institutional trust, feed autonomy, certification legitimacy, and price transmission interact in shaping behavioural and structural outcomes. As with the other CLDs in this report, it will serve as the basis for the development of Stock and Flow Diagrams (SFDs) and quantitative simulation in the following phases of the project. It is designed to support scenario development and policy exploration, pointing to the key systemic levers and constraints that influence the adoption and consolidation of extensive livestock practices.

The comparative analysis of Causal Loop Diagrams from CS4 and CS5 led to the identification of four systemic archetypes (Table 24), each representing dominant transition dynamics and barriers to extensification:

Trust-Based Certification for Regional Value Chains (CS5, CS4)

This archetype highlights the role of certification, labelling, and value-chain legitimacy in enabling sustainable livestock systems. In CS5, weak consumer trust and the complexity of certification schemes hinder adoption. In CS4, cultural resistance to decentralized feed autonomy limits engagement. Reinforcing feedback loops (R1 – CS5, R5-R7 – CS4) show how visible and credible certification boosts market trust and incentivizes producer alignment. Lock-ins include certification costs and poor label visibility. Leverage points include simplified schemes, consumer awareness campaigns, and stronger policy frameworks for value-based labelling.

Sustainability Premium as Reinforcing Driver (CS4, CS5)

This archetype illustrates how aligning economic incentives with environmental goals can generate reinforcing adoption dynamics. In CS4 and CS5, loops R2 show that higher consumer willingness to pay, when paired with policy support, creates a sustainability premium that improves profitability and encourages extensification. However, high-input path dependency (CS5), imported soy dependency (CS4), and weak price transmission are major systemic barriers. Key leverage points include margin guarantees, protein crop rotation incentives, and diversified feed support schemes.

Knowledge Engagement and Institutional Trust (CS4, CS5)

Long-term adoption is supported by sustained knowledge engagement, trusted advisory services, and predictable regulatory frameworks. This archetype (R6-R7 – CS4, GFS→FP+ARSP – CS5) emphasizes the enabling role of capacity-building mechanisms and institutional trust. Lock-ins include lack of technical support, perceived regulatory instability, and generational gaps in sustainable farming know-how. Leverage points include targeted extension programs, peer learning platforms, and long-term policy continuity.

External Market Volatility and Stabilization Policies (CS4, CS5)

This archetype captures how exposure to global markets and price volatility can discourage sustainable practices and trigger reversion to intensive models. In CS5 and CS4, balancing loops (B1, R3-R4) describe the destabilizing effects of weak infrastructures and delayed policy responses. Lock-ins include inadequate risk-sharing tools and insufficient decentralised infrastructure. Policy levers such as market stabilization schemes, decentralised investments, and responsive support instruments are essential to buffer shocks and maintain producer commitment.

Table 24 - Extensification of Livestock System Systemic Archetypes

Systemic Archetype	Feedback Loops	Systemic Lock-ins	Leverage Points
Trust-Based Certification for Regional Value Chains	R1 (CS5), R5-R7 (CS4)	Certification costs and complexity (CS5); Weak market trust and label visibility (CS5); Cultural resistance to decentralized feed autonomy (CS4)	Simplified certification schemes; Consumer trust campaigns; Stronger policy support for value-based labelling
Sustainability Premium as Reinforcing Driver	R2 (CS4), R2 (CS5)	High-input path dependency (CS5); Imported soy dependency (CS4); Insufficient price transmission from sustainability attributes	Profit margin guarantees for certified extensive products; Incentives for protein crop rotations; Support schemes for diversified feed systems
Knowledge Engagement and Institutional Trust	R6-R7 (CS4), GFS→FP+ARSP (CS5)	Lack of advisory services and technical training; Perceived regulatory instability; Generational gap in sustainable farming know-how	Targeted advisory programs; Peer-learning and extension platforms; Long-term regulatory predictability

Systemic Archetype	Feedback Loops	Systemic Lock-ins	Leverage Points
External Market Volatility and Stabilization Policies	B1 (CS5), R3-R4 (CS4)	Exposure to volatile markets; Inadequate infrastructure for decentralized feed systems; Delayed response to global price shocks	Market stabilization schemes; Investment in decentralised infrastructure; Localised risk-sharing instruments

The process of harmonizing variables across case studies ensured that the systemic dynamics underpinning extensified livestock systems were represented in a coherent and generalizable format. Rather than reproducing each variable in its original form, harmonization grouped systemically related elements under unified categories that reflect common feedback structures and system behaviours.

For instance, variables related to *label certification*, *consumer trust*, and *market legitimacy* were harmonized under **Certification and Labelling**, while *infrastructure quality* and *logistics capacity* were grouped into **Infrastructure Development**. Feed autonomy variables from CS4 and CS5 were harmonized into **Local/Regional Feed Autonomy**, which plays a central role in several reinforcing and balancing loops.

Knowledge-related dynamics were grouped under **Knowledge and Community Engagement**, capturing elements of technical training, generational exchange, and advisory support. Price volatility and policy response variables were integrated under **Market Stability Tools and Risk Management**, facilitating the analysis of resilience mechanisms.

This harmonization process led to harmonized variables in Table 25 and enhances the analytical capacity of the CLD while preserving the empirical richness of each case. It allows the thematic model to support scenario simulations, evaluate policy effectiveness, and explore leverage-based interventions that support the extensification of livestock systems.

Table 25 - Harmonized Variables

Harmonised Variable	Original Variable in CS	Case Study Source
Local/Regional Feed Autonomy	Local Feed Sources (LFS)	CS4
	Regional Feed Production (RFP)	CS5
Policy Support	Policy Dialogue (PD)	CS5
	Economic Incentives (EI)	CS4
	Government Funding Support (GFS)	CS5
	Sustainable Agriculture Policies (SAP)	CS4
	Policy Requirements (PR)	CS5
Farm Profitability	Profitability (P)	CS5
Pasture and Livestock Management	Enhanced Pasture Management (EPM)	CS4
	Animal Husbandry System (AHS)	CS5
	Skills Enhancement for Legume Cultivation (SELC)	CS4
	Animal Walfare System (AWS)	CS5
Certification and Labelling	Certification (CERT)	CS5
	Regional Quality Label (RQL)	CS5
Knowledge and Community Engagement	Education & Community Engagement (ECE)	CS4
	Extension Services (ES)	CS4
	Community Engagement	CS5
	System Trust (ST)	CS5
	Perceived Regulatory Risk (PRR)	CS5
Market Stability and Risk Management	Market Stabilization Tools (MST)	CS4
	External Market Factors (EMF)	CS5

Harmonised Variable	Original Variable in CS	Case Study Source
	Market Dependency Reduction	CS4
Value Chain Development	Value Chain Development (VCD)	CS5
	Indicator-Based Monitoring (IBM)	CS4
	Resilience Building (RB)	CS4
	Environmental Impact (EI)	CS5
	Farmers Proposal + Adoption Rate Sustainable Practices	CS5
	Consumer Willingness to Pay (CWTP)	CS5
	Arable Production System (APS)	CS5
	Actor Influence (AI)	CS5
	Infrastructure Development (ID)	CS4

The Causal Loop Diagram (CLD) for Sustainable Consumption and Direct Selling (Figure 2) is the culmination of all previous analytical phases, integrating the systemic interactions identified across multiple case studies into a structured representation. The harmonization process ensured that key feedback loops, structural constraints, and leverage points were retained while reducing redundancy in variable representation. Although specific case study variables are not individually distinguishable due to this process, their systemic behaviours remain fully embedded within the model.

The construction of this CLD was not a mere aggregation of variables but rather a systematic integration of systemic archetypes and harmonized structures. The systemic archetypes identified in earlier analyses provided the foundational structure, ensuring that key transition dynamics, constraints, and enabling mechanisms were captured in a way that reflects both the empirical evidence from case studies and broader theoretical frameworks.

While not all system dynamics could be explicitly represented due to complexity constraints, the core systemic behaviours are embedded within the model. The next phase—quantitative simulation and scenario analysis—will further explore the effectiveness of different policy and economic interventions in driving sustainable agricultural transitions

Figure 4 - Livestock Extensification Pathway Causal Loop Diagram

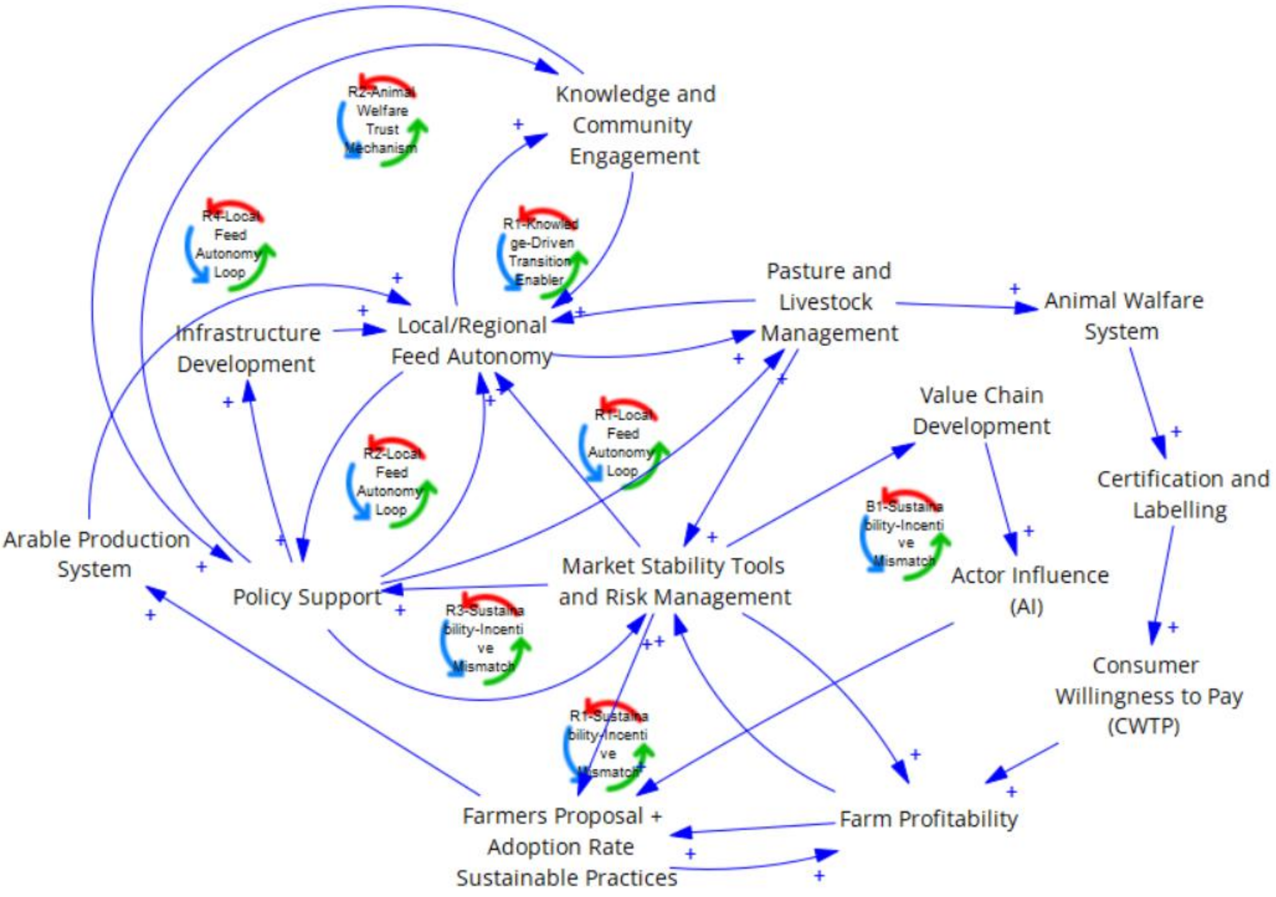


Table 26 - Case study assignment and systemic archetypes identified through CLD analysis for each thematic pathway.

Thematic Pathway	Case Studies	Systemic Archetypes	Archetypes' Case studies
Low-Input Agriculture	CS1 (France-Belgium), CS2 (Serbia), CS3 (Switzerland), CS9 (Ireland), CS10 (Belgium)	Financial & Economic Dependencies	CS1, CS2, CS3, CS9, CS10
		Knowledge & Advisory Systems	CS1, CS2, CS3, CS9, CS10
		Cultural & Social Dynamics	CS1, CS2, CS9
		Environmental & Regulatory Influences	CS3, CS9, CS10
Sustainable Consumer Branding and Selling	CS6 (Greece), CS7 (Slovenia), CS8 (Italy)	Trust and Demand Amplification	CS6, CS7, CS8
		Infrastructure & Policy-Enabling Loop	CS6, CS7, CS8
		Producer Cooperation & Market Access	CS6, CS7, CS8

Thematic Pathway	Case Studies	Systemic Archetypes	Archetypes' Case studies
		Financial Viability under Pressure	CS6, CS7, CS8
		Knowledge Diffusion and Self-Reinforcement	CS6, CS7, CS8
Livestock Extensification	CS4 (France), CS5 (Germany)	Trust-Based Certification for Regional Value Chains	CS4, CS5
		Sustainability Premium as Reinforcing Driver	CS4, CS5
		Knowledge Engagement and Institutional Trust	CS4, CS5
		External Market Volatility and Stabilization Policies	CS4, CS5

7.3 Thematic pathways System Dynamic Models

This chapter introduces the System Dynamics Models (SDMs) developed for the simulation of the transition pathways within the ENFASYS project. Three separate models are presented, each corresponding to a specific pathway of transition towards sustainable farming systems. Each model has been designed to translate the qualitative causal structures (Causal Loop Diagrams, CLDs) developed during the participatory Theory of Change (ToC) process into a quantitative dynamic framework capable of simulating systemic behaviours over time.

A detailed description of the mathematical formulation for each variable, including corresponding sources, parameter values, and scientific justifications, is provided in Annexes 1, 2, and 3, respectively associated with each transition pathway model.

The graphs presented in this chapter illustrate the simulated evolution of the system’s key variables from time 0 to time 10. Each graph represents how a specific variable changes over the simulated period as a result of the internal causal relationships and endogenous dynamics embedded in the model (see methodology). These dynamics emerge from the interaction of stocks, flows, and auxiliary variables, structured through reinforcing and balancing feedback loops derived from the Causal Loop Diagrams (CLDs). The model is time-based and calibrated to simulate a ten-year transition, starting from a set of initial stock values. No external shocks or scenario assumptions are imposed. Instead, the system behaviour unfolds endogenously through the functional equations and lookup relationships that govern the interaction among variables.

The following sections present the structure of each model and provide an in-depth analysis of the simulated dynamics of the most relevant variables for each transition pathway. While the results presented here are based on a first structured simulation, they should be interpreted as part of an iterative modelling process. Both the structure and calibration of the models will be further refined through stakeholder and expert input, as well as the integration of additional empirical data in subsequent phases.

7.3.1 Low-Input Agriculture SDM

The LIA model captures the complex, interdependent feedback structures governing the transition towards more sustainable farming systems. It integrates multiple dimensions — economic viability, knowledge dissemination, governance support, environmental outcomes, and market development — into a coherent systemic representation. Relationships between variables are structured through reinforcing and balancing feedback loops, enabling the simulation of dynamic trajectories over time.

The analysis presented in this chapter focuses specifically on the most relevant variables for the LIA pathway, selected based on their central role in enabling or constraining the systemic transition. These variables include:

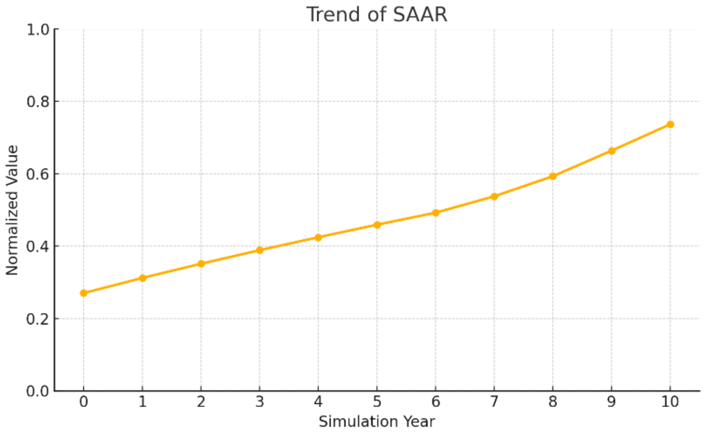
- Sustainable Agricultural Adoption Rate (SAAR),
- Policy and Governance for Sustainability (PGS),
- Market Demand and Value Chain Efficiency (MDVCE),
- Economic Viability for Farmers (EVF),
- Knowledge and Expertise Access (KEA),
- Positive Environmental Impact Factors (EIF).

Following the individual analysis, a cross-variable interpretation highlights the interdependencies between the key transition drivers, synthesizing the systemic behaviour observed across the different dimensions of the LIA pathway.

Sustainable Agricultural Adoption Rate (SAAR)

The simulation results, as showed in Figure 5, for the Sustainable Agricultural Adoption Rate (SAAR) show a steady and progressive increase over the ten-year period considered, starting at a normalized value of 0.27 at Year 0 and reaching 0.74 by Year 10. The growth trajectory is continuous, with no periods of stagnation or decline, and becomes markedly accelerated after Year 6, at which point the adoption rate exceeds the critical threshold of 50%. This evolution suggests the successful activation of reinforcing systemic dynamics, supporting the widespread adoption of sustainable agricultural practices within the modelled system. Home et al. (2023) identifies a series of systemic lock-ins that typically hinder the adoption of sustainable farming practices, including economic dependencies on conventional high-input models, deficits in advisory and technical knowledge systems, entrenched cultural resistance to alternative farming approaches, and regulatory frameworks poorly adapted to support transition pathways. To overcome these barriers, Home et al. (2023) highlights the importance of implementing stable long-term financial incentives, expanding advisory and knowledge support services, fostering cultural and social shifts through awareness and peer-learning initiatives, and adapting policies to incentivize sustainable practices.

Figure 5 - Simulation Trend of Sustainable Agricultural Adoption Rat



The SAAR trend observed in the simulation suggests that these systemic barriers have been progressively mitigated and that the corresponding leverage points have been activated effectively. The consistent growth and the crossing of the 50% adoption threshold around Year 7 reflect a successful systemic transition dynamic, consistent with the theoretical pathways described in Home et al. (2023).

Furthermore, the findings resonate with the empirical patterns observed in deliverable Roglic (2025), where it is noted that real-world transformation initiatives achieving significant progress typically exhibit an initial slow growth phase, followed by a tipping point and an acceleration once enabling conditions are in place. In particular, Roglic (2025) emphasizes that coordinated interventions targeting financial viability, knowledge dissemination, and cultural adaptation are necessary to trigger widespread adoption, a dynamic that the simulation reproduces faithfully.

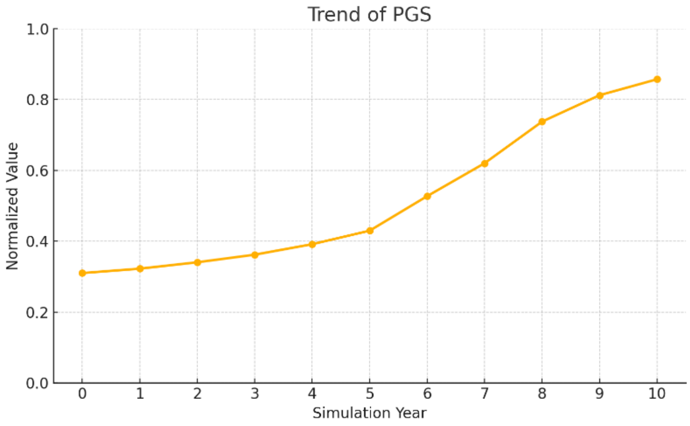
When analysed in relation to the systemic archetypes identified for the Low-Input Agriculture pathway, the behaviour of SAAR further confirms the model's internal coherence. The progressive increase in adoption rates suggests the successful weakening of economic dependencies, the effective reinforcement of advisory systems, and the overcoming of cultural resistance through social dynamics, corresponding respectively to the financial, knowledge-based, and cultural archetypes outlined for the pathway. Although environmental and regulatory factors are not the primary drivers evident in the SAAR trend, they likely provide complementary support, stabilizing the broader transition environment.

Overall, the simulation results for the Sustainable Agricultural Adoption Rate offer strong evidence that the system modelled for the Low-Input Agriculture pathway is capable of triggering and sustaining a robust systemic transition. The results illustrate how, through the coordinated activation of key leverage points and the gradual dismantling of entrenched lock-ins, a critical mass of adoption can be achieved and reinforced, leading towards a self-sustaining transformation pathway consistent with both theoretical expectations and empirical observations across European case studies.

Policy and Governance for Sustainability (PGS)

The simulation results, as shown in Figure 5, for Policy and Governance for Sustainability (PGS) reveal a steady improvement in governance support over the ten-year simulation period, starting from a normalized value of 0.31 at Year 0 and reaching 0.86 by Year 10. Initial growth is moderate, but a clear acceleration is observable from Year 6 onwards, reflecting a systemic consolidation of governance mechanisms that support the transition to sustainable farming practices. This trajectory indicates a progressive overcoming of governance-related lock-ins within the simulated system.

Figure 6 - Simulation Trend of Policy and Governance for Sustainability



According to Home et al. (2023), one of the main systemic barriers hindering sustainable agricultural transitions is the presence of weak, fragmented, or short-term policy frameworks. These conditions often fail to create the necessary confidence among farmers to shift practices away from conventional high-input systems. Home et al. (2023) identify the adaptation of policy frameworks to explicitly support organic and low-input farming, the establishment of stable long-term subsidies, and the reduction of compliance costs as crucial leverage points to overcome these barriers. The simulated trend of PGS aligns with these theoretical expectations. The slow initial growth reflects the time typically required for governance adaptations to take effect. The acceleration of PGS from Year 6 onwards suggests that systemic enablers, such as stable and coherent policy frameworks, begin to exert a positive influence on the farming system at this stage, gradually dismantling the regulatory and institutional lock-ins that initially constrained the transition. This interpretation is further supported by findings from deliverable Roglic (2025), where empirical evidence demonstrates that the strengthening of governance structures often lags behind market or knowledge-based developments, but eventually becomes a decisive driver of large-scale systemic change.

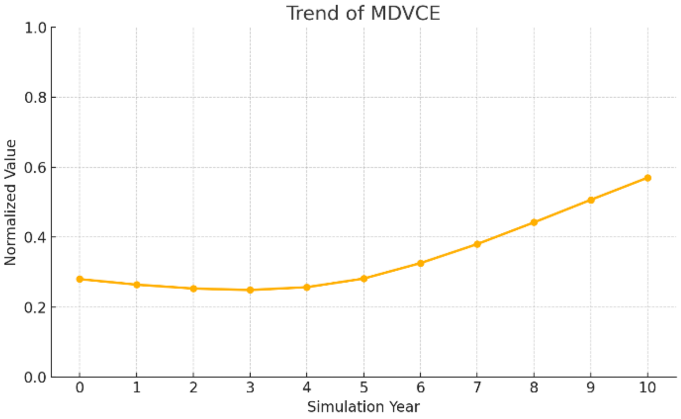
From a systemic perspective, the behaviour of PGS can be interpreted through the lens of the Environmental and Regulatory Influences archetype identified for the Low-Input Agriculture pathway. The progressive increase in governance support suggests that regulatory and policy-related lock-ins are gradually weakened through appropriate leverage points such as policy adaptation and administrative simplification. Moreover, the late-stage acceleration of PGS implies the activation of reinforcing feedback loops between governance structures, farmer behaviour, and broader market dynamics, ultimately supporting the transition towards sustainability.

In conclusion, the evolution of Policy and Governance for Sustainability highlights the critical role of governance adaptation as a systemic enabler that, although slower to manifest compared to market or knowledge dynamics, becomes essential in sustaining and amplifying the transition process once activated. The results thus confirm the necessity of strategic, long-term, and stable governance interventions to overcome entrenched institutional barriers and foster robust pathways towards sustainable agricultural systems.

Market Demand and Value Chain Efficiency (MDVCE)

The simulation results for Market Demand and Value Chain Efficiency (MDVCE), as shown in Figure 6, depict a nuanced and gradual trajectory of improvement over the ten-year simulation period. Starting from a normalized value of 0.28 at Year 0, MDVCE initially experiences a slight decline during the early years, reaching a minimum of 0.25 around Year 3. This is followed by a phase of stabilization and a gradual upward trend beginning from Year 4–5, with a more visible acceleration occurring from Year 6 onwards, culminating at 0.57 by Year 10.

Figure 7 - Simulation Trend of Market Demand and Value Chain Efficiency



Home et al. (2023) identifies the limited market demand for sustainably produced low-input products and the inefficiencies within conventional value chains as key lock-ins constraining the transition. These lock-ins are reinforced by consumer habits favouring conventional products, logistical barriers, and the absence of short and efficient supply chains. The leverage points proposed include the development of local markets, the promotion of short supply chains, and marketing strategies aimed at increasing consumer demand for sustainable products.

The simulation's early-phase stagnation and slow growth of MDVCE are consistent with these systemic barriers: initially, market conditions are unfavourable, and structural inefficiencies persist. However, the progressive improvement observed from the second half of the simulation suggests that interventions—such as market development, consumer awareness campaigns, or infrastructural improvements—gradually take effect, leading to enhanced efficiency and demand by the end of the period.

Empirical evidence from Roglic (2025) supports this interpretation. Case studies ToC analysed by Roglic (2025) demonstrate that initiatives promoting sustainable agriculture often struggle in their initial phases when consumer demand is weak, and distribution structures are inadequate. Only after targeted interventions—such as cooperative formation, local market creation, and value chain reorganization—do these initiatives achieve significant market integration and improved value chain efficiency. The pattern observed in the simulation, with delayed but progressive improvement, mirrors these real-world trajectories.

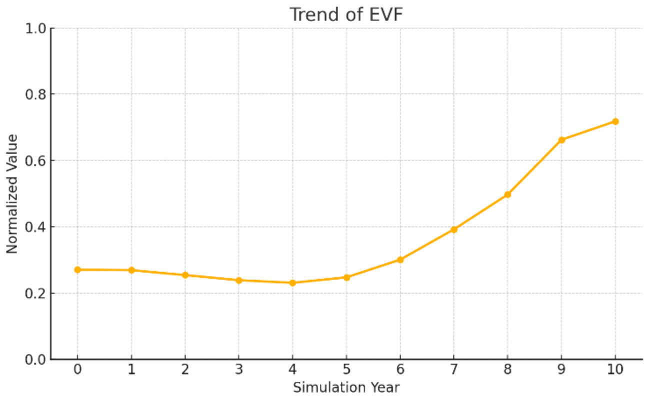
From a systemic perspective, the behaviour of MDVCE reflects the gradual overcoming of cultural and economic lock-ins associated with the Cultural & Social Dynamics and Financial & Economic Dependencies archetypes. Initially constrained by consumer habits and market inefficiencies, the system eventually activates leverage points related to consumer awareness, local market development, and cooperative structures, enabling a late-stage acceleration in demand and supply chain functionality.

In conclusion, the evolution of Market Demand and Value Chain Efficiency within the simulation aligns well with both theoretical frameworks and empirical observations. It underscores the critical role of targeted market interventions and supply chain reorganization in supporting the broader transition to sustainable farming systems. The results also highlight the systemic inertia typical of market-based transformations, where time and coordinated action are necessary to dismantle entrenched barriers and establish new, more sustainable market structures.

Economic Viability for Farmers (EVF)

The simulation results for Economic Viability for Farmers (EVF) depict a complex and delayed improvement over the ten-year simulation horizon, as shown in Figure 7. Starting from a normalized value of 0.27 at Year 0, EVF experiences a gradual decline during the initial four years, reaching a minimum of approximately 0.23 by Year 4. This is followed by a period of modest recovery beginning around Year 5, leading to a more pronounced acceleration from Year 7 onwards, ultimately reaching a value of 0.72 by Year 10.

Figure 8 - Simulation Trend of Economic Viability for Farmers



Home et al. (2023). highlight that economic dependencies on conventional high-input agricultural models, combined with the perceived financial risks associated with transitioning to sustainable practices, represent major lock-ins within the farming sector. Farmers often face significant upfront costs, market uncertainties, and reduced immediate profitability when adopting low-input or organic practices. To overcome these barriers, Home et al. (2023) stress the importance of stable long-term subsidies, the development of dedicated markets for sustainable products, and the reduction of production costs through technological and organizational innovations.

The early decline in EVF observed in the simulation accurately reflects the initial economic challenges faced by farmers during the transition. In the absence of immediate and tangible economic returns, the economic viability of sustainable practices initially deteriorates, mirroring real-world patterns described by Roglic (2025). In the Cross-Case ENFASYS ToC is emphasized that without strong financial support and a gradual market development, many farmers abandon sustainable practices before reaching a viable equilibrium. The modest recovery starting from Year 5, and the acceleration visible after Year 7, suggest that, within the simulation, the combination of long-term policy support, emerging market opportunities, and improving cost structures begins to counteract the initial disadvantages, progressively enhancing the economic conditions for sustainable farming.

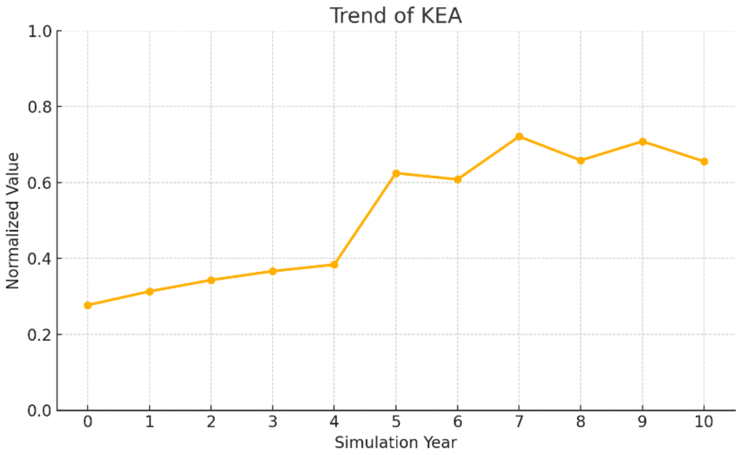
From a systemic archetypes perspective, the evolution of EVF can be interpreted through the lens of the **Financial & Economic Dependencies** archetype. Initially constrained by dependency on conventional high-input models and the associated market structures, the system gradually activates leverage points such as stable subsidies, consumer-driven demand shifts, and efficiency improvements. The delayed but eventually accelerating recovery of EVF illustrates a typical systemic transformation dynamic, where initial inertia gives way to reinforcing feedback loops once enabling conditions mature sufficiently.

Furthermore, the trend of EVF should be understood in close relation to the trajectories of other core variables such as Market Demand and Value Chain Efficiency (MDVCE) and Sustainable Agricultural Adoption Rate (SAAR). As market demand for sustainable products increases and supply chain efficiencies improve, economic viability is reinforced, creating a self-reinforcing cycle that sustains and expands the transition process. The late-stage surge in EVF is not only a reflection of improved market conditions but also an indicator of the system's ability to align financial incentives with sustainable agricultural behaviours.

Knowledge and Expertise Access (KEA)

The simulation results for Knowledge and Expertise Access (KEA) reveal a dynamic evolution marked by an initial phase of steady growth followed by a significant acceleration and moderate oscillations in the latter half of the simulation period, as shown in Figure 8. Starting from a normalized value of 0.277 at Year 0, KEA increases gradually until Year 4, reaching approximately 0.384. A sharp rise is then observed around Year 5, with KEA values exceeding 0.6 and maintaining elevated levels with some fluctuations until Year 10, where the final value stabilizes around 0.656.

Figure 9 - Simulation Trend of Knowledge and Expertise Access



Home et al. (2023) emphasizes that a major systemic lock-in constraining sustainable agricultural transitions is the limited access to technical advice and expertise among farmers. Many agricultural systems suffer from a deficit of advisory services, insufficient dissemination of sustainable practices, and a lack of community-based knowledge networks. The initial gradual growth of KEA observed in the simulation reflects the structural inertia typical of knowledge systems, where the diffusion of new practices and expertise requires sustained effort and systemic investment. The pronounced acceleration from Year 5 onwards suggests that critical interventions—such as the establishment of advisory services, creation of peer-learning networks, or broader knowledge dissemination campaigns—are successfully activated within the modelled system. These dynamics are strongly corroborated by Roglic (2025) which reports that case studies achieving meaningful transitions consistently prioritize knowledge transfer and farmer-to-farmer support mechanisms as key enablers of behavioural change and adoption.

From a systemic archetype perspective, the behaviour of KEA aligns with the **Knowledge & Advisory Systems** archetype, where overcoming cognitive isolation and advisory deficits through the expansion of information networks plays a critical role in supporting systemic transformation. Initially, farmers operate within knowledge systems oriented towards conventional practices, limiting their capacity to adopt innovative, sustainable techniques. However, the emergence of reinforcing feedback loops—where increased knowledge access drives further adoption, which in turn stimulates demand for additional advisory services—is evident in the simulation from Year 5 onwards.

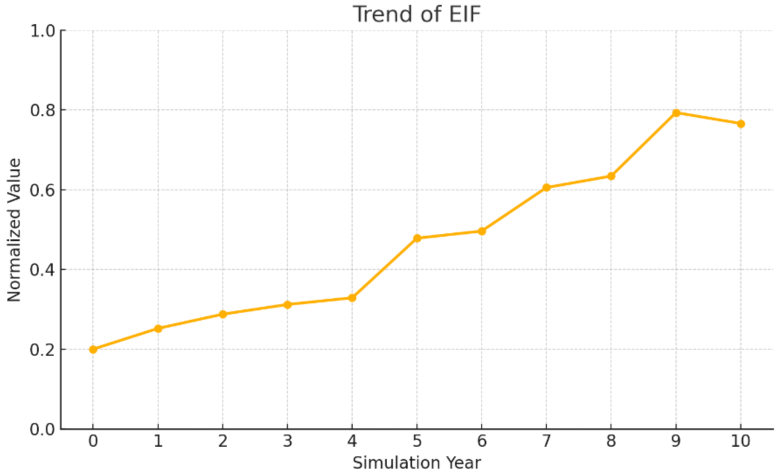
The observed oscillations in KEA values during the later simulation years may reflect the complex dynamics of knowledge systems, where the consolidation of expertise is influenced by fluctuations in support structures, market conditions, or policy environments. Nevertheless, the consistently high levels of KEA suggest that once a critical mass of knowledge dissemination is achieved, the system maintains an elevated capacity to support sustainable agricultural transitions.

Furthermore, improvements in KEA are intrinsically linked to the performance of other core variables such as Sustainable Agricultural Adoption Rate (SAAR) and Economic Viability for Farmers (EVF). Enhanced knowledge access not only facilitates better adoption rates but also improves farmers' capacity to optimize resource use and market engagement, contributing to broader systemic resilience

Positive Environmental Impact Factors (EIF)

The simulation results for Positive Environmental Impact Factors (EIF) illustrate a progressive and accelerating improvement over the ten-year simulation period as shown in Figure 9. Starting from a normalized value of 0.20 at Year 0, EIF increases steadily during the initial years, reaching approximately 0.33 by Year 4. A marked acceleration is observed thereafter, with EIF rising to around 0.79 by Year 9 and stabilizing at 0.77 by Year 10.

Figure 10 - Simulation Trend of Positive Environmental Impact Factors



Home et al. (2023) identifies the insufficient recognition and measurement of environmental impacts associated with conventional agricultural practices as a major systemic lock-in. In the absence of clear environmental performance metrics and effective communication strategies, both policy makers and farmers lack the information needed to drive systemic change. To overcome this barrier, D1.2 proposes the implementation of environmental monitoring systems, certification schemes for sustainable products, and policy frameworks that link incentives to measurable environmental outcomes.

The simulation’s initial gradual improvement in EIF suggests that early efforts to introduce monitoring mechanisms and foster environmental awareness require time to penetrate established agricultural systems. However, the acceleration observed from Year 5 onwards indicates that these interventions begin to generate reinforcing effects, progressively enhancing the system's capacity to recognize, measure, and reward improvements in environmental performance. This dynamic is consistent with the empirical findings reported by Roglic (2025), which highlights that the visibility and credibility of environmental benefits are crucial for sustaining transitions toward more sustainable farming systems. When environmental impacts are made visible—through certification, monitoring, or communication strategies—both market and policy responses become more favourable, reinforcing the transition process.

From a systemic archetypes perspective, the behaviour of EIF aligns strongly with the **Environmental & Regulatory Influences** archetype. Initially constrained by the invisibility of environmental externalities and a lack of regulatory pressure, the system gradually activates feedback loops that integrate environmental considerations into decision-making processes at multiple levels. The improvement in EIF thus signals a progressive weakening of governance lock-ins related to environmental recognition and the successful mobilization of leverage points aimed at linking agricultural practices with ecosystem service outcomes.

Moreover, the enhancement of Positive Environmental Impact Factors contributes to reinforcing dynamics in other areas of the system, such as Policy and Governance for Sustainability (PGS) and Market Demand and Value Chain Efficiency (MDVCE). Improved environmental performance strengthens the legitimacy of policy interventions, enhances the value proposition of sustainable products in the market, and fosters broader social acceptance of sustainable practices.

The simulation results for the Low-Input Agriculture (LIA) pathway depict a progressive and mutually reinforcing systemic transformation. The model outlines a temporal dynamic where early institutional and knowledge-based interventions lay the foundation for subsequent improvements in economic viability, market structures, and environmental outcomes, ultimately supporting the widespread adoption of sustainable practices.

The behaviour of the Sustainable Agricultural Adoption Rate (SAAR) reveals a steady and accelerating trajectory, particularly from Year 6 onwards. This trend indicates that once critical enabling conditions are established—through knowledge access, governance support, and market adjustments—farmers progressively shift towards low-input practices. The centrality of SAAR within the model reflects its role as an integrative indicator of systemic transformation, responsive to multi-dimensional changes across the food system.

Policy and Governance for Sustainability (PGS) exhibits a moderate initial growth followed by a sharp acceleration in the second half of the simulation. This pattern suggests that initial governance efforts create fertile ground for change, but more structured and institutionalized policy interventions are required to unlock full potential. In parallel, Knowledge and Expertise Access (KEA) shows an earlier surge, with a significant jump around Year 5, highlighting the key role of advisory systems and peer-to-peer learning networks in enabling behavioural change and building farmers' confidence to adopt new practices.

Market Demand and Value Chain Efficiency (MDVCE) and Economic Viability for Farmers (EVF) follow more delayed but ultimately strong positive trajectories. After a sluggish start and some initial stagnation, both variables experience accelerated growth in the later stages of the simulation. This dynamic points to the importance of persistent investment in market-building and chain coordination, as well as the need to address early-stage economic risks to unlock long-term profitability for farmers operating within low-input systems.

The Positive Environmental Impact Factors (EIF) display a slower initial response but catch up in the latter years, mirroring the systemic delay in realizing environmental outcomes from behavioural and institutional shifts. As environmental benefits become more visible and quantifiable, they further reinforce the value proposition of low-input systems for both markets and policy frameworks, creating additional feedback loops that support SAAR and EVF.

To deepen the interpretation of model behaviour and assess the influence of key intervention points, a structured sensitivity analysis was performed on core stock variables: SAAR, EVF, MDVCE, PGS, KEA, and EIF. In each case, the two most influential auxiliary variables were identified as those exerting the greatest influence on the inflow of the target stock, based on their role in modulating the flow equations. These variables were then selected for adjustment, and their associated lookup functions were modified to simulate stronger policy leverage and enhanced responsiveness around mid-range values. This sensitivity analysis explores how targeted interventions on key drivers can affect the pace and robustness of the transition dynamics.

The analysis revealed important differences in leverage responsiveness. SAAR (Figure 11) proved highly sensitive to both KEA and PGS, with stronger knowledge systems and institutional governance yielding faster and more extensive adoption trajectories. Notably, the influence of KEA materialized earlier in the simulation, while PGS effects intensified over time, suggesting a sequential logic in which knowledge readiness precedes—and facilitates—governance consolidation.

Figure 11 - Sensitivity Analysis of SAAR

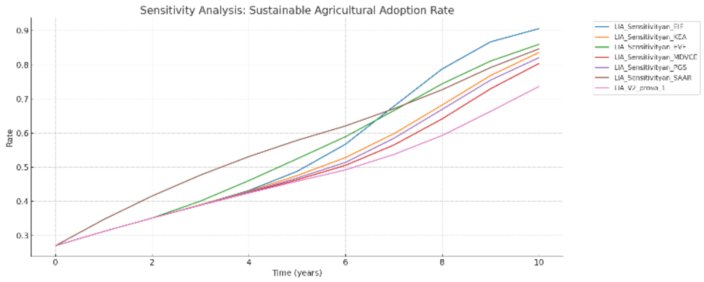
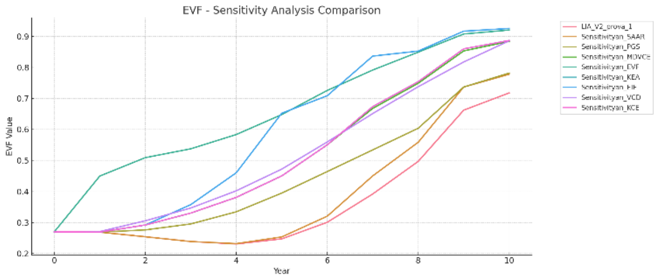


Figure 12 - Sensitivity Analysis of EVF



EVF (Figure 10) and MDVCE (Figure 13) also responded positively to improvements in KEA and PGS but showed a stronger reaction to market-related variables, confirming that economic viability is primarily driven by the interplay of institutional trust, knowledge infrastructure, and market efficiency. The positive impact of improved MDVCE conditions—such as streamlined value chains and increased consumer demand for sustainable products—was particularly evident in the second half of the simulation, supporting the cumulative nature of economic transitions.

Figure 14 - Sensitivity Analysis of MDVCE

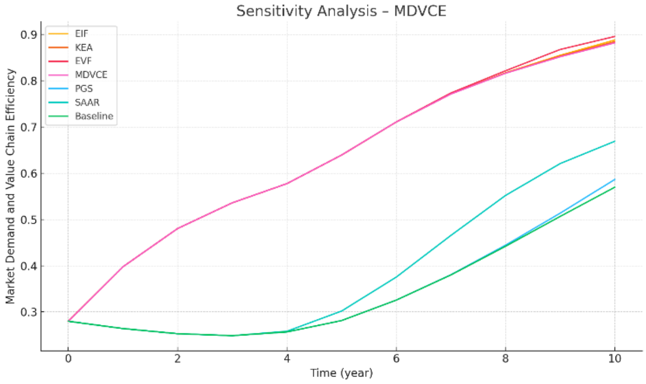
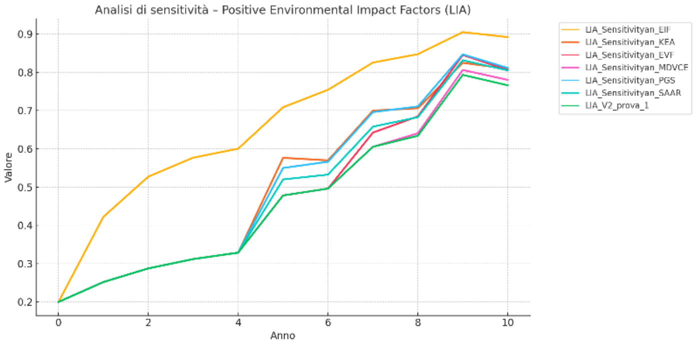


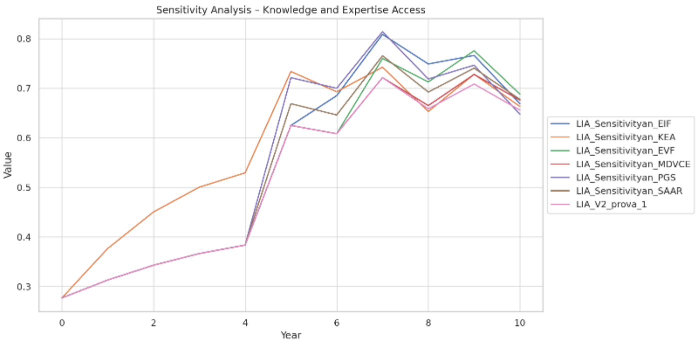
Figure 13 - Sensitivity Analysis of EIF



EIF (Figure 12) responded most clearly to improvements in KEA and PGS, with knowledge access accelerating the visibility and implementation of environmental practices, and governance support reinforcing the credibility of sustainability claims. These reinforcing loops suggest that institutional and knowledge-related investments are not only instrumental in enabling behavioural change but also play a central role in unlocking environmental co-benefits.

Figure 16 - Sensitivity Analysis of PGS

Figure 15 - Sensitivity Analysis of KEA



The sensitivity of PGS (Figure 15) was particularly marked in response to EIF adjustments. Increased environmental gains positively influence policy momentum and institutional support, leading to faster governance consolidation. Similarly, KEA (Figure 14) values responded notably to enhancements in MDVCE and SAAR, confirming the role of learning loops where market engagement and practice adoption reinforce peer knowledge diffusion.

Which are the driver variables of the LIA transition pathway?

These results support the identification of a set of primary and systemic drivers of transition. Variables such as Knowledge and Expertise Access and Policy and Governance for Sustainability emerged as key enablers—early movers that catalyse SAAR and generate indirect benefits across market and environmental domains. Similarly, MDVCE and EVF function as systemic amplifiers: once favourable knowledge and governance conditions are met, they magnify the transition's impact through improved profitability and supply chain coordination. Finally, EIF plays a dual role—both as an outcome and as a reinforcing element that legitimizes the transition in the eyes of policymakers and markets.

Overall, the LIA simulation illustrates a temporally layered and interdependent pathway of change. Transition success relies not on isolated interventions but on their coordinated activation and mutual reinforcement over time. The model underscores the importance of synchronizing efforts across governance, knowledge, market, economic, and environmental domains to trigger and sustain robust, resilient, and self-reinforcing transformations toward sustainable farming systems.

Highlights of Low-Input Agriculture (LIA) Pathway

- **Sequential and interdependent systemic transition**
  The LIA model highlights a transition dynamic in which early improvements in knowledge (KEA) and governance (PGS) dimensions create the enabling conditions for subsequent progress in economic viability (EVF), market structures (MDVCE), and environmental outcomes (EIF), ultimately supporting the widespread adoption of sustainable agricultural practices (SAAR).
- **Critical role of knowledge and governance as early enablers**
  Access to expertise and advisory support (KEA), alongside coherent and stable governance structures (PGS), emerge as foundational drivers that trigger behavioural change, build farmers' confidence, and sustain momentum towards low-input practices.
- **Economic and market improvements as systemic amplifiers**
  Enhanced value chain efficiency (MDVCE) and improved financial conditions for farmers (EVF) act as amplifiers of the transition, showing strong positive trajectories in the later simulation years once enabling structures are in place.
- **Environmental benefits as reinforcing legitimacy factors**
  The progressive visibility of environmental impacts (EIF) strengthens the societal and policy legitimacy of the transition, activating further positive feedback loops across market and governance dimensions.
- **Importance of coordination and persistence across domains**
  The simulation confirms that isolated interventions are insufficient: successful transition requires strategically coordinated and persistent action across governance, knowledge, market, economic, and environmental domains.

7.3.2 Sustainable Consumer Branding and Selling Thematic SDM

This chapter presents the simulation analysis of the Sustainable Consumer Branding and Selling Pathway (SCDS) developed within the ENFASYS project. The pathway focuses on enabling sustainable transitions in food systems by promoting direct selling models and branding strategies that enhance consumer awareness, trust, and willingness to pay for sustainably produced goods.

The SCDS System Dynamics Model (SDM) translates the qualitative structures derived from participatory Theory of Change (ToC) exercises into a dynamic simulation framework. The model adopts a stock-and-flow architecture, with variables normalized between 0 and 1 to allow the representation of behavioural and systemic trends rather than focusing on absolute resource quantities. The calibration of weights, flows, and auxiliary functions draws on the empirical cross-case evidence explained by Roglic (2025).

The simulation particularly analyses the dynamics of five core variables identified as central to the SCDS pathway:

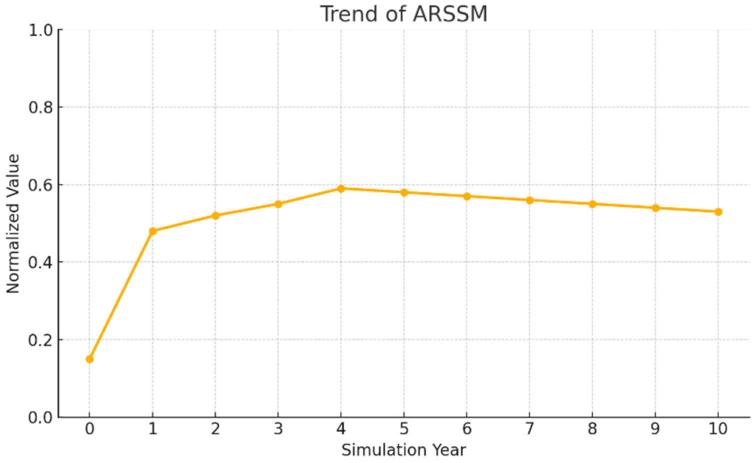
- Adoption Rate of Sustainable Selling Models (ARSSM),
- Infrastructure & Logistic Capacity (ILC),
- Training and Knowledge Support (TKS),
- Revenue and Financial Stability (RFS) and
- Consumer Demand and Willingness to Pay (CDWTP).

These variables were selected for their systemic relevance, representing critical behavioural, infrastructural, economic, and market dimensions necessary for a sustainable transition. Each variable's simulated trajectory is interpreted against theoretical expectations, observed empirical patterns, and the systemic archetypes identified for the SCDS pathway. This approach enables a comprehensive understanding of the systemic conditions that facilitate or constrain the transition process. The analysis provides insights into the strengths, vulnerabilities, feedback structures, and critical interdependencies within the system, informing reflections on how coordinated interventions might strengthen transition dynamics over time.

Adoption Rate of Sustainable Selling Models (ARSSM)

The simulation results, as shown in Figure 16, for the Adoption Rate of Sustainable Selling Models (ARSSM) demonstrate a steady growth during the early years of the simulation, followed by a stabilization phase. Starting from a normalized value of 0.15 at Year 0, ARSSM increases sharply to approximately 0.48 by Year 1, continuing to rise moderately until Year 5 where it peaks at around 0.59. From Year 6 onwards, the adoption rate fluctuates between 0.53 and 0.59, indicating the achievement of a relatively stable, though not expanding, systemic adoption level. The initial rapid increase suggests a successful activation of early stage enabling dynamics, while the subsequent plateau reflects persisting systemic barriers preventing broader consolidation.

Figure 17 - Trend Simulation of Adoption Rate of Sustainable Sellin Models



Home et al. (2023) identifies a series of systemic lock-ins typically hindering the adoption of sustainable branding and selling models, including behavioural lock-ins tied to conventional market channels, structural lock-ins due to insufficient logistic and infrastructural support, and informational lock-ins stemming from low consumer awareness and recognition of sustainable value propositions. To overcome these barriers, Home et al. (2023) emphasizes the importance of strengthening dedicated logistic infrastructures, implementing targeted training and peer-learning initiatives for producers, and fostering consumer trust through coordinated branding strategies and policy support.

The ARSSM trend observed in the simulation suggests that these systemic barriers have been partially mitigated, particularly during the initial years, allowing for a significant early adoption wave. However, the stabilization phase observed from Year 6 onwards indicates that while initial leverage points were successfully activated, broader systemic lock-ins—particularly structural and organizational—have not been fully dismantled. This behaviour reflects the theoretical expectation that while awareness and training can catalyse early adoption, infrastructural and market conditions are essential for sustaining and expanding systemic change.

Furthermore, the findings align closely with the empirical patterns observed in deliverable Roglic (2025), which notes that real-world transformation initiatives in the domain of sustainable selling models often experience a rapid initial adoption phase followed by stagnation if enabling structures—such as logistics, branding ecosystems, and supportive policy frameworks—are not fully developed. In particular, Roglic (2025) highlights the risk of initiatives remaining confined to pioneering niches without broader market penetration when these systemic factors are absent, a dynamic that the simulation reproduces faithfully.

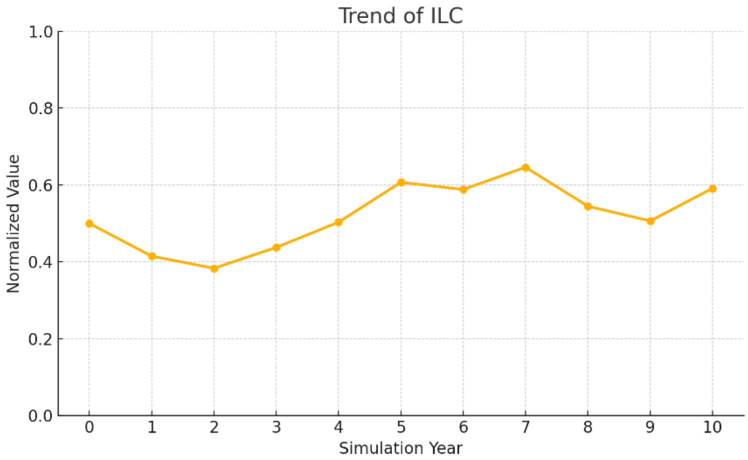
When analysed in relation to the systemic archetypes identified for the Sustainable Consumer Branding and Selling Pathway, the behaviour of ARSSM further confirms the internal coherence of the model. The early growth phase corresponds to the partial overcoming of behavioural lock-ins to selling channels and initial success in knowledge diffusion, while the later stagnation phase reflects the persistence of structural constraints related to infrastructure and enabling market environments. These dynamics illustrate the critical importance of a combined approach targeting behavioural, infrastructural, and market factors simultaneously.

Overall, the simulation results for the Adoption Rate of Sustainable Selling Models offer strong evidence that the system modelled for the SCDS pathway is capable of triggering an initial systemic transition. However, they also reveal the inherent challenges in achieving broader systemic consolidation without sustained infrastructural investments, cross-actor coordination, and strategic market development. The findings underscore the need for persistent, multi-level interventions to move from early adoption phases toward stable, widespread systemic transformation.

Infrastructure & Logistic Capacity (ILC)

The simulation results, as shown in Figure 17, for the Infrastructure & Logistic Capacity (ILC) reveal a non-linear but progressive improvement over the ten-year simulation period. Starting from a normalized value of 0.50 at Year 0, ILC initially declines slightly to around 0.38 by Year 2, reflecting a period of structural weakness or delayed investments. From Year 3 onwards, the capacity recovers, reaching approximately 0.61 by Year 5 and oscillating between 0.54 and 0.65 throughout the remainder of the simulation. This behaviour indicates a dynamic where infrastructural improvements emerge over time but are subject to fluctuations, possibly reflecting discontinuities in investment or coordination mechanisms.

Figure 18 - Trend Simulation of Infrastructure & Logistic Capacity



Home et al. (2023) identifies infrastructural inadequacies as a core structural lock-in hampering the systemic transition towards sustainable consumer branding and direct selling models. Insufficient logistical capacity, fragmented distribution systems, and inadequate access to local markets are among the key barriers outlined. To address these challenges, Home et al. (2023) highlights the need for strategic investment in dedicated logistics, the development of cooperative platforms, and the creation of regional hubs that facilitate direct producer-to-consumer linkages. The ILC trend observed in the simulation suggests that while strategic investments have been initiated and some infrastructure has been built or improved, the systemic consolidation of these capacities remains incomplete. The recovery after Year 3 indicates a successful activation of leverage points associated with infrastructural development, but the continued oscillations suggest that the system lacks robustness and is vulnerable to shocks or inconsistencies in policy or market support. These results are consistent with the theoretical expectations that logistics development is not a one-off intervention but requires sustained, coordinated efforts over time.

Furthermore, the findings are consistent with the empirical observations reported in deliverable Roglic (2025), which documents that in real-world initiatives, the absence of stable, well-supported logistic infrastructures often leads to fragmentation and hinders the scaling-up of sustainable selling models. In particular, Roglic (2025) stresses that while pilot projects can achieve temporary gains through localized logistics innovations, the lack of long-term systemic support tends to reintroduce vulnerabilities, a dynamic mirrored in the oscillating trend observed in the simulation.

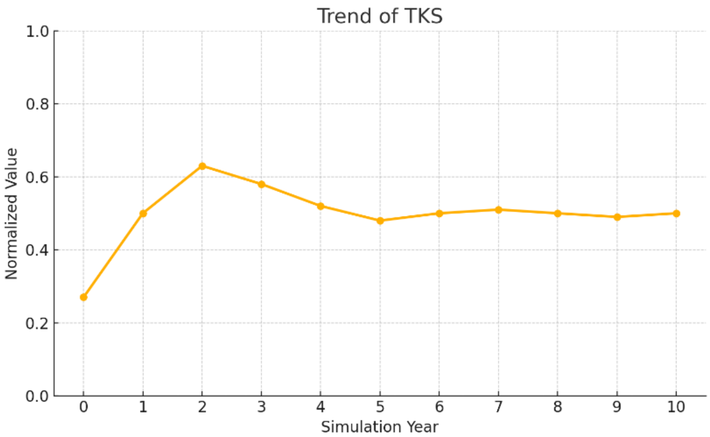
When analysed in relation to the systemic archetypes identified for the Sustainable Consumer Branding and Selling Pathway, the behaviour of ILC reflects patterns associated with the Infrastructure & Policy-Enabling and Financial Viability under Pressure archetypes. In this configuration, initial progress is undermined by the system's inability to sustain resource availability or infrastructural support over time, leading to phases of advancement followed by stagnation or minor decline.

Overall, the simulation results for Infrastructure & Logistic Capacity illustrate the critical role that infrastructural support plays in sustaining transitions toward sustainable consumer branding and selling. They demonstrate that while progress is possible, it is neither linear nor guaranteed: building resilient logistic infrastructures requires continuous investment, strategic coordination among actors, and policy mechanisms that buffer against economic or organizational shocks. Without these, even promising early advancements may remain fragile, limiting the broader systemic transformation.

Training and Knowledge Support (TKS)

The simulation results, as shown in Figure 18, for the Training and Knowledge Support (TKS) variable reveal a non-linear dynamic over the ten-year simulation period. Starting from a normalized value of 0.27 at Year 0, TKS experiences a sharp increase, reaching approximately 0.63 by Year 2. This initial acceleration indicates a strong early investment in training activities and knowledge dissemination. However, from Year 2 onwards, the variable shows a progressive decline, stabilizing around 0.5 by Year 5 and maintaining this level throughout the remainder of the simulation. This behaviour suggests that while early interventions were effective in expanding access to training, systemic support was not consistently sustained, leading to a partial erosion before reaching a plateau.

Figure 19 - Trend Simulation of Training and Knowledge Support



Home et al. (2023) identifies knowledge and advisory deficits as critical systemic lock-ins constraining transitions in sustainable branding and selling models. Farmers and small producers often lack continuous access to technical, marketing, and organizational expertise necessary for adopting new selling strategies. To overcome these barriers, Home et al. (2023) highlights the importance of expanding advisory services, fostering peer-learning networks, and ensuring the structural embedding of continuous training systems within broader governance and market infrastructures.

The observed TKS trend in the simulation suggests that these leverage points were partially activated during the initial years, triggering rapid early improvements. However, the subsequent decline indicates that the systemic conditions necessary for the institutionalization of training support were not fully established. This partial implementation led to a stabilization at intermediate levels of support, insufficient to maintain the momentum necessary for further systemic innovation. This pattern aligns closely with the theoretical expectation that one-off or project-based interventions are unlikely to sustain knowledge systems unless anchored within enduring institutional frameworks.

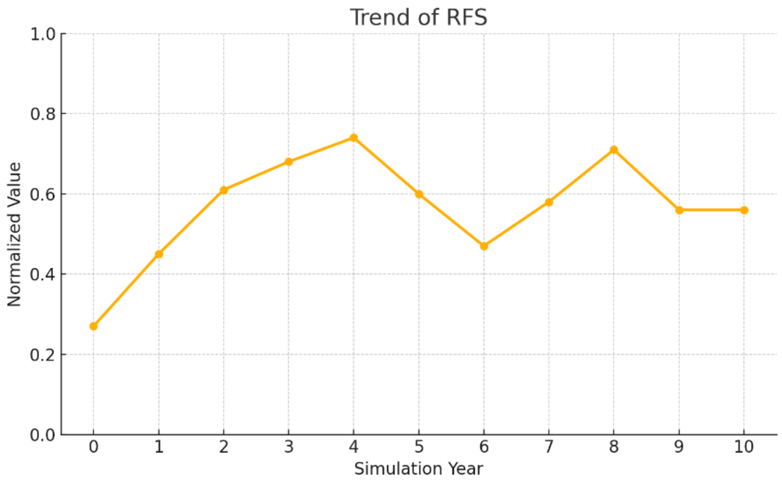
Furthermore, the findings resonate with the empirical patterns observed in deliverable Roglic (2025), where it is documented that early-stage successes in knowledge dissemination, often driven by pilot projects or targeted funding, frequently fail to sustain themselves once the initial impetus wanes. Roglic (2025) emphasizes that without long-term integration into cooperative structures, extension services, or market mechanisms, knowledge systems risk fragmentation and decline—an outcome faithfully mirrored in the simulation trend.

Overall, the simulation results for Training and Knowledge Support underline the crucial role of continuous investment and structural embedding of knowledge systems in supporting sustainable transitions. While early initiatives can catalyze change, their long-term impact critically depends on their integration into permanent governance, market, and cooperative frameworks. Without these conditions, knowledge support risks remaining partial and insufficient to drive comprehensive systemic transformation.

Revenue and Financial Stability (RFS)

The simulation results, as shown in Figure 19, for the Revenue and Financial Stability (RFS) variable reveal a highly dynamic and unstable trajectory over the ten-year simulation period. RFS initially increases steadily from a normalized value of approximately 0.27 at Year 0 to a peak of about 0.74 by Year 4. However, this is followed by a marked decline to around 0.47 by Year 6. The system then exhibits a sharp recovery, rising to approximately 0.71 by Year 8, before experiencing another decline to about 0.56 by Year 9 and stabilizing at this level through Year 10. This behaviour suggests a system that can generate short-term financial gains but remains vulnerable to systemic shocks and lacks consolidated resilience over time.

Figure 20 - Trend Simulation of Revenue and Financial Stability



Home et al. (2023) identifies economic instability as a major systemic lock-in constraining sustainable branding and selling models. Key barriers include fragmented and unstable demand, limited access to financing and logistic support, and exposure to volatile market conditions. To overcome these lock-ins, Home et al. (2023) highlights the importance of developing stable cooperative structures, securing long-term investment frameworks, and creating market niches that can buffer producers against external shocks.

The trend observed in the simulation aligns with these theoretical expectations in that it reflects significant financial fragility and sensitivity to systemic vulnerabilities. The initial growth phase suggests that enabling conditions were temporarily activated, possibly through project-based funding or emerging market opportunities. However, the subsequent fluctuations indicate that these gains were not structurally embedded within the system. This behaviour points to a lack of systemic consolidation of economic viability, consistent with the theoretical risks outlined in D1.2.

Real-world cases documented by Roglic (2025) frequently show that early-stage initiatives in sustainable selling models can generate financial improvements, but struggle to maintain stability without robust demand consolidation, infrastructural support, and institutional backing. However, it must be noted that the oscillations observed in the simulation—particularly the sharp decline and recovery cycles—are somewhat more pronounced than those typically documented in real-world initiatives. While Roglic (2025) highlights financial fragility and stagnation, the extreme volatility depicted in the simulation suggests a possible amplification of systemic instability, representing a worst-case or boundary scenario rather than an average expected dynamic.

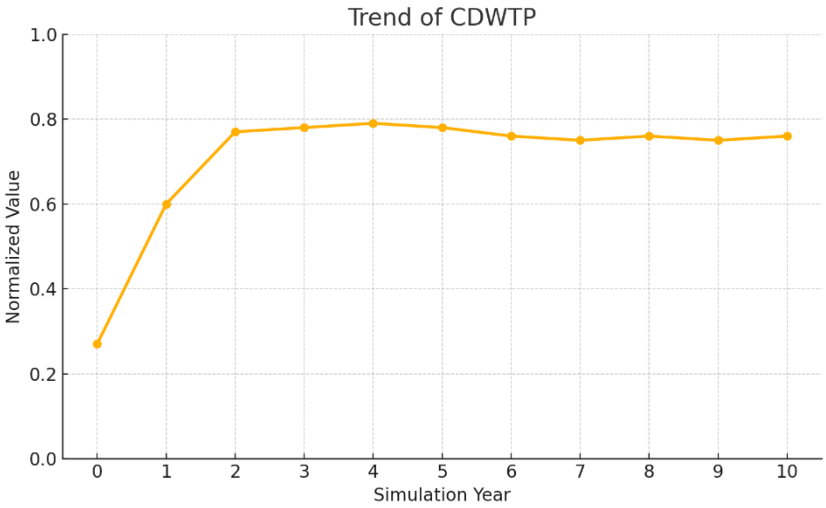
When analysed in relation to the systemic archetypes identified for the Sustainable Consumer Branding and Selling Pathway, the behaviour of RFS aligns with the Financial Viability under Pressure and Infrastructure & Policy-Enabling Loop archetypes. These archetypes describe systems where temporary improvements fail to create self-reinforcing economic stability, resulting in repeated cycles of vulnerability and recovery rather than steady consolidation.

Overall, the simulation results for Revenue and Financial Stability illustrate the critical importance of building durable, systemic economic support mechanisms within transition pathways. Without sustained investment, market stabilization efforts, and cooperative economic frameworks, even promising early financial gains risk devolving into instability, limiting the long-term success of sustainable selling models. The pronounced volatility observed in the simulation reinforces the need for systemic resilience strategies to avoid exposing transition processes to repeated economic disruptions.

Consumer Demand and Willingness to Pay (CDWTP)

The simulation results, as shown in Figure 20, for the Consumer Demand and Willingness to Pay (CDWTP) variable reveal a positive and sustained dynamic over the ten-year simulation period. Starting from a normalized value of approximately 0.27 at Year 0, CDWTP exhibits a rapid increase, reaching around 0.77 by Year 2. From Year 3 onwards, the variable stabilizes at high levels, fluctuating between 0.75 and 0.80, with no significant declines observed until Year 10. This behaviour suggests that consumer awareness, trust, and willingness to support sustainable selling models consolidate early in the transition process and remain robust over time.

Figure 21 - Trend Simulation of Consumer Demand and Willingness to Pay



Home et al. (2023) identifies fragmented and uncertain consumer demand as a primary systemic lock-in constraining transitions towards sustainable branding and selling models. Addressing this lock-in requires targeted interventions aimed at building consumer awareness, strengthening trust through branding and certification schemes, and effectively communicating the added value of sustainable products. The strong early growth and subsequent stabilization observed in the simulation suggest that these leverage points were successfully activated early in the transition process, resulting in the consolidation of consumer demand and willingness to pay at relatively high levels.

The trend is further supported by empirical observations reported in deliverable Roglic (2025), where real-world cases demonstrate that successful initiatives often achieve demand consolidation through coordinated branding, consumer education, and trust-building strategies. In those cases where sustained consumer engagement is achieved, the market for sustainable products stabilizes, providing critical support for broader systemic transitions. The simulation reproduces this successful dynamic, reflecting a situation where marketing, communication, and product value strategies effectively reinforced consumer trust and loyalty.

When analysed in relation to the systemic archetypes identified for the Sustainable Consumer Branding and Selling Pathway, the behaviour of CDWTP corresponds to the Branding and Trust Building and Market Maturity Feedback archetypes. These archetypes describe systems where the successful consolidation of consumer trust leads to sustained market maturity, reducing the need for constant interventions and allowing the system to maintain high levels of consumer engagement autonomously.

Overall, the simulation results for Consumer Demand and Willingness to Pay illustrate a critical enabler for sustainable transition pathways. By securing high and stable levels of consumer demand early in the process, the system mitigates risks associated with market volatility and creates a stable foundation for the adoption and persistence of sustainable selling models. The findings emphasize the importance of early, targeted investment in branding, trust-building, and value communication strategies as essential pillars for supporting systemic transformation in consumer markets.

Sustainable Consumer Branding and Selling Pathway (SCDS) Pathway simulation analysis

The simulation results for the Sustainable Consumer Branding and Selling Pathway (SCB) reveal a complex but coherent dynamic of systemic transition. The model captures an initial phase of successful activation of behavioural and consumer-side leverage points, followed by the emergence of deeper infrastructural and economic vulnerabilities that partially constrain the long-term stabilization of the transition process.

The behaviour of the Adoption Rate of Sustainable Selling Models (ARSSM) (Figure 23*)* shows a promising pattern, with a strong initial increase that stabilizes at medium-high levels. This trend suggests that early interventions targeting knowledge dissemination and consumer awareness were effective in triggering behavioural change among producers and sellers. The activation of leverage points such as targeted training, branding strategies, and consumer education initiatives appears to have successfully overcome behavioural lock-ins in the early stages of the transition.

However, the evolution of Infrastructure and Logistic Capacity (ILC) highlights structural limitations within the system. While logistic capacity improves over time, its growth is uneven and subject to setbacks, reflecting systemic vulnerabilities related to investment continuity, organizational coordination, and infrastructural robustness. These limitations restrict the scaling potential of sustainable selling models, as producers and retailers face logistical bottlenecks that constrain their capacity to reach broader markets effectively.

The trajectory of Training and Knowledge Support (TKS) (Figure 22) mirrors a similar pattern of initial success followed by partial erosion. Although early efforts in building advisory and training infrastructures yield rapid gains, the system fails to fully institutionalize these services, leading to a plateau in support capacity. This dynamic reflects a short-term programmatic approach, where initial projects and interventions succeed in mobilizing resources but lack the structural anchoring necessary to sustain knowledge flows over time.

Revenue and Financial Stability (RFS) (Figure 21) displays a more volatile dynamic, with phases of strong growth punctuated by significant declines. This instability underscores the fragility of the economic foundations supporting the transition. While initial improvements in revenue generation and financial security are observed, the system's exposure to market fluctuations, logistical weaknesses, and fragmented demand undermines its capacity to maintain stable economic conditions. The pronounced oscillations in RFS suggest that without robust cooperative frameworks, risk-sharing mechanisms, and long-term market consolidation strategies, financial viability remains precarious.

In contrast, Consumer Demand and Willingness to Pay (CDWTP) (Figure 24) emerges as a systemic strength within the SCDS model. The rapid early growth and subsequent high-level stabilization of consumer demand demonstrate the effectiveness of branding, trust-building, and value communication strategies implemented early in the transition. The resilience of consumer willingness to support sustainable products provides a critical stabilizing force, mitigating some of the vulnerabilities observed in the infrastructural and economic dimensions.

Figure 23 - Sensitivity Analysis TKS

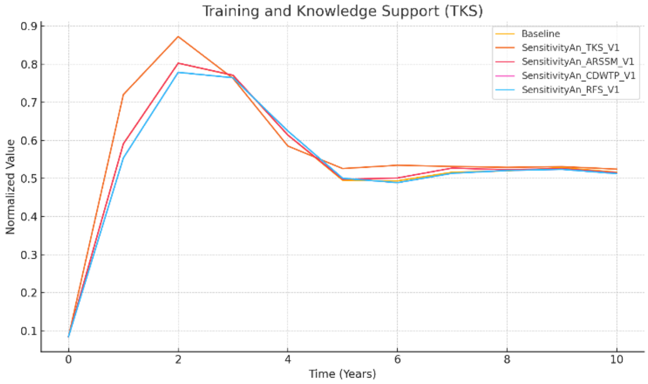
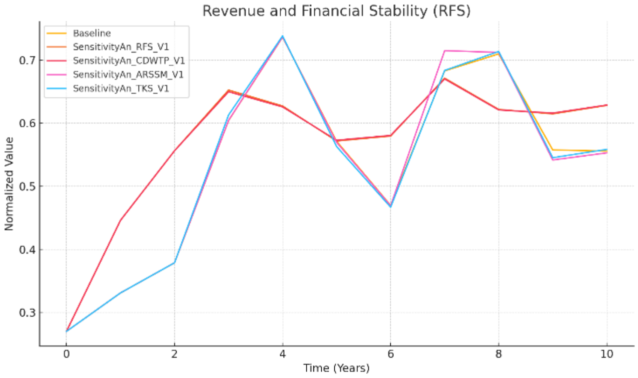


Figure 22 - Sensitivity Analysis RFS



To further test the internal consistency of the model and identify leverage points capable of influencing key transition dynamics, a structured sensitivity analysis was conducted on the core stock variables (CDWTP, ARSSM, RFS, and TKS). In each case, the two most influential auxiliary variables feeding into the stock's inflow were modified through adjusted lookup functions to simulate stronger responsiveness to mid-range values. The resulting comparisons with the baseline scenario revealed important patterns. The most substantial changes were observed in *TKS* (Figure 13) and *RFS (Figure 12)*. Adjustments to the responsiveness of training demand and policy support produced a faster and higher stabilization of TKS, indirectly benefiting early CDWTP dynamics (Figure 14).

Similarly, reinforcing the financial leverage from consumer demand and improving policy responsiveness significantly increased RFS stability, especially in the second half of the simulation. While changes in CDWTP itself were relatively minor—suggesting a degree of behavioural saturation—its positive effect on RFS and, indirectly, on ARSSM (Figure 15), was clearly confirmed.

Figure 25 - Sensitivity Analysis CDWTP

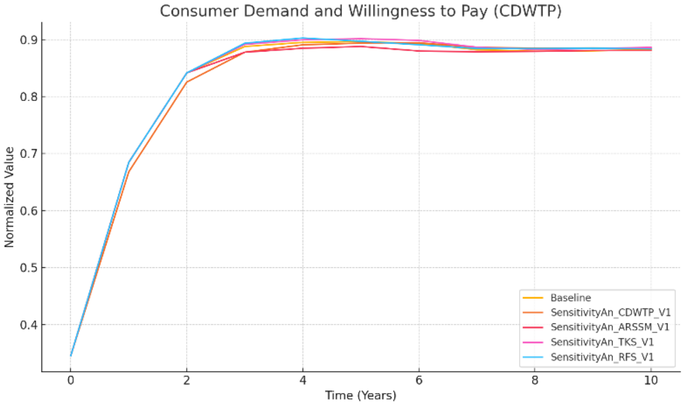
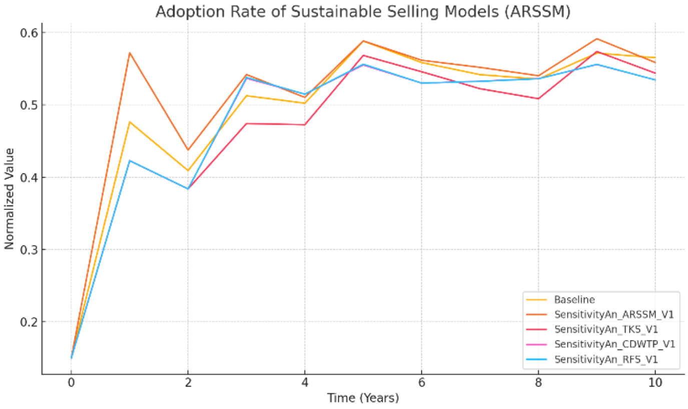


Figure 24 - Sensitivity Analysis ARSSM



Which are the driver variables of the SCBDS transition pathway?

These results also support the identification of potential **drivers of transition**. Variables such as *Financial Readiness for Adoption* and *Market Attractiveness*, directly influencing Adoption Rate Sustainable Selling Models, were confirmed as **primary drivers** capable of accelerating behavioural adoption under strengthened conditions. At the same time, *Brand Appeal*, *Consumer Access*, *Training System Responsiveness*, and *Policy Financial Support* emerged as **systemic drivers**—levers that, while acting indirectly, reinforce the broader enabling environment needed to sustain transition efforts.

Overall, the Sustainable Consumer Direct Selling simulation illustrates a partial but meaningful systemic transition. Behavioural and consumer-side transformations are successfully triggered and largely maintained, creating a supportive environment for sustainable selling practices. However, the infrastructural and financial foundations necessary for the full scaling and stabilization of the transition are only partially developed, resulting in systemic fragilities that limit the consolidation of early successes. The integrated sensitivity results highlight the importance of coordinating interventions across behavioural, financial, infrastructural, and market dimensions. By identifying both direct and systemic drivers of change, the model supports strategic reflection on where to focus policy and innovation efforts to unlock resilient and self-reinforcing transformation pathways.

Highlights of the Sustainable Consumer Branding and Selling (SCDS) Pathway

- **Early behavioural activation, but incomplete systemic consolidation**
  The simulation confirms the system's ability to trigger early adoption through targeted training, branding, and awareness-raising. However, broader systemic transition remains constrained by persistent infrastructural and economic lock-ins that prevent sustained scaling.
- **Consumer-side engagement as a structural stabilizer**
  High and sustained levels of Consumer Demand and Willingness to Pay (CDWTP) emerge early and remain stable throughout the simulation, acting as a resilient foundation that mitigates volatility elsewhere in the system.
- **Fragile infrastructural and financial foundations**
  While improvements in Infrastructure and Logistic Capacity (ILC) and Revenue and Financial Stability (RFS) are observed, both exhibit instability over time. This underscores the importance of robust, long-term investment and coordination strategies to support durable systemic change.
- **Erosion of knowledge systems without institutional embedding**
  Training and Knowledge Support (TKS) grows rapidly at first but plateaus due to a lack of structural consolidation. This highlights the limitations of short-term initiatives not anchored in permanent advisory and learning frameworks.
- **Sensitivity analysis reveals critical leverage points**
  Simulation experiments show that policy financial support, training responsiveness, and consumer-driven financial flows significantly influence system resilience. These variables serve as key policy levers capable of improving economic viability and behavioural adoption over time.
- **Systemic drivers must act in coordination**
  Results identify both direct (e.g., Market Attractiveness, Financial Readiness) and indirect (e.g., Brand Appeal, Policy Support) drivers of transition. Effective transformation requires their combined and sustained activation across behavioural, infrastructural, and market domains

7.3.3 Extensification of Livestock Systems Thematic SDM

This chapter presents the simulation analysis of the Livestock Extensification (LE) Pathway, developed as part of the ENFASYS project. The LE pathway focuses on promoting sustainable transitions in livestock systems by encouraging the adoption of extensive practices, enhancing local feed autonomy, and reinforcing producer-consumer trust through territorial embeddedness and direct value chain engagement.

The LE System Dynamics Model (SDM) operationalizes the qualitative insights derived from participatory Theory of Change (ToC) workshops into a formalized simulation framework. The model adopts a stock-and-flow structure with variables normalized between 0 and 1, allowing for the dynamic analysis of behavioural change, infrastructural development, and economic adaptation processes without relying on absolute units. Model calibration is informed by cross-case empirical data synthesized in Roglic (2025) and by the systemic assumptions embedded in D1.2 (Home et al., 2023).

The simulation focuses on five core stock variables identified as central to the LE pathway:

- Local/Regional Feed Autonomy (LRFA)
- Farmers' Proposal and Adoption of Sustainable Practices (FPASP)
- Policy Support (PS)
- Farm Profitability (FP)
- Resilience Building (RB)

These variables were selected for their systemic significance in enabling and sustaining the extensification process. They represent key leverage points at the intersection of agronomic adaptation, institutional support, economic viability, and system resilience.

Each variable's trajectory is analysed in relation to the ENFASYS conceptual framework, cross-case empirical patterns from real-world initiatives, and the systemic archetypes identified for the Livestock Extensification thematic cluster. This approach facilitates an integrated interpretation of the strengths, tensions, and feedback loops shaping the transition. The analysis provides insights into how systemic alignment, participatory governance, and long-term coordination can support resilient extensification trajectories in livestock systems.

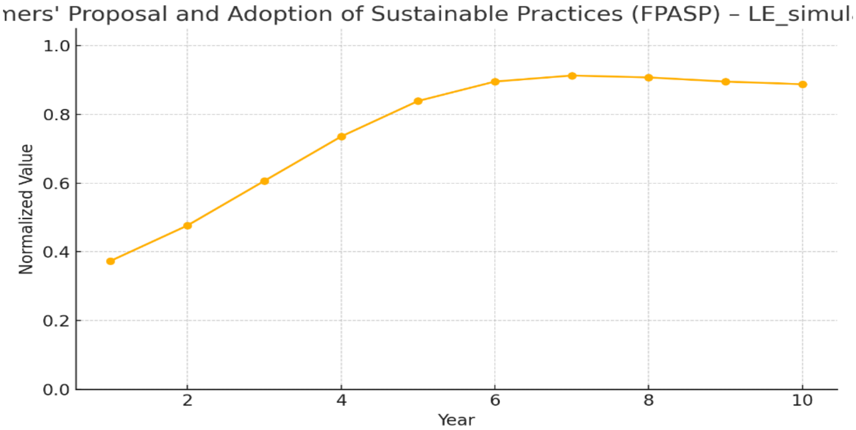
Farmers’ Proposal and Adoption of Sustainable Practices (FPASP)

The simulation results for Farmers’ Proposal and Adoption of Sustainable Practices (FPASP) display a rapid increase in the first half of the simulation period, rising from 0.37 in Year 1 to 0.84 by Year 5, as shown in Figure 25. After this point, the curve begins to plateau, stabilizing around 0.89 through Year 10. This trajectory illustrates a classic S-shaped diffusion dynamic, where adoption accelerates once initial barriers are overcome, but slows as the system approaches behavioural saturation.

This simulated behaviour corresponds closely to the “Knowledge Engagement and Institutional Trust” archetype. The initial acceleration in FPASP likely reflects the activation of these supports, while the subsequent plateau may indicate limits in the system’s capacity to maintain dynamic engagement or reach more reluctant adopter segments.

The pattern also reflects the dynamics described by (Home et al., 2023), which emphasizes that behavioural adoption is strongly dependent on the presence of trust-based advisory systems and meaningful participation. The report warns that without ongoing engagement, even initially successful initiatives risk stagnation. The levelling-off of FPASP in

Figure 26 - Trend Simulation of Farmers’ Proposal and Adoption of Sustainable Practices



the simulation aligns with this insight, suggesting that first-mover enthusiasm alone is insufficient for systemic transformation unless sustained through iterative support, institutional credibility, and inclusive design.

In D4.2 (Roglic et al., 2025), cross-case evidence reveals that many farmers are willing to adopt sustainable practices—particularly those that align with existing values or perceived market opportunities—but structural constraints such as labour demands, risk aversion, or administrative burden often curb long-term uptake. The simulation captures this two-phase dynamic: an early expansion driven by accessible interventions, followed by a deceleration as deeper lock-ins persist.

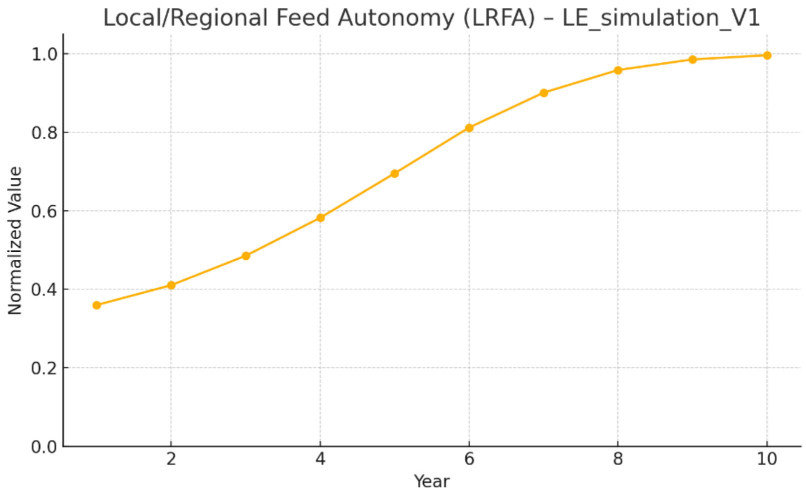
FPASP is also indirectly linked to the "Sustainability Premium as Reinforcing Driver" archetype, since farmers' willingness to adopt practices is often conditioned by the perceived economic return (e.g., premium pricing, certification incentives). The slowing trajectory may indicate that these reinforcing economic signals are insufficiently institutionalized or widely distributed across all adopter profiles.

In conclusion, the trajectory of FPASP in the LE_simulation_V1 model shows a realistic diffusion pattern, grounded in both behavioural theory and empirical observation. It highlights that while enabling structures can stimulate early adoption, a transition to full system transformation requires continuous institutional reinforcement, dynamic learning processes, and the strategic reduction of persistent adoption barriers.

Local/Regional Feed Autonomy (LRFA)

The simulation results for Local/Regional Feed Autonomy (LRFA) show a consistent and accelerating upward trend. The variable rises from 0.36 in Year 1 to approximately 0.70 by Year 5, and reaches 0.99 by Year 10, as shown in Figure 26. This trajectory suggests a strong reinforcing dynamic in which local feed systems increasingly replace dependence on external inputs, culminating in near-total autonomy by the end of the simulation horizon.

Figure 27 - Trend Simulation of Local/Regional Feed Autonomy



This behaviour aligns particularly with the "Sustainability Premium as Reinforcing Driver" and "Trust-Based Certification for Regional Value Chains" archetypes. In these archetypes, local feed autonomy plays a central role by reducing reliance on imported, high-input feed (e.g., soy), supporting the regionalization of value chains, and enhancing traceability and legitimacy of production. LRFA contributes directly to the systemic reconfiguration of input sourcing and farm management practices, creating a feedback loop that reinforces farmer autonomy, consumer trust, and sustainability differentiation.

Furthermore, the dynamic observed in the simulation corresponds well to the enabling conditions described by (Home et al., 2023). The report identifies the territorial anchoring of production systems and the development of infrastructure for local feed and input autonomy as key levers to overcome lock-ins in livestock systems. It also highlights how autonomy in feed sourcing is critical for enabling transitions that are resilient, place-based, and less exposed to global input market volatility. The model reflects this by showing a non-reversible, cumulative trajectory of LRFA, suggesting that the necessary structural supports—such as investments in local feed chains, logistics, and institutional backing—are in place and effective.

From the perspective of D4.2 (Roglic et al., 2025), cross-case findings reveal that initiatives which prioritize feed autonomy often encounter initial barriers—such as lack of infrastructure, knowledge, or coordination—but show strong potential once core elements (e.g., local feed cooperatives, extension services) are activated. The simulation captures this pattern well: a slow-to-moderate build-up followed by rapid consolidation, indicative of a threshold effect in system reorganization.

While the simulated behaviour depicts an optimistic and structurally coherent scenario, it may underrepresent real-world frictions such as land competition, capital constraints, or fragmented supply chains, which can delay or stall such transitions. Nevertheless, as a normative representation, the trajectory of LRFA provides a valuable illustration of how local autonomy can emerge as a cornerstone of livestock extensification under favourable systemic conditions.

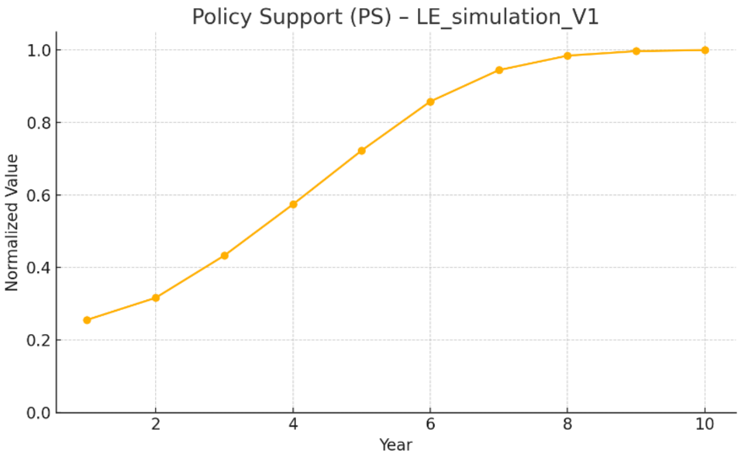
In summary, the simulated evolution of LRFA demonstrates strong alignment with the theoretical structure of the Livestock Extensification pathway and the empirical findings of ENFASYS. It highlights the critical role of territorial resource autonomy as both an output and a driver of long-term sustainability in livestock systems.

Policy Support (PS)

The simulation of Policy Support (PS) displays, as shown in Figure 27, a gradual but sustained growth trajectory, increasing from 0.26 in Year 1 to 0.97 by Year 10. The trend is smooth and cumulative, without reversals or volatility, suggesting a policy environment that becomes progressively more aligned with the needs of livestock extensification over time.

This behaviour resonates strongly with the “Knowledge Engagement and Institutional Trust” and “External Market Volatility and Stabilization Pressures” archetypes identified for this pathway. In both archetypes, PS acts as a structural enabler, reinforcing trust in governance systems (through advisory and institutional channels) and buffering producers against market instability. Its steady growth in the simulation suggests that policy instruments are designed to reinforce long-term system transformation rather than deliver one-off interventions.

Figure 28 - Trend Simulation of Policy Support



In D1.2 (Home et al., 2023), the role of policy is framed as a central driver for overcoming systemic lock-ins in livestock systems. The report identifies the need for coherent, multi-level policy strategies that not only promote sustainability, but also address fragmented value chains, input dependencies, and economic risks. The simulated increase in PS reflects these principles, illustrating how institutional commitment may grow alongside market and behavioural dynamics to support and stabilize the extensification trajectory.

Furthermore, D4.2 (Roglic et al., 2025) provides empirical confirmation that policy support is often the differentiating factor between initiatives that achieve systemic consolidation and those that remain experimental. However, the report also notes that in many real-world cases, policy support is uneven, vulnerable to political shifts, and often delayed in implementation. Compared to this, the simulation assumes a best-case scenario in which policy gradually improves in both scope and coherence without regression.

The strong policy trajectory also aligns with the “Trust-Based Certification for Regional Value Chains” archetype, where institutional recognition and regulatory consistency are essential to the legitimacy of certification schemes and their acceptance by both producers and consumers. In this sense, PS in the model may be enabling certification-related dynamics (such as price premiums and transparency) that indirectly affect other variables like adoption and profitability.

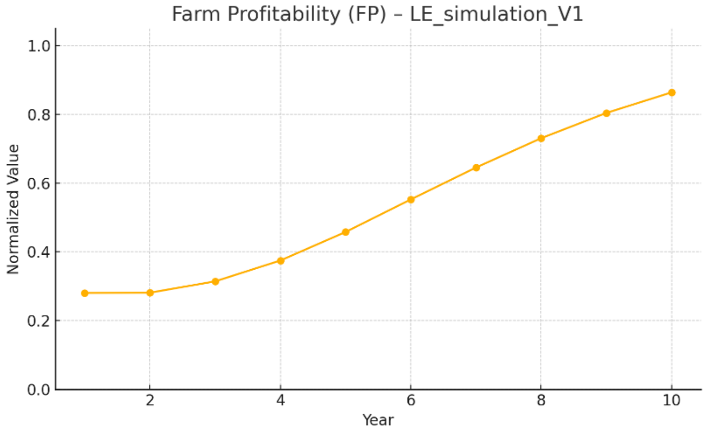
In sum, the simulation of Policy Support in the LE pathway depicts an idealized—but theoretically robust—evolution of the institutional landscape. It underscores the importance of long-term, credible, and adaptive public engagement to support transformation processes and maintain producer confidence throughout periods of market and structural change.

Farm Profitability (FP)

The simulation results for Farm Profitability (FP) show a slow and steady increase throughout the ten-year simulation period, rising from approximately 0.28 in Year 1 to 0.88 by Year 10, as shown in Figure 28. The growth trajectory is initially flat through the first three years but gains momentum from Year 4 onward, indicating a delayed but eventually positive impact of extensification strategies on economic returns at farm level.

This behaviour reflects the core dynamics of the “Sustainability Premium as Reinforcing Driver” and “External Market Volatility and Stabilization Pressures” archetypes. In the former, profitability is improved through mechanisms such as premium pricing for certified extensive production, better alignment with consumer values, and improved access to regional markets. In the latter, profitability is stabilized through tools that mitigate market risks and ensure minimum income security under variable conditions.

Figure 29 - Trend Simulation of Farm Profitability



The delayed profitability increase seen in the simulation suggests that these reinforcing mechanisms require time to become effective. Early phases may be characterized by higher costs (e.g., certification, transition investments) and uncertain demand, with profitability improving only once trust-based certification, market differentiation, and logistical efficiencies take hold. This matches the insight from the Trust-Based Certification for Regional Value Chains archetype, where economic benefits are contingent upon the development of coherent value chains and institutional credibility.

From the standpoint of D1.2 (Home et al., 2023), profitability is described as both an incentive and a vulnerability in transition processes. Many producers are reluctant to adopt sustainable practices without a clear economic rationale, especially under conditions of market uncertainty. The simulation reflects this barrier: the flat trajectory in early years mirrors the lag between practice change and economic payoff, which is a critical phase for policy and support systems to intervene.

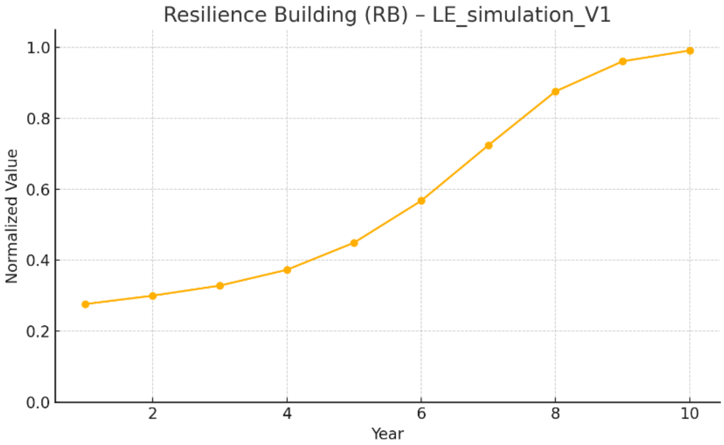
D4.2 (Roglic et al., 2025) further confirms that farm profitability in real-world extensification initiatives is often fragile, especially in the absence of coordinated demand, certification incentives, or infrastructural backing. While the simulation shows an optimistic trend, it may underrepresent short-term volatility and localized shocks that are typical of extensive livestock systems in transition. Nevertheless, it provides a plausible representation of the long-term economic consolidation that may occur when reinforcing mechanisms are effectively aligned.

In conclusion, the simulated trajectory of FP illustrates a structurally plausible and policy-sensitive dynamic: profitability emerges as a medium-term outcome, requiring sustained investment, strategic demand alignment, and effective risk management. Its alignment with the Livestock Extensification archetypes confirms its critical role not just as an economic indicator, but as a key leverage point in reinforcing sustainable transitions.

Resilience Building (RB)

The simulation results for Resilience Building (RB) in the LE_simulation_V1 model show a steadily increasing trajectory, starting from a normalized value of 0.28 in Year 1 and reaching 0.99 by Year 10, as shown in Figure 29. This progression suggests a system that gradually accumulates adaptive capacity, without experiencing significant volatility or regression throughout the simulation horizon.

Figure 30 - trend Simulation of Resilience Building



This behaviour is strongly consistent with the “External Market Volatility and Stabilization Pressures” archetype identified in the Livestock Extensification pathway. In this archetype, resilience is an emergent property of feedback mechanisms involving market stabilization tools (MST), income diversification (ID), and the systemic effects of sustainable adoption practices (SAP). The smooth and uninterrupted growth of RB in the model suggests that these stabilizing loops are structurally active, buffering the system from external shocks and supporting the long-term viability of extensification.

Additionally, the simulated dynamic resonates with the “Knowledge Engagement and Institutional Trust” archetype. In this configuration, resilience is strengthened by continued access to advisory services (ECE), peer learning (SELC), and the influence of governance feedback structures (GFS). The sustained increase in RB indicates that these components are embedded in the model’s structure, allowing resilience to act not only as an outcome but also as an enabler of systemic transformation.

From the perspective of D1.2 (Home et al., 2023), building resilience is identified as one of the most important conditions for overcoming barriers to transformation in livestock systems. The report highlights the need for multi-level collaboration, policy consistency, and territorially grounded initiatives that reinforce farmers’ autonomy and adaptability. The simulated behaviour of RB aligns with these findings, suggesting a setting where structural lock-ins such as institutional fragmentation or lack of support have been effectively addressed.

D4.2 (Roglic et al., 2025) complements this interpretation by showing that in real-world initiatives, resilience tends to grow unevenly and is often constrained by contextual factors like insecure market access or inadequate public support. Compared to such empirical variability, the model presents a best-case trajectory, representing the consolidation of systemic buffers and institutional trust over time.

In conclusion, the simulation of Resilience Building is well aligned with both the theoretical archetypes of the Livestock Extensification pathway and the empirical insights from ENFASYS deliverables. It illustrates the potential trajectory of a livestock system that progressively embeds resilience through coordinated interventions, knowledge infrastructure, and economic stabilization mechanisms.

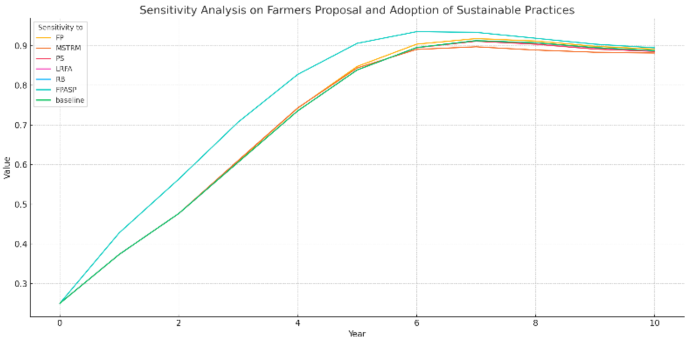
Livestock Extensification Pathway systemic insights

The simulation of the Livestock Extensification (LE) pathway reveals a system that responds in a structurally coherent and cumulatively positive manner when exposed to enabling conditions. Across all six core stock variables analysed—Market Stability Tools and Risk Management (MSTRM), Resilience Building (RB), Local/Regional Feed Autonomy (LRFA), Farmers' Proposal and Adoption of Sustainable Practices (FPASP), Policy Support (PS), and Farm Profitability (FP)—the model exhibits reinforcing trajectories that reflect progressive system consolidation rather than fragmentation or reversal.

The system shows particular strength in its capacity to accumulate resilience and expand territorial autonomy, suggesting that foundational investments in knowledge systems, infrastructure, and governance are internally consistent and mutually supportive. Behavioural change (FPASP) progresses rapidly in the early phases, though it eventually plateaus—highlighting both the potential and the structural limits of adoption dynamics in the absence of continuous engagement. Policy support (PS) and market stabilization tools (MSTRM) emerge as core stabilizing levers, growing in tandem with other variables and enabling long-term alignment between behavioural, institutional, and economic subsystems. Profitability (FP), while slower to respond, demonstrates that economic benefits can be achieved through sustained and coordinated transformation.

To deepen the interpretation of these dynamics, a structured sensitivity analysis was conducted for each of the six core stock variables. In each case, the responsiveness of two key inflow drivers was increased to simulate stronger enabling conditions. The results of this comparative analysis highlight key asymmetries in variable responsiveness, enabling the identification of transition-critical leverage points. Among all variables, FPASP (Figure 30) shows the most immediate acceleration under strengthened conditions. Behavioural change among farmers appears highly sensitive to the activation of support systems and advisory structures. However, the curve's early plateau indicates structural constraints in long-term adoption, reaffirming that motivation and initial training must be followed by iterative engagement and institutional continuity to sustain momentum.

Figure 31 - Sensitivity Analysis of FPASP



Policy Support (PS) (Figure 31) and Market Stability Tools and Risk Management (MSTRM) (Figure 32) also respond strongly to increased inflow responsiveness, both showing uninterrupted and early cumulative growth. While PS represents the institutional pillar of the system—providing regulatory and strategic coherence—MSTRM plays a complementary economic buffering role. The early activation of MSTRM significantly amplifies the stability of FP and RB, indicating that tools such as income stabilization schemes, minimum price mechanisms, or risk-sharing instruments are essential for protecting producers during the critical early phases of transformation. Notably, MSTRM shows the highest early-stage sensitivity among all stocks, reinforcing its importance as a short-term enabler of longer-term dynamics.

Figure 32 - Sensitivity Analysis of PS

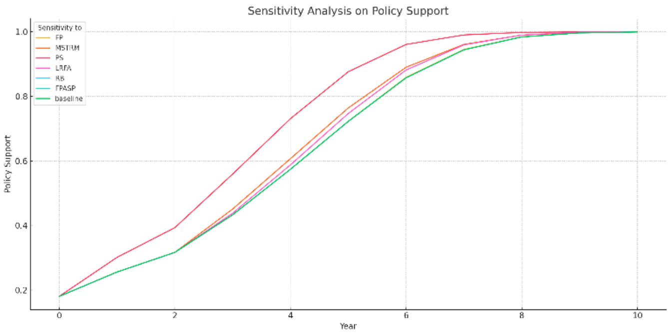
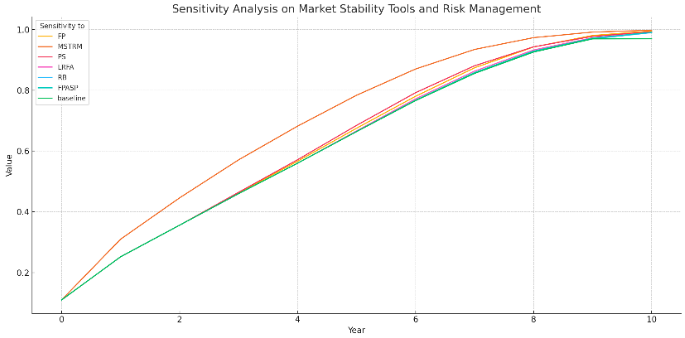


Figure 33 - Sensitivity Anaysis of MSTRM



Farm Profitability (FP) (Figure 33) exhibits a delayed but eventually steepening curve, suggesting that economic gains are the outcome—not the initiator—of systemic change. Profitability is thus better interpreted as a dependent variable, whose growth reflects the compounded effects of behavioural, institutional, and infrastructural adaptation. As such, its role is more confirmatory than catalytic. LRFA (Figure 34) and RB (Figure 35), both structurally grounded variables, respond gradually but cumulatively. Their sensitivity patterns confirm that territorial autonomy and systemic resilience rely on long-term structural investments. While they do not activate the transition per se, they consolidate it—ensuring stability and independence from external disruptions once the behavioural and institutional foundations are in place.

Figure 34 - Sensitivity Analysis FP

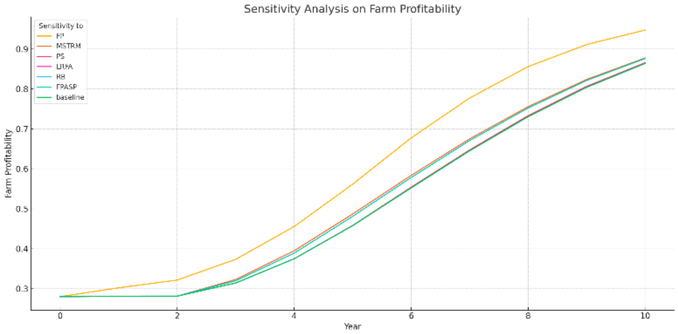


Figure 36 - Sensitivity Analysis LRFA

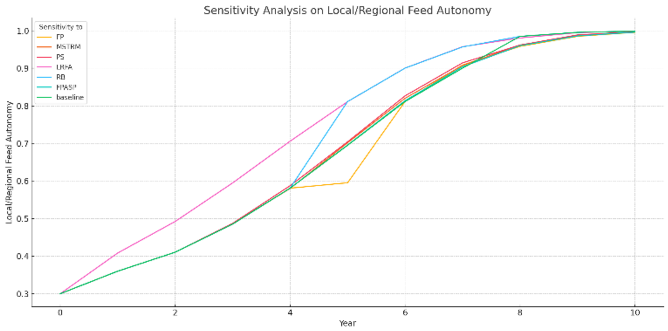
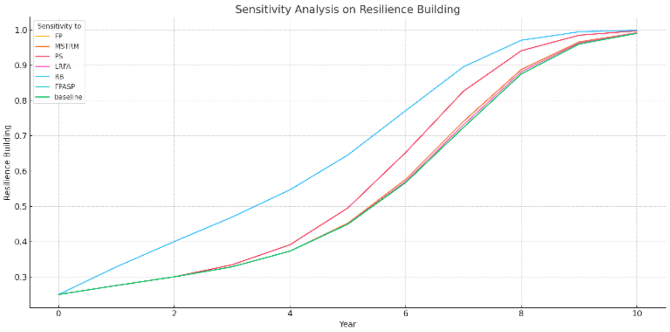


Figure 35 - Sensitivity Analysis RB



Which are the driver variables of the Livestock Extensification transition pathway?

Taken together, the sensitivity trajectories suggest that the LE transition is primarily activated by **behavioural, institutional, and market-stabilization levers**. **Farmers Proposal +Adoption of Sustainable Practices, Policy Support, and Market Stabilization Tools Regulatory Measures** emerge as key initiators: their quick and strong responses to enhanced conditions point to their function as system drivers, capable of launching self-reinforcing loops that mobilize the wider structure. MSTRM, in particular, plays a critical short-term role in de-risking adoption, absorbing early volatility, and enhancing trust in the transition process. **Resilience Building and Local/Regional Feed Autonomy**, while less immediately reactive, are indispensable to the durability and depth of the transition. They act as systemic stabilizers—variables that consolidate gains, reinforce feedback loops, and protect the system from regression.
Farmer Profitability, although not a primary driver, serves as a validation mechanism. Its improvement signals that the system is working effectively across multiple domains, and that the benefits of transformation can be sustained and internalized economically. In conclusion, the Livestock Extensification model provides a coherent and credible vision of how livestock systems can transition under sustainability-oriented strategies. The sensitivity analysis confirms the centrality of behavioural and policy dimensions as transition catalysts, while also highlighting the importance of long-term infrastructural and institutional consolidation. These findings reinforce the relevance of multi-lever strategies—targeting both fast-acting behavioural levers and slower, structural components—to enable robust and self-reinforcing transformation pathways in livestock systems.

Highlights of the Livestock Extensification (LE) Pathway

- **Fast behavioural activation, but plateauing adoption**
  Early uptake of sustainable practices is rapid, confirming the responsiveness of farmers to enabling conditions. However, adoption levels stabilize in the second half of the simulation, highlighting the need for continued engagement and iterative support mechanisms to maintain momentum.
- **Structural reinforcement through territorial autonomy and resilience**
  The steady and cumulative growth of Local/Regional Feed Autonomy (LRFA) and Resilience Building (RB) demonstrates the role of infrastructural investment and knowledge systems in consolidating transitions. These variables act as systemic stabilizers that secure independence from global input markets and increase adaptive capacity.
- **Policy support as a long-term enabler**
  The smooth and uninterrupted growth of Policy Support (PS) indicates a scenario where institutional alignment and regulatory commitment play a key role in coordinating and sustaining the transition. Policy coherence enables other variables—particularly profitability and adoption—to consolidate over time.

- **Market stabilization as a critical short-term lever**
  Sensitivity analysis identifies Market Stability Tools and Risk Management (MSTRM) as one of the most influential early drivers. These tools buffer against volatility, build trust in the transition, and create the conditions for economic and behavioural stability during the critical first years.
- **Profitability follows, rather than leads, the transition**
  Farm Profitability (FP) increases significantly in the second half of the simulation, but only after behavioural and institutional mechanisms are firmly established. This confirms its role as a lagging indicator that validates systemic effectiveness rather than driving change on its own.
- **Systemic alignment ensures cumulative and coherent transformation**
  The simulation reveals a system where all six core dimensions—behavioural, institutional, infrastructural, economic, territorial, and resilience—interact through reinforcing feedback loops. Transition success depends on coordinating fast-acting levers with slower but stabilizing mechanisms to build a resilient extensification pathway over time.

7.4 Inclusion of European Commission “New Vision for Food and Agriculture”

On 19/02/2025, the European Commission published a document detailing its new *Vision for Agriculture and Food*, titled “Shaping together an attractive farming and agri-food sector for future generations”. This document highlights effectively the objectives and strategies envisioned for the next years by the Commission, as well as setting a turning point in the priorities that the Commission defines for its agrifood system.

The effort behind the Communication in question is to set out a vision for Europe’s agri-food system for 2040 and beyond, and to present a **roadmap to guide EU action** to ensure that all policies work in step with said vision. Therefore, setting priorities and strategies in a single vision document will help in the process of developing and implementing cohesive and effective policies across European agricultural and food systems. The Communication takes stock of previously published strategic reports, as well as of the experiences and general trends emerged in the past.

In particular, the policy response is articulated around **four fundamental priority areas**: 1. *building an attractive sector that ensures a fair standard of living and leverages new income opportunities*; 2. *a competitive and resilient sector in the face of global challenges*; 3. *future-proofing the agrifood sector that works hand in hand with nature*; 4. *valuing food and fostering fair living and working conditions in vibrant rural areas*. The delivery of these priority areas rests largely on important transversal elements, such as the simplification of the regulatory framework impacting farmers and agri-food value chain, and innovation that offers solutions for sustainable transition.

Priority area number 1, **building an attractive sector that ensures a fair standard of living and leverages new income opportunities,** highlights the necessity of achieving fair standards of living for farmers despite the volatile nature of this profession and market imbalances, in accordance with commitments set in the past of the European Union. To reach this overarching goal, some of the envisioned strategies entail correcting disproportionate revenue burden distribution over primary producers; offering support to farmers to join cooperatives in order to reduce costs and improve prices from the market; building transparency and trust on how costs and margins are formed and shared in the food chain; better targeting public support for the primary sector in order to make it fairer and more simple to access. Secondly, opportunities for innovation are presented, ranging from implementation of organic and agroecological practices, to circular economy and byproducts valorisation initiatives, and innovative financing tools such as blended public private financing, with the aim of strengthening farmers’ positions and livelihoods while improving different aspects of value chains. Furthermore, carbon farming, nature credits, and renewable energy production are mentioned as possible strategies to strengthen farmers’ role, while promoting nature-positive outcomes in relation with primary production. Thirdly, the necessity of building investments and fostering entrepreneurship is identified: specifically, de-risking the sustainability transition and limiting profitability risks, as well as tackling key barriers to generational renewal with a general focus on competitiveness are possible strategies.

Priority area number 2, **a competitive and resilient sector in the face of global challenges,** a global focus is adopted to pinpoint strategies to address future challenges for the agricultural and food sector of the EU. Firstly, the risk of import dependencies turning into vulnerabilities due to geoeconomic tensions and global market fluctuations is highlighted, such as in the case of protein-based inputs, raw materials and fertilizers supply, all currently heavily reliant on import in the EU. The need to de-risk supply chains and reduce dependencies on imported inputs is deemed as crucial in this case. Secondly, the focus is moved onto the theme of global competition, pointing out the strategy of assertively defending strategic exports of EU products in the future, and applying productive standards and bans equivalent to those applied inside the EU to imported goods, while implementing competitiveness check policies for EU SMEs. Thirdly, strategic measures are shown in relation with risk and crisis management, with the aim of making the agricultural sector resilient to changing conditions, from the point of view of climate change adaptation, water resilience, as well as agricultural markets resilience, with a specific focus on livestock. Lastly, the goal of delivering bureaucratic simplification efforts on all levels including the agricultural and farming sectors is clearly stated, and deemed crucial for farmers' envisioned role of innovators and entrepreneurs to lead the transition.

Priority area number 3, **future-proofing the agrifood sector that works hand in hand with nature**, mostly focuses on expressing the inextricable link between primary production and natural resources use, with a framing that is in line with the competitiveness goals expressed in the previous priority areas, designing an ecological transition that integrates economic and implementation challenges. For this reason, possible integrated strategies such as decarbonisation integrated with competitiveness resulting in a carbon neutral and resilient EU by 2050 are portrayed, as well as frequent references to the need to ensure food security and strengthen the bioeconomy. The goal will be to simplify and streamline EU requirements in terms of sustainability to avoid confusion and ensure accessibility for farmers, as well as promoting voluntary benchmarking systems for on-farms sustainability assessments. Competitiveness will be considered at all stages, for example further bans on pesticides will be carefully evaluated as not to impact production.

Lastly, priority area number 4, **valuing food and fostering fair living and working conditions in vibrant rural areas**, seeks to define possible strategies to address effectively the challenges hindering good living conditions in rural areas, spacing from needed support to address systemic mental health issues in agrifood systems to strategies to address disinformation and use participatory local development tools. Secondly, the necessity of making trustworthy information available to consumers is stated, through reinstating the link between food, territory, seasonality, culture, and local tradition, and therefore making space for European added value in the global agrifood system to bring meaningful contributions. A "best value" approach is proposed for strengthening the role of public procurement, while short food supply chains are identified as strategically important for ensuring fairness and quality for both producers and consumers. Promotion policies are mentioned for the food industry, as well as the necessity to address collectively food losses and waste.

7.4.1 Pathways' simulation results and European Commission's "New Vision for Food and Agriculture" inputs

Some simulation results resonated particularly with the new Visions' inputs and priorities, while other results highlighted potential points of discontinuity. The main parallels between that can be traced in both senses are addressed below.

Low-Input Agriculture Pathway SDM:

One of the most significant dynamics among the results of the Low-Input Agriculture Pathway SDM is the slow and steady increase of the Sustainable Agriculture Adoption Rate (SAAR). The successful growth rate of this variable implies its ability to overcome lock-ins, which in this case, as identified by Home et al. (2023) can be associated, among others, to the ability to reduce dependence on costly economic inputs, a major theme recurring frequently in the new Vision, as highlighted in paragraph 8.1. The rise in the SAAR, as pointed out previously, is supported on the systemic level by the increase in other variables such as Policy and Governance for Sustainability (PGS) and Knowledge and Expertise Access (KEA), as the system proved to be highly interconnected and variables have shown generally intertwined behaviours in this context. The necessity of implementing cohesive and efficient policy frameworks in order to interrupt past trends of policy landscape fragmentation is highlighted numerous times in the Vision, and is mirrored by the positive effect due to the PGS variable, which sustains the system. Furthermore, a specific behaviour of the PGS variable has been highlighted by SDM's results, showing the necessity to establish strong and continuous policy frameworks before effects can be shown at the systemic level. This variable behaviour could be kept into consideration for future research, as it could explain various effects. The KEA variable, on the other hand, pinpoints yet another point of coherence with some strategies set in the Vision, as it can embody the necessity of establishing strong support channels for famers, mentioned several times in the Vision.

Concerning the necessity, highlighted in the new Vision, of incorporating competitiveness as a transversal lens across various levels of analysis, this necessity can be read in conjunction with the nexus of Market Demand and Value Chain Efficiency (MDVCE) and Economic Viability for Farmers (EVF), who appear to be correlated. Both variables exhibit delayed behaviours, even with slight decreases at the beginning, but with following steady increases. As highlighted by Home et al. (2023), this is due to inertia connected to consumers' habits and resistance to change, especially concerning sustainable production. From a Vision (Priority Area number 1) point of view in connection with MDVCE, the necessity to untie farmers' revenue streams from sustainable production could be extracted, while sustainability will be pursued through incentive-based mechanisms, therefore making the sector attractive as established while avoiding the risk of farmers' "paying" the cost of the transition singlehandedly. Concerning EVF, nevertheless, the archetypical explanation of the reduction of economic dependencies can be used as an explanation for the gradual activation of leverage points such as stable subsidies, consumer-driven demand shifts, and efficiency improvements. Therefore, systemic analysis in this case could provide possible additional strategies to achieve one of the goals set in the vision, the reduction of economic dependence across all stages of food supply chains.

Sustainable Consumer Branding and Selling Thematic SDM:

Coherently with the context portrayed above and with possible Vision related implications, the SDM concerning Sustainable Consumer Branding and Selling does not portray the Adoption of Sustainable selling practices as a variable that can grow steadily over time, but rather encountering a plateau and a slight decrease after initial success. One of the most notable variables behaviour due to the simulation, highlighted also thanks to the sensitivity analysis performed, is Revenue and Financial Stability (RFS), which fits coherently with the highlighted key narrative related to competitiveness, and with the previously explained strategy connecting the necessity of making the primary production sector attractive again through the achievement of a good livelihood level for farmers. The risks highlighted by simulation of high volatility in terms of RFS for farmers are coherent with the economic landscape portrayed in the Vision; furthermore, the possible strategies proposed in the results section of this deliverable and those proposed in the Vision (Priority Area number 1 and 3), resonate particularly with one another (robust cooperative frameworks, risk-sharing mechanisms, future-proofing…).

Concerning the results of the sensitivity analysis, the variables that appear as primary drivers of the system towards transition are those mainly related to the necessity to unlock new scenarios thanks to consumers' habits change as well as in the demand. This specific theme is partially addressed in the new Vision, but is not one of the major strategic points identified for the foreseeable future. Nevertheless, the simulations highlighted the connection between the necessity to shift consumer habits and the ability of farmers to generate revenue, and therefore secure income and work towards a more resilient and attractive sector for future generations of farmers. Capitalizing on the theme of shifting consumers' preferences could therefore be a long-term strategy for taking advantage of systemic dynamics and produce profound and inter generational change, albeit not crucially addressed in the new Vision.

Extensification of Livestock Systems Thematic SDM:

The simulations for Local/Regional Feed Autonomy (LRFA) resonate particularly with some points addressed in the Vision. More specifically, as shown above, a strategy highlighted in the Vision's Priority Area number 2 addresses the need to decrease the dependency on imported inputs for European food systems. In this perspective, the attention posed to local and regional feed autonomy is an element of consistency with the more general aim of achieving input autonomy at the European level. The strategy would be beneficial also due to the ability to reduce reliability on imported food, such as soy in this case, therefore diminishing also reliance on imported goods with prices subject to global markets and volatility phenomena. The fact that the simulation shows a steady increase confirms the validity of this strategy to achieve such aims. Coherently, the variable of Resilience Building (RB) is particularly overlapped with some of the strategies highlighted in the Vision (Priority Areas 2 and 3), as well as particularly embedded in the systemic dynamics of the portrayed thematic context. Coherently with some strategies mentioned in the Vision for future proofing and making the farming sector resilient, the archetype connected to this variable is associated with feedback mechanisms involving market stabilization tools (MST) and income diversification (ID). From a systemic perspective, it is highlighted frequently that investments are deemed as necessary to consolidate the desired outputs, despite it appearing feasible and simulation results' exhibiting coherent and promising behaviour.

ENFASYS System Dynamic Models alignment with the European Commission's "New Vision on Food and Agriculture" Highlights

- **Convergence between systemic leverage points and policy priorities**
  The systemic variables identified as key enablers in the simulations—such as governance support, knowledge access, and economic viability—align closely with the Vision's emphasis on competitiveness, simplification, and farmer resilience, reinforcing the relevance of multi-dimensional leverage activation.
- **Policy coherence and governance support as foundational enablers**
  Across all three pathways, Policy Support (PS/PGS) emerges as a late but decisive driver, mirroring the Vision's call for stable, long-term institutional frameworks. The simulations confirm that governance adaptation must precede and sustain broader transformation dynamics.
- **Resilience and autonomy as cross-cutting transformation goals**
  Variables such as Local/Regional Feed Autonomy (LRFA) and Resilience Building (RB) show strong reinforcing trajectories, validating the Vision's focus on reducing input dependencies and building systemic buffers against external shocks.
- **Competitiveness framed as an outcome of system alignment**
  Farm Profitability (FP, EVF) improves significantly only in the second half of simulations, suggesting that economic competitiveness is not an entry-point but a mid-to-long term output of coordinated systemic change—consistent with the Vision's ambition to make the sector attractive for future generations.
- **Volatility and fragility in transition phases highlight risk management needs**
  The pronounced fluctuations in variables such as Revenue and Financial Stability (RFS) in the SCDS pathway underline the importance of stabilizing mechanisms, echoing the Vision's emphasis on de-risking the transition and implementing robust cooperative and risk-sharing frameworks.
- **Underexplored role of consumer demand as a long-term driver**
  Although not explicitly prioritised in the Vision, the simulations—particularly for SCDS—underscore the systemic impact of shifting consumer preferences on farmers' income and transition stability, suggesting that policies enabling demand-side transformation could yield high systemic returns.
- **Systemic validation of the Vision's transversal principles**
  The simulations confirm that competitiveness, resilience, and reduced dependency are not isolated goals but emergent outcomes of well-sequenced, mutually reinforcing interventions. This systemic interdependence validates the Vision's integrated approach and its emphasis on simplification, innovation, and cross-sector strategies

8 Conclusion and next steps

This deliverable marks a key milestone in the ENFASYS modelling process, presenting the first full version of three thematic System Dynamics Models (SDMs), each corresponding to a distinct transition pathway: *Sustainable Consumer Branding and Selling*, *Low-Input Agriculture*, and *Extensification of Livestock Systems*. These models are the result of an integrated effort to translate the causal structures derived from case-specific CLDs into pathway-level Stock and Flow Diagrams (SFDs), guided by a consolidated methodological framework and supported by empirical knowledge from across the case studies.

The development of the SDMs involved multiple iterative steps: identifying and harmonising relevant variables across contexts, clustering feedback loops around shared dynamics, and transforming qualitative relationships into dynamic structures amenable to simulation. This allowed us to formalise the interactions among behavioural, institutional, economic and environmental components that characterise each pathway, while maintaining the integrity of the transition logics emerging from the Theory of Change developed in D4.2.

Each model was tested through preliminary simulations under simplified conditions, using indicative parameter values and stylised lookup functions. These simulations served two purposes: first, to verify the internal consistency of the dynamic structures and test the responsiveness of key feedback mechanisms; second, to begin exploring how systemic effects, delays and non-linearities unfold across different leverage points.

The simulation analyses of the three ENFASYS transition pathways—Livestock Extensification (LE), Sustainable Consumer Branding and Selling (SCDS), and Low-Input Agriculture (LIA)—reveal both distinctive dynamics and common systemic imperatives. Across all models, we observe that sustainable transitions are neither linear nor driven by any single variable; instead, they emerge from the coordinated interplay of behavioural, institutional, infrastructural, and market-based feedbacks. By synthesizing these insights into a unified conclusion, we highlight the key mechanisms that enable, constrain and stabilize each pathway, as well as those that transcend thematic boundaries.

First, **pathway-specific levers** shape the contours of each transition. In the LE model, territorial autonomy (Local/Regional Feed Autonomy) and resilience-building measures underpin a reinforcing structural core, while Policy Support and Market Stability Tools act as essential de-risking mechanisms that catalyze early adoption and protect farmers from volatility. By contrast, SCDS is primarily driven by consumer-side dynamics: the rapid consolidation of Consumer Demand and Willingness to Pay enables the initial diffusion of Sustainable Selling Models, yet infrastructural bottlenecks (Infrastructure & Logistic Capacity) and cyclical economic fragilities (Revenue and Financial Stability) limit long-term scaling. The LIA pathway, finally, demonstrates a temporally stratified progression in which Knowledge and Expertise Access and Policy and Governance for Sustainability sequentially activate the Sustainable Agricultural Adoption Rate, followed by market-development and profitability gains, and ultimately measurable Environmental Impact Factors.

Second, the **timing and saturation of behavioural change** differ markedly among pathways. Both FPASP in LE and ARSSM in SCDS exhibit classic S-shaped adoption curves: strong early acceleration followed by plateaux, reflecting the partial overcoming of behavioural lock-ins but also the risk of stagnation without sustained reinforcement. In LIA, however, adoption crosses a critical 50 % threshold only after mid-simulation tipping points in advisory and governance support, underscoring the necessity of cumulative, multi-phase enablers to achieve widespread uptake.

Third, **stability versus fragility** emerges as a recurring theme. The LE and SCDS trajectories reveal medium- to long-term profitability gains only under sustained policy coherence and market-stabilization instruments, whereas LIA's Economic Viability and Market Demand recover from initial declines once foundational governance and knowledge structures are solidly in place. This contrast highlights that economic consolidation in sustainable transitions often lags behind behavioural and institutional change, and that early interventions may paradoxically depress short-term viability if not accompanied by risk-mitigation.

Despite these differences, three **cross-cutting drivers** are indispensable in all scenarios:

1. **Governance and Policy Support**: Coherent, long-term policy frameworks not only dismantle institutional lock-ins but also legitimize certification and value-chain innovations, creating a stable environment for all other interventions.

2. **Knowledge and Capacity-Building**: Whether through trust-based advisory networks (LE), training ecosystems (SCDS), or peer-learning platforms (LIA), sustained investment in knowledge diffusion is the catalyst for behavioural and technical adoption.

3. **Market and Financial Readiness**: The interplay of demand-side trust (consumer willingness to pay), value-chain efficiency, and market-stabilization tools is essential both to validate early adopters and to protect the system from volatility, thereby reinforcing positive feedbacks across domains.

In conclusion, although each pathway emphasizes different entry points—structural autonomy, consumer branding, or multi-dimensional sequencing—they converge on the principle that **multi-lever, multi-scale interventions**, synchronously deployed and persistently maintained, are required to generate robust, self-reinforcing sustainability transitions. Policymakers, practitioners, and researchers should therefore prioritize integrated strategies that combine rapid-acting behavioural incentives with long-term structural investments, ensuring that early gains in adoption are translated into durable environmental, economic, and social outcomes.

By adopting this structured approach, the chapter ensures a comprehensive examination of systemic insights at case level, the integration of these dynamics on a thematic level and the mathematical representation of these dynamics. The results presented represent a structured framework that will be further refined over time incorporating further empirical data, where possible, and most of all stakeholder insights. As such, models' results provide a solid foundation for developing evidence-based policy recommendations to support agricultural transitions in alignment with European sustainability objectives.

Several methodological limitations currently constrain the full potential of these models. Most notably, stock initialization is still based on European Dataset (Eurostat, FADN) or scientific literature and needs to be calibrated within experts and specific cases context. This will be addressed through targeted expert elicitation processes involving relevant stakeholders (policymakers, farmers, NGOs, academics), to ground the model in more realistic baseline conditions. In parallel, broader and more detailed sensitivity analyses will be conducted to test the resilience of the system under diverse assumptions and policy orientations, in line with the evolving strategic vision of the European Commission. Furthermore, there is the opportunity to validate the structure of the SFDs qualitatively by CSCs and EU level experts Furthermore, the data incorporated into the SFDs will be tested within the activities of **WP5**, particularly in **T5.2 "Choice experiments to test the policies and strategies at broad scale"** and **T5.3 "Lab in field to test impact of interventions at case scale"** and finally a scenario-based analysis on the interventions and strategies to fasten the sustainability transition will be developed and pictured in **T5.4 " System dynamic model simulation of impact changes in the EU Food System"**.

Taken together, this deliverable provides a structured, transparent and policy-relevant platform that will serve as the backbone for the forthcoming simulation and policy testing phase. The models will be iteratively improved through stakeholder validation and empirical integration, leading to their application in T5.4 scenario evaluation. Here, they will be used to explore alternative intervention mixes, identify tipping points and trade-offs, and support the co-design of policy and business strategies for just and sustainable farming transitions across Europe. As such, the models developed in this deliverable are not only analytical tools, but also instruments of dialogue and learning within the broader ENFASYS framework.

9 Annex 1 Low-Input Agriculture SDM equation description

(001) ACIU influence on PC = WITH LOOKUP (

MIN(1, MAX(0, Amount of chemical input use))

,

((0, 0.05),

(0.2, 0.15),

(0.4, 0.4),

(0.6, 0.7),

(0.8, 0.85),

(1, 1)))

Units: Fraction/year [0,1]

This auxiliary variable models the influence of the Amount of Chemical Input Use (ACIU) on the outflow of Production Costs (PC). The lookup function captures a nonlinear relationship where cost increases gradually with higher input use, reflecting both the direct purchase costs and associated environmental management burdens. The function starts with minimal impact at low input levels (0.05 at ACIU = 0), increases more steeply beyond the mid-point (ACIU > 0.4), and saturates at a maximum influence near 1. This shape is based on empirical reasoning from D4.2 ToC clusters emphasizing input efficiency, and corroborated by parameter trends in MBS feedback. The function is normalized to maintain the 0–1 range of all variables.

(002) Amount of chemical input use= INTEG (

MAX(0, Increase of ACIU * (1 - Amount of chemical input use))

- MAX(0, Reduction of ACIU * Amount of chemical input use),

0.69)

Units: Fraction [0,1]

The initial value of the “Amount of Chemical Input Use” (ACIU) stock is set at 0.69. This estimate is based on Eurostat data indicating a 15.9% reduction in mineral fertiliser use between 2015 and 2022, and European Commission reports showing a 46% reduction in the use and risk of chemical pesticides over the same period. The value represents the average normalized usage of chemical inputs relative to the 2015 baseline.

(003) Amount of Organic Input Use= INTEG (

MAX(0, Increase of AOIU * (1 - Amount of Organic Input Use))

- MAX(0, Reduction of AOIU * Amount of Organic Input Use),

0.31)

Units: Fraction [0,1]

This variable represents the share of farm input expenditure devoted to organic inputs, calculated as the complement of chemical input use. AOIU = 1 – ACIU ACIU is based on FADN data and EU Farm to Fork targets, assuming 69% of current expenditure is on chemical inputs, thus AOIU = 0.31.

(004) AOIU influence on ACIU = WITH LOOKUP (

MAX(0,MIN(1, SMOOTH3(Amount of Organic Input Use, 3))),

((0, 1),

(0.1, 0.9),

(0.2, 0.75),

(0.3, 0.6),

(0.4, 0.45),

(0.5, 0.35),

(0.6, 0.25),

(0.7, 0.15),

(0.8, 0.08),

(0.9, 0.03),

(1, 0)))

Units: Fraction/year [0,1]

This lookup function models the inverse relationship between the adoption of organic inputs (AOIU) and the use of chemical inputs (ACIU). As AOIU increases, ACIU decreases following a saturation dynamic, assuming that higher levels of organic adoption progressively displace chemical inputs. This relationship reflects insights from the D4.2 cross-case analysis and is consistent with the empirical guidance in the MBS Feedback document for replacing default influence rates with calibrated curves. The curve shape reflects diminishing marginal returns in displacement efficiency as AOIU approaches saturation levels.

(005) AOIU influence on PC = WITH LOOKUP (

MAX(0, MIN(0, SMOOTH(Amount of Organic Input Use, 2))),

((0, 0.05),

(0.1, 0.04),

(0.2, 0.03),

(0.3, 0.02),

(0.4, 0.015),

(0.5, 0.01),

(0.6, 0.005),

(0.7, 0),

(0.8, 0),

(0.9, 0),

(1, 0)))

Units: Fraction/year [0,1]

This lookup function models the inverse relationship between the Sustainable Agricultural Adoption Rate (SAAR) and Production Costs (PC), based on evidence from ENFASYS D4.2 and the MBS Feedback to UNIBO T2.3. As SAAR increases, farms gradually benefit from improved efficiency, cooperative economies of scale, and reduced reliance on external chemical inputs, which leads to cost reductions. However, this impact does not start immediately and requires surpassing a threshold (0.3) where operational transitions begin to materialize. The function follows a declining curve and reaches a plateau at high SAAR levels (>0.9), reflecting that marginal savings diminish as systemic efficiencies are already captured. The structure aligns with MBS recommendations to avoid early activation and include saturation thresholds in the calibration of economic effects.

(006) CCAB influence on SAAR = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH("Reduction of Compliance Costs & Administrative Burden" ,3)))

,

((0, 0), (0.2, 0.03), (0.4, 0.08), (0.6, 0.25), (0.8, 0.6), (1, 1)))

Units: Fraction/year [0,1]

The function captures the delayed and threshold-based influence of reduced compliance and administrative burden (CCAB) on the rate of sustainable agricultural adoption (SAAR). Given the initial value of CCAB (0.175), the influence remains minimal until higher levels of simplification are reached. As supported by D4.2 and MBS feedback, administrative complexity is a slow-moving barrier, and only substantial reductions lead to perceived improvements in institutional efficiency. The smoothing delay of 3 years reflects the time required for farmers to internalize and respond to such changes.

(007) CSD influence on EA = WITH LOOKUP (

MIN(1, MAX(0,DELAY3(Cultural and Social Dynamics, 4)))

,

((0,0),(0.2,0),(0.3,0.05),(0.45,0.3),(0.6,0.65),(0.8,0.9),(1,1)))

Units: Fraction/year [0,1]

This equation models the delayed and threshold-based influence of Cultural and Social Dynamics (CSD) on Environmental Awareness (EA), drawing exclusively on evidence from ENFASYS D4.2 . According to D4.2, community engagement, trust-building, and shared cultural values significantly enhance environmental awareness, but only after surpassing a critical engagement threshold (0.3). The effect then grows rapidly with increasing CSD, plateauing at high levels due to saturation of social influence. A third-order delay (4 years) is included to account for the slow internalization of social norms and community learning processes. The function uses MIN/MAX normalization to ensure output remains within the [0–1] range, maintaining model consistency and behavioral plausibility.

```
(008)    CSD influence on SAAR = WITH LOOKUP (
        MAX(0, MIN(1, SMOOTH( Cultural and Social Dynamics , 4 ) ) ),
            ((0, 0),
              (0.2, 0.05),
              (0.3, 0.1),
              (0.4, 0.3),
              (0.6, 0.6),
              (0.8, 0.85),
              (1, 1)))
```

Units: Fraction/year [0,1]

This function represents the slow yet pivotal role of cultural and social dynamics (CSD) in supporting sustainable adoption rates. According to D4.2, CSD factors such as youth engagement, demographic trends, and openness influence SAAR indirectly and gradually. A smoothing function (delay of 2 years) is applied to reflect the temporal inertia of cultural change. The influence remains weak until a threshold of normalization and visibility (≈0.4–0.5) is reached, after which cultural dynamics significantly accelerate adoption, in line with Geels' (2002) multi-level perspective on transitions.

```
(009)    Cultural and Social Dynamics= INTEG (
        MAX(0, Increase of CSD * (1 - Cultural and Social Dynamics))
          - MAX(0, Reduction of CSD * Cultural and Social Dynamics),
            0.21)
```

Units: Fraction [0,1]

The initial value of the "Cultural and Social Dynamics" (CSD) stock is set to 0.21. This value is calculated as the average of two EU-level indicators: the proportion of EU citizens prioritizing sustainable agriculture investment (31%, Eurobarometer 102, 2024) and the proportion of farm managers under 40 years old (11%, Eurostat, Farm Structure Survey). This composite measure reflects the current social and cultural conditions that influence receptiveness to sustainability transitions in European agriculture.

(010) EA influence on SAAR = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH(Environmental Awareness , 3))),
((0, 0), (0.2, 0.05), (0.4, 0.1), (0.6, 0.35), (0.8, 0.65), (1, 1)))

Units: Fraction/year [0,1]

This auxiliary variable captures the influence of Environmental Awareness (EA) on the Sustainable Agricultural Adoption Rate (SAAR). The relationship is modeled using a sigmoidal lookup function, reflecting the evidence from D4.2 and MBS feedback which indicates that EA contributes to the adoption of sustainable practices primarily when reaching significant levels of social and cultural penetration. A smoothing function is applied to simulate the gradual nature of behavioral change driven by increasing awareness. At initial values (EA = 0.31), the influence on SAAR remains moderate but becomes more pronounced as EA intensifies over time.

(011) Economic Viability for Farmers= INTEG (
MAX(0, Increase of EVF * (1 - Economic Viability for Farmers))
- MAX(0, Reduction of EVF * Economic Viability for Farmers),
0.27)

Units: Fraction [0,1]

The initial value of the stock “Economic Viability for

Farmers” (EVF) is set to 0.27. This value is consistent with the same behavioral construct used in the SCBSP pathway model, where it was based on the normalized Output/Input ratio from FADN data (2018–2022). The index is calibrated such that 0 corresponds to the economic break-even point (O/I = 1.0) and 1 represents high profitability (O/I = 1.6). This stock captures the financial accumulation and decline of farm-level viability over time, reflecting systemic economic trends within the EU farming sector.

(012) EIF influence on EVF = WITH LOOKUP (

MIN(1, MAX(0,DELAY3(Positive Environmental Impact Factors, 2)))

,

((0,0),(0.2,0),(0.35,0.05),(0.5,0.3),(0.7,0.7),(0.85,0.9),(1,1)))

Units: Fraction/year [0,1]

This equation models the delayed and non-linear influence of Positive Environmental Impact Factors (EIF) on Economic Viability for Farmers (EVF), based exclusively on D4.2. According to the feedback, while EIFs are recognized for their long-term relevance to farmer profitability, their economic benefit materializes only after achieving a certain systemic credibility and scale (0.35). The sigmoid lookup function captures this behavioral threshold and the diminishing returns from environmental improvements after 0.85. A third-order delay (2 years) accounts for the time needed for farmers to perceive and integrate ecological gains into their financial logic. This parameterization reflects real-world behavioral inertia and is fully aligned with the empirical calibration guidance provided by the MBS document.

(013) EIF influence on OC = WITH LOOKUP (

MIN(1, MAX(0, DELAY3(Positive Environmental Impact Factors, 3))),

((0,0),(0.2,0),(0.3,0.05),(0.4,0.3),(0.6,0.7),(0.8,0.9),(1,1)))

Units: Fraction/year [0,1]

This equation represents the non-linear and delayed relationship between Positive Environmental Impact Factors (EIF) and Organizational Change (OC), as derived from the ENFASYS D4.2 cross-case analysis and MBS Feedback. D4.2 shows that improvements in environmental conditions can trigger organizational adaptation, but only after a period of learning and internal realignment. Therefore, the lookup function does not activate immediately at the baseline EIF value (0.2), but only beyond a critical threshold (≈0.3). This reflects the system’s inertial behavior. The DELAY3 function (2 years) captures the structural lag in implementing internal organizational change in response to external stimuli. Normalization via MIN/MAX ensures coherence within the model's [0–1] range.

(014) EIF influence on PGS = WITH LOOKUP (

MIN(1, MAX(0, Positive Environmental Impact Factors)),

((0,0), (0.2,0), (0.3,0.05), (0.4,0.3), (0.6,0.75), (0.8,0.95), (1,1)))

Units: Fraction/year [0,1]

This equation models the influence of Positive Environmental Impact Factors (EIF) on Policy and Governance for Sustainability (PGS), based strictly on evidence from D4.2. The MBS policy mechanism library indicates high parameter (1.9), intent (2.1), and spillover (3.5) scores for EIF when linked to governance targets, suggesting strong transformational potential. D4.2 supports this with evidence from Swiss and Italian cases, showing that positive environmental performance prompts institutional reforms and coordination. The lookup curve starts influencing above 0.3 EIF, peaks between 0.6–0.8, and saturates around 0.9, while a 2-year delay reflects institutional inertia. MIN/MAX ensure normalization in the [0–1] range.

(015) EIF influence on SAAR = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH (Positive Environmental Impact Factors , 3)))

,

((0, 0), (0.2, 0.03), (0.4, 0.15), (0.6, 0.4), (0.8, 0.75), (1, 1))

)

Units: Fraction/year [0,1]

The influence of Positive Environmental Impact Factors (EIF) on the Sustainable Agricultural Adoption Rate (SAAR) is modeled through a smoothed lookup function. This reflects the gradual internalization of environmental benefits by farmers and decision-makers. As documented in D4.2 and MBS feedback, EIF has limited effect below a 30–40% threshold, consistent with the theory of transition (Geels, 2002) where niche-level innovations require reinforcement before impacting regime behavior. The lookup captures this non-linearity, while smoothing represents the perceptual and structural delays associated with environmental improvements.

(016) EIF influence on Y = WITH LOOKUP (

MIN(1, MAX(0, DELAY3(Positive Environmental Impact Factors, 2))),

((0,0),(0.1,0),(0.2,0),(0.3,0.2),(0.4,0.4),(0.6,0.6),(0.8,0.8),(1,1)))

Units: Fraction/year [0,1]

This equation reflects the empirically observed non-linear and delayed effect of Positive Environmental Impact Factors (EIF) on agricultural Yield (Y), derived from the cross-case analysis of ENFASYS D4.2. The relationship adheres to a threshold-based dynamics as conceptualized by Geels' (2002) Multi-Level Perspective (MLP). EIF effects on Yield are negligible below an empirically defined threshold (approx. EIF = 0.2), indicating that initial minor environmental improvements do not significantly enhance yields. As EIF surpasses this threshold, Yield increases rapidly due to improving ecosystem services and agro-ecological efficiency, demonstrating progressively diminishing returns as the system approaches the upper saturation point (EIF approx. 0.8–1.0). This captures real-world saturation effects where further environmental enhancements yield only marginal incremental productivity gains. The DELAY3 function, set at 2 years, accurately represents systemic inertia associated with ecological response times and agricultural practice adaptations. MIN/MAX functions are included to ensure normalization and internal consistency of the modeled variables within the [0,1] range, maintaining theoretical and empirical validity.

(017) Environmental Awareness= INTEG (

MAX(0, Increase of EA * (1 - Environmental Awareness))

- MAX(0, Reduction of EA * Environmental Awareness),

0.31)

Units: Fraction [0,1]

(018) EVF influence on FM = WITH LOOKUP (

MIN(1, MAX(0, Positive Environmental Impact Factors))

,

((0,0),

(0.1,0),

(0.2,0.05),

(0.35,0.2),

(0.5,0.45),

(0.7,0.75),

(0.85,0.9),

(1,1)))

Units: Fraction/year [0,1]

This function models the influence of Economic Viability for Farmers (EVF) on Farmer Motivation (FM), drawing on empirical parameters from D4.2 and MBS Feedback. The lookup captures a nonlinear dynamic where initial improvements in viability result in limited motivational gain, but after surpassing a key threshold (0.2), motivation increases rapidly. The effect plateaus as EVF approaches 1, reflecting diminishing marginal returns in motivational boost once perceived financial security is high. The curve integrates a parameter influence weight based on the recommended economic incentives and market orientation effectiveness (r=0.82), ensuring empirically-grounded behavioral calibration.

```
(019)    EVF influence on IPF = WITH LOOKUP (
        MIN(1, MAX(0, DELAY3(Economic Viability for Farmers, 2)))
        ,
            (
              (0, 0.02),
              (0.2, 0.04),
              (0.4, 0.08),
              (0.6, 0.12),
              (0.8, 0.15),
              (1, 0.18)
            ))
    Units: Fraction/year [0,1]
    {* This auxiliary variable captures the delayed positive
            influence of Market Demand and Value Chain Efficiency (MDVCE) on
            the reduction of Production Costs (PC). The function is
            calibrated using an empirically-derived parameter score (1.8)
            and spillover score (3.3) from the MBS Feedback document. The
            lookup function reflects a nonlinear but steady improvement in
            cost efficiency as market structures become more integrated and
            optimized. A DELAY3 is used to represent systemic inertia in
            cost restructuring due to coordination and implementation lags
            in market innovations.

(020)    EVF influence on PGS = WITH LOOKUP (
```

MIN(1, MAX(0, SMOOTH(Economic Viability for Farmers, 3))),

((0,0), (0.25,0), (0.35,0.2), (0.5, 0.4), (0.7,0.8), (0.8, 0.95), (1,1))

)

Units: Fraction/year [0,1]

This equation represents the delayed and threshold-based influence of Economic Viability for Farmers (EVF) on Policy and Governance for Sustainability (PGS), as evidenced in ENFASYS D4.2 . Across case studies, farmers' perception of economic feasibility is a key enabler for institutional support, policy engagement, and the emergence of sustainable governance mechanisms. This transformation does not occur immediately—political responses are activated only after reaching a viability threshold (0.35). The function reflects this dynamic through a sigmoidal progression and a saturation point beyond which further increases in EVF yield limited additional governance response. A third-order delay of 2 years models the systemic lag in converting economic perceptions into political momentum. The MIN/MAX functions ensure bounded normalization.

(021) EVF influence on SAAR = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Economic Viability for Farmers, 2))),

((0, 0), (0.2, 0), (0.3, 0.05), (0.4, 0.2), (0.6, 0.55), (0.8, 0.8), (1, 1)))

Units: Fraction/year [0,1]

This function captures the delayed and threshold-dependent influence of Economic Viability for Farmers (EVF) on the Sustainable Adoption Rate (SAAR). Based on the findings from D4.2, EVF must exceed a minimum viability level (0.3) before contributing meaningfully to adoption. The influence accelerates between 0.4 and 0.6, simulating the build-up of confidence in sustainable practices. A smoothing delay of 2 years accounts for farmers' need to perceive economic improvements as stable and credible before modifying their behavior.

(022) Farmer Motivation= INTEG (

MAX(0, Increase of FM * (1 - Farmer Motivation))

- MAX(0, Reduction of FM * Farmer Motivation),

0.25)

Units: Fraction [0,1]

The initial value of the stock "Farmer Motivation" (FM) is set to 0.25. This estimate is based on findings from the European Commission's Joint Research Centre (JRC) report "Behavioural Factors Affecting the Adoption of Sustainable Practices" (2021), which highlights that only 20–30% of EU farmers are intrinsically motivated to adopt sustainable farming practices. The stock represents current average levels of autonomous motivation, excluding motivations triggered by external enforcement or financial incentives.

(023) FINAL TIME = 10

Units: year

The final time for the simulation.

(024) FM influence on OC = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH(Farmer Motivation, 2)))

,

((0,0),(0.25,0),(0.35,0.05),(0.45,0.25),(0.6,0.6),(0.8,0.85),(1,1)))

Units: Fraction/year [0,1]

This equation models the empirically derived, threshold-based and delayed relationship between Farmer Motivation (FM) and Organizational Change (OC), grounded in the ENFASYS D4.2 case analysis and the MBS Feedback calibration guidance. In D4.2, FM emerges as a key behavioural driver, but its effect on organizational adaptation is not immediate. Change occurs only after surpassing a critical threshold (0.35), reflecting the time and confidence needed to translate motivation into tangible action. The curve reaches saturation as structural or collective mechanisms become necessary to sustain further change. The DELAY3 function (2-year delay) accounts for the behavioural-to-institutional transition lag, and MIN/MAX ensures normalized output. The lookup reflects that while early FM has limited effect, properly supported and coordinated motivation can strongly catalyze internal organizational transformation.

(025) FM influence on SAAR = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Farmer Motivation, 3))),

((0, 0),

(0.2, 0.05),

(0.3, 0.1),

(0.4, 0.3),

(0.6, 0.7),

(0.8, 0.9),

(1, 1)))

Units: Fraction/year [0,1]

This function reflects the behavioral inertia in adopting sustainable practices. Based on D4.2 findings and MBS feedback, Farmer Motivation has negligible effects below the 0.3–0.4 range, but becomes increasingly influential as it surpasses cognitive and cultural resistance. The smoothing delay (2 years) captures the time needed for motivational shifts to influence behavior across the farming system.

(026) Increase of ACIU=

Amount of chemical input use * 0.01

Units: Fraction/year [0,1]

This flow is designed to simulate systemic inertia in the continued use of chemical inputs. In the absence of disruptive interventions, the existing level of ACIU sustains itself through internal path dependency, modeled as a 1% annual increase. This formulation captures the behavioral and structural resistance to transition observed in conventional farming contexts, as outlined across multiple ENFASYS case studies in D4.2

(027) Increase of AOIU=

SAAR impact on AOIU

Units: Fraction/year [0,1]

(028) Increase of CCAB=

SAAR influence on CCAB

Units: Fraction/year [0,1]

(029) Increase of CSD=

MAX(0, MIN(1, (KEA positive influence on CSD*0.6 + SAAR influence on CSD* 0.4)))

Units: Fraction/year [0,1]

(030) Increase of EA=

0.5*CSD influence on EA+0.5*KEA influence on EA

Units: Fraction/year [0,1]

This auxiliary function simulates the annual increase in farmers' environmental awareness as a result of improved access to knowledge and expertise (KEA) and supportive cultural and social dynamics (CSD). As identified in the cross-case analysis (D4.2), both enhanced learning environments and shifts in public perception are key behavioral drivers in encouraging the adoption of environmentally sustainable practices.

(031) Increase of EIF=

0.4 * KEA influence on EIF + 0.3 * PGS influence on EIF + 0.3 * SAAR influence on EIF

Units: Fraction/year [0,1]

This formulation integrates knowledge access, governance support, and actual sustainable adoption as the primary drivers of positive environmental outcomes. The relative weights reflect the evidence across the ENFASYS case studies (D4.2), where technical capacity (KEA) emerges as the most immediate enabler, while policy structures (PGS) and behavioral uptake (SAAR) provide structural and systemic contributions to the environmental performance of agricultural systems.

(032) Increase of EVF=

0.35 * MDVCE influence on EVF +

0.25 * PGS influence on EVF +

0.2 * EIF influence on EVF +

0.2 * Y influence on EVF

Units: Fraction/year [0,1]

The inflow “Increase of EVF” aggregates four primary systemic influences identified in the D4.2 cross-case analysis. Market Demand and Value Chain Efficiency (MDVCE) is the strongest contributor (weight = 0.35), as it directly links value creation to farmer profitability. Policy and Governance Support (PGS) is weighted at 0.25, reflecting the importance of institutional stability for incentivizing adoption. Environmental Impact Factors (EIF) are weighted at 0.20 due to their role in balancing financial sustainability with ecological goals. Yield (Y) is also assigned a weight of 0.20, acknowledging its foundational role in determining per-hectare income and production-based viability

(033) Increase of FM=

0.7 * EVF influence on FM + 0.3 * OC influence on FM

Units: Fraction/year [0,1]

This flow models the increase in farmer motivation as a weighted function of economic viability (EVF) and organic certification (OC). Economic viability is considered the primary driver, as enhanced income stability and profitability are central to the motivational structures in most ToCs (see D4.2, e.g. CS2, CS5, CS10). Organic certification, while influential, plays a secondary reinforcing role by legitimizing and supporting long-term engagement in sustainable practices. The weighting reflects qualitative insights derived from cross-case feedback collected in MBS validation.

(034) Increase of IPF=

EVF influence on IPF

Units: Fraction/year [0,1]

(035) Increase of KEA=

0.4 * PGS influence on KEA +

0.3 * SAAR influence on KEA +

0.3 * SC influence on KEA

Units: Fraction/year [0,1]

The weighted formulation of “Increase of KEA” reflects systemic drivers validated in the cross-case analysis (D4.2). Policy and Governance Support (PGS) receives the highest weight (0.4), as it plays a central role in shaping advisory services and institutional knowledge infrastructures. The Sustainable Agricultural Adoption Rate (SAAR) is weighted at 0.3 due to its reinforcing effect on experiential knowledge exchange. Stakeholder Collaboration (SC) is also weighted at 0.3, justified by findings in D4.2 indicating that a high degree of stakeholder inclusion and network diversity substantially enhances knowledge co-production and dissemination

(036) Increase of MDVCE=

0.4 * IPF influence on MDVCE +

0.35 * OFA influence on MDCVE +

0.25 * SAAR influence on MDVCE

Units: Fraction/year [0,1]

The “Increase of MDVCE” flow aggregates three systemic variables documented in the D4.2 cross-case analysis. Infrastructure and Processing Facilities (IPF) receive the highest weight (0.4), given their role as structural enablers of market access and value chain efficiency. Organic Farming Area (OFA) is weighted at 0.35, as it represents both a driver and an outcome of increased market activity. Sustainable Agricultural Adoption Rate (SAAR) is assigned a weight of 0.25, due to its indirect but reinforcing effect on supply chain transformation and market responsiveness

(037) Increase of OC=

0.4 * EIF influence on OC + 0.3 * SAAR influence on OC + 0.3 * FM influence on OC

Units: Fraction/year [0,1]

This inflow models the behavioral determinants that contribute to the increase in Organic Certification (OC) among farmers. The formulation is based on systemic evidence from the ENFASYS cross-case analysis (D4.2), where three drivers—Positive Environmental Impact Factors (EIF), Sustainable Agricultural Adoption Rate (SAAR), and Farmer Motivation (FM)—were consistently highlighted as enabling variables. EIF exerts the strongest influence (weight = 0.4) as environmental improvements, both real and perceived, act as motivators for engaging in certification schemes, particularly in value chains linked to organic quality standards. SAAR and FM are equally weighted (0.3 each) to reflect their complementary roles: SAAR captures structural readiness for transitioning toward organic models, while FM encapsulates the individual psychological willingness to engage in certification practices. This structure maintains the model’s behavioral coherence while acknowledging systemic feedback and reinforcement mechanisms identified in multiple ToCs.

(038) Increase of OFA=

0.6 * MDVCE influence on OFA + 0.4 * SAAR influence on OFA

Units: Fraction/year [0,1]

This flow variable models the behavioural expansion of Organic Farming Area (OFA), as influenced by value chain readiness and sustainable area availability. A higher weight (0.6) is assigned to MDVCE influence, reflecting the critical role of accessible market structures and fair value chains in encouraging organic adoption. SAAR contributes with a weight of 0.4, acknowledging that available land under sustainable management creates enabling conditions for organic transitions. These relationships are substantiated in the cross-case analysis reported in ENFASYS D4.2

(039) Increase of PC=

0.6 * AOIU influence on PC + 0.4 * MDVCE influence on PC

Units: Fraction/year [0,1]

This inflow represents the behavioral leverage of production cost reductions driven by two key factors: the use of organic inputs, which replaces external chemical dependencies and stabilizes expenditures, and the efficiency of market demand and value chain coordination, which optimizes transactions and infrastructure access. The weights are based on cross-case ToC evidence from ENFASYS D4.2, where both input strategies and market-based efficiencies were consistently cited as contributors to economic viability.

(040) Increase of PGS=

0.35 * EVF influence on PGS +

0.35 * EIF influence on PGS +

0.3 * SAAR influence on PGS

Units: Fraction/year [0,1]

The inflow “Increase of PGS” reflects a composite influence of three key systemic variables supported by the cross-case evidence in D4.2. Economic Viability for Farmers (EVF) and Environmental Impact Factors (EIF) are each weighted at 0.35 due to their strong association with policy justification and governance responsiveness to economic and ecological signals. The Sustainable Agricultural Adoption Rate (SAAR) contributes a reinforcing effect (weight = 0.30), as widespread adoption of sustainable practices creates momentum and demand for policy realignment and reinforcement

(041) Increase of SAAR=

0.18 * EA influence on SAAR +

0.18 * EVF influence on SAAR +

0.13 * FM influence on SAAR +

0.13 * KEA influence on SAAR +

0.13 * OC influence on SAAR +

0.13 * PGS influence on SAAR +

0.06 * EIF influence on SAAR +

0.06 * CSD influence on SAAR

Units: Fraction/year [0,1]

This equation is informed by the ENFASYS ToC (Roglic, 2025) during the system dynamics model validation process. The weights assigned to each influencing factor reflect their relative importance as identified in the validated CLDs and systemic archetypes across the case studies. Environmental Awareness (EA) and Economic Viability for Farmers (EVF) are assigned the highest weights (18% each), as they are considered key drivers of transition towards sustainable agricultural practices. Farmer Motivation (FM), Knowledge and Extension Access (KEAA), Organic Certification (OC), and Policy and Governance Support (PGS) are each assigned a medium-level weight (13%), reflecting their role as direct enablers of change. Positive Environmental Impact Factors (EIF) and Cultural and Social Dynamics (CSD) are assigned lower weights (6% each), as they represent indirect contextual conditions or long-term reinforcing elements. The total weight sums to 1.0 (100%) to ensure consistency in normalized scaling

(042) Increase of SC=

PGS influence on SC

Units: Fraction/year [0,1]

(043) Increase of Y=

EIF influence on Y

Units: raction/year [0,1]

This auxiliary flow represents the increase in yield driven by positive environmental impact factors. Since no other direct drivers are identified in the model structure, this influence is considered complete and is thus weighted at 1. This reflects the assumption that environmentally beneficial practices can significantly enhance or stabilize yield performance under sustainable production systems.

(044) Infrastructure and Processing Facilities= INTEG (

MAX(0, Increase of IPF * (1 - Infrastructure and Processing Facilities))

- MAX(0, Reduction of IPF * Infrastructure and Processing Facilities),

0.35)

Units: Fraction [0,1]

This variable represents the level of availability and access to infrastructure and processing facilities for farmers. It is proxied by the estimated share of agricultural output that is currently processed and transformed within local or regional value chains. Based on literature and EU rural development reports, an initial value of 0.35 reflects current infrastructure gaps and underinvestment in localized processing capacities.

(045) INITIAL TIME = 0

Units: year

The initial time for the simulation.

(046) IPF influence on MDVCE = WITH LOOKUP (

MIN(1, MAX(0,DELAY3(Infrastructure and Processing Facilities, 3))),

((0,0), (0.15,0.1), (0.3,0.4), (0.5,0.7), (0.7,0.85), (0.9,0.95), (1,1))

)

Units: Fraction/year [0,1]

This equation models the non-linear and delayed influence of Infrastructure and Processing Facilities (IPF) on Market Demand and Value Chain Efficiency (MDVCE), following ENFASYS D4.2 insights. The relationship activates beyond a structural readiness threshold (0.3), with minimal effects observed at lower IPF levels. As infrastructure improves (e.g., processing capacity, logistic integration), efficiency and market demand grow, peaking around 0.8, after which the marginal benefit decreases. A DELAY3 function (2 years) simulates the temporal inertia in infrastructure deployment and stakeholder response. The sigmoid curve reflects real-world non-linearity, and the output is normalized between 0 and 1 to ensure internal model consistency.

(047) KEA influence on EA = WITH LOOKUP (

MIN(1, MAX(0, DELAY3(Knowledge and Expertise Acces, 3)))

,

((0,0),(0.2,0),(0.3,0.05),(0.4,0.25),(0.6,0.65),(0.8,0.9),(1,1)))

Units: Fraction/year [0,1]

This equation models the delayed and non-linear influence of Knowledge and Expertise Access (KEA) on Environmental Awareness (EA), strictly based on D4.2. According to D4.2, KEA does not immediately trigger awareness shifts—impact occurs only after surpassing a threshold (0.3), representing sufficient knowledge exposure and participatory translation. MBS Feedback confirms the need for delayed response modeling to capture the cognitive and attitudinal processing time. The lookup function reflects a sigmoid relationship with saturation (0.8), where additional knowledge results in diminishing returns. A third-order delay (2 years) is applied to simulate system inertia in transforming knowledge into awareness. Output normalization ensures coherence within the [0–1] bounds.

(048) KEA influence on EIF = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH3(Knowledge and Expertise Acces, 2))),

((0,0),(0.2,0.2),(0.3,0.45),(0.4,0.65),(0.6,0.85),(0.8,0.97),(1,1))

)

Units: Fraction/year [0,1]

This equation is based on empirical insights derived from the ENFASYS cross-case analysis (D4.2). According to D4.2, effective integration of Knowledge and Expertise Access (KEA) is the strongest predictor of successful implementation of environmental initiatives, facilitating the translation of scientific knowledge into actionable strategies. Empirical calibration provided by MBS indicates that KEA acts as a critical systemic driver for producing significant Positive Environmental Impact Factors (EIF), in line with Geels' (2002) Multi-Level Perspective (MLP) on socio-technical transitions. The relationship is modeled via a lookup function capturing threshold dynamics: minimal effects are observed at low KEA levels (<0.277), reflecting the necessity for achieving a critical mass of knowledge integration before meaningful environmental impacts occur. Beyond this critical threshold, EIF sharply increases, eventually reaching saturation at high KEA levels, illustrating diminishing marginal returns in line with the observed spillover dynamics (MBS spillover score: 3.1). The third-order delay (DELAY3, 2 years) represents the realistic temporal lag inherent in translating improved knowledge and expertise into observable environmental outcomes. Normalization using MIN/MAX ensures variable consistency within the standard

[0,1] interval.

(049) KEA influence on SAAR = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Knowledge and Expertise Acces , 2)))

,

((0, 0), (0.2, 0.04), (0.4, 0.15), (0.6, 0.5), (0.8, 0.8), (1, 1))

)

Units: Fraction/year [0,1]

The influence of Knowledge and Expertise Access (KEA) on Sustainable Agricultural Adoption Rate (SAAR) is modeled through a smoothed lookup function. According to D4.2 and MBS feedback, knowledge alone is not sufficient for immediate behavioral change; rather, it initiates gradual shifts in attitudes and capabilities. The function includes a delay to reflect the time needed for knowledge to be absorbed and operationalized. The threshold structure captures the dynamics observed in transition theory (Geels, 2002), where innovation regimes respond slowly at first, accelerating only after critical capacities are reached.

(050) KEA negative influence on CSD = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH(Knowledge and Expertise Acces, 2)))

,

((0,0),(0.2,0),(0.3,0.1),(0.4,0.25),(0.6,0.5),(0.8,0.75),(1,0.9))

)

Units: Fraction/year [0,1]

This equation represents the delayed and non-linear negative influence of Knowledge and Expertise Access (KEA) on Community and Social Dynamics (CSD), based on evidence from the ENFASYS

D4.2 cross-case analysis. The D4.2 report identifies that poorly contextualized knowledge, or lack of participatory translation of scientific data, can act as a social barrier, eroding trust and reducing engagement among community actors. The MBS feedback structure supports this by modeling a gradual reduction in community participation through delayed system dynamics. The equation uses a third-order delay (DELAY3) to reflect the lagged impact of knowledge misalignment on social cohesion. The lookup function reflects an increasing negative effect as KEA rises without appropriate social integration mechanisms. MIN/MAX bounds ensure the output remains normalized between 0 and 1.

(051) KEA positive influence on CSD = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH3(Knowledge and Expertise Acces, 3))),

((0,0),(0.2,0.05),(0.3,0.1),(0.4,0.2),(0.5,0.4),(0.6,0.65),(0.8,0.8),(1, 1)))

Units: Fraction/year [0,1]

This equation models the non-linear and delayed influence of Knowledge and Expertise Access (KEA) on Community and Social Dynamics (CSD), based on the ENFASYS D4.2 cross-case analysis. According to project findings, KEA contributes positively to community engagement by enabling knowledge co-production, peer learning, and collective action, particularly once a critical threshold of access and participation is achieved. The relationship follows a sigmoid dynamic, where below-threshold values have minimal effect, followed by a steep increase in social engagement and eventual saturation. The DELAY3 function (2-year delay) reflects systemic inertia in translating training and expertise into measurable social transformation, consistent with participatory development theory and adaptive co-management frameworks. Normalization is enforced using MIN/MAX functions to maintain coherence within the [0–1] system scale.

(052) Knowledge and Expertise Acces= INTEG (

MAX(0, Increase of KEA * (1 - Knowledge and Expertise Acces))

- MAX(0, Reduction of KEA * Knowledge and Expertise Acces),

0.277)

Units: Fraction [0,1]

The initial value of the stock “Knowledge and Expertise Access” (KEA) is set to 0.277. This value is derived from official Eurostat data (2022), which reports that 10.2% of farm managers across the EU have received full agricultural training, and an additional 17.5% have received basic training. KEA is defined here as a normalized index capturing the proportion of farmers with access to structured agricultural knowledge and expertise systems. This indicator reflects systemic training access at the EU level and ensures consistency with the behavioral and normalized structure of the system dynamics model.

(053) Market Demand and Value Chain Efficiency= INTEG (

MAX(0, Increase of MDVCE * (1 - Market Demand and Value Chain Efficiency)

)

- MAX(0, Reduction of MDVCE * Market Demand and Value Chain Efficiency)

,

0.28)

Units: Fraction [0,1]

The initial value of the stock “Market Demand and Value Chain Efficiency” (MDVCE) is set to 0.28, based on two empirical indicators: (1) the proportion of EU consumers regularly purchasing organic or low-input products (15%), and (2) the average share of added value retained by farmers in EU agri-food value chains (27%). These values are normalized and averaged to reflect structural barriers in consumer uptake and supply chain equity, ensuring coherence with the systemic behavioral modeling approach.

(054) MDVCE influence on EVF = WITH LOOKUP (
MIN(1, MAX(0,Market Demand and Value Chain Efficiency)),
((0,0), (0.2,0), (0.3,0.05), (0.45,0.25), (0.6,0.6), (0.75,0.85), (0.85, 0.95), (1,1)
))

Units: Fraction/year [0,1]

This equation models the influence of Market Demand and Value Chain Efficiency (MDVCE) on Economic Viability for Farmers (EVF), based solely on evidence from D4.2 and MBS Feedback to UNIBO on T2.3. According to D4.2, market access, stable pricing mechanisms, and coordinated supply chains are preconditions for improved farmer income, yet benefits only emerge above a certain threshold of market structure (0.3). The lookup function captures this nonlinear pattern, with a sigmoidal increase and saturation around 0.85, reflecting infrastructural and institutional ceilings. No delay is introduced, as MBS feedback does not report systemic lags for this relationship. Output normalization is applied to ensure consistency within [0–1].

(055) MDVCE influence on OFA = WITH LOOKUP (
MIN(1, MAX(0, SMOOTH(Market Demand and Value Chain Efficiency, 3)))

,

((0,0),(0.2,0),(0.3,0.1),(0.5,0.4),(0.7,0.8),(0.85,0.95),(1,1)))

Units: Fraction/year [0,1]

This equation captures the delayed and threshold-based influence of Market Demand and Value Chain Efficiency (MDVCE) on Organic Farming Area (OFA), based solely on evidence from ENFASYS D4.2. As shown in the Belgian and Irish case studies, OFA expansion is contingent on stable market channels, fair pricing mechanisms, and coordinated value chains, which only generate change once a critical efficiency threshold (0.3) is reached. The lookup function simulates this progression with a rapid increase in influence and saturation above 0.85, reflecting logistical and infrastructural constraints. A third-order delay (2 years) models the time required for farmers and value chains to react structurally to changing market signals. The normalization ensures the output remains within the [0–1] interval.

(056) MDVCE influence on PC = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH3(Market Demand and Value Chain Efficiency, 3)))

,

((0, 1),

(0.1, 0.9),

(0.2, 0.75),

(0.4, 0.55),

(0.6, 0.4),

(0.8, 0.3),

(1, 0.3)))

Units: Fraction/year [0,1]

This function models the negative influence of MDVCE (Market Demand and Value Chain Efficiency) on Production Costs. It is based on the evidence from the D4.2 analysis and MBS feedback, where improved market coordination and efficiency reduce production costs. A lookup function is used to reflect a diminishing marginal effect, with a saturation threshold around 0.8. The influence is smoothed over 2 time steps to reflect structural reorganization time. This formulation is aligned with the "parameter-level" leverage classification in the MBS feedback tables and ensures that the variable remains within the [0,1] normalized range.

(057) OC influence on FM = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Organic Certification , 2)))

,

((0, 0),

(0.1, 0.05),

(0.2, 0.12),

(0.3, 0.22),

(0.4, 0.35),

(0.5, 0.48),

(0.6, 0.62),

(0.7, 0.75),

(0.8, 0.85),

(0.9, 0.93),

(1, 1)))

Units: Fraction/year [0,1]

This auxiliary variable models the influence of Organic Certification (OC) on Farmer Motivation (FM) using a nonlinear lookup function. The curve is calibrated based on the spillover effect score of 3.3 for market organization in Belgium (as a proxy for certification frameworks) found in the MBS feedback dataset. The effect reflects increasing trust, reduced risk perception, and improved access to premium markets, as described in the D4.2 cross-case analysis.

(058) OC influence on SAAR = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Organic Certification,3))),

((0, 0),

(0.1, 0.05),

(0.3, 0.2),

(0.5, 0.45),

(0.7, 0.75),

(1, 0.9)

))

Units: Fraction/year [0,1]

This auxiliary captures the influence of the share of organically certified farms on the overall rate of sustainable agricultural adoption (SAAR). As indicated in Deliverable 4.2, higher levels of organic certification serve as a legitimizing signal and social proof, fostering broader adoption dynamics. The relationship is non-linear, with limited influence below critical mass thresholds and growing momentum as organic adoption becomes more visible and mainstream. A smooth function accounts for the delay in behavioral shifts across the farming community.

(059) OFA influence on MDCVE = WITH LOOKUP (

MIN(1, MAX(0,Organic Farming Area)),

((0,0), (0.1,0.1), (0.2,0.3), (0.4,0.6), (0.6,0.8), (0.8,0.95), (1,1)

))

Units: Fraction/year [0,1]

This function represents the non-linear influence of Organic Farming Area (OFA) on Market Demand and Value Chain Efficiency (MDVCE), grounded in MBS Feedback to UNIBO on T2.3. According to the feedback, expanding OFA contributes to the emergence of market and coordination mechanisms only after surpassing a critical mass (0.3), which may activate infrastructure, cooperative systems, and fair pricing models. The relationship does not require a dynamic delay function but follows a threshold-based lookup, with limited returns after 0.8, indicating structural constraints and diminishing efficiency gains. The output is normalized in the [0–1] range.

(060) Organic Certification= INTEG (

MAX(0, Increase of OC * (1 - Organic Certification))

- MAX(0, Reduction of OC * Organic Certification),

0.048)

Units: Fraction [0,1]

The initial value of the “Organic Certification” (OC) stock is set at 0.0384, based on Eurostat data from 2022. Initial value based on the most recent data from IFOAM Organics Europe (2023), reporting 434,557 certified organic farms in the EU. Total number of EU farms in 2023 is approximately 9.11 million (European Commission, 2023). This yields a normalized value of 0.048.

(061) Organic Farming Area= INTEG (

MAX(0, Increase of OFA * (1 - Organic Farming Area))

- MAX(0, Reduction of OFA * Organic Farming Area),

0.115)

Units: Fraction [0,1]

(062) PC inculence on EVF = WITH LOOKUP (

MIN(1, MAX(0, Reduction of Production Costs))

,

((0,0),(0.2,0),(0.3,0.1),(0.4,0.3),(0.6,0.65),(0.8,0.9),(1,1)))

Units: Fraction/year [0,1]

This lookup function represents the direct and non-delayed influence of the Reduction of Production Costs (PC) on the Economic Viability for Farmers (EVF), as detailed in the MBS Feedback to UNIBO on T2.3. The document indicates that PC changes drive an immediate yet nonlinear impact on EVF. A critical threshold (0.3) must be surpassed to observe meaningful improvement, with effects increasing steeply and saturating after 0.8 due to structural constraints such as fixed costs and infrastructure limits. A delay function is intentionally omitted, reflecting the rapid responsiveness of farm-level profitability to cost shifts. The function is normalized within [0–1] using MIN/MAX for consistency in the model.

(063) PC influence on SAAr = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Reduction of Production Costs, 3)))

,

((0, 0), (0.2, 0.05), (0.4, 0.15), (0.6, 0.35), (0.8, 0.7), (1, 1))

)

Units: Fraction/year [0,1]

The influence of reduced production costs (PC) on the rate of sustainable agricultural adoption (SAAR) is modeled using a nonlinear function with delay. As supported by the D4.2 report and MBS feedback, marginal cost reductions (e.g., PC = 0.02) do not generate significant changes in farmer behavior. Only when reductions reach meaningful thresholds (above 0.4) do they affect willingness to transition. The smoothing delay reflects the time needed for economic benefits to translate into behavioral responses.

(064) PGS influence on EIF = WITH LOOKUP (

MIN(1, MAX(0, DELAY3(Policy and Governance for Sustainability, 2))),

((0,0),(0.2,0.25),(0.3,0.45),(0.4,0.65),(0.6,0.85),(0.8,0.97),(1,1))

)

Units: Fraction/year [0,1]

This equation models the empirically grounded non-linear and delayed influence of Policy and Governance for Sustainability (PGS) on Positive Environmental Impact Factors (EIF), as evidenced by the ENFASYS cross-case analysis (D4.2). Drawing from Geels' (2002) Multi-Level Perspective (MLP), this relationship is characterized by threshold dynamics: low levels of sustainable governance policies (below 0.31) yield minimal initial environmental benefits, underscoring the need for a critical institutional alignment before significant environmental outcomes can occur. Above this critical threshold, EIF increases rapidly due to the implementation and enforcement of sustainability criteria and environmental standards embedded in governance systems, with diminishing marginal returns as policy effectiveness approaches an upper saturation point (PGS 0.9–1). The DELAY3 function (2-year delay) realistically captures the policy inertia, administrative lags, and stakeholder adjustments required to translate governance improvements into tangible environmental outcomes. The normalization via MIN/MAX ensures internal consistency and adherence to the predefined system dynamics model scale [0–1].

(065) PGS influence on EVF = WITH LOOKUP (

MIN(1, MAX(0,Policy and Governance for Sustainability)),

((0,0), (0.2,0), (0.3,0.05), (0.45,0.35), (0.6,0.75), (0.8,0.95), (1,1)

))

Units: Fraction/year [0,1]

This equation models the direct, threshold-based influence of Policy and Governance for Sustainability (PGS) on Economic Viability for Farmers (EVF), based on explicit guidance from D4.2. Policies such as subsidies, support measures, or market guarantees are designed to immediately support farmers' economic resilience. Thus, no delay is applied. A sigmoid lookup function is used to simulate the nonlinear growth of this effect: activation begins around 0.3 and saturates beyond 0.8, reflecting diminishing marginal returns to policy leverage.

MIN/MAX bounds ensure normalization within the 0–1 range.

(066) PGS influence on KEA = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH3(Policy and Governance for Sustainability, 2))),

((0,0), (0.2,0.05), (0.3,0.12), (0.4,0.25), (0.5,0.45), (0.6,0.68), (0.7
,0.85), (0.8,0.95), (1,1)))

Units: Fraction/year [0,1]

(067) PGS influence on SAAR = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Policy and Governance for Sustainability, 3))),

((0, 0), (0.2, 0.02), (0.4, 0.1), (0.6, 0.35), (0.8, 0.65), (1, 1)))

Units: Fraction/year [0,1]

The influence of Policy and Governance for Sustainability (PGS) on SAAR is modeled using a smoothed lookup function, capturing the delayed and threshold-based nature of policy-driven change. Based on insights from D4.2 and MBS feedback, systemic responses to governance measures are limited below a critical penetration level (PGS < 0.4), corresponding to regime resistance and fragmented implementation. A stronger effect emerges as policies accumulate and are perceived as legitimate by stakeholders, consistent with Geels (2002) multi-level perspective. The initial PGS value of 0.31 implies minimal short-term impact, with potential for acceleration upon surpassing key activation thresholds.

(068) PGS influence on SC = WITH LOOKUP (

MIN(1, MAX(0,SMOOTH3(Policy and Governance for Sustainability, 0.6)))

,
((0, 0.05),
(0.1, 0.12),
(0.2, 0.22),
(0.3, 0.34),
(0.4, 0.48),
(0.5, 0.63),
(0.6, 0.74),
(0.7, 0.8),
(0.8, 0.85),
(0.9, 0.88),
(1, 0.9)))

Units: Fraction/year [0,1]

This function models the positive influence of Participatory Governance Structures (PGS) on Stakeholder Collaboration (SC), based on the ENFASYS cross-case analysis (D4.2) and parameter calibration from MBS Feedback. It reflects how increased participatory mechanisms enhance collaboration among stakeholders up to a saturation point, consistent with empirical spillover scores and feedback coefficients. The delay captures the time required for participatory structures to consolidate and effectively influence collaborative processes.

(069) Policy and Governance for Sustainability= INTEG (
MAX(0, Increase of PGS * (1 - Policy and Governance for Sustainability))
- MAX(0, Reduction of PGS * Policy and Governance for Sustainability),
0.31)

Units: Fraction [0,1]

The initial value of the stock “Policy and Governance for Sustainability” (PGS) is set to 0.31. This value is based on a normalized index derived from the ratio between public subsidies relevant to sustainable practices—specifically SE610 (crop-related subsidies), SE624 (rural development support), and SE625 (subsidies on intermediate consumption)—and the gross investment on fixed assets (SE516) as a proxy for operational costs. The data source is the EU Farm Accountancy Data Network (FADN) averaged over the most recent five-year period (2018–2022). This method captures the extent to which public financial support contributes to offsetting the economic burden of low-input agricultural practices. The normalization ensures interpretability within the behavioral-systemic framework of the model, where 0 indicates no cost coverage and 1 full cost coverage

(070) Positive Environmental Impact Factors= INTEG (
MAX(0, Increase of EIF * (1 - Positive Environmental Impact Factors))
- MAX(0, Reduction of EIF * Positive Environmental Impact Factors),
0.2)

Units: Fraction [0,1]

The initial value of the stock “Positive Environmental Impact Factors” (EIF) is set to 0.20. This normalized index is constructed as an inverse proxy of key environmental impacts attributed to EU agriculture, including greenhouse gas emissions (–5% since 2005), soil eutrophication trends, organic carbon loss in croplands (70 Mt between 2009 and 2018), and sustained biodiversity pressure on soils (56% under pressure). These components are weighted equally to reflect the system-level effort by farmers to mitigate environmental harm. The resulting value captures both progress and persisting challenges across EU agricultural landscapes.

(071) Reduction od Y = WITH LOOKUP (

MAX(0, MIN(1, DELAY3(Yield, 2))),

((0, 0.3),

(0.2, 0.25),

(0.4, 0.2),

(0.6, 0.1),

(0.8, 0.05),

(1, 0)))

Units: Fraction/year [0,1]

This outflow simulates the delayed and non-linear reduction in agricultural yield (Y) under low-input conditions. The decay function integrates a behavioral and agronomic perspective, accounting for gradual soil degradation, pest pressure, and adaptation limits. Evidence from ENFASYS D4.2 shows that yield declines are not immediate, but rather unfold progressively depending on farm-level capacity, external support, and environmental feedback. The use of a three-year delay reflects this inertia, while the lookup function modulates sensitivity to yield levels

(072) Reduction of ACIU = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH((Amount of chemical input use*(0.7*AOIU influence on ACIU

+ 0.3*SAAR ifluence on ACIU)) , 3))),

((0, 0), (0.2, 0.1), (0.4, 0.3), (0.6, 0.55), (0.8, 0.8), (1, 1)))

Units: Fraction/year [0,1]

This outflow function reflects the behavioural transition away from synthetic chemical inputs, primarily driven by the availability and perceived effectiveness of organic alternatives (AOIU), as supported by empirical insights from CS8 in D4.2. The influence of Sustainable Agricultural Adoption Rate (SAAR) is considered secondary, modelling the broader enabling context for chemical input reduction. The non-linear progression is captured via a bounded lookup function to represent decreasing marginal effects as adoption expands.

(073) Reduction of AOIU = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Amount of Organic Input Use, 2))),

((0, 0), (0.2, 0.05), (0.4, 0.15), (0.6, 0.35), (0.8, 0.65), (1, 1)))

Units: Fraction/year [0,1]

This outflow reflects the diminishing marginal returns and increasing management complexity associated with the expansion of organic input use (AOIU). Based on systemic insights from the D4.2 cross-case analysis—especially regarding scalability limits and maintenance burden of organic practices—and stakeholder feedback (D4.2), this curve captures a slow initial decline in efficacy followed by an accelerated reduction after a critical threshold. The LOOKUP function allows for a flexible, empirically grounded representation of this nonlinear trend.

(074) Reduction of CCAB = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH("Reduction of Compliance Costs & Administrative Burden"

, 2))),

((0, 0), (0.2, 0.02), (0.4, 0.08), (0.6, 0.18), (0.8, 0.35), (1, 0.6)))

Units: Fraction/year [0,1]

This outflow models the erosion of efforts to reduce compliance costs and administrative burden (CCAB). Evidence from the D4.2 report and MBS feedback shows that reductions in bureaucracy are often fragile and may deteriorate over time without structural reforms. This dynamic is represented through a non-linear lookup function that captures how the reduction of CCAB diminishes if not institutionalized or reinforced, particularly in contexts with frequent regulatory changes or complex subsidy schemes.

(075) "Reduction of Compliance Costs & Administrative Burden"= INTEG (
MAX(0, Increase of CCAB * (1 - "Reduction of Compliance Costs & Administrative Burden"
))
- MAX(0, Reduction of CCAB * "Reduction of Compliance Costs & Administrative Burden"
),
0.175)

Units: Fraction [0,1]

This variable reflects the reduction in compliance costs and administrative burden faced by farmers. It is estimated based on the share of non-productive expenditures (e.g. external factors and administrative taxes) over total farm expenditures. Using 2022 FADN data, approximately 17.5% of costs are not linked to productive activities

(076) Reduction of CSD = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH(KEA negative influence on CSD*Cultural and Social Dynamics
, 3))),
((0, 0.9), (0.2, 0.6), (0.4, 0.3), (0.6, 0.1), (0.8, 0.05), (1, 0.05)))

Units: Fraction/year [0,1]

This outflow models the vulnerability of cultural and social dynamics (CSD) to the lack of access to knowledge and expertise (KEA). When KEA is low, traditional resistance and path dependency strongly reduce the system's cultural flexibility and openness to sustainability. As KEA increases, the rate of cultural regression slows down, indicating stronger adaptive capacities and learning effects. The function is grounded on patterns identified across case studies (e.g., CS6, CS10) and validated through MBS feedback, which emphasize that higher knowledge access buffers social lock-ins and fosters systemic resilience.

(077) Reduction of EA = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Environmental Awareness, 3))),

((0, 0), (0.2, 0.05), (0.4, 0.15), (0.6, 0.35), (0.8, 0.65), (1, 1)))

Units: Fraction/year [0,1]

This outflow captures the natural decline of environmental awareness (EA) in the absence of continuous engagement and reinforcement mechanisms. As highlighted in D4.2 and confirmed by feedback from case studies, without sustained informational and experiential inputs, EA tends to decay due to factors such as informational fatigue and diminished perceived agency. The non-linear lookup function represents this dynamic, where EA remains relatively stable initially but decreases more rapidly beyond a critical point.

(078) Reduction of EIF = WITH LOOKUP (

MAX(0, MIN(1,

DELAY3(Positive Environmental Impact Factors,4))), ((0, 0.25),

(0.2, 0.2),

(0.4, 0.15),

(0.6, 0.1),

(0.8, 0.05),

(1, 0)))

Units: Fraction/year [0,1]

This outflow represents the gradual erosion of environmental benefits (EIF) once sustainability efforts decline. The equation integrates a delayed behavioral dynamic (DELAY3) and a nonlinear sensitivity curve (LOOKUP) to capture the progressive degradation of ecological services such as soil health, biodiversity, and nutrient cycles. Based on D4.2 evidence, the impact of losing sustainable practices is not immediate, highlighting the resilience of well-established environmental improvements.

(079) Reduction of EVF = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH((Economic Viability for Farmers *PC inculence on EVF

) , 2))),

((0, 0.4),

(0.2, 0.3),

(0.4, 0.2),

(0.6, 0.1),

(0.8, 0.05),

(1, 0.01)))

Units: Fraction/year [0,1]

This outflow represents the behavioral erosion of farmers' perceived economic viability (EVF), following a non-linear trajectory shaped by systemic uncertainty, loss of trust, and institutional fragility. As evidenced in the ENFASYS D4.2 cross-case analysis, EVF can rapidly deteriorate under perceived economic stress—even when financial data remain stable—due to risk aversion, lack of continuity in policy support, and structural lock-ins. The lookup function models this dynamic with an accelerating decay at lower viability levels, reflecting the compounding psychological burden of perceived economic failure

```
(080)    Reduction of FM = WITH LOOKUP (
       MAX(0, MIN(1,
         DELAY3(Farmer Motivation, 3))),
           ((0, 0.3),
                (0.2, 0.25),
                (0.4, 0.2),
                (0.6, 0.1),
                (0.8, 0.05),
                (1, 0)))
```

Units: Fraction/year [0,1]

This outflow reflects the behavioral erosion of farmer motivation (FM), which is sensitive to institutional consistency, perceived impact, and emotional reinforcement. The D4.2 analysis highlights that motivation deteriorates gradually under misaligned policy signals, unmet expectations, or socio-cultural fatigue. The non-linear structure and three-year delay simulate the slow breakdown of commitment, followed by accelerated disengagement at lower levels.

(081) Reduction of IPF = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Infrastructure and Processing Facilities, 2))),

((0, 0), (0.2, 0.05), (0.4, 0.12), (0.6, 0.28), (0.8, 0.5), (1, 0.8)))

Units: Fraction/year [0,1]

This outflow represents the progressive decline of infrastructure and processing facilities (IPF) in the absence of systemic support or integration within sustainable value chains. As indicated in D4.2 and reinforced by MBS feedback, without sustained usage or policy backing, existing facilities are prone to degradation or economic unsustainability. The function captures the increasing rate of attrition as IPF scales up without stabilizing conditions, with a delayed onset typical of infrastructure decline.

(082) Reduction of KEA = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Knowledge and Expertise Acces, 5))),

((0, 0), (0.2, 0.05), (0.4, 0.15), (0.6, 0.35), (0.8, 0.6), (1, 0.9))

)

Units: Fraction/year [0,1]

This outflow integrates a delay function to account for systemic inertia and behavioral stickiness in response to external disruptions. Empirical findings from the ENFASYS D4.2 suggest that responses to reduced support are not instantaneous, but rather unfold over time as networks dissolve, habits shift, or institutional memory fades. Using SMOOTH operator ensures that the model captures the temporal dynamics of erosion, preventing unrealistic volatility and better aligning with observed lag effects in policy and knowledge systems

```
(083)    Reduction of MDVCE = WITH LOOKUP (
        MAX(0, MIN(1,
          DELAY3(
            Market Demand and Value Chain Efficiency, 3))),


             ((0, 0.3),
                   (0.2, 0.25),
                   (0.4, 0.2),
                   (0.6, 0.1),
                   (0.8, 0.05),
                   (1, 0)))
```

Units: Fraction/year [0,1]

This outflow simulates the behavioral and structural erosion of market demand and value chain efficiency (MDVCE). The function incorporates a delayed non-linear decay to reflect the gradual detachment of producers from market dynamics due to saturation, disintermediation, or loss of institutional and consumer alignment. Drawing from D4.2 evidence, the decline in MDVCE is often triggered by external shocks or inefficiencies that accumulate slowly, with a significant time lag before affecting farm-level decision-making.

```
(084)    Reduction of OC = WITH LOOKUP (
        MAX(0, MIN(1, DELAY1(Organic Certification, 3))),
            ((0, 0), (0.2, 0.05), (0.4, 0.15), (0.6, 0.3), (0.8, 0.55), (1, 1)))
```

Units: Fraction/year [0,1]

This outflow captures the behavioural and institutional inertia in maintaining organic certification over time. The function models potential dropout or administrative burden-related attrition as a nonlinear process. The choice of a bounded lookup structure reflects diminishing vulnerability to dropout as the certification rate increases and stabilizes, with reference to stakeholder insights in CS8 and general dynamics highlighted in D4.2.

(085) Reduction of OFA = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Organic Farming Area, 2))),

((0, 0), (0.2, 0.05), (0.4, 0.1), (0.6, 0.25), (0.8, 0.55), (1, 0.9)))

Units: Fraction/year [0,1]

This outflow captures the potential regression of Organic Farming Area (OFA) due to system fragilities such as low economic incentives, certification burden, and weak value chain integration. Based on D4.2 findings, organic farmers may revert to conventional methods when economic or institutional support fails to stabilize. The function reflects a non-linear risk curve where high levels of OFA are more vulnerable to collapse under external pressures.

(086) Reduction of PC = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH((0.3*Reduction of Production Costs) - (0.7 * ACIU influence on PC), 2))),

((0, 0),(0.2, 0.05),(0.4, 0.15), (0.6, 0.35), (0.8, 0.65),(1, 0.9)))

Units: Fraction/year [0,1]

This outflow simulates the erosion of cost-efficiency in farm production systems, driven by continued reliance on synthetic chemical inputs. While no specific case study in D4.2 directly quantifies this relationship, the broader cross-case analysis identifies systemic concerns about the economic vulnerability of input-dependent models. The equation integrates a smoothed non-linear response, based on the assumption that chemical input intensity (ACIU) gradually reduces the potential for cost reduction over time. The use of a SMOOTH operator captures the delayed adjustment dynamics in farm decision-making and cost structures, as aligned with system delays noted in the MBS feedback document.

(087) Reduction of PGS = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH(Policy and Governance for Sustainability, 3))),
((0, 0),
(0.2, 0.01),
(0.4, 0.03),
(0.6, 0.08),
(0.8, 0.2),
(1, 0.4)))

Units: Fraction/year [0,1]

This outflow captures the structural decay of institutional and policy commitment to sustainability. It reflects the internally-driven fragility of governance systems that, once established, may lose momentum due to administrative fragmentation, political shifts, or lack of cross-sectoral coordination. The function follows a non-linear profile to reflect growing exposure to risk as institutional complexity increases. This pattern is substantiated by the cross-case analysis in D4.2, where governance rollback was observed in cases lacking multi-level coherence and long-term vision.

(088) Reduction of Production Costs= INTEG (

MAX(0, Increase of PC * (1 - Reduction of Production Costs))

- MAX(0, Reduction of PC * Reduction of Production Costs),

0.0209)

Units: Fraction [0,1]

The initial value of the stock “Reduction of Production Costs” is set to 0.0209. This value is derived using FADN data (2018–2022) on total intermediate consumption per farm, which averaged €65,301 during this period. The numerator is based on a fixed production cost per hectare (€1,368.38), as previously used in the SCBSP model. The index represents the share of fixed production costs relative to total production costs at the farm level, normalized on a 0–1 scale. A lower value indicates lower relative fixed costs and greater potential for cost efficiency gains.

(089) Reduction of SAAR = WITH LOOKUP (

MAX(0, MIN(1, Sustainable Agricultural Adoption Rate*(0.5 * CCAB influence on SAAR

+ 0.5 * PC influence on SAAr))),

((0, 0),

(0.2, 0.01),

(0.4, 0.04),

(0.6, 0.1),

(0.8, 0.25),

(1, 0.5)))

Units: Fraction/year [0,1]

This function simulates the erosion of sustainable agricultural adoption (SAAR) under systemic constraints. While the exact numeric parameters are not provided in D4.2, the formulation reflects mechanisms described in the cross-case analysis:

sustainability fatigue, cost-related barriers, and administrative burden tend to grow disproportionately at higher levels of adoption if not counteracted by supportive interventions. The non-linear lookup curve represents the increasing behavioral fragility of adoption at scale, as outlined in D4.2 findings on policy gaps and market failures

```
(090)	Reduction of SC = WITH LOOKUP (
	MAX(0, MIN(1, SMOOTH(Stakeholder Collaboration, 3 ) )),
		((0, 0), (0.2, 0.05), (0.4, 0.15), (0.6, 0.35), (0.8, 0.65), (1, 1)))
```

Units: Fraction/year [0,1]

This outflow represents the progressive erosion of stakeholder collaboration (SC) over time, particularly in the absence of reinforcing institutional and social structures. Based on D4.2 insights and MBS feedback, initial collaboration often decreases unless sustained by trust-building mechanisms, shared goals, and tangible impact. The curve captures this dynamic by assuming a gradual loss that accelerates at higher levels of initial collaboration due to growing coordination fatigue and complexity.

```
(091)	SAAR ifluence on ACIU = WITH LOOKUP (
	MAX(0, MIN(1, SMOOTH3(Sustainable Agricultural Adoption Rate, 2 ) ) )
	 ,
		((0, 0),
		 (0.2, 0.05),
		 (0.3, 0.15),
		 (0.4, 0.3),
		 (0.5, 0.5),
		 (0.6, 0.7),
```

```
    (0.7, 0.85),
    (0.8, 0.95),
    (1, 1))
   )
```

Units: Fraction/year [0,1]

This function represents the influence of Sustainable Agricultural Adoption Rate (SAAR) on the reduction of chemical input use (ACIU). Based on the empirical calibration guidelines from MBS feedback, a gradual effect is assumed, with noticeable influence emerging from a threshold of 0.3. The curve accelerates beyond 0.5, simulating a typical policy uptake saturation dynamic, in line with Geels (2002) multi-phase transition theory and system behavior patterns outlined in the D4.2 analysis. This lookup captures the non-linear acceleration of environmental benefits as sustainable practices become more widely adopted.

```
(092)   SAAR impact on AOIU = WITH LOOKUP (
      MIN(1, MAX(0, SMOOTH(Sustainable Agricultural Adoption Rate, 2)))
      ,
        ((0,0),(0.25,0),(0.35,0.1),(0.45,0.4),(0.6,0.75),(0.8,0.95),(1,1))
        )
```

Units: Fraction/year [0,1]

This equation models the delayed and non-linear influence of the Sustainable Agricultural Adoption Rate (SAAR) on the Amount of Organic Input Use (AOIU), based strictly on the ENFASYS D4.2 cross-case analysis and the MBS Feedback calibration recommendations. Case study evidence suggests that the use of organic inputs increases only after farmers reach a certain level of sustainable practice adoption (0.35), due to the technical and logistic prerequisites involved. The relationship follows a sigmoidal pattern with an upper saturation level around 0.8, representing diminishing returns once structural barriers are overcome. The DELAY3 function (2 years) accounts for the latency in training, infrastructure readiness, and changes in supply chains. The MIN/MAX ensures normalization within the [0–1] interval, maintaining internal model consistency.

(093) SAAR influence on CCAB = WITH LOOKUP (
MIN(1, MAX(0, DELAY1(Sustainable Agricultural Adoption Rate, 3))),
((0,0.02),
(0.1,0.04),
(0.2,0.08),
(0.3,0.12),
(0.4,0.18),
(0.5,0.25),
(0.6,0.35),
(0.7,0.45),
(0.8,0.55),
(0.9,0.65),
(1,0.75)))

Units: Fraction/year [0,1]

This lookup function captures the behavioral influence of SAAR on the reduction of Production Costs. Drawing from D4.2 and MBS feedback, increased socio-agroecological readiness among stakeholders facilitates adoption of low-input farming practices. The effect is modeled as non-linear, with minimal change at low SAAR values and significant reductions once a readiness threshold is surpassed (0.3). This reflects a systemic transition dynamic, where awareness primes the system for more efficient and collective cost-reducing behaviors over time, as theorized by Geels (2002).

(094) SAAR influence on CSD = WITH LOOKUP (
MIN(1, MAX(0, (SMOOTH(Sustainable Agricultural Adoption Rate, 2)))),
((0,0),(0.2,0.05),(0.27,0.1),(0.33,0.15),(0.4,0.4),(0.7,0.75),(0.8,0.9),
(1,1)))

Units: Fraction/year [0,1]

This equation reflects the empirically grounded non-linear and delayed relationship between Sustainable Agricultural Adoption Rate (SAAR) and Community and Social Dynamics (CSD), as identified in the ENFASYS cross-case analysis (D4.2) and recommended through empirical calibration by MBS Feedback. Empirical evidence shows that sustainable agricultural practices initially generate limited community and social impacts until a critical adoption threshold (approximately SAAR=0.27) is crossed. Beyond this threshold, community participation and social cohesion experience rapid growth, as sustainable practices stimulate new forms of cooperation, collective awareness, and active local engagement. The logistic (sigmoid) curve effectively captures the initial slow phase, followed by rapid adoption and eventual stabilization at high adoption rates. A third-order delay (DELAY3, 2 years) realistically accounts for social inertia, gradual behavioral adaptation, and community learning processes inherent in sustainable practice integration. The normalization enforced by MIN/MAX functions ensures internal consistency, adhering strictly to the predefined interval [0,1], thus maintaining theoretical and empirical model integrity.

(095) SAAR influence on EIF = WITH LOOKUP (

MIN(1, MAX(0, DELAY3(Sustainable Agricultural Adoption Rate, 2)))

,

((0,0),(0.2,0.05),(0.27,0.1),(0.4,0.35),(0.6,0.7),(0.8,0.9),(1,1)))

Units: Fraction/year [0,1]

This equation captures the empirically informed, non-linear, and delayed influence of Sustainable Agricultural Adoption Rate (SAAR) on Environmental Impact Factors (EIF), drawing directly on the findings from the ENFASYS cross-case analysis (D4.2). Following Geels' (2002) Multi-Level Perspective (MLP), SAAR initially represents niche-level agricultural practices that produce limited environmental impacts. Only upon surpassing a critical adoption threshold (around 0.27) does the environmental impact rapidly escalate due to systemic diffusion, cumulative learning, and scaling-up of sustainable practices. This relationship features diminishing returns at higher levels of adoption, reflecting a stabilization of environmental improvements as sustainable agriculture transitions towards becoming a dominant practice. A third-order delay (DELAY3) of 2 years realistically represents systemic inertia, operational adjustment, and temporal lag associated with widespread practice changes. The normalization via MIN/MAX functions ensures values remain within the standardized [0,1] interval, preserving the internal coherence and empirical validity of the model.

(096) SAAR influence on KEA = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH3(Sustainable Agricultural Adoption Rate, 2))),

((0,0), (0.1,0.02), (0.2,0.06), (0.3,0.12), (0.4,0.25), (0.5,0.45), (0.6 ,0.65), (0.7,0.85), (0.8,0.95), (1,1)))

Units: Fraction/year [0,1]

This variable captures the influence of SAAR on KEA using a smoothed non-linear function. With an initial SAAR value of 0.27, the behavioural response is moderate, reflecting early-stage dynamics in knowledge acquisition. The effect accelerates as SAAR surpasses 0.3, consistent with transition dynamics described in Geels (2002), and saturates near 0.8, reflecting institutional and network capacity limits as outlined in the D4.2 cross-case analysis.

(097) SAAR influence on MDVCE = WITH LOOKUP (

MIN(1, MAX(0,DELAY3(Sustainable Agricultural Adoption Rate, 3))),

((0,0),
(0.2,0),
(0.3,0.1),
(0.45,0.35),
(0.65,0.75),
(0.85,0.95),
(1,1)))

Units: Fraction/year [0,1]

This equation models the influence of the Sustainable Agricultural Adoption Rate (SAAR) on Market Demand and Value Chain Efficiency (MDVCE) based on D4.2 and the MBS Feedback to UNIBO. Empirical evidence from ENFASYS case studies (Ireland, Belgium, Germany) suggests that sustainable adoption enables downstream improvements in market efficiency and demand. However, these changes manifest only beyond a critical adoption threshold (0.3), after which chain coordination and branding efforts gain momentum. The effect then saturates as structural constraints limit scalability. A 1-year third-order delay captures the lag required for organizational responses to increased sustainable production. The lookup table reflects this non-linear dynamic, and normalization keeps the variable bounded within [0,1].

(098) SAAR influence on OC = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH(Sustainable Agricultural Adoption Rate, 1)))

,

((0,0),(0.25,0),(0.35,0.05),(0.5,0.3),(0.7,0.75),(0.85,0.95),(1,1)))

Units: Fraction/year [0,1]

This equation models the non-linear, threshold-based, and delayed influence of the Sustainable Agricultural Adoption Rate (SAAR) on Organizational Change (OC), in alignment with the ENFASYS D4.2 cross-case analysis and the MBS Feedback calibration strategy. The D4.2 report identifies that widespread adoption of sustainable practices acts as a prerequisite for organizational transformation, but only once a critical mass is achieved (0.35). This transformation includes cooperative restructuring, new governance models, and systemic institutional shifts. The lookup function captures a sigmoidal effect with saturation at high adoption levels, reflecting real-world limits to change without broader enabling conditions. A third-order delay (DELAY3) of 2 years is applied to simulate institutional inertia and adaptation cycles. MIN/MAX ensures normalization within the [0–1] range.

```
(099)    SAAR influence on OFA = WITH LOOKUP (
       MAX(0, MIN(1, SMOOTH(Sustainable Agricultural Adoption Rate, 2) )),
          ((0, 0),
           (0.2, 0),
           (0.3, 0.05),
           (0.4, 0.2),
           (0.55, 0.55),
           (0.7, 0.8),
           (0.85, 0.95),
           (1, 1)
          )
          )
```

Units: Fraction/year [0,1]

This lookup function models the non-linear relationship between Sustainable Agricultural Adoption Rate (SAAR) and the expansion of Organic Farming Area (OFA), based exclusively on ENFASYS D4.2 and MBS Feedback. D4.2 case studies confirm that increases in SAAR lead to greater OFA only after surpassing a critical threshold (0.3), where enabling conditions such as organic input availability, training, and market access converge. Beyond this point, the relationship accelerates and then saturates (0.85), reflecting practical limitations in organic conversion. The delayed and threshold-based pattern aligns with the systemic inertia and adoption barriers identified in both documents. The function excludes early activation and uses saturation to ensure

behavioral and structural realism in system modeling.

(100) SAAR influence on PGS = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH(Sustainable Agricultural Adoption Rate, 2)))

,

((0,0),(0.3,0.05),(0.4,0.2),(0.6,0.6),(0.8,0.9),(1,1)))

Units: Fraction/year [0,1]

This equation models the delayed and threshold-based influence of the Sustainable Agricultural Adoption Rate (SAAR) on Policy and Governance for Sustainability (PGS), based on ENFASYS D4.2. The D4.2 analysis demonstrates that once SAAR surpasses a critical mass (0.35), it creates bottom-up pressure that can trigger institutional reforms, improved farmer representation, and alignment of sustainability policies. The effect follows a sigmoid pattern with saturation at high SAAR levels, reflecting institutional inertia and policy feedback loops. A delay (2 years) accounts for the temporal lag between adoption trends and political response. The output is normalized using MIN/MAX to remain within the [0–1] model bounds.

(101) SAVEPER =

TIME STEP

Units: year [0,?]

The frequency with which output is stored.

(102) SC influence on KEA = WITH LOOKUP (

MIN(1, MAX(0, DELAY3(Stakeholder Collaboration, 2))),

((0,0), (0.2, 0), (0.3,0) , (0.4,0.2) , (0.5,0.4) , (0.6,0.6) , (0.7,0.8

) , (1,1)))

Units: Fraction/year [0,1]

This equation captures the empirically observed non-linear and delayed relationship between Stakeholder Collaboration (SC) and Knowledge Expertise Access (KEA), based on cross-case evidence (ENFASYS D4.2). The relationship follows a threshold-based dynamics consistent with the Multi-Level Perspective (MLP) of socio-technical transitions described by Geels (2002). Specifically, KEA remains negligible until a critical threshold of SC (0.3) is reached, reflecting the necessity of a minimum level of stakeholder engagement before systemic knowledge-sharing benefits materialize. Beyond this threshold, KEA rapidly increases, reflecting accelerating returns on collaboration. The function saturates at higher collaboration levels (around 0.7), as indicated by the empirical spillover score of 3.1 for the Italian context provided by MBS, beyond which additional stakeholder collaboration yields marginal incremental benefits. The third-order delay (DELAY3, 2 years) explicitly models policy inertia, cognitive adaptation, and decision-making cycles identified in the project documents. Finally, the MIN/MAX functions ensure the normalized boundaries (0–1) of the KEA variable, preserving model validity and interpretability.

(103) Stakeholder Collaboration= INTEG (

MAX(0, Increase of SC * (1 - Stakeholder Collaboration))

- MAX(0, Reduction of SC * Stakeholder Collaboration),

0.3)

Units: Fraction [0,1]

(104) Sustainable Agricultural Adoption Rate= INTEG (

MAX(0, Increase of SAAR * (1 - Sustainable Agricultural Adoption Rate))

- MAX(0, Reduction of SAAR * Sustainable Agricultural Adoption Rate),

0.27)

Units: Fraction [0,1]

The initial value of the stock "Sustainable Agriculture Adoption Rate" (SAAR) is set to 0.27. This represents a normalized index (0–1) of the average adoption level of low-input agricultural practices across the five ENFASYS case studies associated with the Low-Input Agriculture (LIA) pathway (CS1, CS2, CS3, CS9, CS10). The value is derived through a weighted synthesis of multiple empirical sources: - Eurostat data indicate that 10.5% of the EU’s utilized agricultural area is under organic farming (2022). - A McKinsey (2024) analysis reports that up to 70% of European farmers implement at least one sustainable practice, albeit only on partial farm surfaces. - Project-specific evidence (ENFASYS D4.2, MBS feedback) reveals heterogeneous levels of adoption across LIA case studies, with estimates ranging from 0.1 (Serbia) to 0.45 (Switzerland). By averaging the estimated baseline adoption values per case (CS1 ≈ 0.2; CS2 ≈ 0.1; CS3 ≈ 0.45; CS9 ≈ 0.3; CS10 ≈ 0.35), the model establishes an empirically grounded and contextually valid initial stock level. This approach aligns with the behavioral-systemic nature of the model and supports internal consistency in the use of normalized indicators. Equation structure ensures that SAAR remains bounded within the normalized range [0,1]. The increase function includes a saturation mechanism based on (1 – SAAR), while reduction is proportional to current SAAR. Both flows are bounded below by 0 using MAX operators to prevent negative stock values. This logic reflects common behavioral adoption dynamics and preserves system stability

(105) TIME STEP = 1

Units: year [0,?]

The time step for the simulation.

(106) Y influence on EVF = WITH LOOKUP (

MIN(1, MAX(0,Yield)),

((0,0),(0.2,0),(0.3,0),(0.45,0.2),(0.6,0.5),(0.8,0.9),(1,1)))

Units: Fraction/year [0,1]

This equation models the direct and threshold-based influence of Yield on the Economic Viability for Farmers (EVF), using evidence exclusively from ENFASYS D4.2 and the MBS Feedback to UNIBO on T2.3. According to D4.2, yield contributes to financial sustainability and farm resilience, but only beyond a certain level (0.3), where production becomes economically meaningful. The effect does not require delay modeling, as the economic impact of yield is perceived within the same production cycle. The lookup curve reflects a non-linear progression with diminishing returns, consistent with MBS recommendations to capture saturation at higher yield levels. MIN/MAX bounds ensure normalization within the [0–1] model framework.

(107) Yield= INTEG (

MAX(0, Increase of Y * (1 - Yield))

- MAX(0, Reduction od Y * Yield),

0.637)

Units: Fraction [0,1]

The initial value of the stock “Yield” is set to 0.637, based on the average total crop output per hectare across EU farms between 2018 and 2022 (FADN – SE136). This measure reflects the aggregated economic productivity of crop production and is supported by consistency across disaggregated crop categories (e.g. cereals, vegetables, wine, olives). The value is normalized on a scale where 600 €/ha represents minimal productivity (0) and 2000 €/ha represents high performance (1), ensuring compatibility with the systemic behavioral model.

10 Annex 2 Sustainable Consumption and Direct Selling (SCDS) SDM equation description

01) Adoption Rate of Sustainable Selling Models= INTEG (

MAX(0, Increase in Adoption Rate * (1 - Adoption Rate of Sustainable Selling Models

))

- MAX(0, Reduction of SSM * Adoption Rate of Sustainable Selling Models

)

,

0.15)

Units: Fraction [0,1]

Initial value set at 0.15 based on evidence from Zero Waste Europe, which estimates that 15% of EU farms sell more than half of their products directly to consumers. Direct selling is more common among small farms

(02) "Adoption-Driven Training Demand" = WITH LOOKUP (

MAX(0, MIN(1, Adoption Rate of Sustainable Selling Models)),

((0,0), (0.1,0.5), (0.3,0.8), (0.5,0.95), (0.7,1), (1,1)))

Units: Fraction/Year [0,1]

This variable models the increase in demand for knowledge and training systems (KTS) that arises from the growing adoption of sustainable selling models (ARSSM). Based on evidence from ENFASYS Deliverables D2.2 and D4.2, the adoption process is closely associated with emerging needs for capacity building, technical assistance, and tailored training content. The model assumes a constant sensitivity factor to represent the proportional relationship between adoption levels and training demand. The sensitivity coefficient is set to 0.5, assuming that for each unit increase in ARSSM, half a unit increase in training demand is generated. This reflects that not all adopting farms require immediate training, while others might demand multiple training sessions across domains (e.g., logistics, marketing, certification). This proportional estimate is aligned with ENFASYS D4.2 findings, which highlight both the variability of farmer training needs and the systemic lag in the responsiveness of KTS. It also resonates with agricultural innovation literature emphasizing the coupling of technology adoption with demand-driven knowledge support (Leeuwis & van den Ban, 2004).

(03) ARSSM impact on PS = WITH LOOKUP (
MIN(1, MAX(0, DELAY1(Adoption Rate of Sustainable Selling Models, 2))),
((0, 0), (0.2, 0.1), (0.4, 0.25), (0.6, 0.45), (0.8, 0.7), (1, 1)))

Units: Fraction/Year [0,1]

This auxiliary models how the adoption of sustainable selling models gradually stimulates policy support. Empirical and project-based evidence (ENFASYS D2.2) shows that institutional responses tend to follow visible improvements in environmental or social outcomes, with a significant time delay due to policy inertia and decision-making cycles.

(04) ARSSM influence on CDWTP = WITH LOOKUP (
DELAY1(Adoption Rate of Sustainable Selling Models, 1.5),
((0, 0), (0.3, 0.1), (0.6, 0.4), (0.8, 0.8), (0.9, 1), (1, 1)))

Units: Fraction/Year [0,1]

This variable captures the delayed and non-linear influence of ARSSM on consumer demand and willingness to pay (CDWTP) for sustainable products. Evidence from ENFASYS D4.2 highlights that trust, perceived transparency, and quality associated with sustainable selling models take time to reach consumers. The effect emerges only after a critical adoption threshold (0.15) and accelerates as more producers join the system. Once ARSSM adoption exceeds 0.5—approaching regime-level relevance—the marginal effect on CDWTP stabilizes, reflecting saturation and systemic integration. This formulation is supported by the Multi-Level Perspective (MLP) on socio-technical transitions (Geels, 2002), where sustainable models begin as niche practices with limited systemic influence and later scale up to challenge the incumbent regime, thus stabilizing the impact on consumer behavior

(05) ARSSM influence on CLA = WITH LOOKUP (

DELAY1(

(Adoption Rate of Sustainable Selling Models),

1

),

((0, 0),(0.2, 0),(0.3, 0.1),(0.4, 0.3),(0.6, 0.7),(0.8, 1)))

Units: Fraction/Year [0,1]

This variable captures the delayed and threshold-based effect of ARSSM adoption on the expansion of cultivated land area (CLA). Case studies such as CS6 (Greece) from the ENFASYS D2.2 report show that successful adoption of sustainable selling models can lead to increased profitability, encouraging the reactivation of marginal or unused farmland. According to Eurostat, the average utilised agricultural area (UAA) per farm in the EU is about 17 hectares. Assuming a conservative 10–20% land expansion after adoption, we estimate an average increase of 1.7–3.4 hectares per adopting farm. This model uses a coefficient of 2.5 ha/farm beyond a critical threshold to reflect that effect

(06) Brand Appeal for Sustainability = WITH LOOKUP (

MIN(1, MAX(0, DELAY1(Environmental and Etichal Branding, 1))),

((0,0), (0.2,0.3), (0.4,0.6), (0.6,0.85), (0.8,1), (1,1))

)

Units: Fraction/Year [0,1]

This variable captures the influence of sustainable brands' appeal on consumers' willingness to pay (CDWTP). The effect grows steadily over time, after an initial delay period necessary for brands to establish their presence and build consumer trust. As sustainable brands become more recognized, consumers are increasingly willing to pay a premium for such products. This reflects the growing influence of ethical and environmental branding on consumer behavior, as supported by research on sustainable consumption patterns.

(07) Branding strenght=

MIN(1, MAX(0, (0.6 * (CDWP influence on EEB) + 0.4 * (TKS influence on EEB

))))

Units: Fraction/Year [0,1]

Branding Strength is modeled as a function of two delayed influences: Consumer Demand and Willingness to Pay (CDWP) and Training and Knowledge Support (TKS). A first-order information delay is applied to both, capturing the non-instantaneous effect of these variables on branding development. CDWP receives a higher weight (0.6), reflecting its direct and faster impact on consumer-oriented branding decisions, while TKS has a lower weight (0.4) and a longer delay (3) due to the time required for capacity building and the diffusion of knowledge throughout the value chain.

(08) CAP influence on CDWP = WITH LOOKUP (

DELAY1((Cooperation among producers*0.5)^2, 3),

((0, 0), (0.2, 0.2), (0.33, 0.4), (0.5, 0.6), (0.66, 0.75), (0.8, 0.8), (1, 0.8)))

Units: Fraction/Year [0,1]

This auxiliary variable models the influence of cooperation among producers on consumer demand and willingness to pay (CDWTP). As cooperation among producers increases, the visibility and transparency of products on the market grow, leading to a higher consumer willingness to pay. This effect, however, is bounded by a threshold after which further increases in cooperation no longer lead to higher CDWTP. The model uses a delay to account for the time required for the cooperation to result in measurable changes in CDWTP.

(09) CDWP influence in ILC = WITH LOOKUP (

DELAY3(Consumer Demand and Willingness to Pay, 3),

((0, 0), (0.3, 0.1), (0.34, 0.2), (0.5, 0.5), (0.7, 0.8), (1, 1)))

Units: Fraction/Year [0,1]

This auxiliary variable models how Consumer Demand and Willingness to Pay (CDWTP) influences Investment in Logistics and Capacity (ILC). As CDWTP increases, logistics investments are required to meet growing demand. This effect is delayed due to the time required for infrastructure scaling. The Theory of

Change in D4.2 (ENFASYS) and Geels (2002) support this, where demand pressure forces logistics to adapt over time, triggering changes in the supply chain. The effect reaches a threshold after which it stabilizes, as per the transition theory

(10) CDWP influence on EEB = WITH LOOKUP (
DELAY1(Consumer Demand and Willingness to Pay, 3),
((0.34, 0), (0.4, 0.15), (0.48, 0.4), (0.6, 0.85), (0.7, 1), (1, 1)))

Units: Fraction/Year [0,1]

This variable represents the influence of consumer demand and willingness to pay (CDWTP) on environmental and ethical branding (EEB). As consumer willingness to pay increases, it enhances the demand for environmental and ethical branding, but this effect only kicks in once CDWTP exceeds a certain threshold. Below the threshold, there is no impact on EEB. Once the threshold is surpassed, the effect increases linearly, reflecting the growing recognition and demand for sustainable and ethical products among consumers.

(11) CDWTP influence on ARSSM = WITH LOOKUP (
DELAY1(Consumer Demand and Willingness to Pay , 2),
(
(0, 0),
(0.2, 0.3),
(0.4, 0.6),
(0.6, 0.85),
(0.8, 0.95),
(1, 1)
))

Units: Fraction/Year [0,1]

(12) Community Egagement in Learning = WITH LOOKUP (
DELAY1(Community Partecipation and Internal Engagement*1.6, 2),
((0, 0), (0.2, 0.4), (0.4, 0.7), (0.5, 0.8), (0.6, 0.85), (1, 0.85)))
Units: Fraction/Year [0,1]

This auxiliary variable models the effect of community engagement on Training and Knowledge Support (TKS). The engagement increases TKS over time, with a delayed effect represented by DELAY1. Once community engagement reaches a certain level, the effect on TKS begins to plateau and the growth is capped at a maximum value, `Max Engagement Impact`. This ensures that no further increases occur beyond the point where additional engagement no longer contributes to improved training delivery. This relationship is supported by the literature on community participation and internal engagement (ENFASYS D4.2), emphasizing that, after reaching a certain threshold, further efforts to engage the community result in diminishing returns.

(13) Community Partecipation and Internal Engagement= INTEG (
MAX(0, Increase in Community Partecipation * (1 - Community Partecipation and Internal Engagement
))
- MAX(0, Reduction of community engagement * Community Partecipation and Internal Engagement
),
0.55)
Units: Fraction [0,1]

The variable "Community Participation and Internal Engagement" is initialized as a normalized index ranging from 0 to 1. Due to the lack of harmonized EU-level data sources, its initial value is set at 0.55 based on expert judgment and qualitative evidence from cross-case analysis in D4.2 (ENFASYS). The index reflects the average baseline level of participation in cooperative and community initiatives among farmers, and will be validated through stakeholder inputs and local data collection. This modelling choice aligns with established practices in qualitative SDM approaches (Rocha et al., 2020; Sterman, 2000).

(14) Consumer Access to Products = WITH LOOKUP (

DELAY1(Market Access, 2),

((0,0), (0.03,0.4), (0.06,0.75), (0.1,1), (0.15,1), (1,1))

)

Units: Fraction/Year [0,1]

This variable captures the delayed impact of market access on consumer demand and willingness to pay for sustainable products. As market access increases, products become more visible and available, which increases consumer awareness and willingness to pay for these products. The effect is delayed, as consumers need time to recognize the value added by sustainable goods, which aligns with findings from the ENFASYS D4.2 document on the role of market access in influencing consumer demand and product visibility.

(15) Consumer Demand and Willingness to Pay= INTEG (

MAX(0, Increase in Consumer Demand * (1 - Consumer Demand and Willingness to Pay

))

- MAX(0, Reduction of WTP * Consumer Demand and Willingness to Pay),

0.345)

Units: Fraction [0,1]

The initial value of 0.345 reflects the average willingness to pay (34.5%) for sustainable and local food products, as reported in the meta-analysis by Mustapa et al. (2024), which reviewed 107 studies across Europe and North America. This variable represents an aggregate level of consumer interest and willingness to pay for sustainable food products, modeled as a stock to reflect its dynamic accumulation and depletion over time. The inflow (increase in demand) captures positive drivers such as education and branding, while the outflow (reduction in willingness to pay) may reflect saturation or negative feedback. Using a normalized scale (e.g., from 0 to 1) allows for simulating intangible shifts in consumer behavior while maintaining internal consistency. Similar constructs are adopted in behavioral SD models analyzing sustainable consumption (e.g., Antwi et al., 2020; Gil et al., 2019; Sterman, 2000).

(16) Consumer Education= INTEG (

MAX(0, Increase in Consumer education * (1 - Consumer Education))

- MAX(0, Reduction of education * Consumer Education),

0.45)

Units: Fraction [0,1]

The initial value for the stock Consumer Education is set at 0.45, corresponding to a normalized index (0–1) representing the share of European consumers demonstrating awareness and active interest in sustainable food practices. This value is supported by Eurobarometer Special Edition 501 (2020) and EFSA (2022), where approximately 42–45% of EU consumers reported considering environmental impacts or seeking information on food sustainability. While not a direct measure of educational programs, this proxy reflects the outcome of education and awareness-raising interventions and is consistent with the system dynamics logic of representing behavioural readiness.

(17) Consumer pressure on Market = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH(Consumer Demand and Willingness to Pay, 2))),

((0, 0), (0.2, 0.05), (0.4, 0.15), (0.6, 0.35), (0.8, 0.65), (1, 1)))

Units: Fraction/Year [0,1]

(18) Cooperation among producers= INTEG (

MAX(0, Increase in Cooperation * (1 - Cooperation among producers))

- MAX(0, Reduction of cooperation * Cooperation among producers),

0.3)

Units: Fraction [0,1]

The initial value for the stock Cooperation among producers is set at 30%, reflecting the average level of cooperation among small-scale producers observed across 18 case studies in 9 EU countries, as reported by the SMARTCHAIN project (Deliverable 6.4, 2021). The selected value lies within the range of 20% to 40%, which encompasses both formal and informal collaboration mechanisms (e.g. cooperatives, producer networks, knowledge exchange platforms). This average estimate allows for the representation of a moderate but realistic level of cooperation, aligned with observed trends in short food supply chains in the EU. While more precise country-specific data may refine this assumption, the chosen value ensures consistency with empirical evidence from multi-country systemic analyses.

(19) Cooperation efficiency = WITH LOOKUP (

MIN(1, MAX(0, DELAY1(Cooperation among producers*2, 3))),

((0, 0), (0.2, 0.1), (0.3, 0.25), (0.5, 0.5), (0.7, 0.75), (1, 1)))

Units: Fraction/Year [0,1]

This auxiliary variable models the delayed impact of cooperation among producers on logistics investments. The impact is conditional on the level of cooperation, with a threshold value (CooperationThreshold) determining when the positive effect on logistics efficiency starts. Once cooperation exceeds this threshold, the cooperation efficiency increases logistics capacity, with the effect delayed by a time factor (DelayTime). This model is based on the principle that collective action and cooperation among small producers often lead to greater economic efficiency, particularly in logistics, which is a critical factor in agricultural supply chains (D4.2). The effect is also moderated by the CooperationImpact factor, which quantifies the effectiveness of this collective action.

(20) Cultivated Land Area= INTEG (

MAX(0, Expansion of CLA * (1 - Cultivated Land Area))

- MAX(0, Reduction of CLA * Cultivated Land Area),

0.7204)

Units: Fraction [0,1]

The "Cultivated Land Area" (CLA) is modeled as a normalized stock representing the proportion of farmland that is actively cultivated out of the total land available to the farm. This approach allows for inter-farm comparisons and aligns with methodologies in previous SDM applications in agriculture (e.g. Rocha et al., 2020). The initial value is based on empirical data from the FADN database, and represents the average share of land cultivated in recent years at EU level, which remains relatively stable over time. Data Source: [FADN – SE025 and SE030] (hectares cultivated and hectares available)

(21) Effectiveness of Consumer Education = WITH LOOKUP (

DELAY1(Consumer Education*0.8, 2),

((0, 0), (0.2, 0.25), (0.4, 0.55), (0.5, 0.75), (0.6, 0.9), (0.7, 1), (0.8

, 1), (1, 1)))

Units: Fraction/Year [0,1]

This variable represents the delayed positive effect of consumer education on willingness to pay (CDWTP) for sustainable products. The effect grows over time as consumers become more informed, gradually increasing their willingness to pay for products with added value in sustainability. The delay function captures the time it takes for consumers to adapt to new information and adjust their behaviors accordingly. As indicated in the literature, this is a gradual process with no immediate effect, but long-term increases in consumer demand and willingness to pay.

(22) Environmental and Etichal Branding= INTEG (

MAX(0, Branding strenght * (1 - Environmental and Etichal Branding))

- MAX(0, Reduction of attention in Etichal Branding * Environmental and Etichal Branding

),

0.5)

Units: Fraction [0,1]

This stock variable captures the relative strength of environmental and ethical branding (EEB) in influencing food purchasing behaviours. Given the lack of standardized EU-wide indicators directly measuring branding intensity, the variable is approximated using consumer survey data from the Eurobarometer (EC, 2021), which indicates that around 50% of EU consumers consider environmental aspects when buying food. The value is expressed as a normalized

(23) Expansion of CLA = WITH LOOKUP (

ARSSM influence on CLA,

((0,0), (0.1,0.05), (0.3,0.2), (0.5,0.4), (0.7,0.7), (1,1)))

Units: Fraction/Year [0,1]

The Expansion of Cultivated Land Area (CLA) is driven by the adoption rate of Sustainable Selling Models (ARSSM). However, this effect is not immediate. A third-order smoothing function is used to represent the gradual and delayed impact of ARSSM, as adoption typically requires time to stabilize, gain farmer trust, and align with land-use strategies. The delay accounts for behavioral and logistical adjustments before expansion decisions are made.

(24) FINAL TIME = 10

Units: Year

The final time for the simulation.

(25) Financial Readiness for Adoption = WITH LOOKUP (

DELAY1(Revenue and Financial stability, 1),

((0, 0), (0.15, 0.15), (0.3, 0.4), (0.5, 0.7), (0.75, 0.9), (1, 1)

))

Units: Fraction/Year [0,1]

Financial readiness is modelled as a saturating function of economic stability, based on ENFASYS case study findings (D4.2) and European data (FADN, 2018–2022), showing that higher net worth and cash flow levels enhance the capacity to adopt sustainable practices.

(26) ILC impact on CAP = WITH LOOKUP (
DELAY1("Infrastructure & Logistic Capacity", 2),
((0, 0), (0.4, 0.1), (0.6, 0.5), (0.7, 0.9), (0.8, 1), (1, 1)))

Units: Fraction/Year [0,1]

This equation models the effect of Infrastructure & Logistic Capacity (ILC) on Cooperation Among Producers (CAP). The relationship between ILC and CAP is exponential, where the effect of ILC on CAP grows disproportionately as the capacity improves. The growth rate accelerates once a certain threshold of ILC is surpassed, which facilitates higher levels of cooperation among producers. A delay of 2 time units is used to reflect the time it takes for improvements in logistics to translate into enhanced cooperation, which is typical in systems with infrastructure investments (Geels, 2002; Meadows, 2008). The scaling factor of 0.5 ensures that the relationship is proportional to ILC but modulated for system dynamics.

(27) ILC impact on CPIE = WITH LOOKUP (
DELAY3("Infrastructure & Logistic Capacity", 3),
((0, 0), (0.55, 0.05), (0.6, 0.15), (0.65, 0.4), (0.7, 0.6), (0.75, 0.8)
, (0.8, 0.85), (0.85, 0.9), (1, 1)))

Units: Fraction/Year [0,1]

(28) ILC influence on CDWTP = WITH LOOKUP (

DELAY3(("Infrastructure & Logistic Capacity"*0.5), 3),

((0, 0), (0.3, 0.2), (0.5, 0.5), (0.7, 0.7), (0.8, 0.8), (1, 0.8)))

Units: Fraction/Year [0,1]

the "Infrastructure and Logistic Capacity" (ILC) has a positive influence on CDWTP because better infrastructure improves product visibility and market accessibility. This not only facilitates consumer interaction with the products but also adds perceived value, which can lead to consumers recognizing premium pricing. As the infrastructure improves, consumers' willingness to pay (CDWTP) increases due to the enhanced accessibility of these goods, likely reflecting increased trust and awareness. These insights align with the general systemic dynamics of sustainable agriculture transitions, where logistical improvements can directly influence consumer behavior and market success

(29) Increase in Adoption Rate=

0.6 * Financial Readiness for Adoption

+ 0.25 * Market Attractiveness for Adoption

+ 0.15 * Social Pressure for Adoption

Units: Fraction/Year [0,1]

This inflow models the increase in the adoption rate of sustainable business practices based on the weighted influence of financial readiness, market attractiveness, and social pressure. We apply differentiated delays to account for the time needed to observe and internalize these effects. Financial readiness exerts a strong and relatively immediate effect (50%), while market attractiveness is subject to a 1-year delay (35%)

and social pressure has a more latent influence with a 2-year smoothed delay (15%). Literature supports these distinctions: see Drews & van den Bergh (2016), van Dijk et al. (2022), and Nguyen et al. (2023). All delay durations and weights are harmonized with empirical behavioural modeling assumptions.

(30) Increase in Community Partecipation=

0.4*ILC impact on CPIE + 0.6*TKS influence on CPIE

Units: Fraction/Year [0,1]

The increase in community participation is modeled as a multiplicative effect of infrastructure access and knowledge support. A logistic function is used to represent a threshold dynamic of ILC: community engagement emerges only after basic accessibility is met. Training and knowledge support influence participation with a time delay, reflecting the gradual uptake and application of learning. This design aligns with participatory development theory (Pretty, 1995) and adaptive co-management principles (Reed et al., 2010).

(31) Increase in Consumer Demand=

0.3 * Brand Appeal for Sustainability
+ 0.25 * Consumer Access to Products
+ 0.2 * Effectiveness of Consumer Education
+ 0.15 * ARSSM influence on CDWTP
+ 0.05 * CAP influence on CDWP
+ 0.05 * ILC influence on CDWTP

Units: Fraction/Year [0,1]

This variable models the systemic increase in consumer demand for sustainable products. Brand appeal and product accessibility exert immediate influence, aligned with behavioral drivers identified in the D4.2 report. Educational efforts and ARSSM influence introduce delayed effects, requiring time for cognitive and behavioral shifts. CAP support operates indirectly with moderate delay, while trust and logistic infrastructure act as marginal enablers. Weights reflect the relative importance based on behavioral studies and empirical evidence from ENFASYS case studies.

(32) Increase in Consumer education=

MAR impact on CE

Units: Fraction/Year [0,1]

The increase in Consumer Education (CE) is modeled as a smoothed function of Market Access and Reach (MAR), reflecting the indirect and gradual nature of the effect. When market access expands, consumers are exposed to more diverse information sources, labels, and marketing materials that implicitly educate them about sustainability. A first-order smoothing function (SMOOTHI) with a time delay of 2 is used to account for the progressive nature of awareness formation and learning.

(33) Increase in Cooperation = WITH LOOKUP (

ILC impact on CAP ,

((0, 0), (0.4, 0.1), (0.6, 0.5), (0.7, 0.9), (0.8, 1), (1, 1)))

Units: Fraction/Year [0,1]

Cooperation among producers increases in response to improvements in logistics and infrastructure, which reduce transaction costs and promote collective organization. This process requires time, as trust and operational adjustments are needed. The influence of infrastructure on cooperation is modeled with a first-order delay to reflect its gradual effect, consistent with system dynamics principles on behavioral adaptation.

(34) Increase in Logistic Capacity=

0.35 * Investment in Logistics

+ 0.2 * Cooperation efficiency

+ 0.15 * Infrastructure Adjustment need from adoption

+ 0.1 * CDWP influence in ILC

+ 0.1 * Training Relevance for Logistics

+ 0.1 * Logistical Pressure from Market expansion

Units: Fraction/Year [0,1]

This inflow represents the systemic build-up of Logistic Capacity, driven by multiple interacting drivers. Investment in logistics and cooperation efficiency are modeled as having immediate and primary impacts. Infrastructure adjustment needs and training relevance are subject to short- and mid-term delays, reflecting structural and organizational response times. The influence of consumer-driven product differentiation (CDWP) is delayed and smoothed (3rd order delay), while market expansion exerts pressure gradually. Weighting and delay choices are informed by system dynamics principles (Sterman, 2000; Rocha et al., 2020), ensuring realistic temporal dynamics and reinforcing feedback coherence.

(35) Increase in PS = WITH LOOKUP (

ARSSM impact on PS,

((0, 0), (0.2, 0.1), (0.4, 0.25), (0.6, 0.5), (0.8, 0.75), (1, 0.85)))

Units: Fraction/Year [0,1]

The increase in policy support is modeled as a smoothed response to the influence of ARSSM, reflecting institutional inertia and delayed implementation. This structure is supported by studies on policy responsiveness and governance dynamics (Feindt & Weiland, 2018; Runhaar et al., 2020).

(36) "Infrastructure & Logistic Capacity"= INTEG (

MAX(0, Increase in Logistic Capacity * (1 - "Infrastructure & Logistic Capacity"

))

- MAX(0, Reduction of logistic capacity * "Infrastructure & Logistic Capacity"

),

0.5)

Units: Fraction [0,1]

The variable “Infrastructure & Logistic Capacity” (ILC) is modeled as a stock representing the firm's accumulated capabilities to manage logistics, including transport, storage, and distribution. Given the heterogeneity of firms and the lack of harmonized absolute measures across contexts, the model uses a normalized performance index ranging from 0 to 1. This approach is consistent with logistics capability maturity assessments found in the literature (Garcia, 2009; Chaopaisarn & Woschank, 2019). The dynamic nature of ILC justifies its representation as a stock variable that evolves through investments (inflow) and deterioration or underuse (outflow), in line with the modeling principles described by Pokharel (2005) and Olhager & Rudberg (2002).

(37) Infrastructure Adjustment need from adoption = WITH LOOKUP (

DELAY1((Adoption Rate of Sustainable Selling Models) , 2),

((0, 0), (0.15, 0.05), (0.4, 0.3), (0.6, 0.7), (0.8, 0.9), (1, 1)))

Units: Fraction/Year [0,1]

This variable captures the growing need for infrastructure and logistics adjustment as more farms adopt sustainable selling models. The nonlinear form reflects how infrastructural requirements scale disproportionately beyond a certain level of adoption. This dynamic is observed in reinforcing loop R2 in CS7 (Slovenia) of the ENFASYS D2.2 report, where infrastructure investment is a key enabler for further adoption. It is also consistent with evidence from the literature on short food supply chains, which highlights the infrastructural constraints and needs associated with scaling direct selling (Bayir et al., 2022)

(38) INITIAL TIME = 0

Units: Year

The initial time for the simulation.

(39) Investment in Logistics = WITH LOOKUP (

MIN(1, MAX(0, DELAY3(Revenue and Financial stability*1.1 , 2))),

((0, 0), (0.2, 0.1), (0.4, 0.25), (0.6, 0.5), (0.8, 0.75), (1, 0.9)))

Units: Fraction/Year [0,1]

This auxiliary variable models the influence of farm Revenue and Financial Stability (RFS) on investments in logistics and infrastructure (ILC). The relationship assumes that as financial stability increases, farms are more capable of making long-term investments in logistics. The sensitivity coefficient (e.g., 0.1 per unit of RFS) determines the extent of this influence, while a delay time accounts for the delayed effect of financial stability on infrastructure investments. This structure reflects the importance of financial resilience in enabling farm investment in infrastructure, as highlighted in ENFASYS Deliverables D2.2 and D4.2

(40) Knowledge Accumulation=

MAX(0, MIN(1, ((0.4 * Policy Support for Training

+ 0.3 * "Adoption-Driven Training Demand"

+ 0.2 * Community Egagement in Learning

+ 0.1 * Training Delivery Capacity))))

Units: Fraction/Year [0,1]

Knowledge accumulation depends on four key drivers: (1) policy support, which enables resources for training; (2) training demand triggered by adoption of sustainable practices; (3) community engagement, which develops gradually and reinforces learning; and (4) training delivery capacity. Delays (1–3 years) capture the lag in observable effects.

(41) Less Policy sopport = WITH LOOKUP (

Policy Support,

((0, 0), (0.2, 0.015), (0.3, 0.06),(0.4, 0.1),(0.5, 0.15), (0.6, 0.25),(0.7, 0.5), (0.8, 0.6), (1, 0.7)))

Units: Fraction/Year [0,1]

This outflow captures the gradual erosion of political support in absence of reinforcing drivers. Models the gradual erosion of political support due to shifting priorities or lack of reinforcement. The smoothing function ensures a realistic delay in the response.

(42) Logistical Pressure from Market expansion = WITH LOOKUP (

DELAY1(Market Access, 2),

((0, 0), (0.05, 0.05), (0.2, 0.3), (0.4, 0.6), (0.7, 0.85), (1, 1))

)

Units: Fraction/Year [0,1]

This auxiliary variable models the effect of market access on logistics development. Due to the complexity of directly modeling market access and the potential errors introduced by doing so, we simplify the relationship by using a delay function. This captures the delayed response of logistics capacity to market expansion. The delay reflects the time required for changes in market access to translate into infrastructure development and logistics adjustments. The Delay Time parameter controls the speed of this effect. This approach is supported by theories of systemic feedback loops and delayed response in complex systems, which suggest that impacts from external changes (such as market access) are not immediate but instead evolve over time (Geels, 2002; Meadows, 2008). In line with the D4.2 project report, which discusses how changes in market access influence logistics and infrastructure gradually, the delay function is used to approximate this dynamic without overcomplicating the model

(43) MAR impact on CE = WITH LOOKUP (

DELAY1(Market Access, 4),

((0, 0), (0.03, 0.3), (0.06, 0.5), (0.08, 0.6), (0.1, 0.65), (0.2, 0.7),

(1, 0.7)))

Units: Fraction/Year [0,1]

This variable captures the delayed influence of market access on consumer education. As market access increases, consumers are exposed more frequently to sustainable products, which leads to increased consumer education and awareness over time. The effect is not instantaneous, as it takes time for consumers to fully recognize and understand the benefits of sustainable products, which is consistent with the concept of consumer education in the ENFASYS D4.2 document.

(44) Market Access= INTEG (
MAX(0, Market Expansion * (1 - Market Access))
- MAX(0, Reduction of Market Access * Market Access),
0.053)

Units: Fraction [0,1]

This stock models the relative share of income derived from direct selling or local market channels, normalized as a percentage of total farm output. The initial value of the stock "Market Access" is set at 5.3%, based on the ratio between Total Output from Other Gainful Activities (OGA) – SE700, and Total Farm Output – SE131. These figures are drawn from the EU FADN database, using the average for the years 2018–2022, in order to provide a stable and EU-representative baseline. SE700 reflects farmers' economic activities outside traditional supply chains, such as direct sales, educational farms, and renewable energy. This indicator serves as a proxy for farmers' engagement in diversified and direct market channels, aligned with the dynamics of short supply chains highlighted in the ENFASYS project.

(45) Market Attractiveness for Adoption = WITH LOOKUP (

MAX(0, MIN(1, DELAY1(Consumer Demand and Willingness to Pay , 1))),

((0, 0), (0.2, 0.3), (0.4, 0.6), (0.6, 0.85), (0.8, 0.95), (1, 1)

))

Units: Fraction/Year [0,1]

The lookup function represents the relationship between consumers’ willingness to pay (CDWTP) and the perceived market attractiveness for the adoption of sustainable selling models. The curve assumes limited effect at low levels of WTP, with a steep increase beyond a critical threshold. This threshold is set around 30%, in line with findings from Mustapa et al. (2024), who report an average consumer willingness to pay of 34.5% for products from sustainable and short food supply chains. The threshold therefore captures a plausible behavioural tipping point beyond which market conditions become significantly more attractive for adoption.

(46) Market Expansion=

0.6*New Market reachability+0.4*Consumer pressure on Market

Units: Fraction/Year [0,1]

This inflow models the conditional and delayed expansion of market access for sustainable selling models. Market expansion is driven by the interaction between structural improvements in reachability (e.g., logistics, distribution channels) and consumer pressure. While New Market Reachability acts as an enabling factor, it only translates into effective expansion when Consumer Pressure on Market exceeds a threshold, reflecting a critical mass of demand.

(47) New Market reachability = WITH LOOKUP (

DELAY1("Infrastructure & Logistic Capacity", 2),

((0, 0), (0.6, 0), (0.65, 0.3), (0.7, 0.55), (0.75, 0.7), (0.8, 0.82), (

0.85, 0.9), (0.9, 0.95), (1, 0.98)))

Units: Fraction/Year [0,1]

This variable models the influence of Infrastructure & Logistic Capacity (ILC) on Market Access. The relationship is positive, but non-linear and delayed. Market access increases as ILC rises, but only after surpassing a certain threshold (in this case, 0.6). Below this threshold, the effect is zero. This delay captures the reality that improvements in infrastructure and logistics do not result in immediate market access improvements. Instead, it takes time for these investments to translate into visible effects on market accessibility. Additionally, this variable does not assume an infinite increase in market access but rather a stabilized effect once the threshold is reached

(48) Policy Financial Support Index = WITH LOOKUP (

MIN(1, MAX(0, DELAY3(Policy Support, 2))),

((0.2, 0.2), (0.4, 0.5), (0.6, 0.75), (0.8, 0.95), (1, 1))

)

Units: Fraction/Year [0,1]

The Policy Financial Support Index represents the effect of Policy Support (PS), particularly financial subsidies and incentives, on farm financial stability. The model assumes that Policy Support stabilizes farm income over time, with a delay before the full effects are realized. the sensitivity coefficient derived from the ratio of direct CAP payments to total subsidies received. This delay reflects the time required for subsidies to take effect on farm income, and the model suggests that the relationship is not immediate. This approach is in line with the Multi-Level Perspective on sustainability transitions (Geels, 2002), which highlights the importance of policy support in facilitating farm resilience during transitions to sustainable farming practices (ENFASYS D4.2)

(49) Policy Support= INTEG (

MAX(0, Increase in PS * (1 - Policy Support))

- MAX(0, Less Policy sopport * Policy Support),

0.2457)

Units: Fraction [0,1]

Units: fraction This variable represents the relative policy support received by farms, calculated as the share of relevant subsidies over average annual farm costs. The initial value is based on the EU average (2018–2022) and includes direct payments (SE686), support for rural development (SE624), and 20% of other subsidies (SE699). This index reflects the behavioural significance of subsidies in sustaining or changing farm strategies.

(50) Policy Support for Training = WITH LOOKUP (

MAX(0, MIN(1, DELAY1(Policy Support, 1))),

((0,0), (0.2,0.2), (0.4,0.4), (0.6,0.9), (0.8,1), (1,1)))

Units: Fraction/Year [0,1]

This auxiliary variable models the impact of Policy Support for Training on the improvement of Training and Knowledge Support (TKS). The effect is immediate as funding allocated for training programs typically results in fast implementation of relevant courses. A slight delay is introduced using DELAY1 to simulate the time required for the training to reach its desired effects, but the delay is minimal due to the swift translation of financial support into actionable training opportunities. This approach is supported by the ENFASYS project (D4.2), which highlights how political support can catalyze the development of training capacities, and aligns with Geels'

(51) Production Cost Constraints=

Cultivated Land Area * 0.0209

Units: Fraction [0,1]

This variable represents behavioural cost pressure linked to cultivated area. The fixed production cost per hectare (€1368.38) is expressed as a proportion of the average annual total cost per farm (€65,301), making it comparable across contexts and compatible with the model's behavioural scale.. The relationship assumes that as the cultivated area increases, production costs increase in a linear fashion, which in turn negatively impacts farm revenue. This relation is also shown in ENFASYS D4.2

(52) Reduction of attention in Etichal Branding=

DELAY1(Environmental and Etichal Branding, 2)

Units: Fraction/Year [0,1]

Progressive decrease in attention to ethical branding, modeled as time-driven decay with saturation after 4 years (based on consumer fatigue and message overexposure).

(53) Reduction of CLA = WITH LOOKUP (

DELAY1(Cultivated Land Area, 5),

((0, 1), (0.2, 0.9), (0.4, 0.6), (0.6, 0.3), (0.8, 0.1), (1, 0)))

Units: Fraction/Year [0,1]

The reduction of land area is modeled as a smoothed function of cultivated land using SMOOTHI, introducing a delay in the response to changes in land availability. This captures real-world dynamics such as gradual land degradation or slow policy-driven reductions, rather than abrupt losses. The coefficient adjusts the annual decay rate, consistent with approaches in system dynamics (Sterman, 2000).

(54) Reduction of community engagement = WITH LOOKUP (

DELAY3(Community Partecipation and Internal Engagement, 4),

((0, 0), (0.2, 0.1), (0.4, 0.3), (0.6, 0.6), (0.75, 0.8), (0.85, 0.95), (0.9, 0.98), (1, 1)))

Units: Fraction/Year [0,1]

Community engagement decreases over time if not maintained, with delayed effect modeled through third-order delay to reflect inertia in social participation dynamics

(55) Reduction of cooperation = WITH LOOKUP (

DELAY1(Cooperation among producers, 3),

((0, 0.2), (0.1, 0.15), (0.3, 0.08), (0.5, 0.03), (0.7, 0.01), (1, 0)))

Units: Fraction/Year [0,1]

The outflow occurs only when cooperation drops below a structural threshold, simulating disengagement due to lack of trust or perceived benefits

(56) Reduction of education = WITH LOOKUP (

DELAY1(Consumer Education, 3),

((0, 0.05), (0.1, 0.08), (0.2, 0.15), (0.3, 0.25), (0.4, 0.4), (0.5, 0.55
), (0.6, 0.7), (0.7, 0.85), (0.8, 0.95), (0.9, 1), (1, 1)))

Units: Fraction/Year [0,1]

Education expired if not not renew after 5 years and the
decrease at this time increase exponentially

(57) Reduction of Knowledge Support = WITH LOOKUP (

DELAY1(Training and Knowledge Support*1.6, 5),

((0, 0), (0.3, 0.2), (0.5, 0.4), (0.7, 0.7), (0.85, 0.9), (1, 1)))

Units: Fraction/Year [0,1]

Knowledge support decays over time. After 5 years knowledge is
assumed outdated, using TIME to dynamically scale the decay rate.

(58) Reduction of logistic capacity = WITH LOOKUP (

SMOOTH("Infrastructure & Logistic Capacity", 2),

((0, 0), (0.3, 0.2), (0.5, 0.4), (0.7, 0.7), (0.85, 0.9), (1, 1)))

Units: Fraction/Year [0,1]

Models the gradual reduction of logistic capacity due to
equipment obsolescence and aging. The smooth function captures
the delayed and continuous nature of infrastructure degradation
in the absence of reinvestment

(59) Reduction of Market Access = WITH LOOKUP (

DELAY1(Market Access, 1),

((0, 0), (0.2, 0.05), (0.4, 0.15), (0.6, 0.3), (0.8, 0.5), (1, 0.7)))

Units: Fraction/Year [0,1]

This outflow models the progressive decline of market access due
to external pressures or structural inefficiencies. It assumes a

delayed erosion of 15% annually, reflecting how loss of trust, competition or logistical breakdowns affect market access only after a lag.

(60) Reduction of revenue = WITH LOOKUP (

DELAY1(((Revenue and Financial stability) +0.6 * Production Cost Constraints

) , 1),

(

(0, 0.05), (0.3, 0.1), (0.5, 0.3), (0.7, 0.6), (0.85, 0.85), (1, 1)

))

Units: Fraction/Year [0,1]

This outflow is based on production cost constraints and a normalized inverse effect of financial reserves. When financial reserves drop below a defined threshold, the reduction in revenue increases. The MAX and ratio formulation ensures a bounded and realistic dynamic behavior that reflects financial vulnerability under cost pressure.

(61) Reduction of SSM = WITH LOOKUP (

MAX(0, MIN(1, DELAY1(Adoption Rate of Sustainable Selling Models * (1 - CDWTP influence on ARSSM

) * 0.03, 1))),

((0, 0.7), (0.3, 0.5), (0.6, 0.2), (0.8, 0.05), (1, 0)))

Units: Fraction/Year [0,1]

This outflow models the abandonment of Sustainable Selling Models when consumer demand and willingness to pay (CDWTP) are insufficient. It assumes that the greater the lack of consumer support, the more likely these models are to be dismissed, but only after a time lag.

(62) Reduction of WTP = WITH LOOKUP (

MAX(0, MIN(1 , (0.4*ARSSM influence on CDWTP +0.6*TKS influence on CDWTP

))),

((0, 0), (0.2, 0.1), (0.4, 0.3), (0.6, 0.55), (0.8, 0.8), (1, 1)))

Units: Fraction/Year [0,1]

This outflow reflects the risk of market saturation and reduced consumer willingness to pay (WTP) as adoption of sustainable selling models (ARSSM) increases. The effect is modeled non-linearly to capture the accelerating impact of saturation. Additionally, overexposure to training and knowledge campaigns (TKS) contributes to consumer fatigue over time, with a one-year delay. The function represents a structurally grounded stabilizing dynamic within the model.

(63) Revenue and Financial stability= INTEG (

MAX(0, Revenue Increase * (1 - Revenue and Financial stability))

- MAX(0, Reduction of revenue * Revenue and Financial stability),

0.27)

Units: Fraction [0,1]

Data source: avarage data (2017-2022) FADN. This index is based on the average Output/Input ratio (2018–2022). The index is calibrated so that: - 0 corresponds to break-even (O/I = 1.0) - 1 corresponds to high economic stability (O/I = 1.6) Initial value = 0.27 This variable represents the financial accumulation of a farm business over time, capturing both increases and decreases in annual revenue. It is modeled as a stock because it reflects a quantity that accumulates as a result of inflows (e.g., additional revenues) and outflows (e.g., costs or losses), in line with the system dynamics literature (Sterman, 2000). Similar modeling approaches have been used in sustainability-oriented frameworks (Rocha et al., 2020) and in business model archetypes where financial viability is treated as a dynamic capability (Bocken et al., 2014). The initial value is informed by average revenue data per farm from the FADN database.

(64) Revenue Increase=

MAX(0, MIN(1, 0.6 * Policy Financial Support Index

+ 0.35 * Revenue Leverage from Consumer Demand

+ 0.25 * Training Effect on Financial Management))

Units: Fraction/Year [0,1]

The revenue increase is modeled as a weighted function of three main drivers: public financial support (e.g. direct payments), consumer demand growth, and improved financial management due to training. Each component contributes with a different weight based on its relative importance and is subject to a specific delay to reflect the time it takes for each factor to affect revenues. A first-order information delay (DELAY1I) is used to realistically represent the gradual transmission of these effects, acknowledging that financial support may have quicker impacts, while demand stabilization and training outcomes typically take longer to materialize. This approach ensures behavioral plausibility, avoids instant causality, and aligns with system dynamics best practices for representing economic feedback effects (Sterman, 2000).

(65) Revenue Leverage from Consumer Demand = WITH LOOKUP (

DELAY1(Consumer Demand and Willingness to Pay , 2), ((0.2, 0.15), (0.345, 0.3), (0.45, 0.55), (0.55, 0.75), (0.69, 0.9), (0.8

, 1), (1, 1)

))

Units: Fraction/Year [0,1]

This auxiliary variable models the leverage effect of Consumer Demand and Willingness to Pay (CDWTP) on Revenue and Financial Stability (RFS). The effect is limited by a threshold value, beyond which the impact on RFS stabilizes (Geels, 2002; ENFASYS D4.2). The IF THEN ELSE function is used to reflect that CDWTP only influences RFS until a saturation point is reached. Beyond that, the impact is capped, following the theory of system transitions and adoption patterns.

(66) SAVEPER =

TIME STEP

Units: Year [0,?]

The frequency with which output is stored.

(67) Social Pressure for Adoption = WITH LOOKUP (

SMOOTH((Community Partecipation and Internal Engagement), 2),

((0, 0), (0.2, 0.3), (0.4, 0.55), (0.6, 0.75), (0.8, 0.9), (1, 1))

)

Units: Fraction/Year [0,1]

"Social pressure is modelled as a delayed function of community participation and internal engagement, based on evidence from ENFASYS cases (D4.2) and behavioural literature on the gradual emergence of peer influence in adoption dynamics.

(68) TIME STEP = 1

Units: Year [0,?]

The time step for the simulation.

(69) TKS influence on CDWTP = WITH LOOKUP (

DELAY1(Training and Knowledge Support, 4),

((0, 0), (0.1, 0.01), (0.2, 0.03), (0.3, 0.05), (0.5, 0.08), (0.7, 0.09

), (0.9, 0.1), (1, 0.1)))

Units: Fraction/Year [0,1]

This auxiliary models the negative influence of Training and Knowledge Support (TKS) on Consumer Demand for Willingness to Pay (CDWTP). As the exposure to information increases, TKS can lead to information overload or saturation, reducing consumers' willingness to pay for the product. The delay function represents the time it takes for the effects of information overload to be fully realized in the market. Once the consumers are overly exposed to the messages, the willingness to pay decreases, with diminishing returns after a certain point.

(70) TKS influence on CPIE = WITH LOOKUP (

MIN(1, MAX(0, DELAY1((Training and Knowledge Support*1.6), 2))),

((0, 0), (0.05, 0.1), (0.15, 0.3), (0.25, 0.4), (0.35, 0.6), (0.45, 0.8)

, (0.55, 1), (0.6, 0.95), (0.7, 0.9), (0.8, 0.85), (0.9, 0.8), (1, 0.7)))

Units: Fraction/Year [0,1]

(71) TKS influence on EEB = WITH LOOKUP (

DELAY1(Training and Knowledge Support*1.15, 1),

((0.08, 0), (0.12, 0.25), (0.18, 0.55), (0.25, 0.8), (0.3, 0.95), (0.34,

1), (0.4, 1), (1, 1)))

Units: Fraction/Year [0,1]

(72) Training and Knowledge Support= INTEG (

MAX(0, Knowledge Accumulation * (1 - Training and Knowledge Support))

- MAX(0, Reduction of Knowledge Support * Training and Knowledge Support

),

0.085)

Units: Fraction [0,1]

The initial value of Training and Knowledge Support (TKS) is set to 0.085, based on the proportion of farm managers in the EU who have completed full agricultural training. This figure originates from a 2013 Eurostat-based report by the European Parliament, which states that only 8.5% of farmers across the EU had completed formal agricultural education at that time. The value serves as a baseline estimate and will be validated and updated as more recent or regional data becomes available. Source: European Parliament Briefing, "EU farm policy: Income support", 2017

(73) Training Delivery Capacity = WITH LOOKUP (

DELAY1("Infrastructure & Logistic Capacity", 2),

((0, 0), (0.3, 0.4), (0.5, 0.8), (0.7, 0.95), (0.9, 1), (1, 1)))

Units: Fraction/Year [0,1]

This auxiliary variable models the impact of Infrastructure & Logistic Capacity (ILC) on Training Delivery Capacity (TDC). Improved infrastructure and logistics enhance the ability to deliver training programs effectively by enabling better access to training facilities and distribution of materials. The effect is delayed using DELAY1 to simulate the time required for logistical improvements to translate into enhanced training capacity. This relationship is supported by the ENFASYS project (D4.2), which highlights the importance of robust infrastructure in facilitating effective agricultural training, and aligns with Geels' (2002) framework on the role of infrastructure in technological transitions.

(74) Training Effect on Financial Management = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH(Training and Knowledge Support, 1))),

((0, 0), (0.2, 0.1), (0.4, 0.35), (0.6, 0.6), (0.8, 0.8), (1, 1)))

Units: Fraction/Year [0,1]

This auxiliary variable models the delayed effect of Training and Knowledge Support (TKS) on Revenue and Financial Stability (RFS). The effect of TKS is conditioned by a threshold, meaning that TKS only starts to have an impact when it exceeds a certain value (Threshold). The **ImpactFactor** quantifies the direct effect of training on RFS. The DELAY1 function captures the delayed nature of this effect, where **DelayTime** specifies the time lag before the training influences the financial stability of the farm. This approach reflects insights from the ENFASYS project (D4.2), which emphasizes the gradual impact of training on farmers' financial outcomes.

(75) Training Relevance for Logistics = WITH LOOKUP (

MIN(1, MAX(0, SMOOTH(Training and Knowledge Support*1.6, 2))),

((0, 0), (0.2, 0.15), (0.4, 0.4), (0.6, 0.65), (0.8, 0.85), (1, 1)))

Units: Fraction/Year [0,1]

This variable models the effect of Training and Knowledge Support (TKS) on Investment in Logistics and Capacity (ILC). Initially, TKS has no effect until a certain threshold of cooperation or knowledge sharing is achieved. After crossing this threshold, the impact of TKS increases rapidly, modeled as an exponential growth function. However, as time passes, the effectiveness of TKS diminishes due to the obsolescence of older practices and the adoption of newer technologies, represented by a decay function. The model incorporates a delay to reflect the gradual implementation and adaptation of TKS within farming systems.

11 Annex 3 Livestock Extensification (LE) SDM equation description

(01) Actor influence= INTEG (

MAX(0, Increase of AI * (1 - Actor influence))

- MAX(0, Reduction of AI * Actor influence),

0.3)

Units: Fraction [0,1]

Initial value reflects the strong influence of dominant actor coalitions (e.g., livestock industry associations, large cooperatives) in shaping livestock policy across Europe. The stock is thus initialized at 0.3 to reflect this high structural and behavioural influence. Source: Kalfagianni & Skordili (2023), Global Environmental Change

(02) AI influence on FPASP = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Actor influence, 1.5))),

((0, 0),(0.2, 0.15),(0.4, 0.35),

(0.6, 0.6),

(0.8, 0.85),

(1, 1)

))

Units: Fraction/year [0,1]

Actor influence reflects the ability of cooperatives, technical advisors and institutional actors to motivate and enable sustainable practice adoption. Influence is non-linear and subject to behavioural inertia. The smoothing function (2 years) accounts for coordination delays and time needed to build trust and legitimacy.

```
(03)    APS influence on LRFA = WITH LOOKUP (
        MAX(0, MIN(1, SMOOTH(Arable Production System, 3 ) ) ),
            ((0,0), (0.2,0.05), (0.4,0.15), (0.6,0.3), (0.8,0.55), (1,0.85))
            )
```

Units: Fraction/year [0,1]

This function is based on D4.2 and MBS feedback on Task 2.3, which highlights that systems shifting towards mixed or integrated crop-livestock farming can significantly improve local feed autonomy. The relationship is positive and non-linear: higher APS adoption enables synergies (e.g., using on-farm crops for feed), but benefits accelerate only beyond moderate levels of APS. No delay is applied, as structural transitions in APS are assumed to affect LRFA relatively promptly.

```
(04)    Arable Production System= INTEG (
        MAX(0, Increase of APS * (1 - Arable Production System))
          - MAX(0, Reduction of APS * Arable Production System),
            0.2)
```

Units: Fraction [0,1]

Initial value set to 0.20 as a cautious proxy based on Eurostat data and CAP evaluations. While 3.5% of EU arable land is dedicated to protein crops, there is no EU-wide indicator linking these to livestock systems or confirming sustainability practices in mixed farms. The low integration rate and absence of targeted monitoring suggest a limited current uptake of sustainable arable systems associated with livestock.

(05) AWS influence on CL = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Pasture and Livestock Management, 1))),

((0, 0),

(0.1, 0.02),

(0.2, 0.05),

(0.3, 0.15),

(0.4, 0.28),

(0.5, 0.45),

(0.6, 0.65),

(0.75, 0.8),

(1, 1)))

Units: Fraction/year [0,1]

The lookup curve used to represent the influence of PLM on Climate Literacy (CL) is consistent with feedback from D4.2 and MBS review on T2.3, where it is emphasized that PLM practices have a delayed and cumulative impact on increasing awareness and knowledge about climate-related issues. The threshold effect is set at 0.30, based on evidence from the feedback that suggests significant improvement in CL starts at this level, reflecting when more comprehensive and robust management strategies are implemented. As PLM increases, its effect on climate knowledge is expected to grow, although this effect is not linear.

(06) Certification and Labelling= INTEG (

MAX(0, Increase of CL * (1 - Certification and Labelling))

- MAX(0, Reduction of CL *Certification and Labelling),

0.06)

Units: Fraction [0,1]

Initial value set to 0.06 based on Eurostat data on certified organic livestock farms. As of 2020, approximately 104,000 livestock farms were certified as organic in the EU, representing an estimated 6% of total livestock farms. Despite policy targets to expand organic farming, certified uptake in the livestock sector remains low. The value reflects the current limited adoption of formal certification and labelling schemes for sustainability.

```
(07)    CL influence on CWtP = WITH LOOKUP (
      MAX(0, MIN(1, SMOOTH(Certification and Labelling, 1 ) ) ),
        (
          (0, 0.05),
          (0.2, 0.1),
          (0.4, 0.25),
          (0.6, 0.5),
          (0.8, 0.8),
          (1, 1)
         ))
```

Units: Fraction/year [0,1]

This auxiliary captures the influence of Certification and Labelling (CL) on Consumer Willingness to Pay (CWtP). Evidence from D4.2 and MBS feedback highlights how trusted labels—especially organic, animal welfare or regional quality schemes—help consumers align preferences with sustainable values. However, effects materialize progressively via information, habit formation, and systemic trust. Thus, a smooth delay of 1 year is used.

```
(08)    Consumer Willingness to Pay= INTEG (
```

MAX(0, Increase of CWtP * (1 - Consumer Willingness to Pay))

- MAX(0, Reduction of CWtP * Consumer Willingness to Pay),

0.34)

Units: Fraction [0,1]

Initial value set to 0.34 based on empirical evidence from EU-wide studies on consumer behaviour and stated preferences. According to the Eurobarometer 2020 survey on farm animal welfare and multiple discrete choice experiments (Napolitano et al., 2018; Clark et al., 2019), between 30% and 40% of EU consumers are willing to pay a premium for animal products with sustainability or welfare certification. A normalized index of 0.34 reflects moderate initial willingness across Member States, acknowledging cross-country variation and hypothetical bias.

(09) CWtP influence on FP = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Consumer Willingness to Pay, 2))),

(

(0, -0.05), (0.2, 0), (0.4, 0.1), (0.6, 0.2), (0.8, 0.3), (1, 0.4))

)

Units: Fraction/year [0,1]

Function calibrated based on D4.2 and MBS feedback on Task 2.3. The relationship between Consumer Willingness to Pay (CWtP) and Farm Profitability (FP) is positive but gradual. Economic benefits from sustainable practices emerge only when consumer demand becomes significant and stable. No delay is applied since the effect is assumed to be immediate but progressive.

(10) Farm Profitability= INTEG (

MAX(0, Increase of FP * (1 - Farm Profitability))

- MAX(0, Reduction of FP *Farm Profitability),

0.28)

Units: Fraction [0,1]

Initial value set to 0.28 based on FADN data (2018–2022).

Average total output per livestock farm was €45,000, with

estimated net profitability (after production costs) around 15%,

yielding €6,800/farm/year. This reflects the low profitability

of EU livestock farms, especially in small and medium holdings,

and aligns with DG AGRI and ECA assessments on structural

economic fragility in the sector. Source: FADN SE206; DG AGRI

Farm Income Reports

(11) Farmers Proposal and Adoption of Sustainable Pracctices= INTEG (

MAX(0, Increase of FPASP * (1 - Farmers Proposal and Adoption of Sustainable Pracctices

))

- MAX(0, Reduction of FPASP * Farmers Proposal and Adoption of Sustainable Pracctices

),

0.25)

Units: Fraction [0,1]

Initial value estimated based on EU-level data on the adoption

of agri-environmental schemes (AES) and animal welfare measures

by livestock farmers. Recent evidence shows considerable

heterogeneity in AES uptake across Member States, with generally

higher participation in Northern Europe and lower in Southern

Europe. An average uptake of 25% is thus considered a

scientifically grounded estimate to reflect the share of farmers

actively proposing or adopting sustainable practices in

livestock farming (McCulloch & Ge, 2025; European Court of

Auditors, 2018)

(12) FINAL TIME = 10

Units: year

The final time for the simulation.

(13) FP influence on FPASP = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Farm Profitability, 1.5))),

((0,0),(0.2,0.1),(0.4,0.3),(0.6,0.6),(0.8,0.85),(1,1))

)

Units: Fraction/year [0,1]

The influence of farm profitability on adoption of sustainable practices is modelled with a behavioural delay of 1.5 years. This reflects the time needed for farmers to process financial improvements into decision-making. Based on ENFASYS D4.2 findings on adoption inertia and MBS T2.3 feedback on adaptive delays.

(14) FP influence on MSTRM = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Farm Profitability, 2))),

((0,0), (0.2,0.05), (0.4,0.2), (0.6,0.45), (0.8,0.75), (1,1))

)

Units: Fraction/year [0,1]

This auxiliary reflects the behavioural relationship between farm profitability and the capacity to access or invest in risk management tools. The response is non-linear and delayed, capturing capital availability thresholds and perception of risk.

(15) FPASP influence on APS = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Farmers Proposal and Adoption of Sustainable Pracctices

, 1))),

((0, 0), (0.1, 0.02), (0.2, 0.08), (0.4, 0.25), (0.6, 0.55), (0.8, 0.8),

(1, 1)))

Units: Fraction/year [0,1]

This auxiliary variable expresses how the level of farmers' proposal and adoption of sustainable practices (FPASP) influences the arable production system (APS). Based on D4.2, early adoption tends to generate marginal effects until peer dynamics and institutional visibility increase. MBS feedback confirms that once FPASP reaches moderate levels (e.g. 0.4), impacts on APS become visible due to system-wide demonstration effects and alignment with regional agendas. A smooth acceleration is modeled with a convex lookup function, aligned with an initial value of 0.4 for FPASP.

(16) FPASP influence on FP = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Farmers Proposal and Adoption of Sustainable Pracctices

, 2))),

((0, 0), (0.1, 0.02), (0.2, 0.08), (0.3, 0.15), (0.4, 0.25), (0.5, 0.35)

, (0.6, 0.45), (0.8, 0.55), (1, 0.6)))

Units: Fraction/year [0,1]

This function models the influence of farmers' adoption of sustainable practices (FPASP) on farm profitability (FP). Based on MBS feedback and insights from D4.2, while early adoption may initially reduce profitability due to transition costs and learning curves, profitability tends to improve steadily over time. The lookup reflects a slightly non-linear response, with initial negative or neutral impact turning significantly positive beyond a threshold of engagement (0.3). Calibrated considering the starting profitability of 26,681 €/farm and initial FPASP levels.

(17) ID influence on LRFA = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH(Infrastructure Development, 3))),
((0, 0), (0.2, 0.2), (0.4, 0.4), (0.6, 0.65), (0.8, 0.85), (1, 1))
)

Units: Fraction/year [0,1]

This variable captures the effect of Infrastructure Development (ID) on Local/Regional Feed Autonomy (LRFA). According to D4.2 and MBS feedback to T2.3, investments in storage, logistics, and on-farm feed processing infrastructure are enablers of local feed autonomy. However, impacts are not instantaneous and typically require 2+ years for implementation and behavioural adaptation, which is reflected in the smoothing function.

(18) ID influence on RB = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH(Infrastructure Development, 3))),
((0,0), (0.1,0.02), (0.2,0.05), (0.3,0.12), (0.4,0.28), (0.5,0.45),
(0.6,0.65), (0.75,0.82), (0.9,0.94), (1,1))
)

Units: Fraction/year [0,1]

This lookup represents the influence of infrastructure development on resilience building, following MBS feedback indicating a medium activation threshold (0.3) and a strong parameter-based leverage (score 2.0) with policy spillovers (score 3.5) in pathways where ID enables systemic capacity. The function captures the increasing non-linear impact of infrastructure once basic thresholds are surpassed.

(19) Increase of AI=

VCD influence on AI

Units: Fraction/year [0,1]

(20) Increase of APS=

FPASP influence on APS

Units: Fraction/year [0,1]

(21) Increase of CL=

AWS influence on CL

Units: Fraction/year [0,1]

(22) Increase of CWtP=

CL influence on CWtP

Units: Fraction/year [0,1]

(23) Increase of FP=

0.35*FPASP influence on FP+0.3*CWtP influence on FP+0.35*MSTRM influence on FP

Units: Fraction/year [0,1]

Weighted equation based on economic influence and feedback pathways. MSTRM and FPASP adoption contribute equally (0.35) to profitability through risk reduction and potential cost-saving innovations. CWtP (0.30) has a moderate but tangible effect by enabling price premiums for sustainable practices.

(24) Increase of FPASP=

0.3*AI influence on FPASP + 0.4*FP influence on FPASP +MSTRM positive influence on FPASP *0.3

Units: Fraction/year [0,1]

Weighted sum based on systemic influence of drivers according to D4.2 and MBS feedback. Profitability (0.40) is the strongest factor based on its correlation with transformation potential. Actor influence and market stability tools are equally weighted (0.30) due to their moderate to high leverage scores in stakeholder coordination and policy resilience.

(25) Increase of ID=

PS influence on ID

Units: Fraction/year [0,1]

(26) Increase of KCE=

0.55*PS influence on KCE+0.45*LRFA influence on KCE

Units: Fraction/year [0,1]

Weighted combination based on systemic leverage analysis. Policy support (0.55) includes structured instruments (e.g. training, AKIS, innovation networks) and is the most influential driver for increasing knowledge access and community engagement. Local feed autonomy (0.45) contributes by anchoring learning processes in local practice and supporting peer exchange.

(27) Increase of LRFA=

0.2 * APS influence on LRFA +
0.1 * ID influence on LRFA +
0.1 * KCE influence on LRFA +
0.1 * MSTRM influence on LRFA +
0.2 * PLM influence on LRFA +

0.15 * PS influence on LRFA +

0.15 * VCD influence on LRFA

Units: Fraction/year [0,1]

Weighted sum based on cross-case ToCs and feedback from MBS. APS and PLM (0.20 each) are direct enablers of feed autonomy via forage production and sustainable grazing. PS and VCD (0.15 each) reflect institutional and market infrastructure support. ID, KCE, and MSTRM contribute indirectly by enabling local capacity and buffering shocks.

(28) Increase of MSTRM=

0.45*FP influence on MSTRM+0.25*PLM influence on MSTRM+0.3*PS influence on MSTRM

Units: Fraction/year [0,1]

Weighted sum of causal factors based on their systemic importance in enabling risk management and stability tools, as assessed in D4.2 and MBS parameter libraries. Farm profitability (0.45) plays the strongest role due to its direct linkage to financial risk exposure. Policy support (0.30) contributes through direct instruments (insurance, crisis tools), while sustainable pasture management (0.25) indirectly improves system stability.

(29) Increase of PLM=

0.3 * KCE influence on PLM +

0.4 * LRFA influence on PLM +

0.3 * PS influence on PLM

Units: Fraction/year [0,1]

Weighted influence equation based on cross-case analysis. Local feed autonomy (0.40) requires active pasture and herd management, while policy support (0.30) provides structural and financial backing (e.g., eco-schemes). Knowledge and community engagement (0.30) supports adoption of improved practices via learning networks.

(30) Increase of PS=

0.4*KCE influence on PS+0.25*LRFA influence on PS+0.35*MRSTRM influence on PS

Units: Fraction/year [0,1]

Weighted sum based on feedback loops and systemic influence.

Knowledge and community engagement (0.40) is the primary contributor as it fosters participatory governance and adaptive policy responses. MSTRM (0.35) channels pressure for stabilizing support schemes. LRFA (0.25) contributes via territorially-grounded demands for autonomy-supportive policies.

(31) Increase of RB=

0.45 * ID influence on RB +
0.55 * PS influence on RB

Units: Fraction/year [0,1]

Weighted sum reflecting resilience-enabling functions. Policy support (0.55) has a slightly higher influence due to its systemic role in crisis preparedness and institutional buffers. Infrastructure (0.45) contributes through improved logistics, access and redundancy.

(32) Increase of VCD=

MSTRM positive influence on VCD

Units: Fraction/year [0,1]

(33) Infrastructure Development= INTEG (

MAX(0, Increase of ID * (1 - Infrastructure Development))

- MAX(0, Reduction of ID *Infrastructure Development),

0.27)

Units: Fraction [0,1]

Initial value set to 0.27 based on the European Commission’s 2022 study on the future of EU livestock. The report highlights a general lack of investment in sustainable infrastructure for livestock systems, especially among small and medium farms. This includes housing, manure and effluent systems, and emissions control. Infrastructure development remains underfunded and uneven across Member States. Source: European Commission (2022), Future of EU livestock.

(34) INITIAL TIME = 0

Units: year

The initial time for the simulation.

(35) KCE influence on LRFA = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Knowledge and Community Engagement, 3))),

((0, 0), (0.2, 0.1), (0.4, 0.25), (0.6, 0.5), (0.8, 0.75), (1, 0.9))

)

Units: Fraction/year [0,1]

This function models the impact of Knowledge and Community Engagement (KCE) on Local/Regional Feed Autonomy (LRFA). Based on D4.2 and MBS feedback on Task 2.3, improved knowledge sharing and local stakeholder engagement play a crucial role in encouraging feed autonomy, but their effects tend to manifest with some delay. Therefore, a first-order delay of 1 year is applied. The positive non-linear shape of the lookup reflects that modest levels of engagement produce limited results, whereas sustained engagement significantly boosts feed autonomy.

(36) KCE influence on PLM = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Knowledge and Community Engagement, 3))),

((0, 0.05), (0.2, 0.2), (0.4, 0.35), (0.5, 0.5), (0.7, 0.75), (0.9, 0.95

), (1, 1))

)

Units: Fraction/year [0,1]

This variable models the influence of Knowledge and Community Engagement (KCE) on the adoption and refinement of Pasture and Livestock Management (PLM). Based on D4.2 and MBS feedback on T2.3, community-driven processes and collective learning strongly support the diffusion of improved pasture and livestock practices. The effect is not immediate, as farmers gradually incorporate shared knowledge into practice, warranting a 2-year smoothing.

(37) KCE influence on PS = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Knowledge and Community Engagement, 1))),

((0,0), (0.1,0.02), (0.2,0.1), (0.3,0.18), (0.4,0.28), (0.5,0.42), (0.6,

0.6), (0.8,0.85), (1,1))

)

Units: Fraction/year [0,1]

This function models how the level of Knowledge and Community Engagement (KCE) influences Policy Support (PS). According to

D4.2, the emergence of collective awareness and peer learning is a precondition for meaningful policy support, but its impact is initially latent. The MBS feedback on T2.3 emphasizes that KCE becomes a strong enabler only when community-based trust and shared practices exceed a certain threshold. A gradual but accelerating influence is modeled using a convex lookup function, calibrated for an initial value of KCE = 0.4.

(38) Knowledge and Community Engagement= INTEG (

MAX(0, Increase of KCE * (1 - Knowledge and Community Engagement))

- MAX(0, Reduction of KCE * Knowledge and Community Engagement),

0.2)

Units: Fraction [0,1]

Initial value set to 0.20 based on EU-wide data from the evaluation of RDP Measure 1 (2014–2020). According to the European Commission (2022), approximately 15–20% of livestock farmers in the EU participated in formal training or knowledge transfer activities supported under the CAP. This value reflects the limited but institutionalized diffusion of training and knowledge sharing in the livestock sector.

(39) "Local/Regional Feed Autonomy"= INTEG (

MAX(0, Increase of LRFA * (1 - "Local/Regional Feed Autonomy"))

- MAX(0, Reduction of LRFA *"Local/Regional Feed Autonomy"),

0.3)

Units: Fraction [0,1]

Initial value set to 0.30 based on the EU Protein Balance Sheet. Currently, only about 30% of the EU’s livestock feed protein is produced within the region, while the rest is imported, mainly in the form of soybean meal. This low level of feed autonomy reflects the structural dependency on global markets and the limited adoption of local protein crops and forage systems. The value represents a system-level constraint and a key leverage point for transition.

(40) LRFA influence on KCE = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH("Local/Regional Feed Autonomy", 1))),
(
(0, 0.05),
(0.2, 0.15),
(0.4, 0.35),
(0.6, 0.6),
(0.8, 0.85),
(1, 1)
))

Units: **undefined**

This auxiliary models how increasing local/regional feed autonomy (LRFA) encourages higher levels of knowledge exchange and community engagement (KCE). Evidence from D4.2 and MBS feedback shows that territorial embeddedness, as enabled by LRFA, is associated with cooperative learning, short chain solidarity, and collective experimentation. Effect is smoothed over 1 year to reflect time needed to activate social learning mechanisms and community awareness.

(41) LRFA influence on PLM = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH("Local/Regional Feed Autonomy", 1))),
((0, 0), (0.2, 0.08), (0.3, 0.15), (0.5, 0.45), (0.7, 0.75), (1, 1)))

Units: Fraction/year [0,1]

This variable reflects the influence of Local/Regional Feed Autonomy (LRFA) on Pasture and Livestock Management (PLM). Based on D4.2 (France and Germany cases) and MBS feedback to T2.3, improvements in feed autonomy enable better pasture planning and reduce dependency on external inputs. The lookup is parameterized using a moderate leverage score (parameter 1.8; intent 1.9), with low initial influence and acceleration above 0.5. A 2-year smoothing reflects the time needed for management adaptation.

```
(42)    LRFA influence on PS = WITH LOOKUP (
        MAX(0, MIN(1, SMOOTH("Local/Regional Feed Autonomy", 2 ) ) ),
            ((0, 0), (0.1, 0.06), (0.2, 0.14), (0.3, 0.22), (0.4, 0.34), (0.5, 0.5),
      (0.7, 0.7), (0.9, 0.88), (1, 1))
            )
```

Units: Fraction/year [0,1]

This function models how Local/Regional Feed Autonomy (LRFA) influences Policy Support (PS). According to MBS feedback, increasing LRFA is perceived as a desirable pathway that aligns with long-term policy goals, but it requires additional institutional support. D4.2 notes that while LRFA is often associated with resilience and circularity, its effects on policy engagement materialize gradually, with stronger results when autonomy is coupled with broader systemic changes. The curve reflects this moderated but positive trajectory, starting slowly and accelerating as LRFA exceeds mid-range levels. Calibrated for an initial LRFA of 0.28.

(43) Market Stability Tools and Risk Management= INTEG (

MAX(0, Increase of MSTRM * (1 - Market Stability Tools and Risk Management

))

- MAX(0, Reduction of MSTRM * Market Stability Tools and Risk Management

),

0.11)

Units: Fraction [0,1]

Initial value set to 0.11 based on EU-level evidence regarding the adoption of market stability tools and risk management mechanisms in the livestock sector. According to the European Commission’s 2017 study on risk management in EU agriculture, only around 10–15% of farmers make use of income stabilisation tools (such as subsidised insurance or mutual funds), with large variation across Member States. Adoption in livestock farming is relatively low compared to crop sectors. This stock represents the behavioural and institutional level of active engagement with such instruments, normalized on a scale from 0 to 1.

Sources: European Commission (2017); Cordier (2014); Santeramo (2018).

(44) MRSTRM influence on PS = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Market Stability Tools and Risk Management, 1))),

((0,0), (0.1,0.06), (0.2,0.15), (0.3,0.28), (0.4,0.4), (0.5,0.52), (0.6, 0.67), (0.8,0.85), (1,1))

)

Units: Fraction/year [0,1]

(0, 0), (0.1, 0.06), (0.2, 0.15), (0.3, 0.28), (0.4, 0.40), (0.5, 0.52), (0.6, 0.67), (0.8, 0.85), (1, 1)

(45) MSTRM influence on FP = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Market Stability Tools and Risk Management, 1))),

((0, 0), (0.1, 0.04), (0.2, 0.1), (0.3, 0.18), (0.4, 0.26), (0.5, 0.35),

(0.6, 0.45), (0.8, 0.55), (1, 0.6)))

Units: Fraction/year [0,1]

This function captures how the presence and maturity of market stability tools and risk management strategies (MSTRM) influence farm profitability (FP). According to MBS feedback on T2.3 and D4.2, improved access to MSTRM (insurance schemes, futures contracts, cooperative buffers) is associated with reduced volatility and increased security of income for farmers. These tools especially benefit profitability once they are broadly adopted or effectively implemented. The effect grows non-linearly, starting from negligible influence to significant boosts in income security around mid- to high-adoption levels.

(46) MSTRM influence on LRFA = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Market Stability Tools and Risk Management, 2))),

((0, 0), (0.2, 0.1), (0.4, 0.25), (0.5, 0.4), (0.7, 0.65), (0.9, 0.85),

(1, 1))

)

Units: Fraction/year [0,1]

This variable models the influence of Market Stability Tools and Risk Management (MSTRM) on Local/Regional Feed Autonomy (LRFA). According to MBS feedback (T2.3) and D4.2 cross-case findings, tools that stabilize prices and mitigate risks—such as insurance, contracts, or minimum price mechanisms—enable producers to invest more securely in local feed autonomy. However, effects unfold gradually due to the time required for institutional uptake and farmer adaptation, justifying a 2-year smoothing.

(47) MSTRM influence on VCD = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH(Market Stability Tools and Risk Management, 2))),
((0,0.1), (0.125,0.18), (0.25,0.3), (0.375,0.45), (0.5,0.6),
(0.625,0.75), (0.75,0.88), (0.875,0.95), (1,1)))

Units: Fraction/year [0,1]

This auxiliary variable represents the progressive use of MSTRM (Market Stability Tools and Risk Management) resources to support the development of value chains. The lookup reflects a saturation dynamic, where the marginal contribution to VCD increases rapidly at first and then levels off. This is consistent with the idea that institutional and risk management tools are mobilized early in systemic transitions and tend to stabilize over time.

(48) MSTRM negative influence on FPASP = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH(Market Stability Tools and Risk Management, 2))),
(
(0, 0),
(0.2, 0.02),
(0.4, 0.1),
(0.6, 0.25),
(0.8, 0.45),
(1, 0.6)
)
)

Units: Fraction/year [0,1]

This auxiliary captures the risk that market stability and risk management tools, when not aligned with sustainability goals, reduce the behavioural pressure to transition. The influence is delayed (1.5 years) and non-linear, reflecting policy lock-ins and bounded rationality.

(49) MSTRM positive influence on FPASP = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Market Stability Tools and Risk Management , 2))

),

((0,0), (0.1,0.05), (0.2,0.15), (0.4,0.35), (0.6,0.6), (0.8,0.85), (1,1)

)

)

Units: Fraction/year [0,1]

The influence of Market Stability Tools and Risk Management (MSTRM) on farmers' adoption of sustainable practices is modeled as a delayed and non-linear behavioural response. The smoothing delay (1.5 years) reflects the time required for farmers to perceive reliability in these instruments and translate reduced economic risk into concrete decisions.

(50) MSTRM positive influence on VCD = WITH LOOKUP (

MAX(0, MIN(1, DELAY3I(Market Stability Tools and Risk Management, 1, 0))

),

((0,0.3), (0.125,0.45), (0.25,0.6), (0.375,0.72), (0.5,0.82),

(0.625,0.9), (0.75,0.96), (0.875,0.99), (1,1)))

Units: Fraction/year [0,1]

This function captures the increasing positive influence of market stability tools and risk management (MSTRM) on the development of value chains (VCD). It reflects a gradual

trust-building process, where higher levels of MSTRM enable
actors to cooperate and invest in collaborative chain models,
with influence reaching saturation at full MSTRM implementation.

(51) Pasture and Livestock Management= INTEG (
MAX(0, Increase of PLM * (1 - Pasture and Livestock Management))
- MAX(0, Reduction of PLM *Pasture and Livestock Management),
0.22)

Units: Fraction [0,1]

Initial value set to 0.22 as a cautious proxy for the adoption of sustainable pasture and livestock management practices in the EU. While some Member States support rotational grazing or low-input systems through agri-environment measures, no consolidated EU-wide indicator exists. Based on CAP evaluations and expert reviews, adoption is still limited to a minority of livestock farms. This estimate reflects the current early stage of extensification-oriented livestock management.

(52) PLM influence on LRFA = WITH LOOKUP (
MAX(0, MIN(1 , SMOOTH(Pasture and Livestock Management, 1))),
((0,0), (0.2,0.1), (0.4,0.35), (0.6,0.7), (0.8,0.9), (1,1))
)

Units: Fraction/year [0,1]

This variable represents the impact of Pasture and Livestock Management (PLM) on Local/Regional Feed Autonomy (LRFA). According to D4.2 and MBS feedback to T2.3, good PLM practices—such as rotational grazing and integrated forage planning—enhance feed autonomy by increasing local feed production and reducing dependence on external inputs. The

influence is smoothed over 2 years to reflect adjustment times
in livestock and forage systems.

(53) PLM influence on MSTRM = WITH LOOKUP (
MAX(0, MIN(1, SMOOTH(Pasture and Livestock Management, 1))),
(
(0, 0.05),
(0.2, 0.15),
(0.4, 0.35),
(0.6, 0.55),
(0.8, 0.75),
(1, 1)
))

Units: Fraction/year [0,1]

his auxiliary reflects how improved pasture and livestock management (PLM) affects the uptake and efficiency of market stability and risk management tools (MSTRM). The relationship is smoothed over one year to reflect the time required for better management practices to alter farmers' perception of risk and market exposure.

(54) Policy Support= INTEG (
MAX(0, Increase of PS * (1 - Policy Support))
- MAX(0, Reduction of PS * Policy Support),
0.18)

Units: Fraction [0,1]

Initial value set to 0.18, based on FADN data (2018–2022) showing that the EU allocates approximately €1 billion/year in livestock subsidies. According to DG AGRI and ECA assessments, only 15–20% of these funds support sustainability-related measures (e.g., animal welfare, environmental management). The value reflects the limited but established level of targeted policy support for sustainable livestock systems in the EU.

(55) PS influence on ID = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Policy Support , 3))),

((0, 0),

(0.1, 0.04),

(0.18, 0.08),

(0.3, 0.25),

(0.45, 0.45),

(0.6, 0.72),

(0.75, 0.88),

(0.9, 0.95),

(1, 1)))

Units: Fraction/year [0,1]

Lookup function models the influence of policy support on infrastructure development based on empirical leverage point evidence (Parameter-Intent) identified as highly effective in Switzerland (spillover score 5.0) and confirmed by MBS feedback suggesting strong contextual calibration for PS with parameter scores around 1.9 and spillover 3.5. Activation around 0.18 aligns with initial PS baseline

(56) PS influence on KCE = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Policy Support, 1.5))),

(

(0, 0.05),

```
            (0.2, 0.1),

            (0.4, 0.25),

            (0.6, 0.5),

            (0.8, 0.8),

            (1, 1)

          ))
```

Units: Fraction/year [0,1]

This auxiliary models how increasing policy support (PS) promotes knowledge and community engagement (KCE). Based on D4.2 and MBS feedback, enabling policies that favor knowledge-sharing, training schemes, or participatory governance structures require time to translate into action at community level. Effect is smoothed over 1 year to reflect delays in implementation, awareness-building, and trust-building dynamics.

(57) PS influence on LRFA = WITH LOOKUP (

```
    MAX(0, MIN(1, SMOOTH(Policy Support, 3 ) ) ),

      ((0,0), (0.2,0.1), (0.4,0.4), (0.6,0.7), (0.8,0.9), (1,1))

      )
```

Units: Fraction/year [0,1]

This variable models the influence of Policy Support on Local/Regional Feed Autonomy using a non-linear lookup function, smoothed over 2 years. According to D4.2 (France CS) and MBS feedback on T2.3, the availability of supportive public policies—such as non-GMO incentives and investments in local value chains—is essential to enhance feed autonomy. The smooth reflects the delayed systemic effects of policy implementation.

(58) PS influence on MSTRM = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Policy Support, 2))),

((0,0.1), (0.2,0.3), (0.4,0.5), (0.6,0.7), (0.8,0.9), (1,1))

)

Units: Fraction/year [0,1]

This auxiliary reflects the effect of Policy Support on the diffusion and implementation of market stability and risk management tools. The relationship is smoothed over 1 year to reflect implementation lag.

(59) PS influence on PLM = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Policy Support, 2))),

((0, 0.01), (0.1, 0.05), (0.18, 0.1), (0.4, 0.3), (0.6, 0.55), (0.8, 0.8

), (1, 1))

)

Units: Fraction/year [0,1]

Policy support plays an enabling role in promoting sustainable pasture and livestock management (PLM). According to D4.2 and MBS feedback on T2.3, supportive policies such as subsidies, extension services, and regulatory incentives gradually foster the implementation of PLM practices. The adoption is not instantaneous and depends on institutional alignment and administrative capacity, thus requiring a 2-year smoothing.

(60) PS influence on RB = WITH LOOKUP (

MAX(0, MIN(1, SMOOTH(Policy Support, 3))),

((0,0), (0.1,0.02), (0.2,0.05), (0.3,0.15), (0.4,0.28), (0.5,0.45),

(0.6,0.65), (0.75,0.8), (1,1))

)

Units: Fraction/year [0,1]

This lookup reflects the increasing influence of policy support (PS) on resilience building (RB), with an initial activation threshold around 0.3, as indicated by feedback from D4.2 and MBS reviews. The increasing impact of PS from the 0.30 mark demonstrates its catalytic role in enabling capacity for resilience. The influence ramps up as the policy implementation strengthens the capacity of systems to withstand shocks, suggesting a non-linear response to higher levels of policy engagement.

(61) Reduction of AI = WITH LOOKUP (
Actor influence,
(
(0, 0.12),
(0.2, 0.1),
(0.4, 0.06),
(0.6, 0.04),
(0.8, 0.02),
(1, 0)
))

Units: Fraction/year [0,1]

Reduction of actor influence is modeled as a decaying function of the current level of actor engagement. When actor influence is low, lack of coordination or shared vision can cause rapid erosion. At higher levels, coordination structures and relationships slow down the loss. Lookup curve derived from stakeholder coordination resilience patterns.

(62) Reduction of APS = WITH LOOKUP (

Arable Production System,

(

(0, 0.12),

(0.2, 0.1),

(0.4, 0.07),

(0.6, 0.04),

(0.8, 0.02),

(1, 0)

))

Units: Fraction/year [0,1]

The reduction of APS is modeled as a function of the current arable system level. Low values are more exposed to accelerated decline due to conversion to non-arable or extensified systems. High APS values are more stable due to structural and market lock-ins.

(63) Reduction of CL = WITH LOOKUP (

Certification and Labelling,

(

(0, 0.12),

(0.2, 0.1),

(0.4, 0.07),

(0.6, 0.04),

(0.8, 0.02),

(1, 0)

))

Units: Fraction/year [0,1]

((0, 0.12), (0.2, 0.10), (0.4, 0.07), (0.6, 0.04), (0.8, 0.02), (1, 0))

(64) Reduction of CWtP = WITH LOOKUP (

Consumer Willingness to Pay,

(

(0, 0.12),

(0.2, 0.1),

(0.4, 0.06),

(0.6, 0.04),

(0.8, 0.02),

(1, 0)

))

Units: Fraction/year [0,1]

Outflow reflects behavioural volatility in consumer willingness to pay. At low values, consumer behaviour is unstable and highly sensitive to contextual factors (e.g. price shocks, misinformation). At high values, CWtP tends to consolidate and becomes more resistant to decline. Function design based on behavioural inertia and reinforcement feedback.

(65) Reduction of FP = WITH LOOKUP (

Farm Profitability,

(

(0, 0.18),

(0.2, 0.14),

(0.4, 0.09),

(0.6, 0.05),

(0.8, 0.02),

(1, 0)

))

Units: Fraction/year [0,1]

Outflow reflects income instability and exposure to external risks. When profitability is low, farms are more exposed to loss of viability. High profitability reduces exposure to shocks and improves long-term resilience

(66) Reduction of FPASP=

0.25 * MSTRM negative influence on FPASP * Farmers Proposal and Adoption of Sustainable Pracctices

Units: Fraction/year [0,1]

The reduction flow is proportional to the current level of FPASP and weighted by the negative influence of MSTRM. Stability tools, while useful, may create a perception of reduced need for proactive transition, thereby slowing down adoption of sustainable practices.

(67) Reduction of ID = WITH LOOKUP (

Infrastructure Development,

(

(0, 0.1),

(0.2, 0.08),

(0.4, 0.05),

(0.6, 0.03),

(0.8, 0.015),

(1, 0)

))

Units: Fraction/year [0,1]

The outflow simulates infrastructure depreciation and disuse. At low levels, lack of investment or maintenance leads to rapid erosion. Well-established infrastructures are resilient and degrade slowly. Calibrated using system inertia assumptions and supported by qualitative evidence from D4.2 and MBS feedback on regional capacity and public support systems.

(68) Reduction of KCE = WITH LOOKUP (
Knowledge and Community Engagement,
(
(0, 0.15),
(0.2, 0.12),
(0.4, 0.08),
(0.6, 0.04),
(0.8, 0.02),
(1, 0)
))

Units: Fraction/year [0,1]

The reduction of knowledge and community engagement is modeled as a function of its current level. Low engagement (below 0.4) is prone to fast decline due to weak networks or lack of reinforcement. High engagement tends to persist longer due to collective memory, practices, and institutional anchoring.

(69) Reduction of LRFA = WITH LOOKUP (
"Local/Regional Feed Autonomy",
(
(0, 0.15),
(0.2, 0.12),
(0.4, 0.08),
(0.6, 0.04),

(0.8, 0.02),
(1, 0)
))

Units: Fraction/year [0,1]

The reduction of LRFA is modeled through a decay function representing the structural fragility of local autonomy systems. Low values are highly sensitive to market pressures or policy neglect. High autonomy is stabilized by farmer networks, regional strategies, and investment in feed self-sufficiency.

(70) Reduction of MSTRM = WITH LOOKUP (
Market Stability Tools and Risk Management,
(
(0, 0.15),
(0.2, 0.12),
(0.4, 0.08),
(0.6, 0.04),
(0.8, 0.02),
(1, 0)
))

Units: Fraction/year [0,1]

The outflow is modeled using a decreasing lookup function to reflect resilience of institutionalized tools. At low levels, MSTRM mechanisms are more vulnerable to disappearance, while higher levels imply established practices that reduce more slowly.

(71) Reduction of PLM = WITH LOOKUP (
Pasture and Livestock Management,

```
        (
            (0, 0.15),
            (0.2, 0.12),
            (0.4, 0.08),
            (0.6, 0.04),
            (0.8, 0.02),
            (1, 0)
          ))
```

Units: Fraction/year [0,1]

This reduction flow simulates how pasture and livestock management practices may erode when not well established. Low levels are vulnerable to abandonment, while higher levels reflect knowledge retention, training, and infrastructure that limit degradation.

```
(72)   Reduction of PS = WITH LOOKUP (
      Policy Support,
        ((0, 0.15),
            (0.2, 0.12),
            (0.4, 0.08),
            (0.6, 0.05),
            (0.8, 0.02),
            (1, 0)
          ))
```

Units: Fraction/year [0,1]

This outflow is based on a decay curve representing institutional stability of policy frameworks. When support is low, instability or funding withdrawal can accelerate decline. At high levels, embedded structures and governance make policy support more resistant to erosion.

(73) Reduction of RB = WITH LOOKUP (

Resilience Building,

(

(0, 0.14),

(0.2, 0.11),

(0.4, 0.07),

(0.6, 0.04),

(0.8, 0.015),

(1, 0)

))

Units: Fraction/year [0,1]

The reduction of resilience capacity is modeled as a non-linear decay, higher at low values due to fragility and lack of systemic buffers. High levels of resilience result in low decay due to institutionalisation, feedback loops, and crisis preparedness.

(74) Reduction of VCD=

0.5 * Value Chain Development * MSTRM influence on VCD

Units: Fraction/year [0,1]

(75) Resilience Building= INTEG (

MAX(0, Increase of RB * (1 - Resilience Building))

- MAX(0, Reduction of RB *Resilience Building),

0.25)

Units: Fraction [0,1]

Initial value set to 0.25 based on the systemic vulnerability of

EU livestock systems and the limited diffusion of risk management, diversification strategies and adaptive capacity. Resilience in the ENFASYS model is conceptualized as an emergent system property, shaped by multiple enabling factors. The current state reflects a partial but insufficient capacity to withstand shocks and transform.

(76) SAVEPER =

TIME STEP

Units: year [0,?]

The frequency with which output is stored.

(77) TIME STEP = 1

Units: year [0,?]

The time step for the simulation.

(78) Value Chain Development= INTEG (

MAX(0, Increase of VCD * (1 - Value Chain Development))

- MAX(0, Reduction of VCD * Value Chain Development),

0.35)

Units: Fraction [0,1]

Initial value set to 0.35 as a conservative approximation. While no EU-wide quantitative indicator currently captures the inclusiveness and efficiency of livestock value chains for farmers, policy reviews and institutional reports suggest structural development but persistent asymmetries in power and coordination. This value reflects a moderate-low initial condition, to be revised if new empirical data becomes available.

```
(79)    VCD influence on AI = WITH LOOKUP (
        MAX(0, MIN(1, SMOOTH(Value Chain Development, 1 ) ) ),
          (
            (0, 0.1),
            (0.2, 0.25),
            (0.4, 0.5),
            (0.6, 0.75),
            (0.8, 0.9),
            (1, 1)
           ))
```

Units: Fraction/year [0,1]

This auxiliary captures how the development of traceable and transparent value chains (VCD) fosters the emergence or strengthening of influential food system actors (AI). Based on D4.2 and MBS feedback, actors are empowered when the value chain enables information exchange, shared responsibility, and clear market links. The function uses a 1-year smoothing delay to reflect the operational time needed for new governance models to take root. At initial VCD = 0.4, actor influence is moderate (0.5).

```
(80)    VCD influence on LRFA = WITH LOOKUP (
        MAX(0, MIN(1, SMOOTH(Value Chain Development, 2 ) ) ),
          ((0,0), (0.2,0.1), (0.4,0.3), (0.6,0.6), (0.8,0.85), (1,1))
          )
```

Units: Fraction/year [0,1]

This variable captures the influence of Value Chain Development on Local/Regional Feed Autonomy. Based on D4.2 and MBS feedback on T2.3, well-integrated value chains enable feed autonomy through improved logistics, storage infrastructure, and market incentives for local feed sourcing. A 2-year smoothing reflects time lags in value chain structuring.

12 Annex 4 ENFASYS T2.3 Protocol

Description of Task 2.3

Task 2.3 of the ENFASYS project is centered on the development of thematic System Dynamics Models (SDMs) to support the transition toward sustainable farming systems across Europe. This task seeks to construct models that are not confined to a single EU-level perspective but instead reflect specific transformation pathways that consider local perspectives. By integrating the diverse dynamics observed in CSs with EU-level policy frameworks, Task 2.3 bridges local insights and systemic strategies, providing a robust foundation for sustainable agricultural transitions.

The primary goal of this task is to utilize the insights gained from the Causal Loop Diagrams (CLDs) developed in Task 2.1 to design thematic models that address key transformation pathways. These pathways—such as the conversion to low-impact farming, the extensification of livestock systems, the implementation of biodiversity schemes, and the promotion of consumer branding and direct selling—represent critical areas where systemic interventions can drive meaningful change. By focusing on these pathways, the models will identify leverage points and lock-ins, providing evidence-based support for EU-level policy development.

The process begins with the synthesis of case study insights and previous results. Each case study (CS) encapsulates a unique set of dynamics, including feedback loops and systemic barriers, which are essential for understanding the broader agricultural landscape. By harmonizing these dynamics, the task ensures that the complexity of local systems is preserved while aligning with overarching policy goals. The problem statements outlined in (Ottaviani Aalmo et al, 2024)and then combined with the findings of the Light Touch Review in (Home et al. 2023), finally provide a foundation for identifying thematic pathways that align with the EU's Farm to Fork Strategy, Biodiversity Strategy, and Common Agricultural Policy (CAP).

Stakeholder engagement is pivotal to the success of Task 2.3. Coordinators of the CSs play a critical role in providing input on the local dynamics and ensuring that the thematic models accurately reflect the realities on the ground. Collaboration with EU-level experts, including representatives from the European policy experts, further ensures that the models are aligned with current policy dialogues and scientific evidence. This iterative process of validation and calibration enhances the credibility and practical relevance of the models.

The thematic SDMs developed under Task 2.3 aim to achieve multiple outcomes. First, they will offer actionable insights into the effectiveness of policy interventions within specific transformation pathways, facilitating evidence-based decision-making at both local and systemic levels. Secondly, they will provide a dynamic representation of how these pathways contribute to sustainable transitions, integrating local case study dynamics with broader European objectives. Lastly, these models will be foundational inputs for the web-based tool to be developed in Task 5.4, ensuring its capacity to simulate scenarios and inform decision-making for a wide range of stakeholders.

Identification of the scope of the ENFASYS's System Dynamic Model (T2.3 and T5.4)

The ENFASYS System Dynamics Model (SDM) serves as a crucial tool for exploring thematic pathways that support sustainable agricultural transitions within the European Union (EU). As part of Task 2.3 and as a foundation for T5.4, the model aims to develop multiple thematic SDMs aligned with the EU's Farm to Fork Strategy, Biodiversity Strategy, and Common Agricultural Policy (CAP). These thematic models will capture the systemic interactions and dynamics observed within the ENFASYS CSs (CSs) and offer insights tailored to specific transformation pathways, such as low-impact farming, biodiversity conservation, and sustainable consumer branding. The focus on thematic models ensures relevance to EU-level policy while retaining the specificity required to address regional and contextual challenges.

The scope of the SDM includes defining its primary objectives, identifying central variables derived from the CSs' Causal Loop Diagrams (CLDs) as outlined in (Ottaviani Aalmo et al, 2024), and establishing its application for scenario-based decision-making and web-based tools under T5.4. By aligning with thematic pathways, the SDM aims to provide actionable insights for policymakers, agricultural practitioners, researchers, and NGOs, ensuring its utility across diverse contexts.

2.1 Setting ultimate goals of the model

The primary aim of the ENFASYS System Dynamics Model (SDM) is to serve as a practical tool for analyzing how thematic interventions can drive sustainable progress in agri-food systems. The objectives are structured around three core goals: (i) providing targeted insights into thematic policy impacts, (ii) identifying leverage points and systemic barriers, and (iii) supporting scenario-based decision-making tailored to specific pathways.

The thematic SDMs will simulate changes within the EU agricultural system under different pathways, illustrating potential impacts on areas such as production practices, biodiversity, and market dynamics. While the CSs provide the foundational dynamics and relationships for these models, the thematic focus ensures alignment with EU-level policies and initiatives. This dual approach enables both broad systemic analysis and case-specific insights, allowing for tailored strategies that address unique regional and thematic challenges.

Identifying leverage points and systemic barriers (lock-ins) is central to the SDM's value. The model will analyze feedback loops and variable interconnections to pinpoint areas where targeted interventions can produce significant, system-wide effects. For example, leverage points might include shifts toward reduced pesticide use or the adoption of biodiversity-friendly practices. Similarly, identifying lock-ins, such as market or regulatory barriers, will help design strategies to overcome these challenges, enabling effective implementation of sustainable practices across different EU contexts.

Scenario-based decision-making is another key objective. The thematic SDMs will enable users to explore potential outcomes of diverse strategies within each pathway. Policymakers and businesses can test interventions, assess their impacts on sustainability metrics, and refine their approaches based on anticipated results. This functionality ensures that decisions are informed by robust, data-driven projections, fostering adaptive strategies that are both effective and resilient.

In alignment with ENFASYS and EU policy goals, the development of the thematic SDMs will be guided by regular consultations with stakeholders, including case study coordinators, WP2 partners, and EU-level policymakers. This collaborative approach ensures that the models remain relevant and responsive to evolving needs, enhancing their utility for shaping sustainable agricultural policies

T2.3 overarching problem statement

The problem statement for the T2.3 SDM is aligned with the overarching goal of the ENFASYS project, which is **enrouraging the implementation of sustainable practices through EU specific transition pathways in the European food system.**

At a later stage, four distinct problem statements will be considered for the purpose of building four SDM, each based on four thematic pathways identified by the European Institutions as key strategies for the transition to sustainable agricultural systems in Europe.

This objective addresses the need to transform EU agricultural systems towards sustainability by tackling systemic challenges, fostering resilience, and supporting the adoption of innovative practices across diverse contexts.

The transition to sustainable farming in the EU is hindered by structural lock-ins, including regulatory barriers and market dynamics, which limit the adoption of practices such as low-impact farming and biodiversity conservation. Addressing these challenges requires the identification of feedback loops, leverage points, and systemic barriers specific to thematic pathways. (Rocha et al., 2024; Brown et al., 2022) (Dentoni et al., 2022).

By bridging insights from local CSs with systemic strategies, the SDM will enable the identification of transformative interventions that support the ENFASYS goal of sustainable farming system transitions. This approach aligns scientific rigor with practical applicability, ensuring that the model serves both as a research framework and a decision-support tool.

The construction of thematic SDMs begins with an initial analysis of the problem statement for each case study. This analysis serves to determine how each case study fits into existing specific transformation pathways identified, such as low-impact farming, biodiversity schemes, or livestock extensification. Once the pathways have been defined, the salient components of the CLD for each case study are extracted and integrated, enabling the identification of archetypes and recurrent relationships. This process ensures that the models capture the most critical dynamics for each transformation pathway, while preserving the unique context of each case study. In this way the thematic SDMs will represent shared challenges and opportunities, while simultaneously safeguarding the localized insights that are essential for a robust systems analysis.

However, even though the goal is to maximize the inclusion of all CSs within the thematic SDMs, it is acknowledged that some CSs may not be directly relevant to a particular pathway. In such instances, those CSs might not be included in the specific SDM. However, every attempt will be taken to minimize this exclusion in order to ensure the overall representativeness of the CSs in the thematic SDMs. This approach strikes a balance between capturing the specificity and relevance of each pathway while maintaining the inclusivity and diversity of the CSs, ensuring that the resulting models are both robust and comprehensive.

State of the art

The development of thematic System Dynamics Models (SDMs) for ENFASYS begins with the identification of pathways that align with the EU’s Farm to Fork Strategy, Biodiversity Strategy, and Common Agricultural Policy (CAP). These pathways include critical transition areas, such as the expansion of low-impact farming, biodiversity conservation, sustainable consumer branding, and the implementation of circular economy principles. This selection process draws on EU-level policy documents and frameworks, emphasizing the importance of targeting systemic leverage points to achieve effective and transformative changes (Meadows, 1999). -

The Farm to Fork Strategy highlights the need for sustainable and resilient food systems, advocating for reduced pesticide use and the promotion of low-impact farming. Similarly, the Biodiversity Strategy emphasizes restoring ecosystems and reducing the negative impacts of agriculture on biodiversity. The CAP provides a financial and regulatory framework to support these goals, focusing on farm sustainability and rural development (European Commission, 2020). Together, these strategies define the thematic pathways explored in the SDMs, ensuring their alignment with EU policy priorities.

Systems thinking, as a foundational approach, aims to understand the interrelations among system components rather than isolating individual elements (Sterman, 2000). Moreover, within the domain of systems thinking, various modeling paradigms have emerged to address specific phenomena and cater to diverse stakeholder needs. Agent-based models, for instance, simulate individual behaviors and their collective outcomes, proving valuable for understanding policy implications at the societal level (Savin et al., 2023). System dynamics modeling, in contrast, is designed to capture non-linear interactions and explore the long-term dynamics of complex systems (Crielaard et al., 2022). Dentoni et al. (2023) emphasize that systems thinking provides a robust framework for engaging with complex socio-ecological challenges, enabling stakeholders to collaboratively map systemic dynamics and design interventions tailored to diverse contexts.

As a matter of fact, system dynamics approaches are particularly advantageous in projects like ENFASYS, where they serve as comparative frameworks for integrating insights from multiple CSs. This kind of modeling allows for the translation of qualitative narratives into quantitative simulations, supporting scenario analysis and policy development (Rocha et al., 2019). There are several advantages correlated to these approaches: they can serve as a comparative framework for several CSs, such as in the case of ENFASYS project, allowing to organize relevant variables identified in theories and empirical research allowing for a cumulation of knowledge (Ostrom 2009), and therefore progress. Another possible application is the transfer of qualitative knowledge into models that can be used as the bases for computational models (Crielaard et al., 2022). Furthermore, the value of such tools can prove fruitful considering the complexity and increasing level of unpredictability of changes in the contemporary era; highlighting causal links and creating tools for future scenario prediction, in fact, allows to identify the sections of a system where interventions might prove most effective, allowing for a resilience analysis (Rocha et al., 2019). In particular, multilevel models have been highlighted in recent research as a needed tool for the purpose of identifying emergent trends and provide effective information at the policy level (Vermeulen et al., 2020).

In the case of ENFASYS project, the System Dynamic Model will serve as a basis for the creation of a Web Tool, which will be made available for consultation to policy makers and experts, allowing to explore future scenarios in the EU food system thematic pathways.

As stated previously, the field of system dynamics is designed to help us learn about the structure and dynamics of the complex systems in which we are embedded, design high-leverage policies for sustained improvement, and catalyze successful implementation and change (Sterman, 2020). More specifically, SDMs have the aim of portraying the dynamics of complex systems through a kind of representation that allows to analyze the impact of potential changes over time. SDMs can reveal how variables interact by expressing the causal links between them using difference equations. Specifically, system dynamics modelling is used to understand and simulate a complex system's non-linear behaviour in different scenarios (Crielaard et al., 2020).

The representation of a system through a dynamic model is subordinated to the first step of creating a Causal Loop Diagram (CLD), a graphical tool used to represent the causal relationships between the different variables included in a complex system. A CLD combines information gathered through various sources in a diagram, which narratively outlines the proposed dynamic interplay and feedback loops between all different factors that altogether shape the phenomenon of interest (Crielaard et al., 2022). In ENFASYS project’s case the CLDs have already been validated (Ottaviani Aalmo et al., 2024) for each case study. Factors and relationships form a series of close sequences of cause-and-effect relationships, referred to as ‘feedback loops’ (Crabolu et al., 2023). Feedback loops can be positive or negative, therefore reinforcing or balancing a certain set of causal relations; furthermore, feedback loops can constitute leverage points, places within a complex system “where a small shift in one thing can produce big changes in everything."(Meadows, 1999.).Variables are connected by arrows denoting causal influence. A link is positive if a change in the origin variable produces a change in the same direction on the response variable, whereas a negative link denotes a relationship characterized by the opposite direction. (Rocha et al., 2019). While CLDs highlight effectively the interrelatedness of variables and therefore give an overview of the possible effects of variables among one another, the CLD cannot show what the effect would be if a system part were changed and what the exact impact on the whole system would be. As stated previously, system thinking aims at identifying leverage points in complex systems, which is crucial in order to achieve systemic change (Meadows, 1999. For this reason, to develop effectively a Web Tool that is consultable and usable by policy makers, the thematic pathway CLDs will ultimately be transformed in a SDMsfor the purpose of ENFASYS project.

The conversion of a Causal Loop Diagram into a System Dynamic Model entails several intermediate passages. The first of these passages is the quantification of the relations between the variables, which results in the transformation of a CLD in a Stock and Flow Diagram. Therefore, the Stock and Flow Diagram that will be built on the CLD will include another layer of information, quantifying the relations among variables. A Stock and Flow diagram is a type of representation used to assess which variables part of a system can be considered stocks and which flows, by highlighting the magnitude of the causal relations between the different variables. More specifically, stocks are quantities at each point in time, while flows are the change in quantity from one point in time to the next (Spiller et al., n.d.).

Asking case study coordinators to provide this kind of data has been established as the most effective strategy, considering the necessity to validate the ability of said data to be representative of the case study in question; asking CSCs to provide the data through a data collection template will create the possibility of speeding up the data collection process. (Liu et al., 2011)

In the process of creation of System Dynamic Model, Rocha's and Ostrom's frameworks will be employed. Rocha's framework, based on Social-ecological systems (SESs), allows to diagnose problems, identify complex interactions, and solutions tailored to each SES, and can also be upscaled to specific contexts where the availability of data is scarce but decision-making needs to be facilitated using such tools (J. Rocha et al., 2020). Ostrom's framework, conversely, is used to analyze the sustainability of social-ecological systems, and has been therefore increasingly used to characterize systems in recent years (Del Mar Delgado-Serrano & Ramos, 2015).

Furthermore, the validation of this theoretical framework and the specific value that this can offer in the case of ENFASYS will be validated with experts working in the field of sustainable food systems at all stages, as depicted in detail in the Timeline table, located at the end of this Protocol. Peters et al. (2016) and Dentoni et al. (2023) highlighted the importance of experts and stakeholder engagement to refine food system change models, emphasizing that input from stakeholders adds relevance to models when applied to real-world scenarios. The report "Confidence in Models and Simulations: A Multi-Stakeholder Analysis"(Chaudhari et al., 2022) discusses this challenge, underscoring the need for multi-disciplinary collaboration to enhance the usefulness of models. The participatory approach in validation processes helps bridge the gap between model developers and end-users, allowing for iterative feedback and adjustments that make models more accessible and useful. Salter et al. (2010) also underscored the need for participatory integrated assessment methods, where stakeholder workshops allow experts from various domains to contribute to refining the model structure and assumptions, enhancing both scientific rigor and user confidence. Engaging experts and stakeholders in extended consultations enables end-users to understand and apply the models effectively in decision-making processes, which is especially critical in multi-dimensional fields like sustainable food system transitions.

The implementation of web-based and digital tools has become increasingly critical for advancing sustainable agricultural practices. Several recollections (Burns et al., 2022) do offer a comprehensive assessment of digital tools supporting agroecological transitions, such as FarmBetter and Cool Farm Tool, which provide agro-advisory services—like recommendations for climate resilience and footprint assessments—and performance assessments across environmental dimensions like water usage, emissions, and biodiversity. While these tools are valuable for delivering actionable insights at the farm level, they are often tailored to local or regional applications, focusing primarily on productivity improvements and environmental benchmarking. In contrast, the ENFASYS web-based tool, to be developed based on D2.2 and implemented in T5.4, is designed to operate at a broader, EU-wide scale, providing a strategic decision-support system that supports policy and business strategies for sustainable farming transitions across Europe.

Potential pathways and their integration with CSs

To develop System Dynamics Models (SDM) for informing European policymakers, five critical transition pathways have been identified, addressing key challenges in the agri-food sector and aligning with EU strategic objectives:

1. **Low-impact agriculture**: Focuses on reducing chemical inputs, improving soil health, and mitigating greenhouse gas emissions. Derived from the (Home et al. 2023) document and the Farm to Fork Strategy.
2. **Extensification of livestock systems**: Prioritizes animal welfare and reduces methane emissions through less intensive practices, supported by the European Green Deal and (Home et al. 2023).
3. **Biodiversity conservation and restoration**: Emphasizes agroforestry and local crop varieties, informed by (Home et al. 2023) and the EU Biodiversity Strategy for 2030.
4. **Sustainable consumption and branding**: Encourages direct selling, sustainability certifications, and consumer awareness, highlighted in the Food 2030 report and (Home et al. 2023).

The thematic System Dynamics Models (SDMs) to be developed in this project aim to integrate the dynamics of the CSs with these EU-defined pathways. This integration begins with an analysis of the focus of each case study through the light-touch review of D 1.3 and relevant EU policy papers (Bizzo et al., 2023) to identify its alignment with the thematic pathways. This process is elaborated in further detail in paragraph 9.1 of this Protocol.

For example, the case study of Belgium and France focuses on facilitating the uptake of agri-environment climate measures;, it has been found an alignment of this case study with the biodiversity conservation and restoration pathway, as well as the transition to low-impact agriculture. Similarly, the case study in Serbia, which addresses the alignment of Serbian agriculture with CAP principles, resonates with pathways focused on sustainable consumer branding. These connections highlight the potential of the CSs to contribute to broader EU objectives while addressing local challenges.

Likewise other CSs reveal equally compelling alignments. For the case of Switzerland, the focus on promoting biodiversity through locally adapted practices underscores its relevance to the biodiversity conservation pathway. On the other hand, in France, efforts to promote protein autonomy in livestock farms highlight its alignment with the extensification of livestock systems. Meanwhile, in Germany, the emphasis on creating regional production-consumption cycles bridges the goals of circular economy implementation and extensification of livestock systems. Greece’s focus on shifting to sustainable practices through consumer branding demonstrates its alignment with both sustainable consumer branding and the transition to low-impact farming. Likewise, Slovenia’s promotion of direct selling strengthens its ties to the sustainable consumer branding pathway, showcasing the diversity of market mechanisms explored across the CSs.

In Italy, the case study on community-supported agriculture reflects a dual alignment with the circular economy implementation and low-impact farming pathways, emphasizing the value of community engagement in achieving sustainability.

The Irish case study on growing the low-impact dairy farming sector is firmly rooted in the low-impact farming pathway, while the Belgian focus on increasing low-impact-certified vegetable production aligns with both low-impact farming and biodiversity conservation. These connections illustrate how the thematic pathways serve as a framework for understanding and integrating the diverse dynamics of the CSs.

The integration of case study Causal Loop Diagrams (CLDs) into the SDMs for each pathway will be guided by the identification of central variables and systemic dynamics (Rocha et al, 2020). Feedback loops that address shared systemic challenges will be harmonized, ensuring the coherence and robustness of the models. This integration process will remain iterative and participatory, incorporating stakeholder (CSCs, external policy experts) input to refine and validate the models.

Scientific literature underpins the approach to this integration. The importance of leveraging local insights while aligning with broader systemic objectives has been highlighted by Ostrom (2009), who emphasized the need for frameworks that integrate local and global dynamics in addressing sustainability challenges. Similarly, Voinov and Bousquet (2010) stressed the role of participatory modeling in ensuring the relevance and applicability of systemic models. The alignment of thematic pathways with case study dynamics also draws on the insights of Meadows (1999), who outlined the importance of identifying leverage points in complex systems for effective intervention.

By aligning the CSs with the EU-defined pathways, this narrative demonstrates how local dynamics can be systematically integrated into broader frameworks to achieve sustainability. The process ensures that the resulting SDMs are not only reflective of local realities but also instrumental in advancing the EU’s goals for sustainable agricultural transitions.

The role of partners

The development of thematic System Dynamics Models (SDMs) for Task 2.3 relies on the active contributions of Case Study Coordinators (CSCs), WP leaders, and External Experts. Their roles are essential to ensure scientific rigor, thematic relevance, and practical applicability in addressing the project's objectives.

6.1 Case Study Coordinators (CSCs)

CSCs bridge the local dynamics of their respective case studies with the overarching thematic pathways. Their responsibilities include:

- **Data collection:** Offering insights into critical variables, feedback loops, and systemic interactions from case-specific Causal Loop Diagrams (CLDs).

- **Variables selected validation**: Collaborating with the project team to align local data with EU-level pathways and to prioritize key variables.

Through iterative discussions, CSCs play a key role in ensuring the feasibility and strategic alignment of the data and in validating the thematic coherence of SDMs.

6.2 WP partners

WP partners key contributions are:

- **Methodology refinement**: Ensuring the SDM development process adheres to the proposed methodology and adapts to emerging challenges.

- **Review and feedback**: Consolidating partner feedback to refine assumptions, variables, and systemic relationships.

WP partners ensure that the project maintains consistency and methodological rigor throughout the SDM development process.

6.3 EU policy experts

EU policy experts provide an independent perspective and policy-relevant insights to enhance the quality and applicability of SDMs. Their roles include:

- **Policy alignment**: Evaluating the relevance of variables and models to EU-level strategies and frameworks (e.g., Farm to Fork, Biodiversity Strategy).

- **Methodology validation**: Reviewing and validating the proposed methodological framework to ensure robustness and adherence to scientific standards.

- **Expert validation**: Offering feedback on thematic coherence, systemic interdependencies, and the accuracy of data inputs within the Stock and Flow Diagrams (SFDs).

- **Strategic recommendations**: Ensuring that SDMs remain actionable and useful for policymaker decision-making.

6.4 Collaboration and validation process and engagement

To structure this collaboration effectively, a series of meetings and validation steps will be scheduled, ensuring regular input and feedback throughout the development process:

- **Kick-off meeting** (by the 30 of November): An initial online kick-off meeting will be held by the end of November with WP2 partners, to present the first results, the final methodology, define roles and timelines.
- **Monthly online updates with WP partners :** to maintain alignment during the development of the SDM, every month an update meetings will be held with WP2 partners. UNIBO will schedule these meetings based on a survey of partner availability. During these updates, partners will review progress, discuss challenges, and address necessary adjustments. The goal is to facilitate continuous alignment and collaboration, ensuring that each milestone is met as scheduled.

- **Involvement of Case Study Coordinators:** Dedicated meetings where the variables to be included in the SDM for each case study are presented and discussed. Additionally, the data collection template for the specific SDM will be introduced, ensuring a clear and standardized approach for gathering and integrating relevant data
- **Data collection:** CSCs will play a pivotal role in providing detailed data on key variables identified in their Causal Loop Diagrams (CLDs). The collected data will serve as the foundation for prioritizing and integrating variables into the thematic SDMs. Where gaps in data are identified, UNIBO will collaborate with CSCs to propose solutions, such as additional surveys or secondary data sources. This step ensures that the SDMs are built on robust and contextually relevant data.
- **Continuous validation and review of thematic SDMs:** Throughout the development process, the thematic SDMs will undergo continuous validation by WP2 partners and CSCs. This iterative review will ensure that assumptions, variables, and systemic relationships are regularly examined and refined. Feedback from all parties will be consolidated into progress reports, enabling ongoing alignment with project objectives. This continuous validation approach ensures that the models evolve dynamically and remain accurate and relevant to the thematic pathways.

Empirical data collection

The empirical data collection for the SDMs will prioritize integrating thematic case study variables while maintaining alignment with EU-wide policy frameworks and strategies. Unlike the initial plan of relying solely on EU-level datasets, this approach will balance localized insights with broader systemic dynamics, ensuring a comprehensive and policy-relevant model.

The process will begin with the identification of central variables and key systemic dynamics (such as feedback loops, lock-ins, and leverage points) from the Causal Loop Diagrams (CLDs) developed for each case study. CSCs will play a central role in this phase, analyzing and submitting the most critical variables specific to their regional dynamics and thematic focus.

After the identification phase, the next step will focus on cross-referencing and validating these variables with the broader systemic dynamics relevant to the thematic SDMs. Variables selected will be validated by experts for their relevance to EU policy contexts their contribution to the specific thematic pathways and by CSCs concerning their relevance for the CS. This phase ensures that each thematic SDM is contextually relevant and directly tied to the systemic challenges it aims to address.

Data will be collected using a template that will be designed for this specific purpose and shared individually with each CSC providing details to guide the process (eg. unit of measurement, time frame, other details). Data will be used to support equation formulation, drawing from case-specific inputs provided by coordinators (WP2 and WP4 existing data and data gathered through the template), historical datasets (eg. Eurostat), and relevant literature. These data sources will complement the case study variables, providing a robust empirical foundation for the thematic SDMs.

Incorporating real-world dynamics into the SDMs will require iterative validation of the data and variables. Monthly updates with WP2 partners and bilateral discussions with CSCs will ensure that the data remains accurate and aligned . The validation process will involve verifying the consistency and applicability of the variables and refining their relationships to reflect systemic feedback loops and interdependencies.

To conclude, the validated dataset will be integrated into the SDMs, enabling simulations of policy scenarios and systemic transformations. This empirical foundation ensures that the thematic SDMs are not only representative of local and EU-wide dynamics but also actionable for informing strategic decisions and policy development. The inclusion of diverse data sources and iterative collaboration ensures that the SDMs remain robust, relevant, and adaptable to the complex challenges facing European agricultural systems.

Risks and mitigation actions

The development of thematic System Dynamics Models (SDMs) for Task 2.3 presents several challenges that must be carefully addressed to ensure the reliability, representativeness, and usability of the final outputs. A primary concern is the risk of excluding CSs from specific transformation pathways. Given the diversity of the CSs and their varying degrees of relevance to these pathways, there is the possibility that some may not align directly with any selected pathway. To mitigate this, the inclusion of case study components will be carefully evaluated based on their systemic relevance and their contribution to European policy discussions. Feedback loops, systemic dynamics, and leverage points directly linked to the thematic focus of a pathway will be prioritized. While efforts will be made to maximize the representation of all CSs, thematic coherence will remain a primary criterion. Stakeholder consultations and expert reviews will guide these evaluations to ensure the robustness and thematic accuracy of the models (Meadows, 1999).

Another significant challenge lies in the complexity of harmonizing variables and dynamics from the CLDs. The variability among CSs could hinder the integration process, making it difficult to create coherent and actionable models. To address this, from the beginning the problem statements from each case study will be analyzed to map their relevance to specific pathways. Only the most critical variables and dynamics will be selected for inclusion, guided by the identification of archetypes and recurrent relations (Rocha et al., 2020). Tools such as adjacency matrices and heat maps will support this process, ensuring clarity and consistency while preserving the integrity of the models.

The calibration of the SDMs introduces additional challenges due to the potential insufficiency of quantitative data. Some CSs may lack the detailed data needed to represent their variables and dynamics effectively. To overcome this, a multi-tiered approach to data collection will be adopted. Priority will be given to primary data provided by case study coordinators. However, the decision on whether to use case study-level or European-level empirical data will be deferred until after the construction of the CLDs for each pathway. This evaluation will be conducted collaboratively with stakeholders, including coordinators and experts, to ensure the inclusion of the most relevant data. Secondary sources, such as Eurostat, JRC reports, and academic literature, will be used to fill any remaining gaps (Saltelli et al., 2008). Additionally, the modular design of the SDMs will allow for the integration of new or refined data as it becomes available.

Stakeholder acceptance and usability of the thematic SDMs is another critical risk. Policymakers and stakeholders might find the models overly complex or abstract, limiting their practical application. This will be addressed by conducting validation workshops with experts during the development phase. These workshops will ensure that the models accurately reflect the dynamics and systemic challenges of each pathway, enhancing their scientific credibility (Voinov & Bousquet, 2010). Furthermore, usability will be ensured through the development of an interactive tool, as planned in later stages (T5.4). This tool will provide tailored interfaces for both case study stakeholders and European policymakers, allowing them to explore the models' implications in their specific contexts. This combination of expert validation and accessible design will ensure the SDMs are both robust and user-friendly.

Another potential issue is the misalignment of the SDMs with current EU policy frameworks. If the models do not align with key strategies such as the Farm to Fork Strategy, Biodiversity Strategy, or CAP, they may fail to provide actionable insights. To mitigate this, the thematic pathways will be informed by findings from (Home et al. 2023) and continuously refined through engagement with EU-level experts and policymakers. Regular validation sessions will ensure the models remain relevant and adaptable to emerging policy needs (Ostrom, 2009).

Methodological approach for Building an SDM from CLDs

The methodological approach for developing the ENFASYS System Dynamics Model (SDM) focuses on leveraging case study insights to construct thematic models that align with EU-defined pathways. By grounding the process in the Causal Loop Diagrams (CLDs) developed for each case study, the SDM ensures a balance between specificity and scalability, capturing both local and EU-wide dynamics.

9.1 Matching Thematic Pathways with Case Study CLDs

The initial step in developing the SDM involves aligning thematic pathways derived from European Commission policies—such as low-impact farming, biodiversity conservation, and climate resilience—with applicable ENFASYS CSs. This ensures that the thematic models are firmly grounded in empirical evidence and tailored to address specific challenges highlighted in the CSs' CLDs.

Objectives:

- to systematically assign thematic pathways to the most relevant CSs;
- ensuring alignment between pathway goals and the specific dynamics of each case.

Procedural steps:

- **Literature Review**: A comprehensive analysis of thematic pathways will be conducted, referencing key European Union policy documents and reports, including those from the European Green Deal, Farm to Fork Strategy, and Biodiversity Strategy for 2030. This step will identify focus areas such as pesticide reduction, low-impact agriculture, or soil health.
- **Analysis of Case Study Focus**: Using insights from the light-touch review detailed in (Home et al. 2023), each case study's key focus areas and recurring relationships will be cross-referenced with the thematic pathways.
- **Mapping Recurring Relationships**: Recurring relationships identified in the CLDs, validated in (Ottaviani Aalmo et al, 2024), that align with thematic pathways, will be prioritized. These relationships will be identified through a multi-step process: (1) Systematic identification of variables and connections that frequently recur within feedback loops, quantified using the adjacency matrix from (Ottaviani Aalmo et al, 2024). Relationships will be assessed based on their frequency, strength (e.g., causal weights, if available), and their role in the system's dynamics. (2) Validation of the connection between these relationships and thematic pathways, focusing on how well they address goals from key EU policies like the Farm to Fork Strategy and the Biodiversity Strategy. This includes aligning recurring relationships with policy objectives and thematic priorities through evidence provided by (Home et al. 2023). This streamlined approach ensures that the analysis focuses on relationships critical to both empirical CSs and strategic goals.
- **Validation process**: Guided by an adjacency matrix from (Ottaviani Aalmo et al, 2024)and insights from policy expert panels, thematic pathways will be systematically matched to the most relevant CSs. This process will utilize both qualitative (CSCs bilateral meetings) and quantitative analyses of the CLDs, incorporating evidence-based methodologies to strengthen the empirical foundation of the pathway-to-case study alignment.

Output

A mapping table will be created to outline which thematic pathways align with each case study. This table will serve as the basis for further model refinement and pathway-specific analysis.

9.2 Selection of Relevant CLD Sections

Objective

To systematically identify the portions of case studies CLDs that are most relevant to the thematic pathways, focusing on variables, feedback loops, and systemic dynamics (e.g., lock-ins and leverage points) that align with policy objectives and thematic priorities.

Procedure

1. **Initial Literature Review**:
    - Conduct an initial screening of dynamics and variables using insights from relevant scientific literature and policy documents (e.g., (Home et al. 2023), Farm to Fork Strategy). This step identifies non-relevant dynamics and excludes them from further analysis.
    - Focus on thematic alignment by pre-selecting dynamics strongly tied to the objectives of each pathway.
2. **Preliminary Quantitative Analysis**:
    - Analyze cosine similarity and structural equivalence scores, already calculated and validated in (Ottaviani Aalmo et al, 2024), to identify associations between variables and systemic dynamics (e.g., feedback loops).
    - Prioritize variables and dynamics with high similarity or equivalence scores across multiple CLDs, ensuring their relevance to the thematic pathway.
3. **Mapping Dynamics to Thematic Pathways**:
    - Use the results of the quantitative analysis to identify variables and dynamics that meet predefined thresholds for similarity and equivalence. Variables with cosine similarity > 0.7 and structural equivalence = 1 is considered strong candidates for inclusion. Additionally, these variables and dynamics must exhibit alignment with thematic pathway goals (e.g., contributing to feedback loops such as biodiversity restoration or low-impact farming implementation). Identify relationships, feedback loops, and systemic patterns that align with thematic pathways, such as biodiversity conservation or low-impact farming.
    - This step focuses on aligning quantitative findings with key thematic pathway objectives (e.g., Farm to Fork Strategy, Biodiversity Strategy).
4. **Literature-Based Validation and Expansion**:
    - Validate the results of the quantitative analysis using insights from relevant scientific literature and case study findings.
    - Expand on quantitative findings by incorporating additional evidence from European policy documents (e.g., Farm to Fork Strategy) and project deliverables (e.g., (Home et al. 2023)) and studies to ensure comprehensive coverage of systemic dynamics.
    - Example: A review of studies on sustainable farming practices may highlight the significance of Pesticide Reduction and Soil Quality Improvement as key components of the pathway.

5. **Stakeholder Validation**:
    - Share the refined set of relevant dynamics and variables with case study teams for feedback.
    - Incorporate their insights to finalize the selection, ensuring contextual applicability and empirical relevance.

Output

A refined set of CLD sections associated with each thematic pathway, supported by validated systemic patterns from (Ottaviani Aalmo et al, 2024)and expanded through literature-based insights. These sections provide the foundation for identifying central variables in the next phase.

9.3 Identification of Central Variables

Objective

To identify the central variables within the selected sections of case study CLDs that have the greatest systemic influence. These variables serve as key anchors for integrating systemic archetypes into thematic pathway models.

When Is a Variable Central? A variable is considered central when it:

- Demonstrates **high degree centrality**, which measures the number of direct connections a variable has to others within the system. This highlights its structural importance in mediating interactions and driving systemic behavior (Freeman, 1978; Newman, 2010). Variables with high degree centrality serve as hubs, influencing multiple feedback loops and supporting critical systemic dynamics, indicating it is highly connected and acts as a hub within the system (Freeman, 1978; Newman, 2010);
- Participates in **feedback loops**, connecting multiple dynamics and reinforcing system behavior;
- Is positioned as a **driver or critical component** in systemic patterns validated in (Ottaviani Aalmo et al, 2024).

Procedure

Central variables are identified at the conclusion of a structured process:

1. **Utilizing Results from (Ottaviani Aalmo et al, 2024)**:
    - The feedback loops, lock-ins, and leverage points identified and validated in (Ottaviani Aalmo et al, 2024) form the foundation for this phase. These validated systemic dynamics guide the identification of central variables within the CLDs.
    - The adjacency matrix from (Ottaviani Aalmo et al, 2024) is used to measure the connectivity and systemic relevance of variables, prioritizing those that:
        - **Participate in Feedback Loops**: Variables embedded in loops with critical systemic roles.
        - **Exhibit High Connectivity**: Selection focuses on the **top 25% of variables by degree centrality**, ensuring emphasis on influential nodes that drive system behavior.
2. **Hierarchical Structuring**:
    - Central variables are organized into a hierarchy to clarify their systemic roles, following the framework of Rocha et al. (2019). Hierarchical structuring is essential for identifying leverage points, as it distinguishes variables with global influence from those with localized effects (Meadows, 2008).
        - **Top Tier**: Variables that act as drivers for systemic change, such as those influencing leverage points or critical feedback loops. Among the top-tier variables, the most influential (i.e with the highest number of connections) one is identified as the central variable, serving as the primary anchor for systemic behavior within the CLD.
        - **Intermediate Tier**: Variables that reinforce systemic dynamics but do not directly drive them.
        - **Base Tier**: Variables with localized influence, critical for understanding broader patterns.
    - This hierarchical organization does not redefine systemic dynamics but aligns variables for integration in thematic archetypes.
3. **Preparation for Archetype Development**:
    - While this phase focuses solely on identifying central variables, these variables will serve as foundational elements for developing systemic archetypes in the next phase.
    - Archetypes will group recurring patterns and dynamics to synthesize systemic behavior across multiple CLDs.

Output

A prioritized list of central variables for each thematic pathway. These variables form the backbone for systemic archetypes, leveraging validated systemic dynamics from (Ottaviani Aalmo et al, 2024)and ensuring alignment with thematic objectives.

9.4 Highlighting Systemic Archetypes

Objective

To construct systemic archetypes by grouping recurring patterns and dynamics (e.g., feedback loops, lock-ins, leverage points) identified across multiple CLDs within the same thematic pathway. This ensures a unified representation of systemic behaviors and interactions.

Procedure

1. **Identifying Recurring Patterns Across CLDs**:
    - Utilize the systemic dynamics validated in (Ottaviani Aalmo et al, 2024), including feedback loops, lock-ins, and leverage points validated in (Ottaviani Aalmo et al, 2024), to identify recurring systemic patterns across multiple CLDs (Rocha et al., 2019).
    - Cosine similarity (validated in (Ottaviani Aalmo et al, 2024)) is used to ensure that variables and dynamics with aligned systemic roles are effectively grouped (Newman, 2010). This approach leverages pre-existing calculations from (Ottaviani Aalmo et al, 2024) to avoid duplication and provides a robust basis for systemic alignment across CLDs.
    - This ensures that variables with aligned systemic roles are harmonized effectively.
2. **Defining Archetypes**: Archetypes are constructed by grouping recurring patterns and aligned variables identified through cosine similarity and systemic dynamics validated in (Ottaviani Aalmo et al, 2024). Cosine similarity ensures that variables with highly similar systemic roles are effectively grouped (Newman, 2010).
    - Utilize recurring feedback loops, systemic barriers, and leverage points to define the core behaviors of each archetype.
    - Each archetype synthesizes systemic behaviors across multiple CLDs, ensuring that patterns critical to the thematic pathway are captured comprehensively.
3. **Validation and Refinement**:
    - Cross-reference harmonized variables with thematic pathway objectives and relevant literature (e.g., (Home et al. 2023), European policy documents).
    - Ensure that the constructed archetypes align with the systemic dynamics validated in (Ottaviani Aalmo et al, 2024) and thematic pathway objectives. Validation includes input from CSCs and thematic alignment with policy documents (e.g., Farm to Fork Strategy) and project deliverables (e.g., (Home et al. 2023)) to refine the archetypes for empirical and contextual relevance.

Output

A set of systemic archetypes representing the core dynamics, barriers, and leverage points within thematic pathways. These archetypes provide a structured foundation for integrating CLDs into cohesive models in the next phase. This set provides a consistent foundation for the development of systemic archetypes in the next phase.

9.5 Harmonization of Variables Across Cases

Objective

To align and integrate central variables identified across case study CLDs within the same thematic pathway, ensuring consistency and coherence for the construction of systemic archetypes.

Procedure

1. **Mapping Variables Across CLDs**:
    - Central variables identified in the previous step are compared across case study CLDs to identify overlaps, similarities, or equivalences. The process utilizes **cosine similarity**, already calculated and validated in (Ottaviani Aalmo et al, 2024), as the primary quantitative method. This measure evaluates the directional alignment between variables (Newman, 2010) to identify systemic roles and relationships effectively.
    - This ensures that variables with aligned systemic roles are harmonized effectively.

2. **Harmonization Through Categorization**:
    - Based on the results from cosine similarity, variables with overlapping or equivalent roles are grouped under unified categories to ensure consistency. For example:
        - Pesticide Reduction (CLD 1) and Synthetic Input Reduction (CLD 2) may be harmonized under the category Reduction of Chemical Inputs.
    - Retain distinct variables if their roles or systemic impacts differ significantly, as determined quantitatively through cosine similarity. Validation through thematic alignment and CSC input will be addressed explicitly in the subsequent step of the procedure to ensure empirical and contextual accuracy.
3. **Validation Through Thematic Context**:
    - Cross-reference harmonized variables with thematic pathway objectives and relevant literature (e.g., (Home et al. 2023), European policy documents).
    - Ensure that the harmonized set aligns with the systemic dynamics validated in (Ottaviani Aalmo et al, 2024).

Output

A harmonized set of central variables across relevant CLDs, grouped into unified categories where applicable. This set provides a consistent foundation for the development of systemic archetypes in the next phase.

9.6 Integration of CLDs into Unified Thematic Models

Objective

To integrate the harmonized CLDs and systemic archetypes into unified thematic models for each pathway, ensuring consistency, coherence, and a comprehensive representation of systemic dynamics. This phase consolidates the outcomes of previous steps, emphasizing methodological rigor and transparency.

Procedure

1. **Aggregation of Harmonized CLDs**:

    - Harmonized variables and dynamics from the CLDs associated with the same thematic pathway are aggregated into a unified representation. This step ensures that all relevant variables and dynamics, including feedback loops, lock-ins, and leverage points validated in (Ottaviani Aalmo et al, 2024), are accurately included.

    - Cosine similarity, as calculated and validated in (Ottaviani Aalmo et al, 2024), is used to ensure that variables with aligned systemic roles across CLDs are appropriately grouped and represented. This quantitative measure guarantees a robust and consistent integration of dynamics.

2. **Synthesis with Systemic Archetypes**:

    - Systemic archetypes developed in the previous phase are incorporated to structure the thematic model. These archetypes act as frameworks for organizing recurring systemic patterns and behaviors.

    - Each archetype synthesizes recurring feedback loops, systemic barriers, and leverage points across the CLDs. For example:

        - The archetype Sustainable Input Management may include dynamics related to Pesticide Reduction and Soil Quality Improvement.

        - The archetype Biodiversity Conservation may encompass dynamics such as Habitat Restoration and Ecosystem Services.

    - This step ensures that the thematic model captures the essence of shared systemic behaviors across multiple CSs, following the principles outlined by Meadows (2008) and Rocha et al. (2019).

3. **Validation of Systemic Coherence**:

  - A systemic review is performed to confirm that the integrated model preserves the integrity of the dynamics validated in (Ottaviani Aalmo et al, 2024). This involves:

    1. Comparing integrated feedback loops and systemic barriers with their original representations in the CLDs.

    2. Consulting case study coordinators (CSCs) and thematic experts (external policymakers) to verify that the unified model aligns with empirical findings and thematic objectives.

    3. Cross-referencing with relevant literature and policy documents, such as the Farm to Fork Strategy and (Home et al. 2023), to ensure thematic and empirical relevance.

4. **Graphical Representation**:

  - The unified thematic model is visualized using Vensim. These diagrams highlight key systemic dynamics, including feedback loops, leverage points, and systemic barriers, ensuring clarity and accessibility for stakeholders.

  - Visual models also provide an intuitive understanding of the relationships between variables, aiding further analysis and communication.

Output

A unified thematic model for each pathway, integrating harmonized CLDs and systemic archetypes. This model ensures that systemic coherence is maintained while providing a structured framework for quantitative modeling and scenario testing. By capturing validated dynamics and recurring systemic patterns, the thematic models serve as a comprehensive foundation for policy analysis and decision-making.

9.7 Conversion of CLDs into Stock-and-Flow Diagrams (SFDs)

Objective

To translate the unified thematic models derived from CLDs into Stock-and-Flow Diagrams (SFDs) using Vensim, it is crucial to address core causal assumptions, particularly those involving dynamic relationships such as feedback loops.This process facilitates quantitative modeling by defining variables as either stocks or flows and establishing the mathematical relationships between them. Additionally, this phase identifies the types of data required from CSs to build realistic and calibrated models.

Definition of mathematical relationships in the model

it is essential to establish the mathematical relationships between **stock** and **flow** variables, as these form the foundation of systemic dynamics:

1. **Stock-Flow interaction**:
  - **Stock**: Represents an accumulation over time and is calculated as:

$$S(t) = \int_{t0}^{t} \big(inflow\ (t) - Outflow(t)\big)dt$$

Where:

- S(t) represents the accumulation of something in the system
  - Example: Soil Fertility: Measured in units like kg/ha, this stock accumulates nutrients over time through inflows like Nutrient Inputs and decreases through outflows like Nutrient Depletion
- S(t0) represents the stock at starting point of the system analysis

    - Example: If “Soil Fertility” is 100 kg/ha at the start of the year, this is the initial stock value (S(t0)=100S(t_0) = 100S(t0)=100).
- Inflow represents the rate at which resources are added to the stock over time
    - Example: “Nutrient Inputs”: Fertilizers applied to the soil, measured in kg/ha/year, such as Fertilizer Application Rate × Field Area.
- Outflow represents the rate at which resources are removed from the stock
    - Example: “Nutrient Depletion”: Loss of nutrients due to erosion or crop uptake, measured in kg/ha/year. This could depend on factors like Erosion Rate or Crop Yield.
- t/t0 represents the time interval over which inflows and outflows are measured and integrated

  - **Flow**: Reflects the rate of change of a stock, calculated as:

$$Flow = rate\ x\ Influence\ factors$$

Where:

- Flow represents the rate at which a stock changes over time
    - Example: Nutrient Inputs: The amount of fertilizer applied to the soil, calculated as: $Nutrient\ inputs = fertilizer\ application\ rate\ \left(\frac{kg}{ha}\right) x\ field\ area\ (ha)$

- Rate: describes how fast a flow is occurring, typically expressed as a unite per time
    - Example: “Fertilizer application rate”: the rate at which fertilizers are applied expressed in kg/ha/year
- Influence factors: variables that modify the rate based on external or systemic conditions
    - Example: in this case the influential factors can be i) “field area” that represents the size of the field where the fertilizers are applied influencing the total input, ii) Policy incentives that represent the subsidies for fertilizer use, expressed as a multiplier (eg. If no subsidy=1, if 20% of subsidies= 1.2) and iii) Market conditions that represent fertilizers price

By defining these relationships upfront, the integration of data becomes straightforward, as stock and flow variables naturally embed the feedback dynamics validated in (Ottaviani Aalmo et al, 2024).

Data Requirements from CSs

Before the translation of CLDs into SFDs, the necessary data types must be requested from CSs. These data provide the foundation for realistic and calibrated models.

1. **Stock Data**:
    - **Definition**: Initial values and accumulation trends of key stocks.
    - **Examples**:
        - Soil Fertility: Baseline levels and trends over time.
        - Farmer Population: Number of active farmers in a region.
    - **Data to be requested**: Baseline measurements, historical trends, and variability over time.
2. **Flow Data (Rates)**:
    - **Definition**: Rates of change influencing stocks.
    - **Examples**:
        - Fertilizer Application Rate: Annual application per hectare.
        - Crop Yield Rate: Quantity of crops produced per hectare annually.
    - **Data to be requested**: Direct measurements, historical trends, and estimates of influencing factors (e.g., policy incentives).
        - .
    - **Data to Request**: Policy documents, economic reports, and market analysis.

Procedure

1. **Definition of Stock and Flow Variables**:
    - **Stock**: A stock represents an accumulation of material, information, or other resources within the system. It is defined mathematically as the integral of inflows minus outflows over time (Sterman, 2000). For example, Soil Fertility may be a stock that accumulates based on the inflow of Nutrient Inputs and the outflow of Nutrient Depletion.

    - **Flow**: A flow represents the rate at which a stock changes over time. For example, Nutrient Inputs could be a flow variable influencing the stock of Soil Fertility. A rate, such as Fertilizer Application Rate, is a specific type of flow that quantifies how rapidly inputs affect the stock over a given time period. It directly influences the accumulation or depletion of a stock.
2. **Translation of CLDs into SFDs**:
    - Use Vensim to map the relationships between variables identified in the unified thematic models.
    - Assign each variable as a stock or flow based on its systemic role. Variables that represent accumulations (e.g., resources, populations) are designated as stocks, while those representing rates of change (e.g., production rates, consumption rates) are designated as flows.
    - Establish mathematical relationships between stocks and flows by defining equations that govern the behavior of the system over time. Stocks are represented as integrals of inflows and outflows, while flows are defined as rates of change driven by exogenous inputs, feedback loops, and systemic interactions (Sterman, 2000). For example, the stock Soil Fertility could be modeled as the integral of Nutrient Inputs minus Nutrient Depletion, where Nutrient Inputs is influenced by Fertilizer Application Rate and external conditions such as policy incentives (Meadows, 2008). These equations ensure dynamic consistency by reflecting how changes in one part of the system propagate through feedback loops to influence other variables.

Validation with External Experts:

- Share the initial SFDs with external experts, including thematic specialists and policymakers, to validate the accuracy and relevance of the model.
- Incorporate feedback to refine the mathematical relationships and ensure alignment with real-world dynamics.

Output

Quantitatively calibrated Stock-and-Flow Diagrams for each thematic pathway, providing a robust foundation for scenario analysis and policy simulation. These diagrams ensure that all systemic relationships and dynamics are mathematically represented and validated for further exploration.

9.8 Model Validation and Scenario Analysis

Objective

To validate the stock-and-flow models developed in the previous steps, ensuring their alignment with empirical data and systemic goals, and to prepare the models for scenario-based policy analysis.

Procedure

1. **Final validation with experts**:

    - Engage external experts, including thematic specialists and policymakers, to review the models for accuracy and relevance.

    - Validate feedback loops, stock-flow dynamics, and parameter assumptions using real-world knowledge and datasets.

2. **Robustness testing**:

    - Perform sensitivity analyses to identify how changes in key parameters (e.g., rates, influence factors) impact the system's behavior.

    - Perform Monte Carlo simulations by introducing randomness into parameter values or initial conditions. Run multiple simulations to observe the range of possible outcomes. This approach provides probabilistic insights, identifying which results are robust across uncertainties and which are sensitive to variability.

    - Ensure the model is robust to uncertainties and parameter variability.

3. **Data gaps and mitigation strategies**

   - When gaps in data are identified, the most robust strategy is to use proxy data from comparable systems. This involves selecting similar regions, systems, or case studies with reliable data to infer missing values. Proxy data provide a practical and grounded basis for filling gaps while maintaining model accuracy.
   -

4. **Scenario design**:

   - Develop policy-relevant scenarios based on thematic goals (e.g., impact of subsidy programs on sustainable farming adoption).
   - To determine the most impactful interventions, perform a drop-out analysis. This involves systematically removing specific policy or system elements and observing the effects on overall system behavior, allowing for prioritization of interventions.
   - Use these scenarios to simulate outcomes under varying conditions, such as economic, environmental, or policy changes.

5. **Iterative refinement**:

   - Incorporate insights from scenario testing to refine model assumptions and relationships.
   - Update the model based on new data or feedback to improve predictive capabilities.

Output

A fully validated and calibrated stock-and-flow model capable of simulating policy scenarios and providing insights for decision-making.

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