UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas

From Theory to Practice: Leveraging Systems Thinking and Complexity Science to Support Food Systems Transformation

DOCTORAL THESIS

Submitted for the degree of Doctor by:

María del Pilar Bustamante Liria
B.Sc. in Forest Engineering
M.Sc. Project Planning for Rural Development and Sustainable Development

Madrid, 2023

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Para mi abuela.

Ojalá algún día romper la mitad de barreras que tú.

Acknowledgment

I am deeply grateful for the opportunity to pursue doctoral studies linked to a topic I strongly believe in – a commitment that transcends the academic and professional realms. The opportunities and challenges we face as a society regarding food and how we produce, trade, and consume it have been a central topic in my life for as long as I can remember. Having the opportunity to contribute, through this academic journey, a tiny grain of sand to move toward a future with more sustainable, fair, equitable, and healthy food systems holds a very special meaning for me.

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Abstract

Food systems are central to addressing humanity's most pressing challenges sustainably. As recognized in scientific and sociopolitical agendas, the complexity of food systems and their interconnectedness with global sustainability issues call for transformative changes that challenge the current way of doing things.

Understanding the food systems' structure, behavior, and dynamics is critical to inform and catalyze the needed transformations. In this regard, within the evaluation field, there is a growing call for engaging with Systems Thinking and Complexity Science to enhance the understanding of intricate issues among agents involved in addressing complex challenges, empowering them to provide valuable insights supporting transformations.

Despite the diverse and innovative efforts to inform and support food system transformations from increasingly systemic perspectives, these have not yet been translated meaningfully into practice.

Given the above, this thesis aims to contribute to ongoing efforts by promoting deeper engagement with Systems Thinking and Complexity Science among agents within food systems evaluation to inform and support transformation processes. Contributions in three dimensions are highlighted:

Theoretical contribution: This thesis conducts a comprehensive, literature-based exploration of the systems and complexity fields, synthesizing the broad range of ideas and practices into a principles-based framework that aims to guide and inspire agents engaged in assessing complex issues to support transformations.

Methodological contribution: Actionable ways to strengthen existing food systems frameworks to inform and support transformations are proposed, guided by the Systems Thinking and Complexity Science principles. Food systems frameworks are analyzed to identify exemplary practices to leverage among them and areas to strengthen to address barriers preventing food systems transformations.

Practical contribution: A Participatory Food Systems Modeling framework is designed based on the findings of the analysis of food systems frameworks. It focuses on engaging

diverse stakeholders and perspectives in making sense of current food systems challenges, envisioning a collective desired future, and identifying desirable and feasible transformation pathways. Real-world applications of this methodology in poultry systems in Ghana and Southern Senegal demonstrate its value in informing and supporting food systems transformations by enabling the collective identification of desirable and culturally feasible transformation pathways, which elevates the thesis's contribution to a practical realm. Moreover, this thesis has the potential to resonate in national and regional agendas in West Africa concerning food security and poverty alleviation, particularly in rural communities.

In conclusion, this thesis contributes to bringing Systems Thinking and Complexity Science meaningfully and substantially into practice to understand and address food systems' complex challenges. This is done by providing solid theoretical foundations, fostering methodological improvements, and testing their value through practical implementations to move towards more productive and prosperous, equitable and inclusive, empowering and respectful, resilient and regenerative, and healthy food systems.

Resumen

Los sistemas alimentarios son fundamentales para abordar de forma sostenible los retos más acuciantes de la humanidad. Tal y como se reconoce en las agendas científicas y sociopolíticas alrededor del mundo, la complejidad de los sistemas alimentarios y su interconexión con los retos globales exigen cambios transformadores que desafíen la forma actual de hacer las cosas.

Para informar y catalizar dicha transformación, es crucial fortalecer nuestro conocimiento de la estructura, el comportamiento y la dinámica de los sistemas alimentarios. A este respecto, en el ámbito de la evaluación, se reconoce y promueve cada vez el uso de ideas y prácticas del Pensamiento Sistémico y las Ciencias de la Complejidad para mejorar la comprensión de cuestiones complejas por parte de los agentes implicados en su evaluación y resolución, capacitándoles para aportar ideas valiosas en apoyo a la necesaria transformación.

A pesar de los diversos e innovadores esfuerzos para informar y apoyar la transformación de los sistemas alimentarios desde perspectivas cada vez más sistémicas, estos aún no se traducen de manera significativa en la práctica.

Teniendo en cuenta lo anterior, esta tesis tiene como objetivo contribuir a los esfuerzos en curso mediante la promoción de un compromiso más profundo con el Pensamiento Sistémico y las Ciencias de la Complejidad entre los agentes vinculados a evaluación de los sistemas alimentarios para informar y apoyar los procesos de transformación. Las contribuciones de la tesis se dan en tres dimensiones:

Contribución teórica: Esta tesis realiza una exploración exhaustiva, basada en la literatura, de los campos de los sistemas y la complejidad, sintetizando la amplia gama de ideas y prácticas en un marco basado en principios que pretende guiar e inspirar a los agentes implicados en la evaluación de cuestiones complejas para apoyar transformaciones.

Contribución metodológica: Se proponen formas prácticas de fortalecer los marcos existentes de los sistemas alimentarios en su propósito de informar y apoyar las transformaciones, guiadas por los principios del Pensamiento Sistémico y las Ciencia de

la Complejidad. Se analizan los marcos de los sistemas alimentarios para identificar tanto las prácticas ejemplares que pueden aprovecharse fomentando el intercambio entre ellos como las áreas que podrían reforzarse a partir de un mayor diálogo con el Pensamiento Sistémico y las Ciencias de la Complejidad para hacer frente a los obstáculos que impiden la transformación de los sistemas alimentarios.

Contribución práctica: A partir de los resultados del análisis de los marcos, se diseña un marco de Modelización Participativa de los Sistemas Alimentarios. Este marco fomenta la participación de diversas partes interesadas y perspectivas para dar sentido a los retos actuales de los sistemas alimentarios, imaginar un futuro colectivo deseado e identificar vías de transformación deseables y viables. Las aplicaciones de esta metodología en los sistemas avícolas de Ghana y el sur de Senegal demuestran su valor para informar y apoyar la transformación de los sistemas alimentarios al permitir la identificación colectiva de vías de transformación deseables y culturalmente viables, lo que eleva la contribución de la tesis a un ámbito práctico. Además, esta tesis tiene el potencial de resonar en las agendas nacionales y regionales de África Occidental relativas a la seguridad alimentaria y la mitigación de la pobreza, especialmente en las comunidades rurales.

En conclusión, esta tesis contribuye a llevar el Pensamiento Sistémico y las Ciencias de la Complejidad a la práctica de forma significativa y sustancial para comprender y abordar los complejos retos a los que se enfrentan los sistemas alimentarios. Para ello, se proporcionan fundamentos teóricos sólidos, se fomentan mejoras metodológicas y se pone a prueba su valor mediante implementaciones prácticas para avanzar hacia sistemas alimentarios más productivos y prósperos, equitativos e inclusivos, empoderadores y respetuosos, resilientes y regenerativos, y saludables.

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Abbreviations and Acronyms

AGAL	Livestock Information, Sector Analysis and Policy Branch
ASF	Animal-Source Food
CATWOE	Customers-Actors-Transformation-Worldview-Owners-Environment
CECAN	Centre for the Evaluation of Complexity Across Nexus
CLD	Causal Loop Diagrams
CSIR - STEPRI	Council for Scientific and Industrial Research – Science and Technology Policy Research Institute
FAO	United Nations Food and Agriculture Organization
FCM	Fuzzy Cognitive Maps
FOLU	The Food and Land Use Coalition
FSA	Food Systems Approach framework
GDP	Gross Domestic Product
HLPE	High-Level Panel of Experts on Food Security and Nutrition
IDEEA Group	The Institute for Development of Environmental-Economic Accounting
IOM	Institute of Medicine
IPES-Food	International Panel of Experts on Sustainable Food Systems
ISRA	Institut de Sénégalais de Recherches Agricoles
ITA	Institut de Technologie Alimentaire
NRC	National Research Council
PFSM	Participatory Food Systems Modelling
PRAVIS	Senegalese Poultry Recovery Plan
PVC	Poultry Value Chain
R&D	Research and Development

SDG	Sustainable Development Goal
SETIG	Systems in Evaluation Topical Interest Group
SSM	Soft Systems Methodology
STCS	Systems Thinking and Complexity Science
TEEB	The Economics of Ecosystems and Biodiversity
TEEBAgriFood	The Economics of Ecosystems and Biodiversity for Agriculture and Food
UNEP	United Environment Program
UPM	Universidad Politécnica de Madrid
VDA	Vision Design and Assessment framework
WHO	World Health Organization

1. BACKGROUND, OBJECTIVES, AND METHODOLOGICAL APPROACH

This first chapter serves as an introduction to the research presented in this thesis document. It provides an overview of the food systems' challenges and transformative potential (Section 1.1) while emphasizing the undeniable need to explore and address them from increasingly systemic views to harness their potential as transformation levers toward sustainability (Section 1.2).

Next, this chapter introduces the research project on which this thesis was framed, briefly describing the project’s main objectives, activities, and contributions (Section 1.3).

With the background set, this chapter introduces the objectives of this thesis (Section 1.4) and how each objective is being addressed through different but coherent methodological approaches in the following chapters (Section 1.4).

1.1. Food systems challenges and transformative potential

Although hunger and malnutrition have been at the forefront of sustainable development agendas for decades, these issues remain significant challenges for humanity (FAO et al., 2021; United Nations Economic and Social Council, 2021; Kakar et al., 2021; WHO, 2020). After growing exponentially in 2020 due to the COVID-19 shock, in 2021, 11.7 percent of the global population experienced severe food insecurity, and an estimated 8.9 to 10.5 suffered hunger (FAO et al., 2022).

Some of the worst food insecurity problems occur in countries under conflict or facing political instability (Global Network Against Food Crises & Food Security Information Network, 2023). Moreover, population groups vulnerable to food insecurity usually face poverty or financial instability, preventing them from adequate food consumption without adopting strategies that stress or deplete essential livelihood assets (FAO et al., 2022). On the other hand, the availability and affordability of food are heavily impacted by the increasingly frequent climate shocks like droughts and floods that lead to food shortages and price instability, preventing households from covering their food and nutritional needs (Global Network Against Food Crises & Food Security Information Network, 2023). The above illustrates how sociocultural, political, economic, and environmental contexts affect food systems (HLPE, 2020b). Contextual conditions such as climate change, biodiversity loss, migration and population growth, political and social conflicts, inequalities, and economic instability act together, posing challenges to food systems with detriments to food security (Fanzo et al., 2020; FAO et al., 2021; Global Panel on Agriculture and Food Systems for Nutrition, 2020). While discussions traditionally focused on systems vulnerabilities to such trends, it is important to recognize that the context, in addition to posing challenges, creates opportunities for improving food systems, as highlighted by Fanzo et al. (2020).

The linkages between food systems activities and the multidimensional context also goes the other way around. Besides struggling to reduce hunger and malnutrition, the way food is being produced, processed, marketed, and consumed is questioned for contributing to other socioeconomic and environmental challenges such as poverty

(Gassner et al. 2019; Giller et al. 2021; Raza & Soares, 2020), social inequalities and injustices (HLPE, 2020a, Leeuwis et al., 2021), and climate change (Crippa et al., 2021).

The COVID-19 pandemic, while exacerbating the unsustainable trends in our food systems, shed light on the synergies and trade-offs between food insecurity and other challenges rooted in how food is produced, processed, traded, and consumed. This awareness of the interdependencies between challenges emphasizes the potential of food systems as powerful levers for change toward meeting the Sustainable Development Goals (SDG) and 2030 commitments (Calicioglu et al., 2019; Dury et al., 2019; FAO et al., 2021; Global Panel on Agriculture and Food Systems for Nutrition, 2020; HLPE, 2020a).

The growing awareness of the strong interlinkages between challenges traditionally linked to food and agriculture and broader sustainability issues faced by humanity nowadays supports the global claim for structural changes in food systems in a way that provides food security without compromising other sustainability outcomes (Béné et al., 2019; Calicioglu et al., 2019; Dury et al., 2019; El Bilali et al., 2019; Ericksen, 2008; FAO, 2017; HLPE, 2020a; TEEB, 2018). The High-Level Panel of Experts on Food Security and Nutrition (HLPE, 2020a) states that a sustainable food system should contribute to productivity, prosperity, equity, inclusivity, empowerment, respect, resilience, regeneration, and health.

The urgent need to transform food systems is widely recognized in the scientific community (e.g., Béné et al., 2019; Fanzo et al., 2020; FAO et al., 2021; Garnett, 2014; Global Panel on Agriculture and Food Systems for Nutrition, 2020; HLPE, 2020a; Kopainsky et al., 2018), but what exactly does such a transformation imply? Béné (2022) suggests that transforming food systems requires substantial changes that challenge the current way of doing things to create a more sustainable food system with positive outcomes for people and the environment.

The idea of food systems that contribute to the Sustainable Development Goals is widely used to describe the normative nature of food systems' transformations (Haddad & Hawkes, 2016; Willett et al., 2019). However, not everyone has the same understanding of what a "better food system" means, nor do they agree on what the transformation implies and how to get there. Systems thinking theory argues there is no single solution or right answer when dealing with complex systems (Reynolds & Holwell, 2010) and that defining the values and nature of transformation should involve dialogue and negotiation between stakeholders. Therefore, systemic approaches call for acknowledging and exploring different perspectives, fostering democratic and inclusive deliberations and discussions among them on the values determining what a "better" system entails, and identifying ways to move towards it.

1.2. Toward a systemic understanding of food-and-agriculture-related challenge: Food systems approaches and frameworks.

Within the long-standing tradition of research on food-and-agriculture-related issues, the approaches under which these issues are understood and assessed have been evolving in response to the global imperative to think systemically in dealing with the complexity inherent to real-world situations (Béné et al., 2019; Burns & Worsley, 2015; HLPE, 2020a; Reynolds et al., 2016; Reynolds & Holwell, 2010; Walton et al., 2021; Williams & Hummelbrunner, 2009).

The growing awareness of the complexity of food systems challenges have encouraged the use of systemic approaches to inform the food systems field of research (see e.g., Allen & Prosperi, 2016; Ericksen, 2008; Halbe & Adamowski, 2019; Hubeau et al., 2017; Ingram, 2011; Kopainsky et al., 2018; Peano et al., 2014; Raza et al., 2020; TEEB, 2018; van Berkum et al., 2018; van Mil et al., 2014; Waterlander et al., 2018) and the political agendas and debates worldwide on food security (Calicioglu et al., 2019; Dury et al., 2019; FAO, 2017; FAO et al., 2021; HLPE, 2020a).

A key landmark in adopting food systems approaches was the "first-ever United Nations Food Systems Summit" (United Nations, 2021) as part of the Decade of Action for delivery of the SDGs by 2030. The Summit aimed to "deliver progress on all 17 SDGs through a food systems approach, leveraging the interconnectedness of food systems to global challenges such as hunger, climate change, poverty, and inequality" (United Nations, 2021).

Along the same line, the FAO is developing efforts to implement a green agenda into agrifood system policies to transform agrifood systems. To contribute to more efficient, inclusive, resilient, and sustainable agrifood systems, the FAO proposes promoting green agriculture, which involves "the good management of natural resources, biodiversity, and ecosystem services while building sustainable and resilient agroecosystems capable of tackling current and future challenges" (FAO, 2023).

As Brouwer et al. (2020) highlighted, the shift toward more systemic approaches for addressing challenges in food and agriculture emerged approximately two decades ago. This shift was in response to the dissatisfaction with the impact of linear supply-side interventions and programs. As elaborated in Chapter 3, the initial linear approaches aimed at addressing hunger and food insecurity by maximizing food production. However, they often overlooked the elements affecting the affordability and access to food and its use to provide healthier, sustainable diets. This omission, especially in vulnerable groups affected by social conflicts, poverty, and extreme climate events (Caron et al., 2018), brings unintended trade-offs and externalities, contributing to several sustainability challenges.

Many food systems frameworks have been developed in the last two decades to foster the adoption of systemic approaches in understanding the complexity of food and agricultural-related challenges and finding suitable ways to address them. One way to illustrate the evolution towards increasingly systemic approaches is by looking at the food systems description made by these frameworks.

The food system was firstly defined as a complex set of activities involved in providing food - from the inputs supply for the farm to food production, consumption, and waste – and the interactions among them and with the environment that create interdependent relationships (Kneen, 1993; Labianca, 1991; Sobal et al., 1998). Both Labianca (1991) and Kneen (1993) emphasized the interdependencies and dynamic behavior of food systems over the long term and warned about the consequences of describing food systems in reductionist or linear terms. Later on, Sobal et al. (1998) stated that "while the term food systems is common, the concept of a system is often used loosely and not linked with systems theory" (p. 853).

Later, the notion of food systems started to be formulated around a sustainability perspective that placed food security as the primary expected outcome. Figure 1.1 illustrates the food systems framework proposed by Ericksen (2008), which marked a trend of food systems understood around three main components. First are the major activities and actors involved in food systems – from production to consumption. Second, the processes and factors from the socioeconomic and environmental context that act as drivers in food systems outcomes. And third, the food system outcomes, with food security as the primary one. Broader sustainability outcomes are also contemplated within the third component.

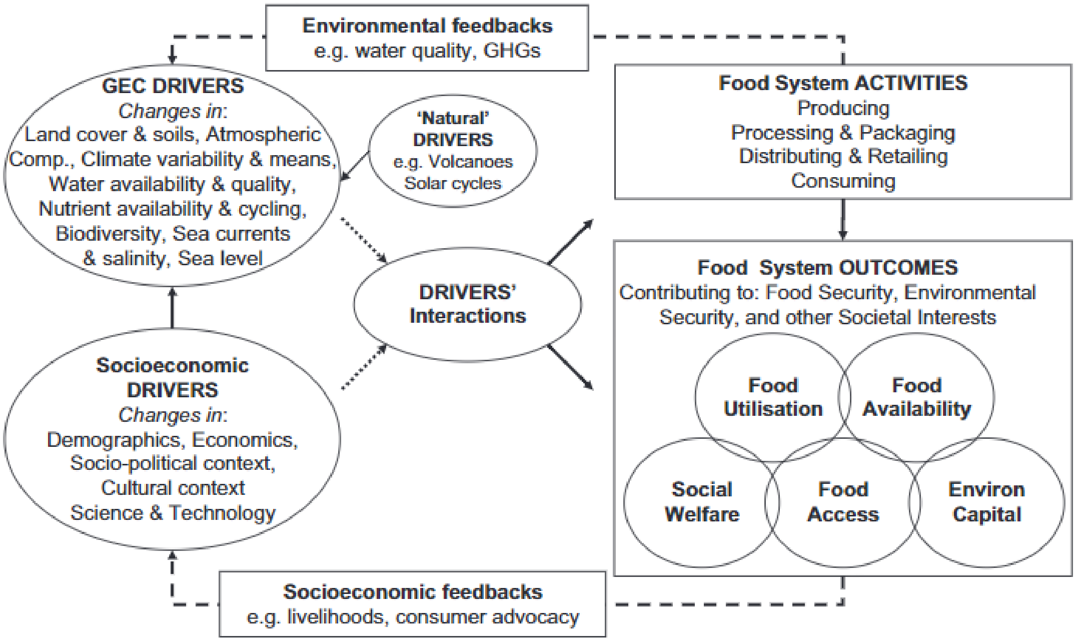

Figure 1. 1. Food systems structure. Source: Ericksen (2008)

From then on, food systems frameworks continue to define food systems around the same three broad components, albeit with some variations and additions that contribute to a more systemic understanding of the challenges and the barriers that prevent its transformation.

Figure 1.2 shows the Sustainable Food Systems framework developed by the High-Level Panel of Experts on Food Security and Nutrition (HLPE) in 2020 – one of the most recent food systems frameworks reviewed in this research – to illustrate the evolution towards increasingly systemic approaches. The HLPE framework (2020a) envisions food systems outcomes as food security – in terms of food availability, access, utilization, and the stability of the three – and includes agency and sustainability.

The agency is defined as "the capacity of individuals or groups to make their own decisions about what food they eat, what food they produce, how that food is produced, processed and distributed within food systems, and their ability to engage in processes that shape food system policies and governance" (HPLE, 2020a, p. xv). In this regard, food systems should empower and respect all people and groups by ensuring their agency.

Concerning sustainability, food systems practices are called to respect and protect the socioeconomic and environmental systems that are the basis for food systems to continue to have the ability to provide food security and nutrition for future generations (HLPE, 2020a).

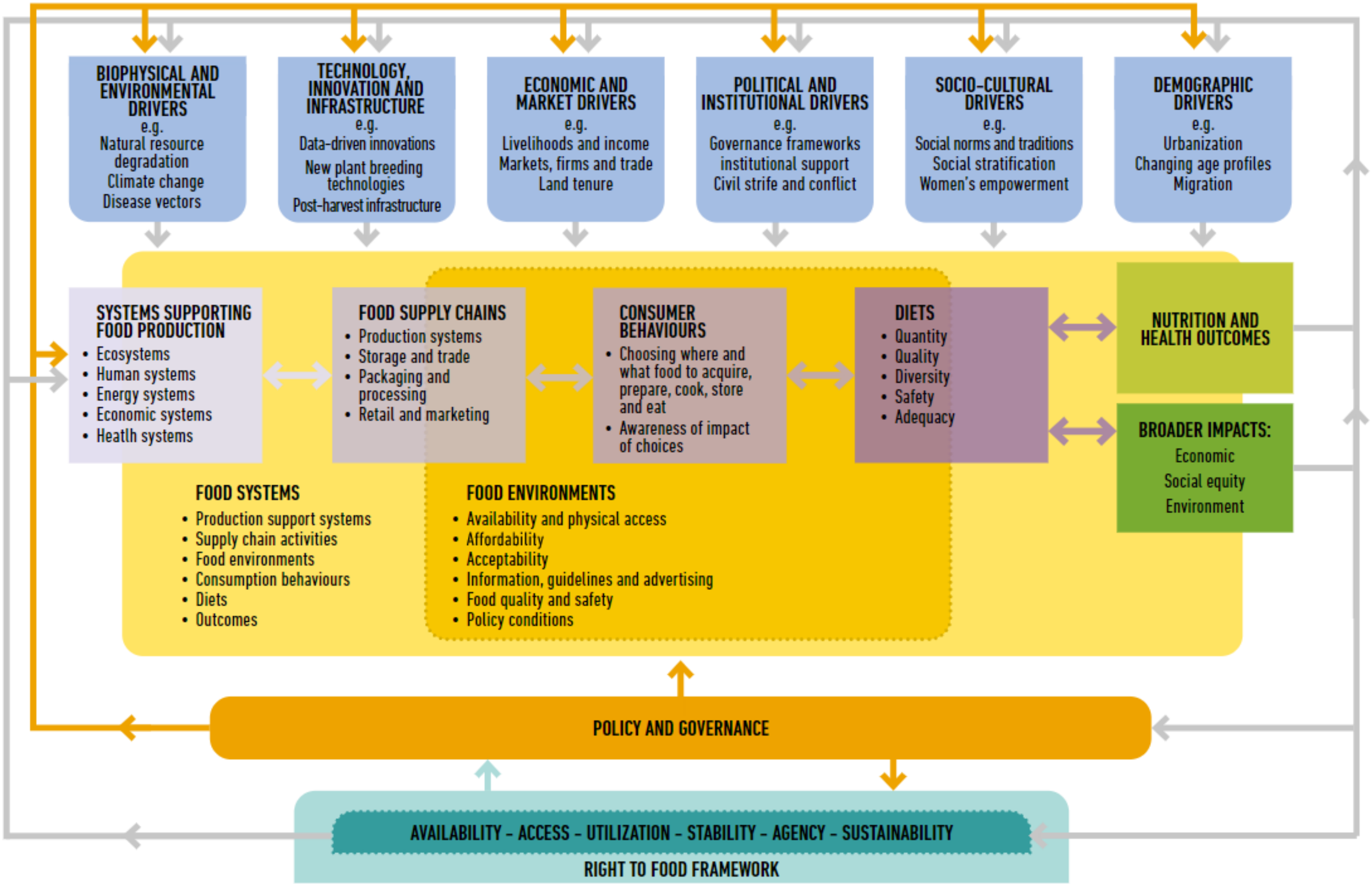

Figure 1. 2. Sustainable Food Systems Framework (HLPE, 2020).

Despite the widespread adoption of systemic approaches and frameworks aimed to contribute to the needed transformations to move towards sustainable development (Pelling et al., 2015; Schot & Steinmueller, 2018), insights gained do not yet translate into practice in substantial and meaningful ways (Brouwer et al., 2020).

The barriers preventing such transformations seem rooted in the complex and systemic nature of food systems (Leeuwis et al., 2021). In this sense, one of the hypotheses of this thesis is that food systems frameworks could be strengthened in their ability to address the complexities of systemic challenges linked to food and agriculture in support of food systems transformations by ensuring a substantive dialogue with Systems Thinking and Complexity Science.

This premise is built upon the growing call that exists within the evaluation field for systemic approaches to engage with Systems Thinking and Complexity Science (STCS) ideas and practices to make sense of systemic changes and support transformations (Gates, 2016; Gates et al., 2021; Walton et al., 2021). According to Reynolds et al. (2012), engaging with STCS would strengthen complexity awareness among decision-makers, practitioners from different fields, and civil society, thus enabling them to provide valuable insights to better deal with complex challenges such as food insecurity, poverty, and climate change.

When it comes to identifying desirable and feasible pathways for transforming food systems, the need to engage diverse stakeholders and perspectives in collective processes of exploration, exchanges, and reflections is highlighted by authors such as Schot & Steinmueller (2018), Checkland & Poulter (2010); Checkland & Scholes (1999). In this regard, several authors call to recognize the power imbalances and governance structures that shape the way stakeholders exert their agency when making sense of what is failing in the current situation, deciding a future to aim for and identify ways to move from the current situation to the desired one (Blesh et al., 2019; Garcia-Gonzales & Eakin, 2019; HLPE, 2020a; IPES-Food, 2017; Leeuwis et al., 2021).

1.3. Research project in which this thesis is developed: SPEAR

The research activities conducive to this thesis and the funding for these come from the SPEAR project, under which this thesis is framed. SPEAR stands for "Empowering small-scale farmers (SPEAR): towards the SDGs through participatory, innovative, and sustainable livestock and poultry value chains."

This project was funded by the LEAP-Agri Call 2017 (Long-term EU-Africa Research and Innovation Partnership on Food and Nutrition Security and Sustainable Agriculture) through the African-European ERA-NET Co-fund program of the European Union's Framework Program for Research and Innovation – Horizon 2020.

The Long-term EU-Africa Research and Innovation Partnership on Food and Nutrition Security and Sustainable Agriculture was launched in 2016. It gathered 19 African and European countries and funded 27 joint projects. The 27 projects officially started in August 2018. After the extension due to the COVID-19 outbreak, they were finalized at different times for different countries before the end of the LEAP-Agri program in August 2022. The SPEAR project at the Technical University of Madrid was closed as of May 2022.

The SPEAR project was developed in Kenya, Ghana, and Senegal, together with the Kenyan Agricultural and Livestock Research Organization (KALRO), the Ghanaian CSIR-Science and Technology Policy Research Institute (STEPRI), and the Senegalese Institute of Food Technology (ITA); and along with the Technical University of Madrid, and the Norwegian Institute of Bioeconomy Research (NIBIO), which acted as the coordinator of the consortium.

Based on the socioeconomic relevance of the agriculture and livestock sector in African countries – as a source of income and food security for families, and economic growth for the country – and the current challenges faced to meet the demand of a growing population for quality animal products, the SPEAR project aimed to improve the productivity and quality on local livestock and poultry value chain in African, thus strengthening the competitiveness of local production – mainly small-scale farmers – in the domestic market.

Specifically, SPEAR aimed to contribute to research, innovation, and policy spheres.

- Research: Developing and testing a Participatory Modelling approach for analyzing local livestock and poultry value chains to collectively identify evidence-based challenges and opportunities for small-scale farmers, especially women and youth.
- Innovation: Provide small-scale farmers with evidence-based tools and practices to empower them with knowledge and technologies to raise productivity and meet quality standards.
- Policy: Provide policy makers with evidence-based strategies to enhance the smallholders' ability to compete in the livestock markets.

The project tasks were organized into five work packages, the first one being responsible for coordination and management activities within the project and thus led by the coordinator of the consortium NIBIO. Work package five was charged with disseminating project results (led by STEPRI), and work package four focused on testing innovations in the field (with STEPRI, KALRO, and ITA engaged). Work package two performed value chain analysis in the three countries (by NIBIO) that fed into work package 3, which involved developing the "Participatory Systems Modelling Framework" led by the UPM.

Work package three provided the methodological framework for the SPEAR project, using participative modeling as the basis. The initial goal of this work package was to transcend the linear thinking on which the value chain analysis is based by adopting a systemic approach that allows delving into the complex and dynamic behavior of livestock and poultry systems.

The main reason for adopting systemic approaches in the SPEAR project was the opportunity to analyze and test different scenarios of interventions and policies within the livestock and poultry systems in order to gain insights to inform decision-making processes. These approaches were conceived and developed through participatory processes, particularly Participatory Modeling.

Participatory Modelling is at the core of one of the novelties of SPEAR, as an approach that facilitates collaboration among key stakeholders, improving the understanding of the dynamics and interrelationships between social, economic, and ecological consequences.

1.4. Objectives and hypothesis

Grounded on the above brief state-of-the-art, the **general objective of this thesis** is:

> *To contribute to ongoing research and practice efforts aiming to steer food systems away from their present unsustainable trajectories and direct them toward a sustainable future. This will be achieved by promoting meaningful use of Systems Thinking and Complexity Science to inform and support transformative processes.*

Feeding to this main goal are the following specific objectives:

- **Specific objective 1:** *To guide and inspire diverse agents involved in assessing complex issues to engage meaningfully with Systems Thinking and Complexity Science, focusing on those involved in food systems work.*

  This is done by designing and testing a principles-based framework that synthesizes substantive Systems Thinking and Complexity Science (STCS) theory into a practical framework. The hypothesis is that enhanced use of STCS in the exploration of complex systemic issues will strengthen the understanding of these situations and thus will improve the design and implementation of any intervention measures aiming to foster systemic change.

- **Specific objective 2:** *To identify actionable ways to strengthen the different frameworks used to explore, unpack, assess, and act on food systems issues by leveraging Systems Thinking and Complexity Science principles.*

  This is done by identifying food systems frameworks developed over the last two decades and assessing their adherence to Systems Thinking and Complexity Science principles, identifying excelling areas and areas where improvements are advisable. Cross-learning among frameworks is advanced as the core means to keep advancing and refining food systems frameworks.

The hypothesis is that the more the frameworks leverage the vast theory and practice developed under Systems Thinking and Complexity Science, the better systemic understanding these frameworks will provide, leading to decisions that effectively inform and support food system transformations.

- **Specific objective 3:** *To contribute to the design of STCS-informed frameworks that allow for the collective identification of desirable and culturally feasible transformation pathways for food systems.*

This is done by bringing forward a Participatory Food Systems Modelling (PFSM) approach that fosters the engagement of diverse stakeholders and perspectives in exploring and making sense of complex situations, envisioning a desired state, and identifying potential pathways to move from the current situation to the envisioned future.

The hypothesis is that fostering discussions, exchanges, and reflections among stakeholders with different worldviews will lead to individual and collective learning, giving rise to valuable insights to support and inform meaningful transformations.

1.5. Methodological approach and overview of the thesis

This thesis comprises six chapters. Chapter 1 provides the essential background information, setting the stage for the entire thesis. Chapters 2 to 5 are dedicated to fulfilling the three specific objectives outlined in Section 1.3. Chapter 6 synthesizes the findings from these chapters, offering overall conclusions on how these insights contribute to achieving the overarching goal.

After the overview provided by Chapter 1, Chapter 2 responds to the first specific objective and focuses on designing a principles-based framework that synthesizes key insights and practices from Systems Thinking and Complexity Science (STCS), providing practitioners, researchers, and others engaged in food systems change processes with meaningful guidance to make sense of and address complex challenges. By doing so, Chapter 2 lays the foundation to better contribute to food systems' transformations towards sustainability.

Building on the STCS principles-based framework proposed in Chapter 2, Chapter 3 aims to strengthen food systems frameworks by leveraging Systems Thinking and Complexity Science to identify areas for improvement and foster cross-learning among existing frameworks. Through an evaluation of 20 food systems frameworks published over the last two decades, this chapter identifies actionable ways to advance their role in informing and supporting food systems transformations. This work is developed on the premise that the main barriers to transforming food systems are rooted in the complex and systemic nature of food systems (Leeuwis et al., 2021).

The findings on how food systems frameworks accounted for features currently posing barriers to transformations laid the groundwork for, in Chapter 4, designing a Participatory Food Systems Modeling (PFSM) framework that – being informed on STCS – facilitates collective exploration, discussion, learning, and reflection among stakeholders to identify desirable and culturally feasible transformation pathways for food systems.

The PFSM framework's practical implementation and value in identifying transformation pathways are further explored in Chapter 5, where it is applied to two case studies in poultry systems in Ghana and Southern Senegal. The insights from these applications offer empirical evidence of the PFSM framework's value in informing decision-making to foster transformations, providing valuable lessons for future research and practice in advancing food systems challenges in the region and beyond.

The methodological approach followed throughout these chapters enables the integration of theoretical, methodological, and practical insights. This integration contributes to meaningfully bringing Systems Thinking and Complexity Science into food systems research and practice, ultimately informing and supporting transformative processes that guide food systems toward sustainability.

Below is a brief description of the methodological approach adopted to address each specific objective.

1.5.1. Addressing specific objective 1: Designing an STCS principles-based framework.

Systems Thinking and Complexity Science (STCS) emerged to transcend the traditional linear ways of thinking to systemic approaches that address complex issues and support transformational processes (Gates, 2016; Gates et al., 2021; Reynolds et al., 2012; Walton et al., 2021). As dynamic fields of knowledge, there are different schools of thought within Systems Thinking and Complexity Science, each with its own philosophical assumptions on which theories, ideas, concepts, approaches, methods, and tools are proposed. One of the main barriers to substantially engaging with STCS is this broad array of ideas and practices that, if decoupled from their associated theory and philosophical assumptions, prevent the engagement needed to support meaningful responses to complex challenges (Patton, 2019).

In this regard, the second chapter of this thesis aims to design an actionable principle-based framework that provides guidance and inspires practitioners and other agents engaged in assessing complex issues to inform their practice in Systems Thinking and Complexity Science (STCS). The framework synthesizes the approaches, concepts, ideas, and practices of STCS to support the work of those engaged in assessing complex issues related to sustainability and development. Particularly, the challenges linked to how food is being produced, processed, marketed, and consumed to inform and support transformations that lead to more productive and prosperous, equitable and inclusive, empowering and respectful, resilient and regenerative, and healthy food systems.

To design the principles-based framework, academic and grey literature on the use of Systems Thinking and Complexity Science in evaluation were identified and reviewed. The information gathered from the literature review was presented in a hierarchical framework structured into three levels. The first level comprises three dimensions corresponding with three significant considerations to deal with complex issues. Each dimension fleshes out overarching principles – ten in total – that summarize the main STCS insights for understanding and addressing complex issues in the second level of the STCS-principles-based framework. Lastly, the conceptual and methodological guidance offered by literature to better understand and address features of complex issues informed the design of 26 operating principles that provide specific guidance for the practical implementation, adaptation, and evaluation of the ten overarching principles.

The STCS-principles-based framework was applied to the meta-evaluation of the TEEBAgriFood framework. This STCS-informed evaluation framework aims to make sense of food systems' complex challenges and inform the design of socially desirable measures to address them. This application allowed for an assessment of the TEEBAgriFood adherence to the principles, gaining valuable insights about the meaningfulness of the STCS principles-based framework to understand and address complex issues. Moreover, it informed reflections on the meaningfulness of the STCS principles in guiding and inspiring agents engaged in evaluation practice to draw upon STCS as a way to better support their responses to global challenges, particularly those related to food systems.

1.5.2. Addressing specific objective 2: Leveraging STCS principles to strengthen food systems frameworks.

Food systems frameworks have been developed over the last two decades to explore and shed light on the complexity of food systems challenges and find suitable ways to address them. Despite these frameworks' undeniable contributions to making sense of food systems challenges, their support for food systems transformations is still limited (Brouwer et al., 2020; Hebinck et al., 2021; Zou et al., 2020).

Under the assumption that the barriers hindering food systems transformations are rooted in their complex and systemic nature (Leeuwis et al., 2021), the second chapter of this thesis aims to find ways to strengthen the guidance offered by food systems frameworks to deal with systems and complexity features posing barriers to transformation. In that regard, 20 food systems frameworks developed over the last two decades were identified from a literature review and assessed using the STCS-principles-based framework proposed in the second chapter to identify ways to strengthen food systems frameworks in their role to inform and support transformations. To this end, an evaluation rubric (Davidson, 2004) was designed based on the ten overarching principles of STCS as criteria to assess the extent to and ways in which food systems frameworks address the main barriers to leveraging food systems transformations.

The assessment shed light on how the guidance food systems frameworks offer, as accounting for systems and complexity features of food systems, help address the barriers to advance their transformation. In that sense, the assessment showcased exemplary practices proposed by food systems frameworks and set the groundwork for exchanges and cross-learning within the food systems field of research to uphold their contributions to transformation. On the other hand, the assessment revealed areas where food systems frameworks could benefit from further dialogue with Systems Thinking and Complexity Science fields.

1.5.3. Addressing specific objective 3: Designing a Participatory Food Systems Modeling Framework.

The assessment of food systems frameworks from a Systems Thinking and Complexity Science perspective, conducted in Chapter 3, yielded valuable insights into the extent to which barriers preventing food systems transformations are being addressed. Building on these findings, Chapter 4 highlights the importance of involving diverse stakeholders and perspectives in exploring and making sense of the problematic situation, envisioning a desired state, and identifying potential pathways to move from the current situation to the envisioned future. According to Schot & Steinmueller (2018), this engagement is crucial to facilitate the needed transformations of food systems.

In that regard, Chapter 4 proposes a Participatory Food Systems Modelling (PFSM) framework that aims to identify desirable and culturally feasible transformation pathways for food systems by fostering collective processes of exploration, discussion, learning, and reflection among stakeholders holding different perspectives.

The proposed PFSM is built adopting the participatory modeling approach as heuristic, the Soft Systems Methodology as the guiding methodology to design the stages and activities to implement the PFSM framework, and the TEEBAgriFood framework to nuance the participatory modeling approach to food systems analysis. The PFSM framework comprises three stages that are part of the iterative process of collectively making sense of problematic situations to gain insights from engaging with diverse perspectives that allow identifying potentially desirable and culturally feasible pathways for transformation. This framework is implemented in two case studies in poultry systems in West Africa, specifically in Ghana and southern Senegal, to test its value in identifying desirable and culturally feasible transformation pathways for food systems.

Chapter 4 details the PFSM theoretical foundations and methodological approach, as well as the nuances in implementing the PFSM framework in the case studies in Ghana and Southern Senegal. The implications of the adaptations made to the PFSM frameworks in the case studies and their implications are also discussed in this chapter.

Chapter 5 describes the results of the applications of the PFSM framework in the two case studies mentioned above and includes some reflections on the value of the PFSM framework in advancing the challenges of food systems in Ghana, Senegal, and West Africa in general. Lastly, based on the results of the two applications, Chapter 5 concludes on the value of the PFSM for food systems transformations and shares some lessons learned for future research and practice.

2. SYSTEMS THINKING AND COMPLEXITY SCIENCE: FOSTERING A MEANINGFUL USE IN UNDERSTANDING AND ADDRESSING COMPLEX SITUATIONS

In response to the global imperative to think systemically to address the complex and multifaceted challenges confronting humanity, insights from the Systems Thinking and Complexity Science (STCS) have been informing the evaluation practice that aids in making sense of complex issues and inform strategies to address them. Despite the growing interest in STCS, questions remain about how to meaningfully bring these fields of knowledge into practice to respond to global challenges.

Given the above, Chapter 2 aims to bridge the gap between the extensive knowledge within STCS and the evaluation practice. This chapter proposes a principles-based framework that synthesizes key insights from Systems Thinking and Complexity Science into actionable principles to guide and inspire those engaged in comprehending and addressing complex issues. These principles offer theoretical and methodological guidance for understanding and addressing the features inherent to complex issues.

Subsequently, the STCS principles-based framework is tested by assessing the extent to which TEEBAgriFood – an STCS-informed food systems evaluation framework – advances STCS into evaluation. Results provide learning and insights about the use of STCS in food systems evaluation practice and their meaningfulness to understand and address complex issues.

2.1. From linear to systemic approaches: A turn to Systems Thinking and Complexity Science to respond to global challenges.

For several decades, a paradigm shift towards increasingly systemic understandings has been reshaping research, debates, and interventions in diverse fields that explore and address complex issues. This shift is demonstrated by a growing interest in Systems Thinking and Complexity Science (Gates, 2016; Gates et al., 2021; Walton et al., 2021). In the evaluation field, this interest has been growing in the last three decades (Gates et al., 2021).

Despite the different schools of thought within the Systems Thinking and Complexity Science fields, as well as the broad array of approaches, concepts, theories, methods, and techniques offered by each, Systems Thinking and Complexity Science (STCS) remain one banner in the evaluation field as a way to evidence the shift in mindsets from traditional linear and reductionist ways of thinking and practicing evaluation to systemic approaches that address complex issues and support transformational processes (Gates et al., 2021).

According to Patton (2019a), a substantial engagement with STCS in evaluation practice is necessary to stop perpetuating the linear and narrow thinking that hinders the role evaluation can play in supporting meaningful responses to the challenges humanity currently faces. Engaging with STCS would strengthen complexity awareness among decision-makers, practitioners from different fields, and civil society, thus enabling them to provide valuable insights to better deal with complex challenges such as food insecurity, poverty, and climate change (Reynolds et al., 2012).

To meaningfully bring STCS to evaluation practice, barriers must be addressed. Some barriers are the broad and constantly evolving array of insights developed within the two disciplines, the use of technical language and terms, evolving debates, epistemological discrepancies, or philosophical assumptions underpinning different systems thinking and complexity theory schools of thought. These barriers can lead to attempts to bring STCS into evaluation practice that rely on the use of some mainstream concepts, methods, or tools without delving into the associated theory and assumptions underpinning different Systems Thinking and Complexity Science traditions and approaches (Walton et al., 2021).

Several efforts have been developed in the last two decades to support bringing STCS approaches, methods, ideas, and concepts into practice. Set of principles (SETIG, 2018), introductory guides (Burns & Worsley, 2015; CECAN, 2019; Rickles et al., 2007; Westhorp, 2012; Williams & Iman, 2006), and practical guides/ workbooks (Reynolds & Holwell, 2010; Williams & Hummelbrunner, 2009; Williams & Van't Hof, 2014) count among those efforts.

The efforts mentioned above set the foundation to propose in this chapter an STCS principles-based framework that aims to help practitioners from different fields overcome barriers to meaningfully bring STCS into practice and thus inform the design of meaningful responses to complex challenges related to sustainability and human wellbeing, particularly those linked to food systems.

According to Patton's GUIDE framework for effective principles (2018), principles intend to (a) provide meaningful guidance on the use of STCS in different evaluation activities and for different evaluation roles, particularly to better understand and address global complex challenges; (b) be useful in supporting better decisions in embracing STCS in evaluation; (c) inspire evaluation researchers, practitioners, and commissioners to acknowledge and further explore how STCS can improve their practice; (d) be context-sensitive, adaptable, and enduring; (e) be evaluable in whether they are being followed, useful, and effective.

A second objective of this chapter is to test the proposed STCS principles-based framework by applying it to the meta-evaluation of an STCS-informed evaluation framework: The Economics of Ecosystems and Biodiversity for Agriculture and Food Evaluation Framework (TEEB, 2018), hereafter referred to as TEEBAgriFood. Considering the guidance of Patton (2018) for a principles-based evaluation, this application seeks to test the STCS principles-based framework by critically assessing the adherence and meaningfulness of the proposed principles and learning from using them.

The decision to apply the STCS-principles-based framework to the TEEBAgriFood framework responds to two factors: (i) to the general interest of this thesis in food systems and their contributions to sustainable development, and (ii) to the solid theoretical foundations of TEEBAgriFood in STCS. Regarding the latter, a review of this framework states that TEEBAgriFood "likely constitutes the most advanced, state-of-art model for comprehensive systems evaluation that exists – a multidimensional, integrated, systems-based, and complexity-informed approach" (Patton, 2019b, p.1).

2.2. Use of principles to foster an STCS-informed evaluation practice

Among the many efforts performed to overcome barriers preventing a meaningful use of STCS in the evaluation practice, the use of a principles-based approach is seen as an effective way to inform and guide choices of diverse actors involved in evaluation practice to meaningfully engage with Systems Thinking and Complexity Science (Patton, 2017; Richardson & Patton, 2020; SETIG, 2018; Walton et al. 2021).

Michael Q. Patton proposes using principles to guide evaluation, sense-making, learning, and decision-making processes in complex settings (Richardson & Patton, 2021). Principles inform and guide those choices, and they do so by telling us how to act (Patton, n.d.).

Principles-focused evaluation informs choices about which principles are appropriate for what purposes in which contexts, helping to navigate the treacherous terrain of conflicting guidance and competing advice (Patton, 2017). What principles work for what situations with what results is an evaluation question. Thus, from an evaluation perspective, principles are hypotheses, not truths. They may or may not work. They may or may not be followed. They may or may not lead to desired outcomes. Whether they work, whether they are followed, and whether they yield desired outcomes are subject to evaluation. Learning to evaluate principles and applying what you learn from doing so takes on increasing importance in an ever more complex world where our effectiveness depends on adapting to context. Principles guide that adaptation (Patton, n.d.).

Principles-focused evaluation examines (1) Whether principles are clear, meaningful, and actionable, and if so; (2) Whether they are actually being followed and, if so; (3) Whether they are leading to desired results (Patton, 2017).

A high-quality principle provides guidance about what to do, is useful for informing decisions and actions, provides inspiration as an expression of values, is relevant to diverse contexts and situations, and can be evaluated. These criteria for effective principles are further developed under the GUIDE framework proposed by Patton (2017).

Essentially, GUIDE criteria provide an evaluability assessment framework applied to principles. According to the GUIDE framework (Patton, 2017), principles are expected to:

- Provide meaningful <u>Guidance</u> on what to do, how to think, what to value, and how to act. It offers direction that is sufficiently distinct that it can be distinguished from contrary or alternative guidance.
- Be <u>Useful</u> in supporting choices and decisions leading to desired results. Its utility resides in being actionable, interpretable, feasible, and pointing the way toward desired results for any relevant situation.
- Be <u>Inspiring</u> by meaningfully evoking a sense of purpose and incorporating and expressing ethical premises. They articulate value-based expressions of what matters, both in how to proceed and the desired result.
- Be <u>Developmental</u> – enduring, context-sensitive, and complexity-adaptable to diverse contexts and over time. A principle is thus both context-sensitive and adaptable to real-world dynamics, providing a way to navigate the turbulence of complexity and uncertainty. In being applicable over time, it is enduring (not time-bound) in support of ongoing development and adaptation in an ever-changing world.
- And be <u>Evaluable</u> so it can be tracked, documented, and assessed whether they are meaningful, adhered to, and relevant to achieve desired results.

2.3. Methodology: Design of an STCS principles-based framework

2.3.1. Review of academic and gray literature on the use of STCS in evaluation

The first step to developing a principles-based framework based on STCS literature was to identify key literature on the use of STCS in evaluation. A search was done in the Scopus and Web of Science bibliographic databases and the Google Scholar search engine to identify both academic and gray literature on STCS in evaluation, using a combination of terms on systems, complexity, and evaluation. Additional resources were identified through a snowball technique starting from the reference lists of relevant literature found.

The literature reviewed focused on resources providing guiding insights for enhancing evaluation practice through systems thinking and complexity sciences. Resources not exhibiting a clear link with evaluation practice and those focused on specific case studies, methodologies, or interventions without providing theoretical links to STCS were excluded from the review.

As a result, 11 documents that address systems thinking in evaluation were identified, 12 addressing complexity science in evaluation, and three addressing the implications of using both in evaluation (Table 2.1).

Table 2.1. Literature addressing systems thinking and/or complexity science in evaluation.

nº	Title	Author(s) (Year)	Field of knowledge
1	Navigating Complexity in International Development	Burns & Worsley (2015)	CS
2	Complexity Theory and the Social Sciences: the state of the art	Byrne & Callaghan (2014)	CS
3	Evaluating Complex Social Interventions in a Complex World	Byrne, D. (2013)	CS
4	Systems Thinking	Cabrera, Colosi & Lobdell (2008)	ST
5	Complexity Evaluation Framework	CECAN (2019)	CS
6	Softs Systems Methodology. In Reynolds & Holwell (Eds), *Systems Approaches to Managing Change: A Practical Guide*	Checkland & Poulter (2010)	ST
7	Systems Evaluation Protocol	Cornell Office for Research on Evaluation (2009)	ST
8	Applying Complexity Theory to New Zealand Public Policy. Principles for Practice	Eppel, Matheson & Walton (2011)	CS
9	Putting the System Back into Systems Change: A Framework for Understanding and Changing Organizational and Community Systems	Foster-Fishman, Nowell & Yang (2007).	ST
10	Making Sense of the Emerging Conversation in Evaluation about	Gates (2016)	STCS

	Systems Thinking and Complexity Science		
11	Systems Thinking and Evaluation	Hummelbrunner (2011)	ST
12	Introduction. In B. Williams, I. Iman (Eds.) *Systems Concepts in Evaluation: An Expert Anthology*	Iman, LaGoy & Williams (2006)	ST
13	Capturing the Complexity of Evaluations of Health Promotion Interventions. A scoping review	Kania et al. (2012)	CS
14	Systems Thinking for Evaluation. In B. Williams & I. Iman (Eds.) *Systems Concepts in Evaluation: An Expert Anthology*	Midgley (2006).	ST
15	Exploring the Science of Complexity. Implications for Development and Humanitarian Efforts	Ramalingam, Jones, Reba & Young (2008)	CS
16	Introducing systems approaches. In M. Reynolds & S. Holwell (Eds.) *Systems Approaches to Managing Change: A Practical Guide*	Reynolds & Holwell (2010)	ST
17	Complexity, Systems Thinking, and Evaluation - an Emerging Relationship?	Reynolds, et al. (2012)	STCS
18	Towards Systemic Evaluation	Reynolds, et al. (2016)	STCS
19	A Simple Guide to Chaos and Complexity	Rickles, Hawe & Shiell (2007)	CS
20	Principles for Effective Use of ST in Evaluation	SETIG (2018)	ST

21	Complexity Theory: An Overview with Potential Applications for the Social Sciences	Turner & Baker (2019)	CS
22	Critical Systems Heuristics. In B. Williams & I. Iman (Eds.) *Systems Approaches to Managing Change: A Practical Guide*	Ulrich & Reynolds (2010)	ST
23	Insights from Complexity Theory for the Evaluation of Development Action	Vincent (2012)	CS
24	Applying Complexity Theory: A Review to Inform Evaluation Design	Walton, M. (2014)	CS
25	Using Complexity-consistent Theory for Evaluating Complex Systems	Westhorp (2012)	CS
26	About Systems, Thinking Systemically, and Being Systemic. In *Systems concepts in action: A Practitioner's Toolkit*	Williams & Hummelbrunner (2009)	ST

*ST: Systems Thinking; CS: Complexity Science; STCS: Systems Thinking and Complexity Science

2.3.2. Making sense of the information gathered: Three significant considerations to deal with complex situations.

From the literature review, key features or concepts that help make sense of complex issues were identified and described, identifying commonalities and similarities between Systems Thinking and Complexity Science upon which to build categories that facilitate the design of an STCS principles-based framework.

The information from complexity science was organized into three categories – systems, changes, and agency – based on the groups proposed by Ramalingam et al. (2008). About systems thinking, the information was organized around three concepts that summarize the application of systems thinking in evaluation – interrelationships, perspectives, and boundaries (Midgley, 2006; Reynolds & Holwell, 2010b; Williams & Iman, 2006).

The key features extracted from the literature review are underlined within each category described below.

Complexity Science

- *Systems*

The first group describes the complex systems' structure, delving into aspects such as their hierarchical and multidimensional structure, their multiple constitutive elements, the nonlinear relationship between these elements, and the properties and behavior emerging from the multiple interrelations. It should be noted that when referring to elements, the diversity of agents involved in the systems – individuals, groups, and institutions – and their worldviews are included.

Defining the systems' elements requires deciding what to include and what to exclude by setting boundaries. According to Walton (2014), those boundaries are social constructs that reflect the position of the agents making the decisions.

The structure of complex systems is hierarchical, composed of multiple elements that interact with each other, constituting different levels of organization where the lower levels nest in the higher ones. The linkages between systems elements form relationships of causality and dependence that constitute the system as a whole. Non-linearity is the main feature of those relationships, which means that perturbations in one element can disproportionately affect other elements and the system as a whole. This is partly explained by the presence of feedback loops that can accelerate or suppress changes in complex systems, leading to unpredictable consequences and outcomes.

From the set of elements and interrelationships with the system emerge properties and behavior that cannot be predicted from its constitutive elements. This condition, called emergence, can only be understood by recognizing that system elements interrelate with each other and with the whole, configuring the behavior and properties of the system, which in turn influence the behavior of their elements.

- *Changes*

The second group includes concepts that explain the behavior of complex systems over time. To make sense of the behavior of complex systems, these are recognized as adaptive and far from equilibrium systems. The latter means they are systems that, being easily disrupted to swap attractors, cannot operate in stability for long periods (Byrne & Callaghan, 2014; Kania et al., 2012).

In the absence of significant perturbations, complex systems can maintain their normal trajectory and remain stable. However, once a point of disruption is reached, and if the internal behavior of the system is conducive, the system can undergo structural changes that allow it to adapt to extreme changes, evolving towards new development paths (Byrne & Callaghan, 2012; Vincent, 2012).

The first concept for understanding the dynamic behavior of complex systems is the phase or state space, a mathematical space determined by all the relevant dimensions for understanding the system's behavior and the possible values that those dimensions can take (Ramalingam et al., 2008). Delimiting this space allows for describing all possible states of the complex system (Byrne, 2013).

The system's state at a given time is defined by the values taken by its variables at that time and is represented as a point in the phase space (Rickles et al., 2007). While the state of the system may be described in terms of the value taken by a large number of its variables, only a few determine the actual character of those states (Byrne & Callaghan, 2014).

There are two concepts of interest to make sense of the system's ability to undergo structural changes and shift states: order and control parameters. "Order parameters are systemic features that indicate how system's elements cooperate or compete with each other…. Control parameters are external inputs that can be tuned to change the order parameters and thus shift the system from one state to another" (Rickles, 2007, p. 935).

Rickles (2007) also pointed out that "when a control parameter reaches a critical point, the degree of connectivity between the units of the system is extremely high" (p. 935). Consequently, any minor change leads to the tipping point where the system undergoes substantial changes, switching states (CECAN, n.d., Vincent, 2012; Westhorp, 2012).

A system's trajectory is determined by its state changes over time (Ramalingam et al., 2008; Rickles et al., 2007). One way to make sense of such trajectories is by exploring attractors (Byrne & Callaghan, 2014; Ramalingam et al., 2008). Attractors are subsets of the phase space that illustrate how complex systems change from one equilibrium point to another (Burns & Worsley, 2015). A simple way to understand the notion of attractors is as the behavior or state that the system reaches after undergoing a perturbation (Rickles et al., 2007; Vincent, 2012). Several attractors can be in the phase space (Rickles et al., 2007).

According to Walton (2014), attractors draw a pattern of behavior that represents stability. Changes in such states mean a substantial change in the system that may impact its overall behavior and emergent properties. Understanding how these two features or concepts relate to each other provides a useful framework for understanding stability and change in complex systems.

In addition to the aforementioned concepts, it is essential to recognize the sensitivity of systems' behavior to its historical trajectory and initial conditions (Burns & Worsley, 2015; Byrne & Callaghan, 2014; CECAN, n.d., Kania et al., 2012; Westhorp, 2012). This path dependence means that a decision made at a certain point in time enables a range of possible future states but limits others that could have been enabled with other decisions being taken (Byrne, 2013; Kania et al., 2012; Ramalingam et al., 2008), thus explaining the role of history in the evolution of complex systems (Vincent, 2012). Along the same line, there is systems' sensitivity to context (Burns & Worsley, 2015; Kania et al., 2012).

Given these last two features, transferring an intervention from one context to another is not advisable without understanding the interrelationships between its elements and how certain properties and behaviors emerge from them (Burns & Worsley, 2015).

Phase shifts in complex systems represent their dynamic behavior (Byrne & Callaghan, 2014). Hence, its exploration will shed light on how changes are triggered and how they might be catalyzed (Burns & Worsley, 2015).

Changes in the behavioral dynamics of systems are essential to create sustainable changes. Only changing behavioral dynamics will avoid re-establishing the dominant pattern and marginalizing initiatives that are proposed outside it (Burns & Worsley, 2015).

- *Agency*

The third group delves into the notion of adaptive agents, understood as agents that have their own purposes and views of the situation, which shape their behavior and actions within the system (CECAN, n.d., Ramanligam et al., 2008). Adaptive agents also have the capacity to learn and modify their behavior over time in response to interactions with other agents, contextual elements, and systems' dynamics (Kania et al., 2012; Ramalingam et al., 2008).

Engaging and bringing together agents with different perspectives and kinds of expertise through participatory approaches is highly encouraged to build a broader picture of complex systems (Eppel et al., 2011; Kania et al., 2012) and facilitate the co-creation of interventions that make sense in practice (Vincent, 2012).

Besides acknowledging and engaging with different perspectives, it is crucial to understand the *governance structure* within complex systems, especially in social systems where agents' behavior, interactions, and social structures play a pivotal role in systems' dynamics and outcomes (Byrne, 2013). In this sense, Byrne (2013) and Vincent (2012) call for understanding the negotiated order to act on social systems by delving into the system's structural conditions, power relations, and communication processes.

Adaptive agents have a self-organization capacity that adds complexity to the design of interventions in social systems (Eppel et al., 2011). Self-organization happens when systems order themselves without external tuning of a control parameter (Rickles et al., 2007) due to the interactions between adaptive agents (Ramalingam et al., 2008). This property enables systems to change adaptively to cope with their environment (Kania et al., 2012; Vincent, 2012).

Systems Thinking

- Interrelationships between elements of a system

Systems thinking is about gaining an understanding of real-world situations by looking at the multiple elements and actors interrelated with one another and with their environment (Reynold et al., 2016). These situations can be framed as complex systems with a hierarchical structure consisting of interrelated elements or subunits, which can themselves be systems into the broader system they are embedded in (Cornell Office for Research on Evaluation, 2009; Iman et al., 2006; Midgley, 2006).

Systems are considered sets of interrelated parts that together form a whole (Cabrera et al., 2008; Foster-Fishman et al., 2007; Hummelbrunner, 2011; Williams & Hummelbrunner, 2009). Midgley (2006) points out that the system as a whole can impact its subunits, while the subunits contribute to challenging the stability of the whole.

Interrelations refer to how systems' elements or subunits are linked to each other (Reynolds et al., 2016). Exploring interrelations involves making sense of their non-linear nature (Williams & Hummelbrunner, 2009) and delving into feedback loops and interdependencies (Midgley, 2006; Williams & Hummelbrunner, 2009). Understanding the consequences and implications of these interrelations is vital in comprehending emergent properties and the non-linear behavior of systems (Foster-Fishman et al., 2007; Reynolds et al., 2012; Reynolds & Holwell, 2010).

For observing the properties and behavior emerging from interrelations, it is essential to consider the system as a whole rather than focusing solely on its parts (Midgley, 2006; Reynolds & Holwell, 2010). In other words, understanding how system elements are organized and interrelated is crucial to grasping the emergent properties and changing behavior of complex systems (Reynolds et al., 2012).

For coping with systems' dynamic behavior and their ability to evolve and adapt to their changing environment, evaluation should be designed as an iterative process of learning and adaptation (Cornell Office for Research on Evaluation, 2009; Gates, 2016; Hummelbrunner, 2011; Midgley, 2006; Reynolds et al., 2012; Reynolds et al., 2016; SETIG, 2018).

- Perspectives from which a situation can be understood.

Systems are inevitably simplifications of reality, shaped by the worldviews of the people who define them (Hummelbrunner, 2011; Williams & Hummelbrunner, 2009). Consequently, the different understandings of real-world situations (Reynolds et al., 2016) should be explored to identify key perspectives (Williams & Hummelbrunner, 2009).

Recognizing different perspectives when exploring complex situations is essential to obtaining a closer-to-reality view (Checkland & Poulter, 2010; Cornell Office for Research on Evaluation, 2009; Midgley, 2006). By involving a broad range of stakeholders in framing the situation, defining its desirable state, and proposing pathways to reach it, evaluators can tap into the richness of perspectives that build up the complex reality (Midgley, 2006; Reynolds & Holwell, 2010). This considers that how systems are conceptualized – in terms of elements, interrelationships, and boundaries – is determined by the perspectives adopted to frame the system (Cabrera, Colosi & Lobdell, 2008; SETIG, 2018).

Fostering participatory processes becomes essential in systems thinking to bring together diverse perspectives and promote dialogue and sharing among stakeholders (Cornell Office for Research on Evaluation, 2009). Such processes enable a shared and deeper understanding of the situation to emerge, informed by an enhanced awareness among stakeholders of the values and assumptions underlying diverse perspectives (Foster-Fishmand, Nowell & Yang, 2007; Williams & Hummelbrunner, 2009).

Reynolds et al. (2012) warn that not all perspectives are equally shared and considered when making decisions concerning a complex situation. In that regard, it is crucial to recognize the role of power relations in shaping social group's behavior and influencing decision-making processes (Midgley, 2006). Systemic approaches should address the power inequalities associated with diverse perspectives coexisting in the system and consider their consequences (SETIG, 2018).

- Boundaries

In systems inquiry, boundaries play a crucial role in defining what is relevant for evaluation and making situations manageable (Gates, 2016; Williams & Hummelbrunner, 2009). Boundaries, as human constructs, depend on the perspectives under which a situation is explored (Cornell Office for Research on Evaluation, 2009; Gates, 2016). Since it is not feasible to be entirely comprehensive or holistic in the strictest sense, setting boundaries is essential to focus the evaluation (Hummelbrunner, 2009; Iman, LaGoy & Williams, 2006).

Boundary decisions require value judgments (Gates, 2016; Reynolds et al., 2016), for which engagement with diverse perspectives is critical (Reynolds et al., 2012). Through spaces for dialogue and exchanges, stakeholders engaged in the evaluation process can question the underlying values and assumptions of different perspectives (Midgley, 2006), increasing their awareness of the consequences of prioritizing certain elements and excluding others to achieve the desired change in the situation (Foster-Fishman, Nowell & Yang, 2007; Williams & Hummelbrunner, 2009).

Power and marginalization issues are closely tied to boundary decisions. Therefore, a critical reflection on which perspectives and associated values are privileged and which ones are excluded is needed (Iman, LaGoy & Williams, 2006; Reynolds et al., 2012; Reynolds et al., 2016; Williams & Hummelbrunner, 2009).

This reflection must encompass both ethical and practical considerations of boundary setting, including potential injustices and the practical consequences of excluding perspectives (Williams & Hummelbrunner, 2009).

Systems approaches are valuable in identifying boundaries and assessing their consequences (Hummelbrunner, 2011; Iman, LaGoy & Williams, 2006; SETIG, 2018), shedding light on how a situation is approached and managed, and with what purpose (Williams & Hummelbrunner, 2009).

Having in mind the concept of boundaries in systems thinking allows evaluators to navigate the complexity of boundary decisions and power imbalances while dealing with their practical and ethical consequences.

In the second stage, the features and concepts from both disciplines were reorganized – to avoid duplications and reduce overlaps – around three significant considerations to deal with complex issues.

The first consideration involves exploring the big picture as comprehensively as possible, recognizing the multiple dimensions, elements, and interrelationships that make up the system of interest. The second consideration is about understanding the dynamic behavior of the systems by delving into the factors and conditions that come into play to determine if the system remains stable or undergoes structural changes and how these changes go. Finally, the third consideration involved acknowledging the role of agents in how the system of interest is framed and configured and what decisions are made to improve it.

Table 2.2 organizes the key STCS features identified from the literature review around the dimensions above.

Table 2.2. STCS key features around three major considerations to deal with complex issues.

Considerations to deal with complex issues	STCS key features
I. Exploring the big picture	• Hierarchical structure and multidimensionality. • Interrelated elements • Interrelations and interdependencies • Non-linearity and feedback loops • Emergence
II. Understanding systems dynamics	• Phase space, system's states, and trajectories. • Patterns of behavior • Attractors and phase shifts • Control parameters and tipping points • Path dependence • Context sensitivity
III. Acknowledging the role of agents	• Adaptive agents • Self-organization • Perspectives and underlying values & assumptions • Participatory approaches and power relations. • Boundaries and governance structures.

Along with theoretical foundations regarding key features of complex issues, the reviewed literature on STCS offers conceptual and methodological guidance to better understand and address those features in order to cope with complex issues. Annex A summarizes all the information from the literature review, including theoretical and methodological guidance to deal with complex issues.

2.3.3. Assumptions upon which the STCS principles-based framework was built.

Given the purpose of meaningfully informing evaluation practice for diverse actors in diverse and complex contexts, all the information collected was synthetized through a principles-based approach (Patton, 2018).

The STCS principles-based framework is developed assuming that systems are means of re-presenting phenomena of the real world – ontological nominalism (Reynolds, 2011) – and that the knowledge is socially constructed, based upon subjective interpretations, and imbued with human purpose – epistemological constructivism, interpretivism, and critical idealism, respectively (Reynolds, 2011). These positions are aligned with the traditions of the soft and critical systems (Reynolds & Holwell, 2010) and with the metaphorical and critical pluralism schools of thought of complexity science (Raisio & Lundströn, 2017; Richardson, 2008).

From these ontological and epistemological stances, a multimethodological approach was applied, bringing together aspects, concepts, and considerations from different paradigms, traditions, and schools and presenting them as complementary to better deal with complex issues (Mingers & Brocklesby, 1997). This approach intends to enhance STCS-informed evaluation's capacity to better cope with the complexities of the diverse, context-dependent, and often conflicting situations of interest that evaluation is expected to shed light on and support.

2.4. Systems Thinking and Complexity Science (STCS) principles-based framework

This section presents the STCS principles-based framework (Table 2.3) designed to better understand and effectively address complex issues by paying attention to key features and elements, as identified in the literature review of Systems Thinking and Complexity Science (STCS) in evaluation.

The STCS principles-based framework is organized around three dimensions corresponding to the three considerations necessary for dealing with complex issues.

Within this framework, ten overarching principles summarized the main STCS insights for understanding and approaching complex issues in the context of evaluation practice.

In support of the ten overarching principles, 26 operating principles provide specific guidance at both theoretical and methodological levels for the practical implementation, adaptation, and evaluation of each overarching principle.

In summary, the hierarchical structure of the STCS principles-based framework centers around three dimensions that align with the considerations for managing complex issues. The ten overarching principles capture the main STCS insights to grasp and address complex issues in evaluation, while the 26 operating principles further elucidate and provide actionable guidance for effectively applying each overarching principle.

Table 2.3. Systems thinking and complexity science principles-based framework: dimensions, principles, and references supporting each principle.

DIMENSIONS	OVERARCHING PRINCIPLES	OPERATING PRINCIPLES	REFERENCES
I. Exploring the big picture	1. Acknowledge the **multidimensionality** and hierarchical structure of complex systems	1.1 Acknowledge that complex systems are built up of **subunits and elements interrelated** to each other in diverse and often unexpected ways while immersed in a broader and multidimensional context.	*Cornell Office for Research on Evaluation (2009); Eppel, Matheson, & Walton (2011); Iman, LaGoy, & Williams (2006); Kania et al. (2012); Rickles, Hawe, & Shiell (2007); Turner & Baker (2019); Vincent (2012); Walton (2014).*
		1.2 Provide methods and tools supporting the **mapping of the systems,** including their elements, the interrelations among them, and the interrelations with the context, to improve the understanding of the situations.	*Cornell Office for Research on Evaluation (2009); Williams & Hummelbrunner (2010).*

2. Engage with **interrelations** and interdependencies	2.1 Enable **understanding of the nature, characteristics, properties, and consequences of the interrelations** among elements, dimensions, levels, and scales within the system and its context.	*Burns & Worsley (2015); Byrne & Callaghan (2014); Cabrera, Colosi, & Lobdell (2008); Hummelbrunner (2011); Kania et al. (2012); Ramalingam, Jones, Reba, & Young (2008); Reynolds, Forss, Hummelbrunner, Marra, & Perrin (2012); Reynolds & Holwell (2010).*
	2.2 Provide analytical approaches, methods, and tools that acknowledge **non-linearity and capture feedback, delays, and other properties** in analyzing the multiple interrelations.	*Gates (2016); Reynolds et al. (2012); Turner & Baker (2019); William & Hummelbrunner (2010).*
3. Address **emergent properties** and unpredictable behavior	3.1 Focus on understanding the situation as a whole (systemically) to identify **emergent properties and dynamics that arise from interactions** among the system's elements and with the context.	*Byrne & Callaghan (2014); Eppel et al. (2011); Midgley (2006); Ramalingam et al. (2008); Reynolds, Gates, Hummelbrunner, Marra, & Williams (2016); Rickles et al. (2007); Turner & Baker (2019); Vincent (2012).*

		3.2 Provide methods and tools that help **identify emergent properties and address unpredictable behavior**.	*Gates (2016); Reynolds et al. (2012); Williams & Hummelbrunner (2010); Vincent (2012).*
II. Understanding the dynamics of the system	4. Map the system's movements through the **phase space** to identify underlying **patterns** of change	4.1 **Delimit the system's phase space** by understanding the possible values that variables and dimensions of the system can theoretically take to enable a better understanding of the system's behavior.	*Byrne (2013); Byrne & Callaghan (2014); Ramalingam et al. (2008); Rickles et al. (2007).*
		4.2 Enable an understanding of **systems' patterns of change** by using methods and tools that map the system's trajectory through the phase space.	*Kania et al. (2012); SETIG (2018); Vincent (2012).*
	5. Understand **how a system changes** between phases or states	5.1 Acknowledge the capacity of complex systems to remain **stable** in a dynamic context by absorbing changes without modifying their fundamental behavior. Also, acknowledge **tipping points** where the system modifies its behavior to adapt to or to change the context.	*CECAN (n.d).; Kania et al. (2012); Turner & Baker (2019); Vincent (2012).*

	5.2 Explore the **control parameters** and their role in triggering the **phase shifts** while acknowledging the limited existence of stability points where the system can move to - known as **attractors**.	*Burns & Worsley (2015); Byrne & Callaghan (2014).; Ramalingam et al. (2008); Vincent (2012); Walton (2014).*
	5.3 Provide methods and tools that allow (i) **identifying the attractors or points of stability** in the phase space and (ii) identifying when the control parameters reach the **tipping points** that trigger phase shifts.	*Vincent (2012); Walton (2014).*
	5.4 Contemplate a **time horizon** that allows exploring attractors and phase shifts to understand systems' patterns of change.	*CECAN (n.d).; Kania et al., (2012); SETIG (2018); Walton (2014).*
	5.5 **Be flexible and adaptable** enough with framings, processes, methods, and timelines to cope with the system's dynamic behavior. Review periodically the purpose and approach to the analysis. Learn from and adapt to as needed.	*5.5 CECAN (n.d); Cornell Office for Research on Evaluation (2009); Eppel et al. (2011); Kania et al. (2012); SETIG (2018).*

	6. Acknowledge the **path dependence** and **context sensitivity** of complex systems	6.1 Acknowledge that, in complex systems**, results may not be generalizable or transferable** due to the heavy dependency on systems' history and context.	*Burns & Worsley (2015); CECAN (n.d).; Ramalingam et al. (2008); Rickles et al. (2007); Turner & Baker (2019); Vincent (2012).*
		6.2 **Map the systems' evolution over time**. Acknowledge the initial state and the path history to better understand its dynamics and emergent behavior.	*Vincent (2012).*
III. Acknowledging the role of agents in framing systems	7. Understand **adaptive agents** and the self-organization capacity that arises from the interactions among them	7.1 Acknowledge the self-organization of the system emerging from the adaptive behavior of agents. The dynamic of the system and the changing context influence and are influenced by the learning, knowledge, and way of acting of the agents. This is an iterative process by which **adaptive agents influence and are influenced by the system and the context**.	*CECAN (n.d); Eppel et al. (2011); Kania et al. (2012); Ramalingam et al. (2008); Turner & Baker (2019); Vincent (2012).*
		7.2 Provide approaches and methods that **capture the links between changes in agents, context, and other systems' components** to	*Checkland & Poulter (2010); Eppel et al. (2011); Hummelbrunner (2011); SETIG, (2018); Vincent (2012).*

	understand how agents adapt to and co-evolve with the system and its context.	
8. Acknowledge diverse **perspectives** as part of the same big reality	8.1 Acknowledge that systems are conceptualizations of complex issues rooted in and responding to different and sometimes conflicting perspectives. Therefore, any systemic inquiry needs to **collectively explore these different worldviews and the consequences of them in framing the system and its analysis**.	*CECAN (n.d); Checkland & Poulter (2010); Cornell Office for Research on Evaluation (2009); Eppel et al. (2011); Kania et al. (2012); Ramalingam et al. (2008); Reynolds & Holwell (2010).*
	8.2 Actively **engage stakeholders in exploring their motivations, interests, concerns, and values on the situation being explored** to identify perspectives concerning how the system is, how it should be, desired pathways, and how it conditions how to approach the systemic analysis.	*CECAN (n.d.); Cornell Office for Research on Evaluation, (2009); Eppel et al. (2011); Foster-Fishman, Nowell, & Yang (2007); Hummelbrunner, (2011); Reynolds & Holwell (2010); SETIG (2018); Williams & Hummelbrunner (2010).*

9. Promote **dialogue and mutual appreciation** among perspectives to decide how to frame the situation	9.1 Promote and enable meaningful **dialogues and exchanges among perspectives** to co-create a common initial understanding from which to negotiate how to frame the situation.	*Eppel et al. (2011); Foster-Fishman et al. (2007); Hummelbrunner (2011); SETIG (2018).*
	9.2 Bring attention to **power relations and structural conditions** that shape how stakeholders share their interests, expectations, and perspectives, how they negotiate the framing of the situation, and the result of those negotiations.	*Hummelbrunner (2011); Midgley (2006); Reynolds & Holwell (2010).*
	9.3 Provide methods and/or tools that enable meaningful dialogues and fruitful exchanges among different perspectives while collectively acknowledging the links between power relations and the prioritization/ marginalization of perspectives and boundary decisions **in search of mutual understanding**.	*Checkland & Poulter (2010); Cornell Office for Research on Evaluation (2009); Foster-Fishman et al. (2007); Williams & Hummelbrunner (2010).*

	10.1 Acknowledge that **placing boundaries is essential in any systemic inquiry** and that not everything can be considered. In fact, boundaries determine what and who is considered relevant for the analysis.	*Cornell Office for Research on Evaluation (2009); Hummelbrunner (2011); Westhorp (2012).*
10. Place **boundaries** to manage complexity	10.2 Engage diverse perspectives on highly participatory and collaborative processes that provide spaces for discussion and mutual appreciation. **Support stakeholders in counting on as informed arguments as possible when deciding which perspectives and values to privilege when defining the system's boundaries**.	*Burns & Worsley (2015); Byrne & Callaghan (2014); CECAN (n.d); Cornell Office for Research on Evaluation (2009); Hummelbrunner (2011); Iman et al. (2006); Reynolds et al. (2016); SETIG (2018); Walton (2014); Williams & Hummelbrunner (2010).*
	10.3 Explore the values that sustain stakeholders' perspectives**.** Support collective critical assessment of the links between the **values that underpin different perspectives and the decisions about the boundaries in the system**.	*Cornell Office for Research on Evaluation (2009); Iman et al. (2006); Westhorp (2012).*

	10.4 Acknowledge, explore, and support critical assessment of the **ethical and practical consequences** of the boundaries placed and how the systems are framed. Plan how to address these consequences.	*Eppel et al. (2011); Ulrich & Reynolds (2010); Williams & Hummelbrunner (2009).*

2.5. Application of the STCS principles-based framework to the meta-evaluation of TEEBAgriFood

The STCS principles-based framework was applied to the meta-evaluation of an STCS-informed evaluation framework focused on complex issues related to food systems – TEEBAgriFood – to test it and learn from its use.

TEEBAgriFood aims to make a case for a paradigm shift in the way food is produced and consumed by increasing the awareness of economically visible and invisible externalities and impacts—both negative and positive—of the value chain activities on the human, social, produced, and natural capitals through a comprehensive system-wide evaluation of the eco-agrifood system (TEEB, 2018). Among its potential uses, TEEBAgriFood is expected to support the identification of pathways for systemic improvement and thus inform the decision-making of farmers, researchers, policymakers, investors, companies, and other actors in the food system. It also allows the comparison between interventions in different systems by providing a common framework for their analysis. Finally, it is expected to be used in an interdisciplinary and participatory way by facilitating engagement and dialogue among stakeholders and allowing the design of socially desirable measures to improve food systems (TEEB, 2018).

The meta-evaluation of TEEBAgriFood is made by assessing the concepts, approaches, and methods described in the seminal TEEBAgriFood Scientific and Economic Foundations Report (TEEB, 2018), hereafter referred to as the TEEB report.

This meta-evaluation assessed the adherence and meaningfulness of the operating and overarching principles of the STCS framework in TEEBAgriFood. The evaluation of adherence is based on the extent to which and ways in which each of the operating and overarching principles are addressed in the following sections of the TEEB report (TEEB, 2018): the theoretical justification for using systems thinking as a guiding perspective for TEEBAgriFood (Chapter 2), the conceptual and methodological development of the TEEBAgriFood evaluation framework (Chapter 6 and the introductory section of Chapter 7), and the pathways to reach the expected paradigm shift (Chapter 9). The evaluation of the meaningfulness of the STCS principles stems from reflections on their contributions to enhancing the TEEBAgriFood framework in their goals of supporting the identification of pathways for systemic improvements to inform decision-making on food systems. While this evaluation offers valuable insights into the potential of STCS principles for understanding and addressing food systems challenges within the context of TEEBAgriFood, it is crucial to note that this application represents just one test case.

2.6. Results from the application of the STCS principles-based framework to TEEBAgriFood

This section presents the results derived from applying the STCS principles-based framework to the meta-evaluation of TEEBAgriFood. Results are structured and delivered according to the three dimensions of the STCS principles-based framework and the overarching principles (OP) within each dimension. Although it is not explicit in the results, it is worth noting that the TEEBAgrifood framework was assessed in its adherence to each of the 26 operating principles. This adherence assessment allowed us to reflect on the strengths, weaknesses, and possible pathways for enhancing TEEBAgriFood as an STCS evaluation framework, which ultimately informed the reflections on the meaningfulness of the proposed STCS principles.

Dimension 1: Exploring the big picture.

TEEBAgriFood acknowledges the multidimensional and hierarchical structure of the eco-agrifood systems—value chain elements embedded in and interrelated to a multidimensional context composed of four capitals: human, social, produced, and natural—and provides system-associated methodologies like causal loop diagrams, Bayesian maps, and mind maps, to map this complexity (OP1). It develops a conceptual framework that helps understand interrelations and interdependencies between eco-agrifood systems' elements by describing the linkages between the value chain and the four capitals; however, it lacks guidance on addressing non-linear features like feedback and delays when exploring interrelations (OP2). Finally, it provides methodologies to map the complexity of food systems, like life-cycle assessment and propensity scoring methods, and other methodologies to identify and anticipate emergent behavior by modeling interrelationships, like systems dynamics (OP3). The evaluation of this first dimension of the STCS principles-based framework highlights the special attention paid by TEEBAgriFood to the complex structure, elements, and interrelationships of eco-agrifood systems, providing comprehensive descriptions of these along with concepts and methods that facilitate their understanding and further exploration.

Dimension 2: Understanding the dynamics of the system.

To understand the dynamics of the eco-agrifood systems, TEEBAgriFood maps the patterns of change that emerge from the interrelationships between the system and its context across the phase space. The phase space – understood as the space where the food systems can exist – is indirectly delimited by the range of values that the variables describing the context where food systems exist could possibly take. In TEEBAgriFood, these variables represent the changes in the four capitals that support eco-agrifood systems. Although the proposed methods aim to understand the interrelations at the time of the analysis, they do not pay special attention to the system's historical trajectory through the phase space, which is crucial for exploring and understanding patterns of change (OP4).

TEEBAgriFood defines systems change triggers as those factors and events changing the system's resilience, defined as the maintained capacity of capital stocks to provide goods and services. TEEBAgriFood then proposes simulation methodologies and models to explore how interrelations across the system change over time while contemplating making regular and ongoing measurements through periods to cope with the system's dynamic behavior. However, the significance of identifying the key variables that trigger phase shifts—or changes in systems' resilience—to understand food systems dynamics is not acknowledged (OP5).

By describing the eco-agrifood systems according to four capitals, TEEBAgriFood indirectly recognizes these systems' sensitivity to the context. Besides context sensitivity, path dependence is acknowledged theoretically but not sufficiently referenced in the TEEBAgriFood framework (OP6).

The assessment of this second dimension of the STCS principles–based framework shows that TEEBAgriFood can be improved by incorporating concepts and methods focused on systems behavior, the conditions that shape that behavior, the ways transformations are triggered, and the enabling conditions for those to happen. To better cope with the dynamic behavior of eco-agrifood systems, the methodological framework of TEEBAgriFood could be reframed as an ongoing, iterative, and adaptable process instead of a snapshot of the system—or a series of them—taken by applying a set of linear steps.

Dimension 3: Acknowledging the role of agents in framing systems and deciding how to improve them.

TEEBAgriFood acknowledges that agents in eco-agrifood systems can learn and adapt to changes but does not delve into the system's self-organization that emerges from those capacities nor proposes approaches or methods capable of capturing how agents adapt and coevolve with the system and its context (OP7). On the other hand, TEEBAgriFood also acknowledges that agents' diversity often involves a variety of perspectives about how the situation is understood and framed, how the purposes and desired changes are established, and the pathways to achieve those. All of this is encouraged to be explored and appreciated to gain a more substantive understanding of the situation. Despite that, TEEBAgriFood does not offer guidance to meaningfully engaging stakeholders to explore, understand, and appreciate diverse motivations, interests, concerns, and values involved in the situation and shape it (OP8).

TEEBAgriFood emphasizes and promotes shared understanding among stakeholders in framing and addressing the situation under analysis. However, the methods recommended in this regard—causal loop diagrams—do not pay sufficient attention to how power relations can influence stakeholders' dynamics, even when TEEBAgriFood considers power issues to be a critical element of systems transformations toward the common good. Platforms that integrate less powerful voices to redirect structural power are mentioned, but no further theories, concepts, or methods are included in the framework (OP9).

Facilitating common understanding among stakeholders through duly embracing power issues and imbalances has at its core the collective definition of the boundaries defining what is relevant for the situation of interest. TEEBAgriFood acknowledges the need to set boundaries for managing the complexity of eco-agrifood systems by promoting dialogues and exchanges among stakeholders in defining the perspective(s) that will be the starting point for the evaluation. Although it encourages efforts in that sense, it does not promote needed reflections on the values, structural underpinnings, and consequences of implicit and explicit boundary decisions (OP10).

The assessment of this third dimension of the STCS–principles–based framework shows that TEEBAgriFood acknowledges the importance of engaging with different perspectives and defining boundaries to better understand the situation. However, the STCS principles reveal that TEEBAgriFood could be further enhanced by delving into how the behavior of agents—coevolution and adaptation—and the power relations, dynamics, and issues can influence the processes of framing and bounding the situation, especially when it comes to deciding whose voices are considered – and whose are not – with what purpose, and with what consequences.

2.7. Concluding remarks

Applying the proposed STCS principles-based framework to TEEBAgriFood clarified TEEBAgriFood's main strengths and opportunities for further development. TEEBAgriFood is solid in providing a comprehensive and detailed description of the eco-agrifood system structure—elements, hierarchies, and interrelations—and supporting highly participatory processes in which diverse perspectives are acknowledged and included in defining how to frame and address a situation of interest. On the other hand, TEEBAgriFood's further development, under an STCS perspective, relates to the following three main areas: (1) delving into systems' patterns of behavior, the conditions that shape that behavior, how transformations occur, and the enabling conditions for those to happen; (2) proposing an iterative methodological framework that better copes with the dynamics and highly changing contexts in which the eco-agrifood systems operate; and (3) delving into power relations, dynamics, and issues as critical influencing factors for how any situation is bounded, framed, assessed, and ultimately addressed.

Besides providing insights on TEEBAgriFood's main strengths and pathways for improvement toward a better STCS-informed evaluation practice, the application of the STCS principles-based framework informed reflections on the meaningfulness of the STCS principles in guiding and inspiring agents engaged in evaluation practice to draw upon STCS as a way to better support their responses to the widespread current complex challenges humanity face.

In that sense, the conclusions about the main contributions of the STCS principles-based framework follow. First, the STCS principles-based framework offered meaningful guidance on how to engage with STCS in evaluation practice by providing actionable and useful theory-based principles that provide a comprehensive view of both systems thinking and complexity science insights for evaluation under a multimethodological approach. Thus, it helps to transcend the shallow use of some partial mainstream concepts and the misleading application of methods previously decoupled from their critical underlying assumptions.

Besides that, thanks to its hierarchical structure around three dimensions, ten overarching principles, and 26 operating principles, the STCS principles-based framework provides guidance that goes from general to specific to shed light on complex issues and how to address them. The STCS framework dimensions and the overarching principles act as the backbone, while the operating principles provide specific and adaptable guidance to different contexts and purposes.

In conclusion, while applying the STCS principles in the TEEB AgriFood framework offers promising insights, their meaningfulness extends beyond this specific application. To fully grasp their potential for shedding light on complex issues and how to address them, it is imperative to explore their applicability in diverse contexts.

This broader exploration and application are vital, as they will provide valuable insights and evidence to support the adoption of STCS principles in evaluation practice and contribute to a deeper understanding of and more suitable responses to complex global issues.

In the upcoming chapter, this exploration continues by applying STCS principles to a selection of food systems frameworks. The objective is to identify actionable strategies to enhance these frameworks' capacity to inform and support food system transformations. This assessment will reveal areas where food systems frameworks can be strengthened to address the intricate features that pose barriers to food systems transformations more effectively.

3. NAVIGATING FOOD SYSTEMS TRANSFORMATIONS: THE CONTRIBUTIONS OF SYSTEMS THINKING AND COMPLEXITY SCIENCE TO FOOD SYSTEMS FRAMEWORKS

Amidst the urgent need for food systems transformations towards sustainability, the path forward remains challenging. Despite the significant progress made in exploring and comprehending food- and agriculture-related challenges from increasingly systemic approaches and frameworks – as detailed in Section 3.2 – the transformation of food systems remains elusive.

The lack of progress in transforming food systems seems rooted in their complex and systemic nature. Under that assumption, this chapter builds on the Systems Thinking and Complexity Science principles developed in Chapter 2 to assess a set of key food systems frameworks, shedding light on the guidance offered to address the barriers preventing the transformation of food systems. The rationale underpinning this approach is elaborated upon in Section 3.3.

A customized rubric, employing STCS principles as evaluation criteria was explicitly developed to assess food systems frameworks (Section 3.4). As a result of the assessment, practices that contribute to progress in food systems transformations were identified and elevated among the 20 frameworks (Section 3.4). The assessment also revealed gaps and opportunities for improvement that could be leveraged by fostering a deeper engagement with Systems Thinking and Complexity Science ideas and practices (Section 3.5).

In essence, this chapter shows that STCS can play an instrumental role in elevating food systems frameworks to inform and support transformations by fostering dialogue and cross-learning within the food systems field of research and with Systems Thinking and Complexity Science ideas and practices (Section 3.6).

3.1. The potential of food systems approach and frameworks to move toward sustainability

As stated in the introductory chapter, the need to move food systems away from current unsustainable trajectories is unquestionable (Béné et al., 2019; Fanzo et al., 2020; FAO et al., 2021; Garnett, 2014; Global Panel on Agriculture and Food Systems for Nutrition, 2020; Haddad & Hawkes, 2016; HLPE, 2020a; Kopainsky et al., 2018; Willet et al., 2019). To do so, it is essential to explore what is hindering the needed transformations (Béné, 2022).

Significant progress has been made in exploring and comprehending food-and-agriculture related challenges by acknowledging them as complex issues that require thinking systemically to be addressed (Béné et al., 2019; Burns & Worsley, 2015; HLPE, 2020a; Reynolds & Holwell, 2010; Walton et al., 2021). Part of this progress has been the growing adoption of food systems approaches in the sociopolitical, scientific, and technical spheres (Brouwer et al., 2020; HLPE, 2020a; IPES-Food, 2021; von Braun et al., 2020; Willett et al., 2019), which has been critical to moving, over the past 50 years, towards more systemic understandings of the food-and-agriculture related challenges (HLPE, 2020a; Shaw, 2007; Westengen & Banik, 2016).

The use of systemic approaches to explore food- and agriculture-related challenges has contributed to shedding light on their complexity, thus informing debates and agendas around food security and other global challenges. Along the same path, a growing number of food systems frameworks has been designed to explore the complexity of food systems challenges – in terms of the elements, interrelationships, and dynamics that explain their outcomes and trajectories – and find suitable ways to address them (e.g., Béné et al., 2019; Ericksen, 2008; FAO et al., 2021; Global Panel on Agriculture and Food Systems for Nutrition, 2020; Halberg & Westhoek, 2019; HLPE, 2017, 2020a; Hubeau et al., 2017; IPES-Food, 2015, 2017; IPES-Food & ETC Group, 2021; TEEB, 2018; UNEP, 2016).

Despite the undeniable contributions of the food systems approach and frameworks, the knowledge gained is not leading to substantial support for food systems transformations. Of note are recent studies that reveal the limitations of food systems frameworks to inform and support policy processes and interventions that advance transformations toward more sustainable food systems (e.g., Brouwer et al., 2020; Hebinck et al., 2021; Zou et al., 2020).

Leeuwis et al. (2021) attribute the lack of progress in food system transformations to a limited understanding of their complex and systemic nature, linking the main barriers currently preventing food system transformations to properties inherent to that character.

Given the above, the main goal of this chapter is to contribute to elevating food systems frameworks in their role of informing and supporting transformations toward more sustainable food systems. To do so, it proposes analyzing the extent to and ways in which food systems frameworks account for features that currently pose barriers to their transformations. Such analysis is made from a Systems Thinking and Complexity Science perspective, assuming that what prevents food systems' transformations is usually rooted in their systemic and complex nature (Leeuwis et al., 2021).

3.2. Toward a systemic understanding of food systems challenges

This section outlines the evolution towards a progressively systemic understanding of challenges in food and agriculture. To that end, three milestones in the sociopolitical and scientific discourse on food security are described. These milestones illustrate the relation between how food security is perceived - as an expected outcome of food systems - and the specific features of food systems that should be addressed to move toward a future where food systems deliver sustainable food security.

3.2.1. Broadening the understanding of food security: from feeding the world to nourishing it.

The concept of food security has evolved significantly from simply "feeding the world" to a more comprehensive goal of "nourishing it" (Haddad & Hawkes, 2016, p.30). This expanded perspective is illustrated by the food security definition coined by FAO in 1996, which states that "food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (p. xx). As a result, food security went from focusing on food availability to encompassing four pillars – food availability, access, utilization, and stability – thus outlining a food system that would not only be productive and prosperous but equitable and inclusive, resilient and regenerative, and healthy and nutritious (HLPE, 2020a).

This shift in focus called for exploring the complex web of human, social, political, environmental, and economic factors affecting and being affected by how food is produced, processed, marketed, and consumed (Mausch et al., 2020). As a result, experts developed numerous frameworks that provide comprehensive descriptions of the elements and interrelations that explain food systems' behavior and outcomes (Béné et al., 2019; Ericksen, 2008; FAO et al., 2021; Global Panel on Agriculture and Food Systems for Nutrition, 2020; Halberg & Westhoek, 2019; HLPE, 2017, 2020a; Hubeau et al., 2017; IPES-Food, 2015, 2017; IPES-Food & ETC Group, 2021; TEEB, 2018; UNEP, 2016).

3.2.2. Engaging with a long-term perspective: Recognizing sustainability as a central dimension of food security.

The Sustainable Development Goal "Zero Hunger" treats food insecurity as a complex challenge, recognizing its interlinkages with environmental challenges, public health-related issues, and socioeconomic and political factors related to agriculture and food (Blesh et al., 2019). In this sense, the HLPE (2020a) maintains that ecological, social, and economic systems must work together in regenerative ways for food systems to deliver food security in the long term while advancing other sustainability goals.

Elevating sustainability as a dimension of food security highlights the value of recognizing and exploring the effect of the broader context on the behavior of the food systems over time, and how such dynamics shape the delivery of food security for today and coming generations (El Bilali et al., 2019; HLPE, 2020a).

3.2.3. Acknowledging the centrality of agency in food security

By placing agency as a central dimension of food security, the HLPE (2020a) argues that food systems should be transformed to empower and respect traditionally marginalized voices, people, and groups. This transformation requires ensuring that all agents – in different geographic, economic, sociocultural, or political contexts - have the ability to make choices based on their values and expectations and exercise their voice in shaping food systems' policies and governance (Burchi & De Muro, 2016; HLPE, 2020a). In support of that perspective, van Bers et al. (2019) urge exploring how individuals and institutions exercise their agency to influence food systems' governance and sociopolitical processes that determine how issues are understood and prioritized and how transformations are framed and fostered.

According to the HLPE (2020a), strengthening the agency of food systems' stakeholders implies recognizing and addressing power imbalances in their governance structures. In that regard, da Costa & McMichael (2007) argue that the market-and-corporate-led food regime reinforces the power and authority of dominant players, such as transnational companies, preventing interventions aimed at redirecting unsustainable trends in food systems from prospering.

3.3. STCS Principles as an opportunity to address the main barriers hindering food systems transformations.

With the premise that the systemic and complex nature of food systems – when not adequately understood nor addressed – may pose barriers to transformations (Leeuwis et al., 2021), this section explores the potential of System Thinking and Complexity Science (STCS) to strengthen food systems frameworks in their role to support and inform the necessary transformations.

As illustrated in Chapter 2, STCS provides a broad range of traditions, concepts, approaches, methods, and tools that have been central to the paradigm shift from linear and reductionist thinking toward addressing complex challenges and supporting systemic changes (Gates, 2016; Gates et al., 2021; Reynolds et al., 2016; Walton et al., 2021).

The potential of STCS to address barriers preventing food systems transformations is explored using the ten overarching principles of STCS developed in Chapter 2 as part of a principles-based framework to guide a substantive use of systems thinking and complexity science in addressing complex issues. Recent research on food systems transformations and their determinants was consulted to identify which food systems' conditions or features are recognized as barriers or challenges for transformations.

Table 3.1 illustrates the potential of the ten STCS principles to address barriers hindering food systems transformations by including references made in recent research on the importance of addressing features related to food systems' complex and systemic nature. By linking the barriers to transforming food systems with STCS principles, this section also illustrates the shortcomings of linear approaches to address the main challenges related to food and agriculture.

Table 3.1. Potential of STCS principles to address the barriers hindering food systems transformations.

STCS Overarching Principles	Barriers hindering food system transformations
1. Acknowledge the multidimensionality and hierarchical structure of complex systems	Recognizing and comprehensively exploring food systems structure - identifying drivers, outcomes, and positive and negative externalities in different dimensions (Brouwer et al., 2020; Caron et al., 2018; TEEB, 2018; van Bers et al., 2019) - is essential to drive the desired transformations.
2. Engage with interrelations and interdependencies	Exploring the interrelationships and feedback loops between internal components of food systems and their broader, multidimensional context contributes to understanding the intricate network of elements and actors that shape food systems' behavior and outcomes, which is crucial for driving transformations (Dentoni et al., 2017; Klerkx & Rose, 2020). Specifically, it facilitates managing the synergies and trade-offs between food systems' competing goals, which need to be carefully considered in any attempt to transform food systems (Brouwer et al., 2020; Caron et al., 2018; Dornelles et al., 2020; Giller et al., 2021; Mausch et al., 2020; van Bers et al., 2019).
3. Explore emergent properties and unpredictable behavior	Understanding emergent properties provides valuable insights to manage trade-offs and synergies between food systems outcomes and thus maximize their contributions to advance food insecurity, poverty, inequality, and environmental degradation (Béné, 2022; Leeuwis et al., 2021; Ruben et al., 2021).
4. Define the phase space of complex systems to explore their	Exploring the behavior of food systems over time is crucial to gaining an understanding of systems' patterns of change and thus identifying leverage points for transformation (Abson et al., 2017; HLPE, 2017; Leeuwis et al. 2021; Oliver et al., 2018)

movements through time and identify patterns of change	
5. Explore how and why complex systems change phases and/or states, leading to transformations	Understanding the conditions that shape transformations - fostering or preventing them - would shed light on the diverse pathways through which food systems can be transformed (Abson et al., 2017; Leeuwis et al., 2021), highlighting the need for adaptive management and tailor-made solutions that account for systems diversity and dynamic behavior (Garbero et al., 2021).
6. Acknowledge the path dependence and context sensitivity of complex systems	Among the conditions that shape transformations are food systems' governance structures (Leeuwis et al., 2021; Ruben et al., 2021), contextual factors and trends (Dengerink et al., 2021; Gaitán-Cremaschi et al., 2019), and historical trajectories (Kuokkanen et al., 2017; van Bers et al., 2019).
7. Recognize the role of adaptive agents in the dynamics and behavior patterns of complex systems	Examining how governance actors exercise their agency - through learning, self-organization, and adaptation (van Bers et al., 2019) - is crucial to understanding what shapes policies and decision-making processes that determine how food systems behave and evolve (Brouwer et al., 2021; HLPE, 2020a; Ruben et al., 2021).

8. Engage with the diverse perspectives that are part of the same big reality	Agents with diverse and often conflicting perspectives co-exist and interact within food systems. It is crucial to recognize this diversity and engage with it to minimize tensions, conflicts, and trade-offs that could hinder transformations (Béné, 2022; Caron et al., 2018; Eakin et al., 2017; Hubeau et al., 2019; Körner et al., 2022; van Bers et al., 2019). A lack of acknowledgment and engagement with the diversity of perspectives involved in food systems underlies agency limitations and power imbalances within food systems governance structures (van Bers et al., 2019; Zurek et al., 2021), leading to conflicts and undesirable trade-offs that prevent transformations (Béné, 2022; Hubeau et al., 2019).
9. Promote dialogue and mutual appreciation among perspectives to decide how to frame and address problematic situations	Creating platforms that bring together and empower stakeholders with diverse interests, concerns, expectations, and knowledge to engage on equal footing in dialogue helps minimize tensions, conflicts, and trade-offs that emerge from dismissing the diversity of perspectives within food systems (Bené, 2022; Caron et al., 2018; van Bers et al., 2019). Sharing perspectives would increase stakeholders' awareness of the diversity of values and motivations that drive them (Béné, 2022; Caron et al., 2018; Leeuwis et al., 2021), facilitating convergence around shared visions, and providing them with a shared directionality (Boogaard et al., 2011; Brouwer et al., 2020; Caron et al., 2018; HLPE, 2020a; Leeuwis et al., 2021; Ruben et al., 2021). Furthermore, by setting the foundations for stakeholders to generate insights based on realistic assumptions, the spaces for dialogue would allow for catalyzing collective actions, broadly supported by stakeholders, toward the desired transformations (Boogard et al., 2021; Leeuwis et al., 2021).

10. Place boundaries to manage complexity	Recognizing that food systems are dominated by those benefiting from the current regime is essential to overcome the lock-in effects that hinder the transformation of food systems. From their positions of power, these actors perpetuate the marginalization of those already excluded from decision-making processes about the future of food systems (Brouwer et al., 2020; Caron et al., 2018; FOLU, 2019; IPES-Food, 2017; Lam et al., 2020; Leeuwis et al., 2021). These boundaries, upon which the current food regime is built, are at the core of the problem and thus need to be critically examined (O'Brien, 2012). This implies questioning the structure that supports the status quo and the values and motivations underlying the decisions regarding transformations (Béné, 2022; Kuokkanen et al., 2017; Oliver et al., 2018).

3.4. Methodology: Analysis of food systems frameworks under the lens of STCS

This section proposes a methodology to assess food systems frameworks from an STCS perspective, which builds on the already illustrated potential of STCS to address the barriers preventing the transformation of food systems. The assessment aims to shed light on how and to what extent food systems frameworks – by acknowledging and addressing features related to systems and complexity – contribute to coping with barriers to transformations.

The methodology starts with a systematic search and selection of food systems frameworks, made by reviewing academic and grey literature that proposes or discusses frameworks published from 2008 to 2021. Next, a rubric based on STCS principles is designed to support a more robust and transparent assessment of food systems frameworks. Finally, the rubric is applied to assess the alignment of food systems frameworks with STCS principles.

The methodology proposed allows, on the one hand, to find and elevate the theoretical and methodological practices proposed by food systems frameworks with the potential to support transformations and, on the other hand, to identify opportunities for improvement. In doing so, the assessment lays the groundwork for fostering further dialogue and learning between food systems frameworks and with the ideas, concepts, and tools offered by Systems Thinking and Complexity Science to better understand and address complex issues. The assumption is that bringing STCS closer to food systems frameworks would enable a deeper understanding of food systems' complex issues and thus support the desired transformations.

3.4.1. Systematic search and selection of food systems frameworks

Literature on food systems frameworks considered for this paper was academic and grey, limited to documents published in English and published from 2008 – when the food system approach started being broadly used (UNEP, 2016; van Berkum et al., 2018) – to 2021, both years included.

Search engines and databases were explored to identify academic literature. Searches on the Web of Science and Scopus databases were done using the terms "food system*" in the title AND "framework" AND (sustainab* OR "food security" OR "food and nutrition security") in the title, abstract, or specified keywords. The resulting list of academic literature was complemented by a Google Scholar search using the term "food system* framework." Additionally, documents and reports of international agencies and research institutions were identified using the terms "food system," AND "framework," AND "analysis" in the Google search engine.

As a result of these search strategies in scientific databases, 414 publications were retrieved and listed. All their abstracts were reviewed to select those that propose or discuss conceptual and methodological frameworks for analyzing food systems. This second filtering was done using the following exclusion criteria:

i. Food systems frameworks with a partial scope of analysis were excluded – understood as frameworks focused on exploring certain elements or interrelationships without considering the big picture of value chain activities immersed and interrelated with a broader socio-economic and environmental context.
ii. Food systems frameworks that, being broader in scope, did not delve into the interrelationships and elements within the food system (e.g., the water-energy-food systems frameworks, SDGs focused, and frameworks exclusively dealing with sustainability) were excluded.
iii. Publications on case studies were excluded if they lacked discussion regarding the food systems framework applied. Publications applying a previously

designed and discussed framework were also excluded if they did not include decisive changes for its application.

iv. Food systems frameworks limited to specific methods or tools (e.g., Life Cycle Assessment, Multi-criteria assessment, Systems Dynamics Models, among others) were excluded if they lacked discussions regarding the definition of food systems and how to improve our understanding of them.

As a result, 11 academic publications were selected. For the grey literature, the same selection process led to the identification of 11 international reports published by international agencies – United Nations Food and Agriculture Organization (FAO), United Nations Environmental Program (UNEP), High-Level Panel of Experts on Food Security and Nutrition (HLPE) – policy advocacy networks – International Panel of Experts on Sustainable Food Systems (IPES-Food), Global Alliance for the Future of Food, The National Academies of Science, Engineering, and Medicine – research agencies – Wageningen Economic Research – and consultancy groups – The Institute for Development of Environmental-Economic Accounting (IDEEA Group).

Table 3.2 provides an overview of the publications selected and their correspondence with the assessed frameworks. It is worth noting that two of the identified food systems frameworks were developed through two subsequent publications. One is the TEEBAgriFood framework, created by The Economics of Ecosystems and Biodiversity (TEEB, 2018) in “The Economic and Scientific Foundations Report for The Economics of Ecosystems and Biodiversity for Agriculture and Food”, and complemented later with an “Implementation Guidance to apply the TEEBAgriFood framework” (Eigenraam et al., 2020). The other is the FSA framework, developed by Wageningen University in a study about the Food Systems Approach (FSA) (van Berkum et al., 2018), which was later complemented with a report that summarizes information about systems thinking and food systems (Posthumus et al., 2018). For both the TEEBAgriFood and FSA frameworks, we decided to treat the two respective publications as part of the same framework.

Table 3.2. Food systems frameworks and publications assessed.

	Publication number	Framework number	Author	Year	Title	Publisher/ Journal
Grey literature	1	1	Bortoletti & Lomax	2019	Collaborative framework for food systems transformation: A multi-stakeholder pathway for sustainable food systems	United Nations Environment Program (UNEP)
	2	2	Dury et al.	2019	Food systems at risk: new trends and challenges	United Nations Food and Agriculture Organization (FAO)
	3	3	Institute of Medicine (IOM) & National Research Council of the National Academies (NRC)	2015	A framework for assessing the effects of the food system	The National Academies Press
	4	4	IPES-Food	2015	The new science of sustainable food systems	International Panel of Experts on

					Sustainable Food Systems (IPES-Food)
5	5	Nguyen	2018	Sustainable food systems. Concept and framework	United Nations Food and Agriculture Organization (FAO)
6	6	The Economics of Ecosystems and Biodiversity (TEEB)	2018	TEEB for agriculture and food. Scientific and Economic Foundations Report	United Nations Environment Program (UNEP)
7		Eigenraam et al.	2020	Applying the TEEBAgriFood evaluation framework: Overarching implementation guidance	IDEEA Group and Global Alliance for the Future of Food
8	7	High-Level Panel of Experts on Food Security and Nutrition (HLPE)	2017	Nutrition and food systems	HLPE High-Level Panel of Experts on Food Security and Nutrition
9	8	United Nations Environment Program (UNEP)	2016	Food systems and natural resources	United Nations Environment Program (UNEP)

	10	9	van Berkum et al.	2018	The food systems approach. Sustainable solutions for a sufficient supply of healthy food	Wageningen Economic Research
	11		Posthumus et al.	2018	Food systems: From concept to practice and vice versa	Wageningen Economic Research
Academic Literature	12	10	Allen & Prosperi	2016	Modeling sustainable food systems	Environmental Management
	13	11	Béné et al.	2019	When food systems meet sustainability. Current narratives and implications for actions	World Development
	14	12	Connolly-Boutin & Smit	2016	Climate change, food security, and livelihoods in sub-Saharan Africa	Regional Environmental Change
	15	13	Ericksen	2008	Conceptualizing food systems for global environmental change research	Global Environmental Change-Human and Policy Dimensions

16	14	Halbe & Adamowski	2019	Modeling sustainability visions: A case study of multi-scale food systems in Southwestern Ontario	Journal of Environmental Management
17	15	Hubeau et al.	2017	A new agri-food systems sustainability approach to identify shared transformation pathways towards sustainability	Ecological Economics
18	16	Jackson et al.	2020	System of hunger: Understanding causal disaster vulnerability of indigenous food systems	Journal of Rural Studies
19	17	Paloviita et al.	2017	Food security Is none of your Business? Food supply chain management in support of a sustainable food system	Operations and Supply Chain Management: An International Journal
20	18	Raza et al.	2020	Conceptual framework of food systems for children and adolescents	Global Food Security

21	19	Vallejo-Rojas et al.	2016	Developing an integrated framework to assess agri-food systems and its application in the Ecuadorian Andes	Regional Environmental Change
22	20	Zurek et al.	2018	Assessing sustainable food and nutrition security of the EU food system: An integrated approach	Sustainability

3.4.2. Design of a rubric based on STCS principles

To analyze the extent and ways to which selected food systems frameworks address the main barriers to leveraging food systems transformations, an evaluation rubric was designed and applied to the selected food systems frameworks. This rubric is based on the STCS principles-based framework presented in Chapter 2.

According to Davidson (2004), a rubric is an assessment tool used to enhance transparency, engagement, learning, and adaptation through evaluative processes. Rubrics set out the two fundamental elements for any transparent evaluation: criteria – the dimensions around which the assessment is performed — and standards – the different performance levels aligning with or meeting the criteria. Davidson also stresses that rubrics are especially useful as they describe what performance would look like for each criterion at each level of alignment defined by the standards.

To design the rubric – presented in Table 3.3 – the ten overarching principles of STCS were incorporated as assessment criteria. In turn, the information provided by the 26 operating principles was used to design levels of alignment that provide clarity and transparency to the assessment of food systems frameworks. Four levels of alignment were defined, as shown in Table 3.4.

Table 3.3. STCS principles-based rubric for food systems frameworks assessment

		Levels of alignment and definitions			
Dimensions	**Overarching Principles**	**The principle is absent**	**The principle is acknowledged**	**The principle is addressed at a theoretical level**	**The principle is addressed both at theoretical and methodological levels**
I. Exploring the big picture	1. Acknowledge the multidimensionality and hierarchical structure of complex systems	It does not mention the multidimensionality or hierarchical structure of food systems/ There is not enough information to understand the level to which the multidimensionality or hierarchical structure of food systems is acknowledged.	It acknowledges the importance of considering the hierarchical and multidimensional structure of the food systems to deepen our systemic understanding of them.	It acknowledges and addresses the multidimensional and hierarchical structure of the food system through a clear description of its components and the way they are interrelated - internally and with the broader socio-political, economic, and	It provides both theoretical and methodological insights for mapping and describing the structure of food systems and exploring the diversity of elements and interrelations across levels.

			environmental context - to achieve the expected outcomes.	
2. Engage with interrelations and interdependencies	It does not mention the interrelations or interdependencies/ There is not enough information to understand the extent to which the non-linear nature of interrelations within and across food systems is acknowledged.	It acknowledges the non-linear nature of interrelations within and across food systems.	It describes the main interrelations in the food system, evidencing characteristics such as feedback, delays, and multiple causality.	It provides both theoretical and methodological insights to explore interrelations, interdependencies, and non-linearity.

	3. Explore emergent properties and unpredictable behavior	It does not mention emergent properties or unpredictable behavior of food systems / There is not enough information to understand the extent to which the need for exploring the big picture of interrelated elements to make sense of food systems' behavior is acknowledged.	It acknowledges the need for exploring the big picture of interrelated elements to make sense of the system's emergent properties and unpredictable behavior.	It describes the way properties and dynamics at the food system's level emerge from interrelations among lower-level elements, influencing the ability of the food system to maintain/ enhance the expected outcomes.	It provides both theoretical and methodological insights to identify and explore emergent behavior.
II. Understanding the dynamics of the system	4. Define the phase space of complex systems to explore their movements	It does not mention the phase space or the patterns of change that could be identified by exploring	It acknowledges the need to define the phase space of the food systems – by identifying value	It acknowledges and delves into the importance of defining the phase space of food systems to explore their	It provides both theoretical and methodological insights to map food systems' movements

through time and identify patterns of change	movements within the phase space / There is not enough information to understand the extent to which the need to define the phase space to make sense of food systems' behavior is acknowledged.	ranges for variables that explain the possible states of food systems in their multiple dimensions – to make sense of their behavior.	evolution over time and identify patterns of change.	within the phase space and to identify patterns of change.
5. Explore how and why complex systems change phases and/or states, leading to transformations.	It does not mention the phases and/or state shifts behind the transformation processes in food systems when talking about their dynamic	It acknowledges the dynamic behavior of food systems and the consequent need to design evaluations that are flexible enough to adapt to changes both within	It explores phases and/or state shifts, delving into the conditions that allow food systems to remain stable or suffer transformations.	It provides both theoretical and methodological insights to better understand the dynamics of food systems, with an

	behavior/ There is not enough information to understand the extent to which the dynamic behavior of food systems and the consequent need to design flexible and adaptable evaluations are acknowledged.	the food system and in its broader context.		emphasis on transformations.
6. Acknowledge the path dependence and context sensitivity of complex systems	It does not mention the path dependence or context sensitivity of food systems/ There is not enough information to understand the extent to which the diversity	It acknowledges that food systems are diverse and, therefore, interventions need to be adapted to contextual and/or historical diversity.	It describes how the dynamic of food systems is sensitive to the context and path dependent.	It provides both theoretical and methodological insights to have in mind the contextual conditions and historical trajectories of food systems when exploring the system's

		of food systems and the consequent need to adapt interventions to contextual and/or historical diversity are acknowledged.			dynamics.
III. Acknowledging the role of agents in framing systems	7. Recognize the role of adaptive agents in the dynamics and behavior patterns of complex systems	It does not mention adaptive agents when discussing food systems dynamics or behavior patterns/ There is not enough information to understand the extent to which the role of adaptive agents in food systems' dynamics and behavior	It acknowledges that adaptive agents - individuals or institutions - play a crucial role in the food systems' dynamics and behavior patterns.	It evidences the relationships between diverse agents, their behavior, and the structure and dynamics of the system. In this sense, it recognizes that these agents co-evolve with the food systems through learning and adaptation processes.	It provides both theoretical and methodological insights to explore and address adaptation and self-organizing processes in the food systems, which arise from interactions among adaptive agents and other system components.

	patterns is acknowledged.			
8. Engage with the diverse perspectives that are part of the same big reality	It does not mention that the same situation could be understood and conceptualized differently, depending on the perspective taken/ There is not enough information to understand the extent to which diverse perspectives of a situation are acknowledged/ engaged when	It acknowledges the need to engage with diverse perspectives when exploring food systems since the same situation could be understood and conceptualized differently, depending on the perspective taken.	In addition to acknowledging the need to engage with diverse perspectives, it highlights the need to explore what lies behind each of them (interests, concerns, expectations, etc.) to make sense of the situation and identify feasible and desirable pathways to improve it.	It offers both theoretical and methodological insights to identify and explore perspectives concerning how the food system is and how it ought to be, along with respective feasible and desirable pathways to transform it and how the diverse perspectives privileged condition the systemic analysis.

	exploring food systems.			
9. Promote dialogue and mutual appreciation among perspectives to decide how to frame and address problematic situations	It does not mention the importance of promoting dialogue and mutual appreciation between perspectives to decide how to frame and address problematic situations in food systems/ There is not enough information to	It acknowledges the importance of promoting dialogue and sharing among stakeholders with diverse perspectives to decide how to frame and address problematic situations in food systems.	It recognizes and explores the influence of power relations in collective decision-making, especially regarding the framing and addressing of problematic situations in food systems.	It offers theoretical and methodological insights to promote dialogue and exchanges among perspectives while dealing with power issues that emerge from and shape collective decision-making about how to frame and address

	understand the extent to which dialogue and mutual appreciation between perspectives are promoted to decide how to frame and address problematic situations in food systems.			problematic situations in food systems.
10. Place boundaries to manage complexity	It does not mention boundaries as essential to manage complexity when assessing problematic situations in food systems/ There is not enough information to understand the extent to which placing	It acknowledges that boundaries are essential to justify the decision of what to include and exclude when assessing problematic situations in food systems.	It acknowledges that decisions about boundaries involve privileging some perspectives at the cost of marginalizing others, which ultimately requires sense-making and deliberation among	It offers both theoretical and methodological insights to discuss and reflect on boundary decisions and the ethical and practical consequences of them.

	boundaries is acknowledged as a critical activity to justify the decision of what to include and exclude when assessing problematic situations in food systems.	the values underpinning these perspectives.

Table 3.4. Levels of alignment are defined for the STCS principles-based rubric for assessment of food systems frameworks.

Level of alignment		Meaning and implications
1	The principle is absent.	Neither the principle nor closely related concepts are mentioned. Or, when mentioned, there is insufficient information about how the principle is addressed or with what consequences.
2	The principle is acknowledged.	The condition stated in the principle is at least acknowledged. The consequences of adhering to the principle are outlined, but without mentioning any theoretical or practical implications.
3	The principle is addressed at a theoretical level.	Implications of acknowledging and addressing the principle are provided, along with theoretical guidance to support and further develop what the principle states.
4	The principle is addressed both at theoretical and methodological levels	Both theoretical and methodological insights are provided to address what the principle states, ranging from general guidelines and concepts to specific methods and tools.

3.4.3. Application of the STCS rubric to assess food systems frameworks

Once designed, the rubric was applied to each of the 20 food systems frameworks in Table 5. Documents respective to each framework were reviewed, summarizing the information provided by each regarding the systems-and-complexity features addressed in the ten STCS principles (Annex B). The information gathered was then critically reviewed to assign a level of alignment for each of the ten STCS principles as per the rubric in Table 3.3. The raw results of this assessment, detailing the alignment levels assigned to each framework concerning the ten STCS principles, are included in Annex C.

The assessment of food systems frameworks, although providing information by each, was not intended to render value judgments of any particular framework. Instead, it aims to gain insights into the role food systems frameworks play in addressing the barriers that hinder transformations to find ways to uphold their contributions, making them more informative and supportive of food systems transformations.

The analysis of food systems frameworks individually, from an STCS perspective, allowed for showcasing and elevating practices suggested by them that can support food systems transformations. The findings of this assessment hope to set a sufficiently robust and transparent foundation to promote exchanges and foster learning within food systems research.

Additionally, applying the rubric to food systems frameworks reveals how fostering a more substantial dialogue and engagement with STCS could contribute to strengthening the frameworks as instruments for informing and supporting food systems transformations.

3.5. Alignment of food systems frameworks with Systems Thinking and Complexity Science: Insights and exemplary practices to support transformations.

This section describes the results of applying the rubric to the 20 food systems frameworks selected. Table 3.5 includes the compiled results, showing the distribution of frameworks in the four levels of alignment for each STCS principle – which go from simply recognizing features of food systems that may prevent their transformations to providing theoretical and practical guidance to account for those features and deal with them to support transformations.

Table 3.5. Percentage out of the 20 assessed food systems frameworks on each of the four levels of alignment for each of the ten overarching principles as defined in the STCS rubric proposed in this paper.

STCS principles	Levels of alignment with STCS principles: The principle is absent	The principle is acknowledged	The principle is addressed at a theoretical level	The principle is addressed both at theoretical and methodological levels
(I) Exploring the big picture	**3%**	**22%**	**35%**	**40%**
1. Acknowledge the multidimensionality and hierarchical structure of complex systems	0%	5%	45%	50%
2. Engage with interrelations and interdependencies	5%	30%	35%	30%
3. Address emergent properties and unpredictable behavior	5%	30%	25%	40%
(II) Understanding the dynamics of the system	**42%**	**21%**	**14%**	**23%**

4. Map the system's movements through the phase space to identify underlying patterns of change	30%	60%	30%	30%
5. Understand how a system changes between phases or states	55%	10%	15%	20%
6. Acknowledge the path dependence and context sensitivity of complex systems	40%	25%	15%	20%
(III) Acknowledging the role of agents in framing systems	**38%**	**26%**	**17%**	**19%**
7. Understand adaptive agents and the self-organization capacity that arises from the interactions among them	40%	30%	20%	10%
8. Acknowledge diverse perspectives as part of the same big reality	20%	45%	10%	25%
9. Promote dialogue and mutual appreciation among perspectives to decide how to frame the situation	25%	20%	30%	25%
10. Place boundaries to manage complexity	65%	10%	10%	15%

The subsections below present the results of analyzing the food systems framework by the three dimensions of the STCS principles-based framework. Each subsection begins by referring to the number of frameworks that at least recognize the STCS principles. It continues with those that address the STCS principles at a theoretical/ conceptual level. And finally, it concludes with those that address the STCS principles at theoretical and methodological levels.

Besides offering an overview of how and to what extent the frameworks account for the complex and systemic nature of food systems, exemplary practices – conceptual or methodological – proposed in specific frameworks are highlighted, considering their potential contributions in addressing barriers to food systems' transformations.

3.4.1. Exploring the big picture

Almost all the food systems frameworks assessed pay attention to the multidimensional context – e.g., socio-political, human, economic, financial, and environmental context – that affects and is affected by the way food is produced, processed, marketed, and consumed. Moreover, they recognize that the way elements within these dimensions relate to each other and with elements within the value chain is non-linear and could reinforce or balance the effect caused by particular interventions in the system, giving rise to emergent and hard-to-predict properties and results. Regarding emergent properties, some authors mention the food systems' capacity to adapt and evolve with changes, capacities they relate to vulnerability and resilience concepts (Allen & Prosperi, 2016; Connolly-Boutin & Smit, 2016; Jackson et al., 2020; Vallejo-Rojas et al., 2016).

The conceptual basis for exploring food systems is provided by frameworks that organize and present the elements considered relevant to understanding the complex structure of food systems. Here we highlight the use of the multiple capitals framework, usually linked to the broader perspectives of sustainability, human livelihoods, and well-being (Connolly-Boutin & Smit, 2016; Hubeau et al., 2017; TEEB, 2018); the use of the Driver-Pressure-State-Impact-Response framework (Hubeau et al., 2017) and the Structure-Conduct-Performance paradigm (Nguyen, 2018) to illustrate the cause-effect relationship between human activities and the broader and multidimensional context that trigger societal responses; and the characterization of drivers and outcomes linked with the concepts of vulnerability and adaptation (Allen & Prosperi, 2016 and Connolly-Boutin & Smit, 2016).

In addition, around 40% of the assessed food systems frameworks propose methods and tools to explore the non-linear behavior of food systems. These are focused on understanding interrelationships, feedback loops, and delays to shed light on emergent properties and behavior. Agent-based Modelling (IOM & NRC, 2015), Causal Loop Diagrams (Eigenraam et al., 2020; TEEB, 2018), Systems Dynamics (Eigenraam et al., 2020; Halbe & Adamowski, 2019; TEEB, 2018), Fuzzy Cognitive Mapping (Halbe & Adamowski, 2019), and a set of output and transition equations (Allen & Prosperi, 2016) are proposed in some the assessed food systems frameworks.

3.4.2. Understanding the dynamics of the system

In contrast with the above, food systems frameworks do not pay much attention to understanding systems dynamics. Even though more than half of the frameworks describe the variables delineating the space where the system can exist – known as phase space (Ramalingam, 2008) – only 35% provide theoretical insights to map and make sense of the movements across that space, i.e., the systems' behavior. When it comes to providing methodological information, about one-third of the assessed food systems frameworks propose methods to monitor the behavior of the systems over time, and only 20% delve into the conditions that allow the food system to remain stable over time, or, on the contrary, to transform by changing state (Allen & Prosperi, 2016; IOM & NRC, 2015; TEEB, 2018; Vallejo-Rojas et al., 2016). Furthermore, very few food systems frameworks explicitly acknowledge that the present and past states of the system determine which pathways are enabled – and which are not – for future development (Allen & Prosperi, 2016; TEEB, 2018).

To explain the behavior of food systems, Allen & Prosperi (2016) explore the trajectory traced by the system across the phase space over time. For this, they propose a set of transition functions that explore the behavior of state and control variables, with the variables in this last group acting to trigger changes or transformations in the system.

Although not always explicit, the concepts of vulnerability and resilience are used in food systems frameworks to describe the role of control variables in driving food systems toward stability or transformation (Allen & Prosperi, 2016; Connolly-Boutin & Smit, 2016; Jackson et al., 2020; TEEB, 2018; Vallejo-Rojas et al., 2016; van Berkum et al., 2018). In that sense, IOM & NRC (2015) point out that simulation models allow measuring the probability that a given effect exceeds the threshold from which the system's resilience is affected, thus triggering transformations. Besides the transition functions proposed by Allen & Prosperi (2016), modeling methods like Agent-based Modelling (IOM & NRC, 2015), Systems Dynamics (Eigenraam et al., 2020; Halbe & Adamowski, 2019; TEEB, 2018), and Fuzzy Cognitive Mapping (Halbe & Adamowski, 2019) are proposed to delve into the conditions determining food systems stability or transformation, as part of exploring the non-linear behavior of food systems.

3.4.3. Acknowledging the role of agents in framing systems

Although more than half of the assessed food systems frameworks recognize that agency has a role to play in food systems dynamics, only 30% describe how, thanks to their capacities to learn, adapt, and respond to changes, agents can influence food systems dynamics and co-evolve with them. To represent these processes, IOM & NRC (2015) propose using Agent-based Modelling, while Posthumus et al. (2018) mention Soft Systems Methodology to acknowledge the role of diverse agents in food systems dynamics.

Most of the assessed food systems frameworks recognize that agents involved in food systems have their own perspectives on the situation to be addressed, which translates into different ways of understanding the same situation. Thus, the frameworks proposed by IPES-Food (2015), Béné et al. (2019), Bortoletti & Lomax (2019), and UNEP (2016) acknowledge that the interests and concerns of involved agents determine which sustainability dimension – social, economic, or environmental – is prioritized. On the other hand, IOM & NRC (2015) go a step further, highlighting the biases behind the perspectives involved and the need to make them transparent.

The acknowledgment of multiple perspectives results in 80% of the food systems frameworks promoting spaces for dialogue and exchange among them. In this sense, Soft Systems Methodology (Hubeau et al., 2017), Vision Design & Assessment (VDA) framework (Halbe & Adamowski, 2019), Causal Loop Diagrams (TEEB, 2018; Halbe & Adamowski, 2019; Posthumus et al., 2018) and Bayesian Belief Networks (Posthumus et al., 2018) are proposed to enable sharing, co-creation, learning, and negotiation processes to build a shared understanding of the situation and its desired transformation. Moreover, and to call attention to an under-addressed aspect in food systems frameworks, Bortoletti & Lomax (2019) and Posthumus et al. (2018) highlight the need to create spaces to reflect on and understand the values, goals, beliefs, and assumptions behind perspectives to inform mutual understanding between them.

Another key aspect is the role of power relations when fostering discussion spaces to inform decision-making, described in close to half of the assessed food systems frameworks. In this sense, both Nguyen (2018) and UNEP (2016) highlight the need to explore the power relations among stakeholders that underlie governance mechanisms, which finally fed back to the decision-making processes (HLPE, 2017). Food systems frameworks propose some methodological insights to control or minimize the hierarchical effect of the most powerful, as well as to ensure the participation of groups that are usually marginalized or have less decision-making power. Thus, IOM & NRC (2015) recommend taking distance from the influence of powerful agents, while IPES-Food (2015) bets on engaging them in a way their dominant positions can be constructively challenged. In line with this last idea, Zurek et al. (2018) highlight the importance of transparency in constructing indicators to avoid them becoming a tool for the already powerful. Furthermore, the creation of smaller group discussions (Jackson et al., 2020b), targeted focus groups (Hubeau et al., 2017), and multi-stakeholder platforms (Bortoletti & Lomax, 2019; TEEB, 2018) are proposed to ensure the participation of less powerful and marginalized groups on equal footing.

Although 80% of the assessed food systems frameworks recognize that the same situation can be understood differently, only 25% acknowledge that framing the situation and discussing pathways to improve it implies prioritizing some perspectives over others. Thus, Ericksen (2008) understands food systems as “problem-determined systems” that depend on the perspective taken, while IPES-Food (2015) highlights the need for discussion spaces that encompass different perspectives to reflect on which values and preferences to prioritize when framing food systems and proposing transformation pathways. In methodological terms, boundary decisions in food systems frameworks are made by reflecting collectively on the dimensions, elements, and agents that are considered important and significant for the analysis from an outcome or impact perspective (Allen & Prosperi, 2016; IOM & NRC, 2015; TEEB, 2018). Interestingly, in the framework proposed by Allen & Prosperi (2016), boundary decisions are linked to the conditions of vulnerability and resilience, asking “vulnerability/ resilience to what and for what” (p. 964).

3.6. Leveraging Systems Thinking and Complexity Science in food systems frameworks to advance transformations.

The STCS principles work as instruments to bring STCS into dialogue with food systems frameworks and food systems frameworks to each other, thus offering valuable insights to address barriers and challenges to food systems transformations. Below is described how the guidance food systems frameworks offer, as accounting for systems and complexity features of food systems, help address the barriers to advance their transformations.

The comprehensive description of food systems structure made by most food systems frameworks sheds light on the drivers, outcomes, and externalities associated with food systems performance, thus providing valuable insights to manage trade-offs and synergies between food systems goals that may hinder their transformations towards sustainability (Brouwer et al., 2020; Leeuwis et al., 2021). Moreover, by proposing methods and tools that explore the complex network of elements that give rise to food systems properties and results, food systems frameworks help comprehend "why, despite the efforts, current food systems configurations contribute to challenges such as food insecurity, malnutrition, poverty, and environmental degradation, instead of moving towards the desired transformations (Leeuwis et al., 2019, p. 762)".

Despite proposing tools that help explore how interrelationships and feedback loops between elements of food systems shape their outcomes, most food systems frameworks do not delve into the behavioral patterns underlying transformations. Vulnerability and resilience are adopted as framing concepts in the few frameworks exploring the conditions behind transformation - fostering or preventing it. Through that lens, food systems frameworks illustrate how systems' internal sensitivity to stressors and their adaptive and transformation capacities determine whether socioeconomic and environmental drivers trigger changes - or not - in the systems (Allen & Prosperi, 2016; Connolly-Boutin & Smit, 2016; Jackson et al., 2020). Understanding how internal capacities and external conditions converge to shape food systems dynamics is essential to identifying leverage points for transformation (Abson et al., 2017; Leeuwis et al., 2021; Oliver et al., 2018). In this sense, we propose leveraging the insights gained by Allen & Prosperi (2016) – by applying the lens of vulnerability and resilience to model food systems dynamics – to explore the potential of different STCS modeling tools to analyze food systems' patterns of change and gain insights into how to support transformations.

Food systems frameworks recognize the importance of engaging with diverse stakeholders and perspectives to deal with food systems challenges from more informed positions. By proposing approaches, methods, and tools that facilitate mutual appreciation and cross-learning between stakeholders (e.g., Soft Systems Methodology, Bayesian Belief Networks, Vision Design & Assessment framework), food systems frameworks help reduce conflicts and trade-offs that result from overlooking other worldviews and ignoring the limitations of our own (Béné, 2022; Hubeau et al., 2019). Additionally, they guide stakeholders in developing a shared understanding of what is failing in food systems. This shared understanding gives them the information to generate insightful discussions on how to support transformations based on realistic assumptions (Leeuwis et al., 2021).

According to Brouwer et al. (2021), engaging stakeholders in food systems transformations is necessary to change the governance structures that limit their agency, allowing groups that have been traditionally marginalized to participate in debates and decision-making. Although food systems frameworks offer some insights into dealing with power imbalances, they do not provide guidance to deal with the lock-in effects generated by powerful agents that, to continue benefiting from the food systems' current regime, use their dominant positions to prevent transformations (Bernstein, 2016; Brouwer et al., 2020; IPES-Food, 2015). To effectively overcome the lock-in generated by power imbalances in food systems, we must challenge the status quo by questioning the boundaries imposed by the current regime and their underlying values (Béné, 2020; Lam et al., 2020; Leeuwis et al., 2021). One instrument that could support boundary reflection is the materiality assessment proposed by Eigenraam et al. (2020), which illustrates the consequences of privileging certain purposes or perspectives over others through a transparent and systematic process that explores impact pathways.

The above confirms that fostering further dialogue between food systems frameworks and STCS can help food systems frameworks better inform and support transformations that advance food systems' most pressing challenge. In this sense, we propose to explore STCS approaches, methods, and tools that address power imbalances and strengthen the agency of marginalized and vulnerable groups, drawing on their capacities of self-organization and adaptation.

3.7. Concluding remarks

Food systems frameworks are intended to play a vital role in facilitating the necessary transformations of food systems (Brouwer et al., 2020; HLPE, 2020a; IPES-Food, 2019; von Braun et al., 2020; Willet et al., 2019). However, their effectiveness could be limited if they fail to recognize and address the barriers preventing transformations.

Built on the assumption that those barriers are inextricable linked with the systemic and complex nature of food systems (Leeuwis et al., 2021), this chapter focused on assessing food systems frameworks from a Systems Thinking and Complexity Science (STCS) perspective to find ways to elevate their contributions to food systems transformations. Such assumption was tested by broadly exploring the potential of the ten overarching principles of STCS – proposed in Chapter 2 – to address what authors researching food systems transformation recognize as barriers. The results of this exploration illustrate the need to continue moving from linear to systemic approaches to support the transformations needed to address the food systems' most pressing challenges.

Some of the barriers preventing food system transformations are briefly described below.

First, there are the synergies and trade-offs between food systems' purposes and outcomes that prevent their sustainability (Dentoni et al., 2017; Klerkx & Rose, 2020), which can only be understood and addressed by making sense of the emergent properties that arise from the interrelationships among different elements within the system (Abson et al., 2017; Béné, 2022; Ruben et al., 2021).

Second, there is the need to explore and understand the dynamic behavior of the system to identify leverage points for transformation (Abson et al., 2017; HLPE, 2017; Leeuwis et al., 2021; Oliver et al., 2018); in this regard, it is necessary to explore the conditions that determine the system to remain stable despite external perturbations, or to transform as a result of them or internal properties like self-organization (Abson et al., 2017; Dengerink et al., 2021; Gaitán-Cremaschi et al., 2019; Leeuwis et al., 2021; Ruben et al., 2021; Van Bers et al., 2019).

Third, there are the tensions, conflicts, and trade-offs that arise from the interactions between agents with different perspectives (Béné, 2022; Caron et al., 2018; Eakin et al., 2017; Hubeau et al., 2019; Körner et al., 2022; van Bers et al., 2019), where governance and power structures play a crucial role (van Bers et al., 2019; Zurek et al., 2021). To address these barriers it is essential to promote exchanges among agents with different perspectives through platforms that manage power imbalances and empower those traditionally marginalized to foster an exchange of ideas and knowledge (Béné, 2022; Caron et al., 2018; van Bers et al., 2019) that strengthens individual and collective awareness of diversity and facilitates informed and conscious decision making (Béné, 2022; Brouwer et al., 2020, Caron et al., 2018; Leeuwis et al., 2021; Ruben et al., 2021).

Finally, there is the lock-in effect on transformation generated by power imbalances within the system, which, as managed by agents whose interests are aligned with the current regimen, prevent the design of interventions that challenge the status quo (Brouwer et al., 2020; Caron et al., 2018; FOLU, 2019; IPES-Food, 2017; Lam et al., 2020; Leeuwis et al., 2021); in this regard, it is necessary to question the boundaries that shape the system's current and future outcomes and behavior (Béné, 2022; Kuokkanen et al., 2017; Oliver et al., 2018).

Based on the STCS principles designed in Chapter 2, a rubric was designed and applied to assess 20 food systems frameworks developed between 2008 and 2021. Applying the rubric to assess food systems frameworks revealed that although they aim to inform and support food systems transformations, they do not account to the same extent for features that pose barriers to such transformations. Far from being a disadvantage, the differences among food systems frameworks illustrate complementarities to be leveraged through dialogue and joint work.

In that sense, one of the main expected impacts of this chapter is to showcase the diversity of practices proposed by food systems frameworks to promote exchanges and cross-learning within the food systems field of research. Although there are several practices to be highlighted, given that most food systems frameworks delve into food systems' structure but pay less attention to their dynamic behavior and the role of agents in their transformations, below are highlighted practices that contribute to the last two dimensions.

Among the practices that improve the understanding of food systems dynamics and patterns of change, vulnerability and resilience frameworks stand out, as they provide a solid explanation of the different elements or properties that come into play in determining the consequences and responses of food systems to changes. These frameworks help identify variables within the system that shape its current and future states in light of stressful conditions (e.g., Allen & Prosperi, 2016; Connolly-Boutin & Smit, 2016; Jackson et al., 2020; Vallejo-Rojas et al., 2016).

Practices highlighted concerning the third dimension of the STCS rubric encourage engagement with diverse perspectives to create awareness of underlying values while attempting to control or minimize power imbalances that prevent challenging the status quo to foster food system transformations. On the one hand, there is the Soft Systems Methodology with targeted focus groups (Hubeau et al., 2017), designed with homogeneous groups of stakeholders to minimize the impact of power imbalances and hierarchy in the generation and sharing of ideas from different perspectives to move the system of interest from its current state to the desired one (Hubeau et al., 2017). On the other hand, Bayesian Belief Networks are used to facilitate different stakeholders to externalize their knowledge with a group, combine the knowledge, and learn from each other (Posthumus et al., 2018). Lastly, given that challenging the status quo implies questioning the boundaries upon which the current food regime is built, of note is the systematic guidance offered by authors such as Eigenraam et al. (2020) and IOM & NRC (2015) to describe the rationale behind the decision to prioritize certain goals or impacts over others when deciding how to act on the food system.

From this chapter, it is clear that food systems frameworks account – to different extents each – for the features posing barriers to their transformations. Nevertheless, the results from applying the rubric based on STCS principles show that food systems frameworks could benefit from further dialogue with STCS. Especially to better understand the determinants of food systems' response to a perturbation – leading either to the system remaining on the same trajectory or changing to a new one – which would reveal leverage points for transformation. And to address power imbalances and strengthen the agency of marginalized and vulnerable groups, drawing on their self-organization and adaption capacities to challenge governance structures that lock in the necessary transformations.

As illustrated in section 3.6, to address the barriers mentioned above, it is essential to understand food systems dynamics and their determinants, the role of adaptive agents in such dynamics, and the boundaries that determine how food systems are understood and governed, being transparent on the values, interests, and the power imbalances supporting the systems' current regime.

Having outlined some opportunities for strengthening the guidance offered by food systems frameworks to better address barriers in food systems transformations, this chapter sets the groundwork to inform exchanges among diverse agents involved in food systems research, especially in light of the opportunities for cross-learning across food systems frameworks. In addition, this chapter facilitates cross-learning between researchers and practitioners from food systems and STCS fields of knowledge, laying the foundations for debates and exchanges about the usefulness of STCS principles to address complex challenges and support transformations in food systems and beyond.

Finally, the insights gained in this chapter to enhance food systems frameworks laid the groundwork for, in Chapter 4, proposing a Participatory Food Systems Modeling framework informed on Systems Thinking and Complexity Science to contribute to the ongoing efforts in moving food systems toward the necessary transformations.

4. PARTICIPATORY FOOD SYSTEMS MODELLING FRAMEWORK TO IDENTIFY DESIRABLE AND CULTURALLY FEASIBLE TRANSFORMATION PATHWAYS

Building upon the findings gained in Chapter 3 on actionable ways for elevating the contributions of food systems frameworks in supporting transformations, this chapter introduces a methodological proposal informed by Systems Thinking and Complexity Science to better account for features posing barriers to transformation.

The methodological proposal within this chapter is named the Participatory Food Systems Modeling (PFSM) framework. It aims to facilitate collective exploration, discussion, learning, and reflection among stakeholders to identify desirable and culturally feasible transformation pathways for food systems.

As explained in Section 4.1, Chapter 4 aims to contribute to the transformation of food systems by designing a framework that accounts for the role agents and governance structures play in these processes. This effort aligns with the third dimension of the STCS principles-based framework introduced in Chapter 2 and applied in Chapter 3 to identify actionable ways to strengthen food systems frameworks.

The proposed PFSM framework consists of three phases – detailed in Section 4.2 – that foster dialogue, knowledge exchange, and cross-learning among stakeholders with diverse perspectives. It enhances their understanding of food systems' complexity and facilitates the emergence of ideas and accommodations that lead to the identification of suitable transformation pathways.

The value of the PFSM framework in identifying desirable and culturally feasible pathways for the transformation of food systems is tested by applying it to poultry systems in Ghana and Southern Senegal. Section 4.3 includes some background information about the case studies and describes the nuances made to the PFSM framework in each case study. Lastly, section 4.4 reflects on these nuances and their implications in achieving the objectives of each of the phases of the PFSM and the ultimate goal of supporting and informing food systems transformations.

4.1. Identifying suitable pathways for transforming food systems: What is needed?

Despite the efforts to contribute to food systems' necessary transformations, the predominant food regime – understood as the way food is being produced, processed, marketed, and consumed worldwide – continues exacerbating key sustainability challenges such as food and nutrition insecurity (FAO et al., 2022), poverty (Gassner et al., 2019; Giller et al., 2021; Raza & Soares, 2020), climate change and biodiversity loss (Crippa et al., 2021), social conflicts and inequalities (HLPE, 2020; Leeuwis et al., 2021), among others.

According to Schot & Steinmueller (2018), for transformations to happen, it is essential that people involved in the situation of interest collectively make sense of what is failing, decide what the desired future looks like, and think of potential ways to move from the current situation to the desired ones, and reflects on who was the power to create the needed shifts.

Collectively making sense of what is failing in the current situation implies broadening people's knowledge by engaging and bringing together different perspectives in processes of exploration and learning (Checkland, 2000; Checkland & Haynes, 1994; Checkland & Poulter, 2010; Checkland & Scholes, 1999). Fostering dialogue and exchanges among people with different perspectives creates a shared language that allows them to negotiate a future that makes sense to all and collectively identify desirable and feasible pathways to move toward it.

Blesh et al. (2019) and Garcia-Gonzales & Eakin (2019) argue it is essential not only to recognize the diversity of perspectives involved in food systems but also the power relations among stakeholders in order to reach the needed transformations. Along the same line, the HLPE (2020) highlights the role of governance structures in addressing power imbalances, fostering spaces for dialogue and participation of vulnerable and traditionally marginalized people, and upholding the rights of all people to contribute to a free, just, and democratic society. Da Costa & McMichael (2007) associate such power imbalances to the dominant market-and-corporate-led regime, which reinforces the power and authority of the already dominant players – private sector, government, donors – and perpetuates the vulnerable and marginalized position of agents like – e.g., smallholder farmers – whose knowledge, interests, and concerns are already in the sideline of dialogues and negotiations to diagnose problems and propose solutions (IPES-Food, 2017; Leeuwis et al., 2021).

Among the systemic approaches widely used in practice, Participatory Modeling is recognized as an effective way to foster knowledge exchange and collaborative learning between agents with different perspectives (Barreteau et al., 2007; Duboz et al., 2018; Voinio et al., 2016; Voinov & Bousquet, 2010). Creating spaces that increase stakeholders' awareness of diversity eases managing diverse and often divergent values, interests, and perspectives involved in democratic processes (Schwandt & Gates, 2021), thus laying the groundwork for negotiations that eventually lead to accommodations on what is failing in the system of interest and how to address it (Daniell et al., 2006).

Considering what is missing for transformations to happen and keeping in mind the potential of participatory modeling approaches in this regard, this chapter proposes a Participatory Food Systems Modeling (PFSM) framework to identify desirable and culturally feasible transformation pathways. The PFSM framework presented in this chapter is applied in Chapter 6 to poultry systems in Ghana and Senegal to explore its value in informing and supporting transformations that effectively address the complex challenges of food systems.

4.2. Methodology: Design of the Participatory Food Systems Modeling (PFSM) framework

This section provides a comprehensive overview of the Participatory Food Systems Modeling (PFSM) framework, designed by leveraging STCS to foster an active engagement of diverse agents and perspectives to collectively explore, make sense, and identify suitable ways to transform food systems.

Firstly, it delves into the theoretical underpinnings that guide the design of the Participatory Food Systems Modeling (PFSM) framework. Then, it describes the diverse methods and tools integrated into the PFSM framework. Finally, it offers a detailed look at the implementation phases, activities, and outcomes of the PFSM framework.

4.2.1. Theoretical foundations

The theoretical foundations on which the PFSM framework was designed are described below. Firstly, the participatory modeling approach, adopted as the heuristic of the methodological proposal to leverage systems modeling methods and tools in participatory processes of exploration and learning among stakeholders with different perspectives (Jones et al., 2009), aimed to collectively generate and debate potential solutions that aid decision making (Daniell et al., 2006; Duboz et al., 2018; Voinov & Bousquet, 2010). Secondly, the Soft Systems Methodology (SSM) offers detailed methodological guidance for stakeholders collectively exploring and conceptualizing the problematic situation to jointly identify desirable and culturally feasible transformation pathways (Checkland, 2000; Checkland & Scholes, 1999). Lastly, the TEEB AgriFood framework (TEEB, 2018) and its implementation guidance (Eigenraam et al., 2020) nuance the participatory modeling approach to food systems analysis by offering a comprehensive description of the elements and interrelations that determine food systems' behavior and outcomes, as well as methodological guidance to help practitioners systemically explore and address food systems' challenges and unsustainable trends.

Participatory Modeling Approach

The participatory modeling approach combines participatory procedures with modeling techniques to facilitate and inform collective decision-making among stakeholders with different perspectives in order to support the necessary transformations to deal with complex issues (Barreteau et al., 2007; Duboz et al., 2018; Jacobson et al., 2009).

In this regard, agents with different types of knowledge, representations of reality, and viewpoints are gathered and integrated into the modeling process to foster individual and collective learning about complex issues (Daniell et al., 2006). Moreover, participatory modeling encourages stakeholders to build a collective vision of the system of interest to co-generate potential solutions that aid decision-making processes (Daniell et al., 2006; Jones et al., 2009).

It is worth noting that models are not presented as final products or solutions in participatory modeling approaches but as intermediary devices used to foster dialogue and knowledge exchange between people with different perspectives to shed light on systems' dynamics and inform decision-making processes upon the insights gained (Barreteau et al., 2007; Daniell et al., 2006; Duboz et al., 2018; Stirling, 2010; Voinov et al., 2016; Voinov & Bousquet, 2010).

According to Daniell et al. (2006), a participatory modeling approach improves the legitimacy of a model to assist collective decision-making processes and action in support of transformation processes since it integrates the knowledge and perspectives of a broad range of stakeholders. Moreover, these authors highlight the usefulness of participatory modeling approaches to reduce conflicts by explicating the tacit knowledge, preferences, and values underlying different points of view.

Van den Belt (2004) sustains that any form of participation in the modeling process could be labeled participatory modeling. In this regard, Voinov et al. (2016) propose a generic framework for the modeling process, arguing that the level of engagement or participation would vary throughout the participatory modeling process in response to the specificities of the modeling technique and ultimately to the characteristics of the systemic inquiry being developed.

A wide range of methods and tools can support different stages or components of the modeling process. Moallemi et al. (2021) explain the diversity of instruments in two dimensions: level of participation and level of formalization (Figure 4.1). Across the first dimension, methods range from engaging stakeholders to extract knowledge with limited participation to fostering an intensive engagement and co-learning process (e.g., rich pictures and causal loop diagrams). Across the second dimension, methods range from qualitative to quantitative. Moallemi et al. (2021) sustain that quantification formalizes the assumptions upon which a model is built, enhancing the model's ability to delve into the dynamic behavior of the system and explore different scenarios (e.g., systems dynamics, agent-based modeling); nevertheless, performing a quantitative analysis leads to prioritizing a type of information, which may diminish the richness of knowledge and insights, in comparison to qualitative assessment (e.g., fuzzy cognitive mapping, causal loop diagrams, rich pictures).

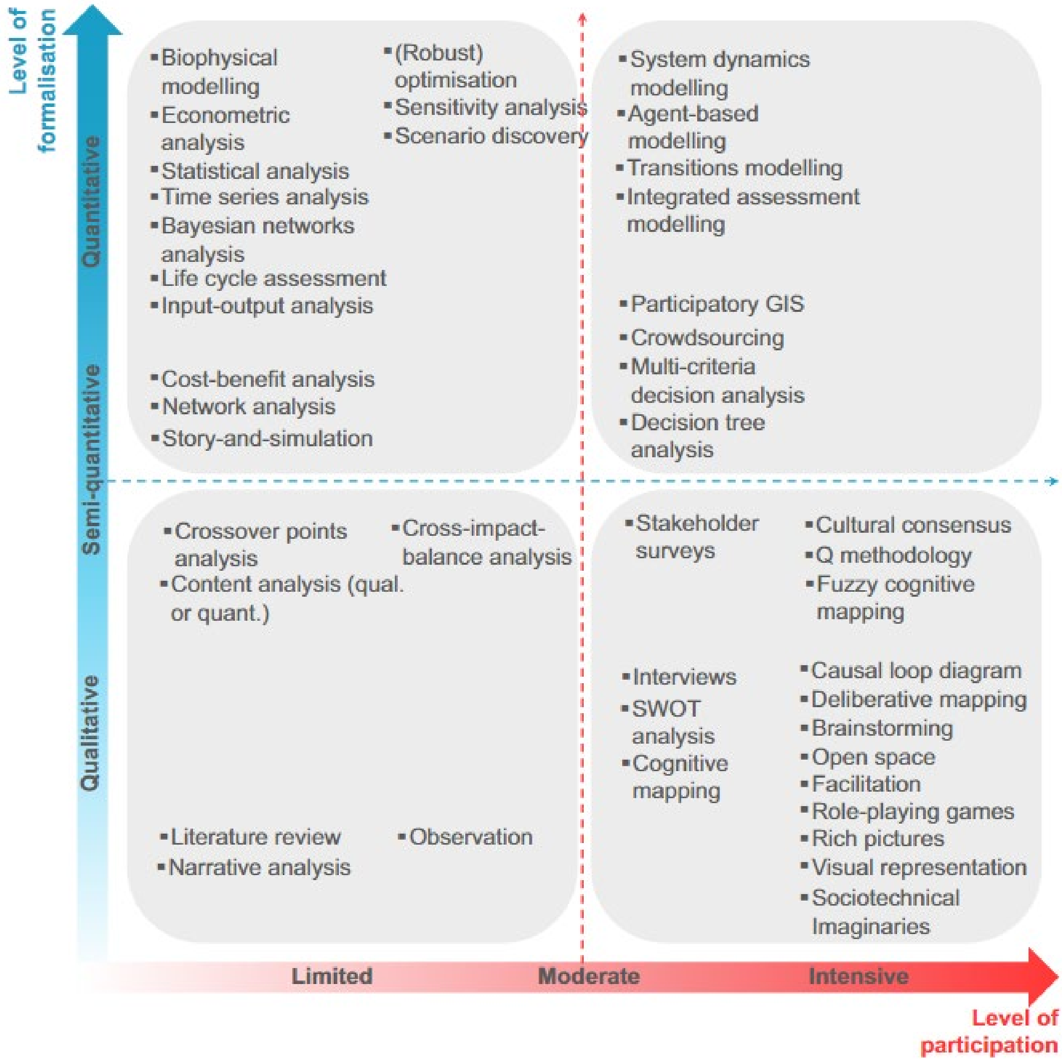

Figure 4. 1. Participatory Modeling methods distributed across a two-dimensional matrix: level of participation (x-axis) and level of formalization (y-axis). Source: Moallemi et al. (2021).

Soft Systems Methodology (SSM)

The SSM is part of the soft systems tradition, which considers systems as social constructs influenced by individual knowledge and social values and structures (Scotland, 2012), moving away from the idea that problems are obvious and clearly defined and such, how to solve them (Checkland, 1995).

Among the different ways SSM could be graphically represented, Figure 4.2 focuses on the logic behind SSM when used as a sense-making and learning device that draws on exploring how people understand a problematic situation and decide to act on it. This exploration is made by building conceptual models that illustrate what, from each perspective, is considered relevant to progress in addressing the problematic situation. The conceptual models are used as devices to foster and help structure the exploration of the problematic situation from different perspectives, promoting individual and collective learning on what is failing, why, and how to improve it (Checkland, 1995; Checkland, 2000). These conceptual models are also called “models of purposeful activities” and are structured around the expression of a transformation process that is considered necessary to address the problematic situation. More information about these conceptual models is provided below when describing the CATWOE analysis (Checkland, 2000; Checkland & Poulter, 2010).

In the end, with an enhanced awareness of the situation's complexity, stakeholders discuss potential pathways to transform the system of interest until reaching accommodations among perspectives on what is considered desirable and culturally feasible to move toward a future different perspective could live with (Checkland, 1995; Checkland, 2000; Checkland & Poulter, 2010; Williams & Hummelbrunner, 2009).

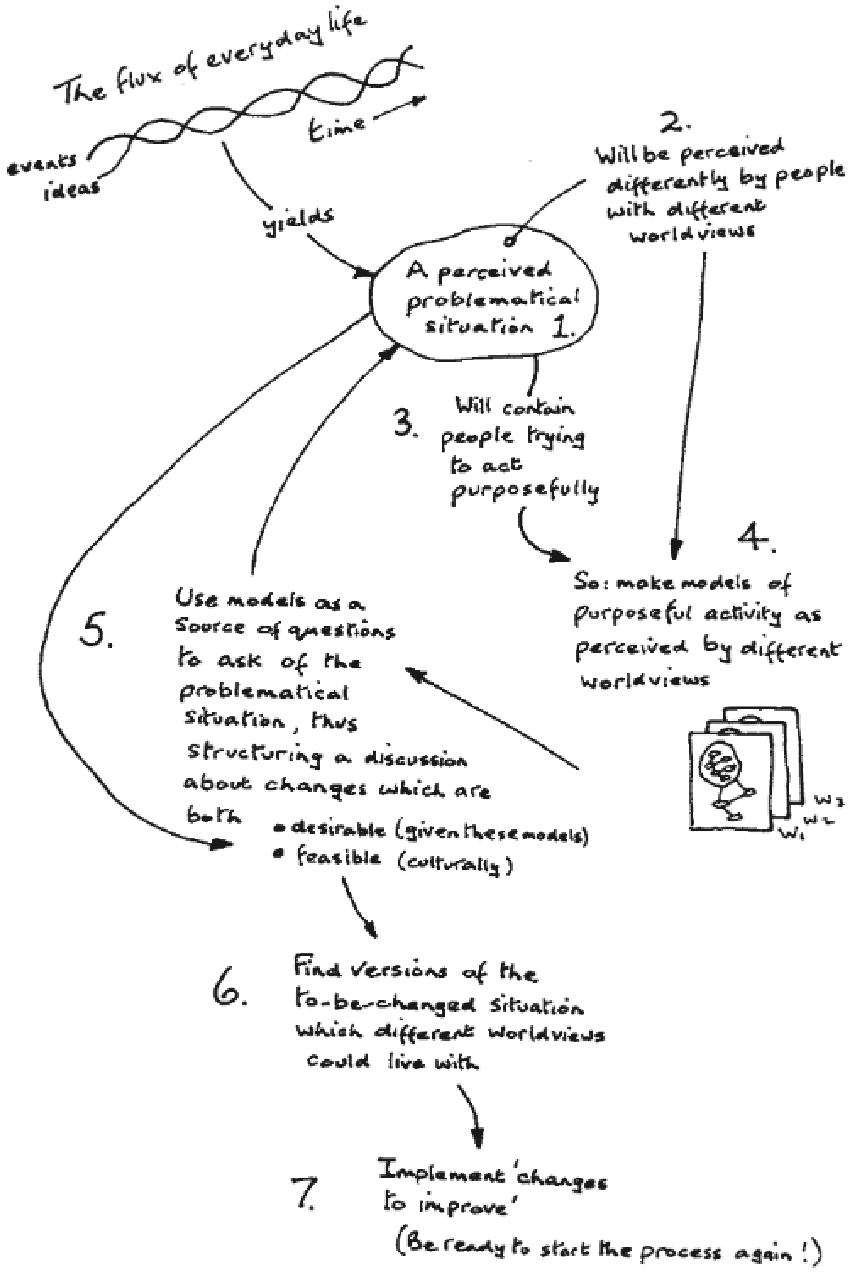

Figure 4. 2. Soft Systems Methodology as a sense-making and learning approach. Source: Checkland & Poulter (2010).

The PFSM framework aligns with the philosophical underpinnings of the soft systems tradition. Hence, it draws upon the Soft Systems Methodology to define the phases and activities that guide the exploration and conceptualization of the problematic situation in food systems to identify feasible and desirable transformation pathways. It is worth noting that, beyond being methodology-oriented, the SSM is an iterative process of exploration, learning, and accommodation between perspectives (Checkland, 2000).

TEEB for agriculture and food (TEEBAgriFood) framework

Among the food systems frameworks developed over the past two decades to better understand and address complex challenges related to food and agriculture, TEEBAgriFood (TEEB, 2018) stands out as a systemic evaluation model that substantively brings systems thinking into practice (Patton, 2019).

The TEEBAgriFood conceptual framework recognizes and explores the multidimensional nature of food systems by comprehensively describing the elements within human, social, economic, and natural capitals that shape the behavior, outcomes, and trends of food systems. It does so by illustrating the drivers and outcomes of food systems' behavior in terms of the four capitals, as shown in Figure 4.3. As a result of the detailed description of food systems' structure, TEEBAgriFood set the groundwork for, through regular and ongoing measurement, gaining insights on food systems dynamics and monitoring the progress towards goals like sustainability or food security. Moreover, describing food systems in terms of human, social, economic, and natural capital makes TEEBAgriFood a flexible and adaptable framework that allows the exploration of food systems in different contexts and for diverse purposes (TEEB, 2018).

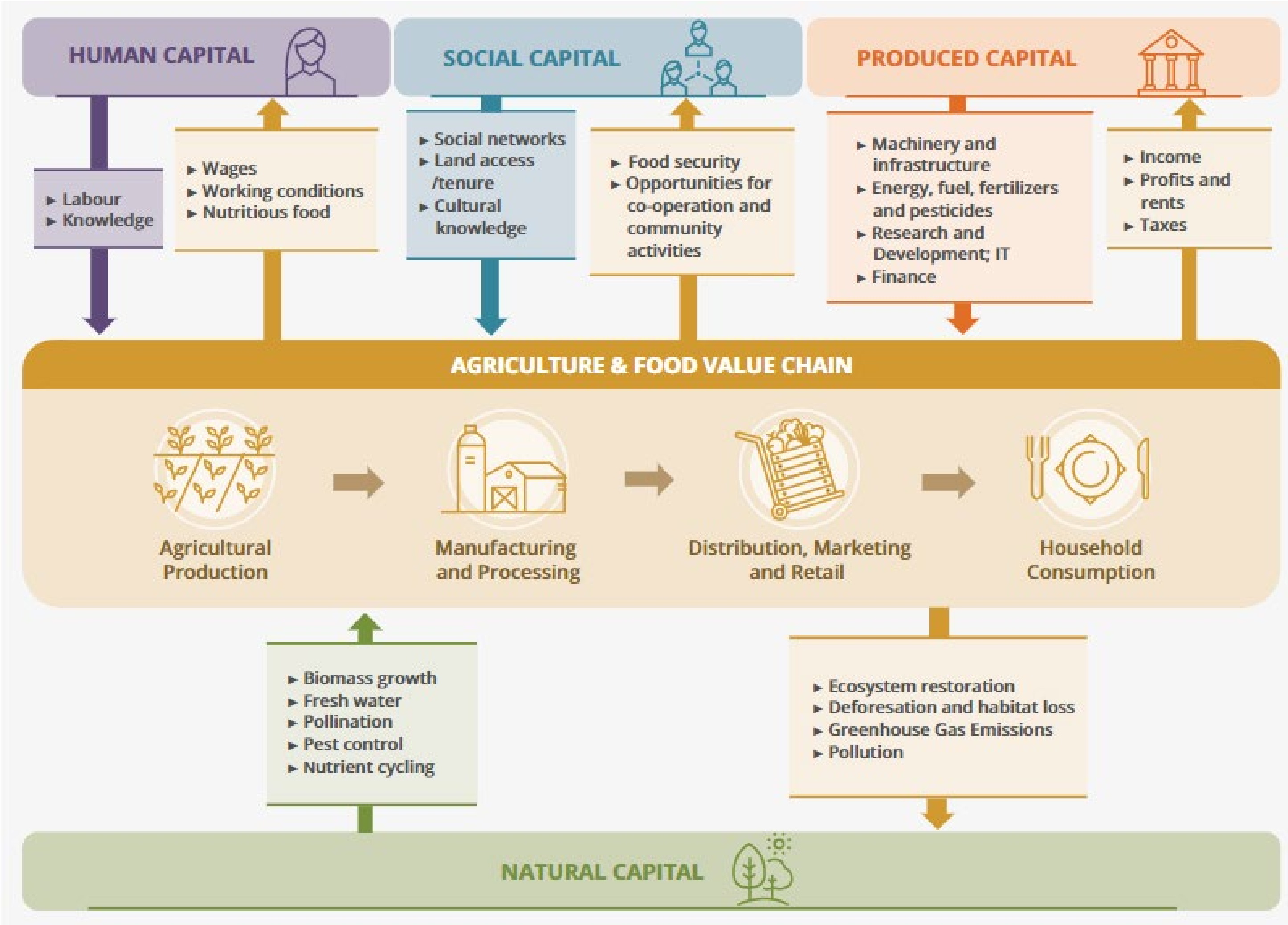

Figure 4. 3. TEEB AgriFood conceptual framework. Source: TEEB (2018).

4.2.2. Overview of the modeling methods and tools

Adopting a participatory modeling approach as the heuristic of the proposed methodological approach implies applying systems modeling methods and tools. Below is a brief description of the modeling instruments used in applying the proposed PFSM framework in the case studies of poultry systems in Ghana and Senegal.

CATWOE analysis

The CATWOE analysis is at the heart of the Soft Systems Methodology, being the main device for building conceptual models that illustrate different ways of seeing complex reality. As explained above, when introducing the Soft Systems Methodology, the conceptual models – or models of purposeful activities – are used as devices to foster an organized learning process (Checkland & Poulter, 2010).

The models of purposeful activities describe purposeful activity "as a transformation process, in which some entity is transformed into a different state" (Checkland & Poulter, 2010, p. 219). As illustrated in Figure 4.4, the CATWOE analysis comes to enhance the models, providing a mnemonic to think about elements that will shed further light on any purposeful (transforming) activity (Checkland & Poulter, 2010; Williams & Hummelbrunner, 2009).

- The purposeful activity, defined by a transformation process (T)
- The worldview (W) the transformation process is based on.
- People (A) that do the activities that enable the transformation to take place.
- People affected by the transformation process either as beneficiaries or victims (C – for customers).
- Environment (E), which includes important factors that enable or constrain the transformation and that must be taken as "given."
- People who can be regarded as owing (O) the entity to be transformed.

According to Williams & Hummelbrunner (2009), building the conceptual model from the transformation is essential. For that, they propose the following order: Transformation-Worldview-Customers-Actors-Owners-Environment.

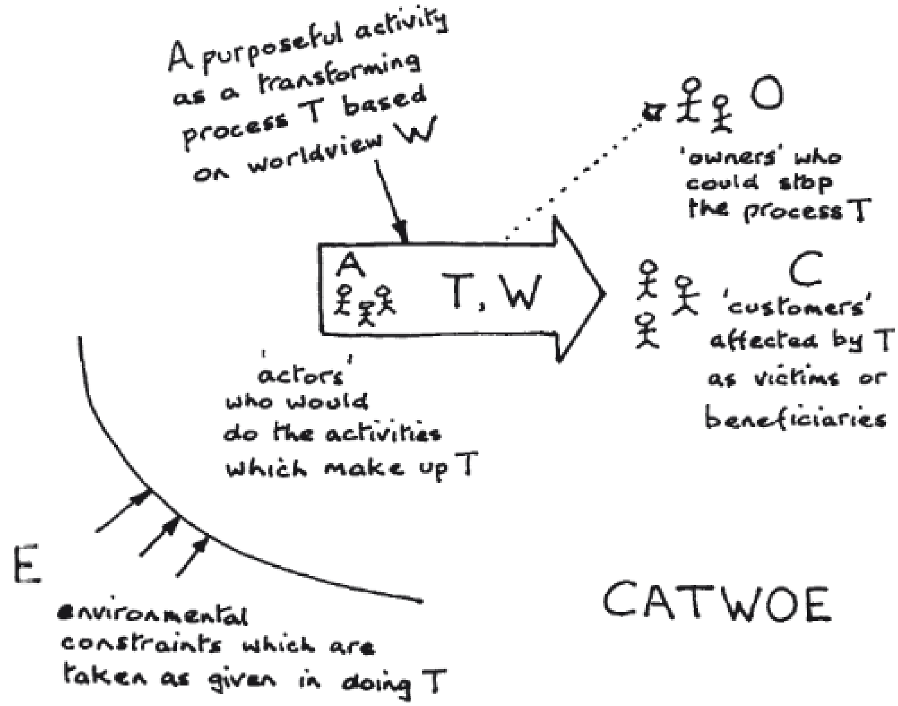

Figure 4. 4. CATWOE analysis to build models of "purposeful activities." Source: Checkland & Poulter (2010).

Causal Loop Diagrams (CLD)

CLD is a method that offers useful ways of diagramming and gaining insights into a situation with non-linear behavior. In this sense, CLDs are not an end in themselves but a device to facilitate – through the generation of debates among people with different worldviews – a better understanding of complex problematic situations and how to address them (Williams, 2021).

CLDs map how elements making sense of a complex situation relate to each other, focusing on the sequence of causes and effects that explain how things change (Williams, 2021). By illustrating variables and their relationships over time, CLDs allow the analysis of complex situations' structure, which explains the situations' current state and is responsible for their dynamic behavior (Williams & Hummelbrunner, 2009).

Williams (2021) suggests a process to construct Causal Loop Diagrams, briefly introduced below. The whole process highlights the importance of engaging with diverse stakeholders with diverse perspectives.

i. Identify the purpose of diagramming.

ii. Identify the key framing and the core problem: In other words, define the perspective that will guide the diagramming process. Here, it is highly encouraged to collectively build a view of the situation of interest as comprehensively as possible by involving people with diverse perspectives to inform this decision (Williams, 2021).

iii. Decide the boundaries of the problem: Discuss the problem to be explored and place boundaries around it to diagram only the factors related to the identified problem, not the entire situation (Williams, 2021).

iv. Identify key factors (variables): In a participatory process, write down ideas that describe the problem within the chosen boundaries, cluster those ideas, and identify one or more variables within each cluster that may be used to construct the CLD (Williams, 2021).

   Williams & Hummelbrunner (2009) sustain that identifying these factors most likely will require an iterative approach that includes rethinking the core problem, redefining the boundaries, and eliminating or including new variables in response. For this iterative process, it is particularly relevant to engage different perspectives to nurture the decision process (Williams, 2021).

v. Identify relationships between key variables: The relations between variables are illustrated by connecting them with arrows, which can include a positive or negative link to indicate the direction of the influence (Williams, 2021).

   Positive causal links indicate that the connected variables are changing in the same direction. Meaning that an increase in variable B leads to an increase in variable B, and a decrease in A leads to a decrease in B. On the other hand, negative causal links indicate an inverse correlation, where an increase in variable A leads to a reduction in variable B and vice versa (Williams & Hummelbrunner, 2009).

vi. Identify and categorize critical loops: CLDs are based on the concept of feedback loops – understood as closed sequences of causes and effects – which appear in two types: reinforcing and balancing feedback loops (Williams & Hummelbrunner, 2009).

Reinforcing feedback loops have zero on an even number of negative directions. They lead to exponential growth and thus tend to get out of control. On the other hand, balancing feedback loops have an odd number of negative directions and usually appear to counteract the reinforcing ones, resulting in exponential growth that is followed by correctional behavior (Williams, 2021).

Williams (2021) suggests creating a narrative of the dynamics observed in the feedback loops by walking through the diagram to discuss among stakeholders.

vii. Validating the diagram: Williams (2021) talks about validation in the sense of analyzing whether the behavior described in the narrative reflects what is happening in reality.

Fuzzy Cognitive Mapping (FCM)

Fuzzy Cognitive Mapping is a method that builds semi-quantitative systems models by graphically illustrating the interrelations between systems' key elements, including feedback relations (Gray et al., 2015; Jetter & Kok, 2014). FCM has been used in several disciplines to indicate relationships among variables, understand system dynamics, and promote learning (Gray et al., 2013).

Fuzzy Cognitive Maps are considered highly structured versions of cognitive maps that represent the variables of a system as concepts and assess qualitatively the strength of the direct and indirect causality by assigning a fuzzy value between -1 and 1 to the connections between the concepts (Kosko, 1986). For connections to have a positive causality means that an increase in the value of concept A leads to the increase of the value of concept B or that a decrease in the value of concept A leads to a decrease in the value of concept B. A negative causality means that an increase in the value of concept A leads to a decrease in the value of concept B and vice versa (Stylios et al., 1997).

The nature of FCM makes it easy for stakeholders to participate in the modeling directly or by contributing with knowledge (Edwards & Kok, 2021; Özesmi & Özesmi, 2004). Because of its nature, FCMs allow the inclusion of both quantifiable and difficult-to-quantify aspects of a complex system (Kafetzis et al., 2010). One typical strength of FCMs is their modeling language, which allows the aggregation of diverse sources of knowledge to build a representation of shared knowledge, known as a social cognitive map (Gray et al., 2013).

FCM is a powerful instrument for modeling complex systems, leveraging the knowledge of the structure and operation of cognitive maps (Stylios et al., 1997; Gray et al., 2013). Gray et al. (2015) suggest that FCM can be used to understand socio-ecological systems' dynamics by (i) collectively defining the state space of the system – understood as the set of variables and interrelations that make sense of the system of interest; (ii) analyzing the structure of the system of interest in terms of their variables, interrelations, and feedback loops; (iii) running "what if" scenarios and comparing them with scenarios without disruptions.

The first step in building an FCM is determining the concepts describing the system of interest. Then, interconnections among them must be established, considering three parameters: how strongly concept A influences concept B, the sign of the weight – depending on whether causality is positive or negative – and whether concept A causes concept B, or vice versa. To identify the concepts and establish the interrelationships between them, Stylios et al. (1997) strongly recommend using social cognitive maps that combine or aggregate the inputs provided by agents with different perspectives and types of knowledge.

Once the FCM model is built, valuable insights emerge from exploring its structure. In this sense, having the relationships between variables represented in a matrix allows for calculating their indegree and outdegree, indexes that provide information on how variables within the system act concerning other variables (Nyaki et al., 2014). The outdegree shows the cumulate strengths of connections exiting the variable, and the indegree shows the cumulate strengths of connections entering the variable (Özesmi & Özesmi, 2004).

Another relevant index for understanding the structural relationships between variables is centrality. Centrality is the sum of the indegree and outdegree and shows how connected the variable is to other variables and the cumulative strengths of these connections (Özesmi & Özesmi, 2004). It is considered an expression of how important a variable is to the whole system structure. It can be interpreted in terms of the indegree and outdegree, which shows whether the variable is mainly influenced by others, if other variables influence it, or both.

Additionally, FCM can be used to run and compare “what if” scenarios with the steady state of the system – that illustrates its behavior in the absence of perturbations – allowing users to evaluate the system’s dynamics by simulating increase or decrease in specific variables (Gray et al., 2012) and foster collective discussion on potential interventions in terms of their desirability to the agents involved (Gray et al., 2015).

4.2.3. Proposed methodological approach: PFSM Phases, activities, and outcomes.

The PFSM framework comprises three phases that are part of the iterative process of collectively making sense of problematic situations to gaining insights that allow identifying potentially desirable and culturally feasible pathways for transformation. Figure 4.5 illustrates the three phases of the participatory food systems modeling process, highlighting the purpose of each and their corresponding results.

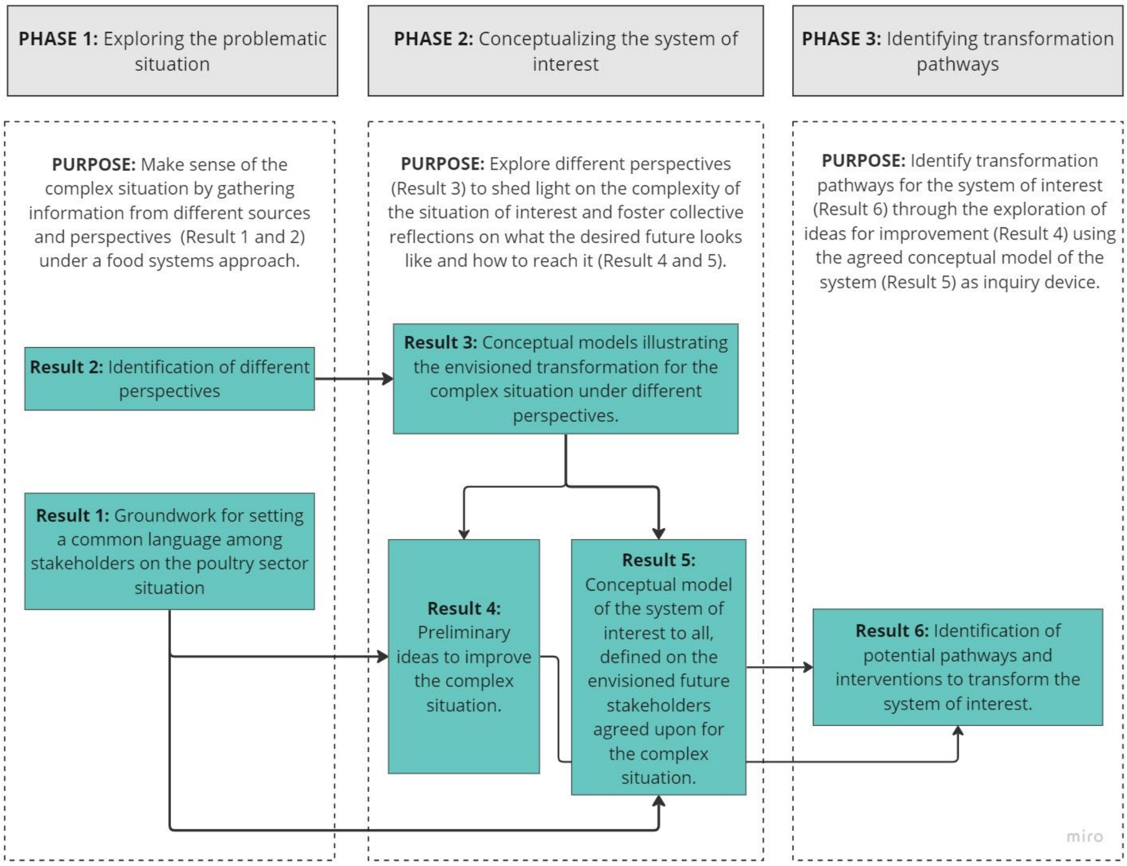

Figure 4. 5. Overview of the Participatory Food Systems Modeling Approach

The first phase focuses on exploring the problematic situation as comprehensively as possible. In this sense, a food systems approach – guided by the TEEBAgrifood conceptual framework (Eigenraam et al., 2020; TEEB, 2018) – is adopted to foster an exploration that goes beyond value chain activities, including aspects and interlinkages that otherwise could remain unnoticed.

This first exploration aims to reflect the information obtained from different sources, people, and perspectives without prioritizing or discriminating any insight but presenting them as a part of the same complex whole. In that sense, it sets the groundwork for establishing a common language among stakeholders on the poultry sector's problematic situation (Result 1), which is essential to – in phase two – foster discussions and debates on what needs to be changed and how. The insights shared by stakeholders at this stage, especially during the interviews, reveal the diversity of perspectives on the poultry sector's problematic situation (Result 2).

The second phase aims to acknowledge and explore different ways of understanding the problematic situation of the poultry sector to shed light on its complexity and how to move towards a desirable – or at least acceptable – future for all the agents involved. First, a common language among stakeholders is set by sharing the poultry sector situation using a systems diagram as a device. Causal Loop Diagrams were used to illustrate the dynamics of the poultry sector by creating a narrative from the interrelations and feedback loops and sharing it among stakeholders.

Once the underlying narrative of the poultry sector's problematic situation was shared, the different ways of understanding it are delved into by verbalizing the transformation each perspective envisions for the poultry sector (Checkland, 2000; Checkland & Haynes, 1994; Checkland & Poulter, 2010). The information obtained from delving into each perspective is expressed in conceptual models (Result 3), used as inquiry devices for stakeholders to collectively explore the problematic situation from different lenses and gain insights into its complexity (Checkland & Poulter, 2010). The emerging insights from the dialogue and sharing among stakeholders with different perspectives suggest ideas to improve the poultry sector situation (Result 4) (Williams & Hummelbrunner, 2009).

The discussions and debates taking place among stakeholders when collectively exploring the problematic situation of the poultry sector increased their awareness of diversity and complexity, setting the groundwork for them to negotiate until they agree on a future for the poultry sector that is desirable – or at least acceptable – for all (Checkland & Poulter, 2010). In this sense, it is worth noting that, given the diversity of perspectives involved in most complex situations, it is rarely possible to agree on a future that everyone desires with the same intensity. Still, stakeholders can reach accommodations to make a collective effort to move in the same direction. Considering this agreed-upon future, stakeholders define a system of interest to all and illustrate it in an agreed-upon conceptual model (Result 5).

Lastly, phase three aims to systematically explore potential pathways to move the poultry system from its current problematic situation to the future agreed upon among stakeholders. As detailed above, during the second phase of the methodology, stakeholders share ideas to change/ improve the poultry sector situation, informed by different perspectives. Those ideas were explored in this phase using the poultry system conceptual model (Result 5) to simulate interventions in the poultry system and inform the identification of transformation pathways that are both desirable and culturally feasible (Checkland & Haynes, 1994; Checkland & Poulter, 2010; Eigenraam et al., 2020; TEEB, 2018) (Result 6). Desirable according to the conceptual model of the system of interest to all – built around a future agreed upon among perspectives – and culturally feasible in the sense of being possible for agents involved in the system, considering the social norms, values, and power structures that guide their behavior and actions (Checkland & Poulter, 2010).

The COVID-19 restrictions prevented the development of the methodology as initially planned, affecting mainly the in-person participatory activities. A hybrid approach that combined online and in-person collaboration between research teams was adopted to address this challenge while preserving the research's nature and purpose. This involved extensive knowledge exchange and collaborative work between the local research teams of ITA in Senegal, CSIR-STEPRI in Ghana, and the foreign research team of UPM in Spain.

The methodology was nuanced to the contextual conditions, information availability, timing, and stakeholders' engagement in each case study. Further information on each phase of the methodology is provided below, delving into the nuances of each case study.

4.3. Application of the PFSM framework: Case studies on poultry systems in Ghana and Senegal.

4.3.1. Case studies background: Livestock and poultry farming contributions to food security and households' economy in West African countries.

The proposed PFSM framework is applied in two case studies on poultry systems: one in Ghana at the national level and the other in Senegal in the regions of Kolda and Ziguinchor. These applications aim to identify desirable and culturally feasible transformation pathways for poultry systems.

This section offers an overview of the context where case studies are conducted, broadly on West Africa and particularly on Ghana and Senegal. Firstly, it provides an overview of food insecurity in West Africa, highlighting the situation of smallholder farmers and their role in moving towards more sustainable food systems. Then, it discusses the relevance of the agriculture and livestock sector for rural households, emphasizing poultry farming. Finally, it provides an overview of the poultry sector in West Africa, particularly in Ghana and Senegal.

By providing an overview of the context where the case studies are conducted, this section lays the groundwork for discussing the value of the PFSM framework in advancing the challenges of food systems in Ghana, Senegal, and West Africa in general.

Food insecurity in West Africa: Smallholder farmers as a vulnerable group and levers of change

The Global Network Against Food Crisis and the Food Security Information Network (2023) registered 41.5 million people facing acute food insecurity in West Africa in 2022, against 30.4 million in 2021. It is worth mentioning that 3 million fewer people were analyzed in 2022 compared to 2021. Below is a summary of the region's main drivers of food insecurity.

Regional security crises and conflicts have been persistent challenges – particularly in Central Sahel and the Lake Chad Basin – leading to large-scale population displacements and adversely impacting the livelihoods of rural communities, particularly farmers and pastoralists. For Burkina Faso, Cameroon, Chad, Mali, Niger, and Nigeria, security crises and conflicts are the main drivers of food insecurity (Global Network Against Food Crisis & Food Security Information Network, 2023).

Economic shocks such as the COVID-19 pandemic and the war in Ukraine continue to have significant repercussions on domestic economies in the region. These shocks generate inflation and disrupt income-generating activities by increasing the price of key products and leading to a reduction of household purchasing power across the region (Global Network Against Food Crisis & Food Security Information Network, 2023), especially among vulnerable people like the rural poor (FAO-GIEWS, December 2021).

Moreover, West Africa continuously faces the effects of climate change. The droughts and below-average rains experienced in the Sahelian countries during 2021 led to a shortfall in food production in 2022. This, coupled with the market and livelihood disruptions caused by flooding in 2022 – which impacted 7,5 million people in 14 countries – has further constrained local food availability and access, exacerbating the acute food insecurity in the region (Global Network Against Food Crisis & Food Security Information Network, 2023).

Both in Ghana and Senegal, the main drivers of acute food insecurity are the economic crises resulting in currency depreciations and high inflation, with a consequent reduction of household purchasing power (Global Network Against Food Crisis & Food Security Information Network, 2023; World Food Program, 2023). Figure 4.6 shows the food price inflation derived from the economic crisis as of December 2022 in the West African countries/ territories where food price inflation was over 10 percent.

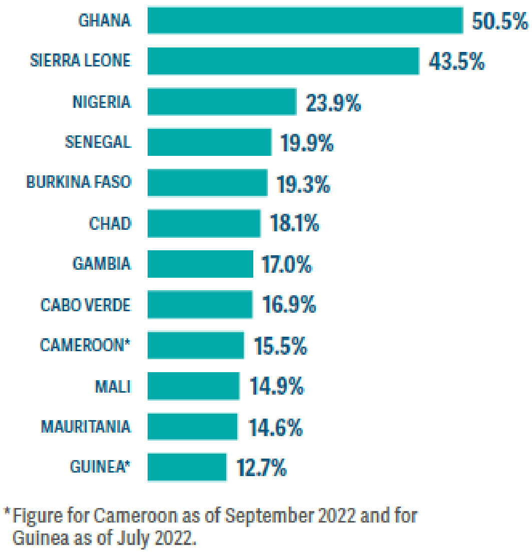

Figure 4. 6. Food price inflation in West African countries December 2022. Source: Global Network Against Food Crisis & Food Security Network, 2023.

Concerning security crises and armed conflicts, Ghana and Senegal are among the least impacted countries in the region. However, the northern part of Ghana recently started suffering from the effects of the expansion of the Central Sahel crisis (Global Network Against Food Crisis & Food Security Information Network, 2023; World Food Program, 2023).

Figure 4.7 illustrates that people in the emergency phase or worse – i.e., in need of immediate assistance – were close to 6% of the population analyzed in Senegal and close to 7% in Ghana as of March 2022. Both countries registered the lowest numbers of people facing acute food insecurity in the region, although information for more than half of the population in Ghana is still lacking. Moreover, 22% of households in Senegal adopted stress-coping strategies to address their nutritional needs in 2022, mainly in response to inflation (Baoua et al., 2022). For Ghana, the information available as of March 2022 indicates 19% of households (Cadre Harmonisé, 2022).

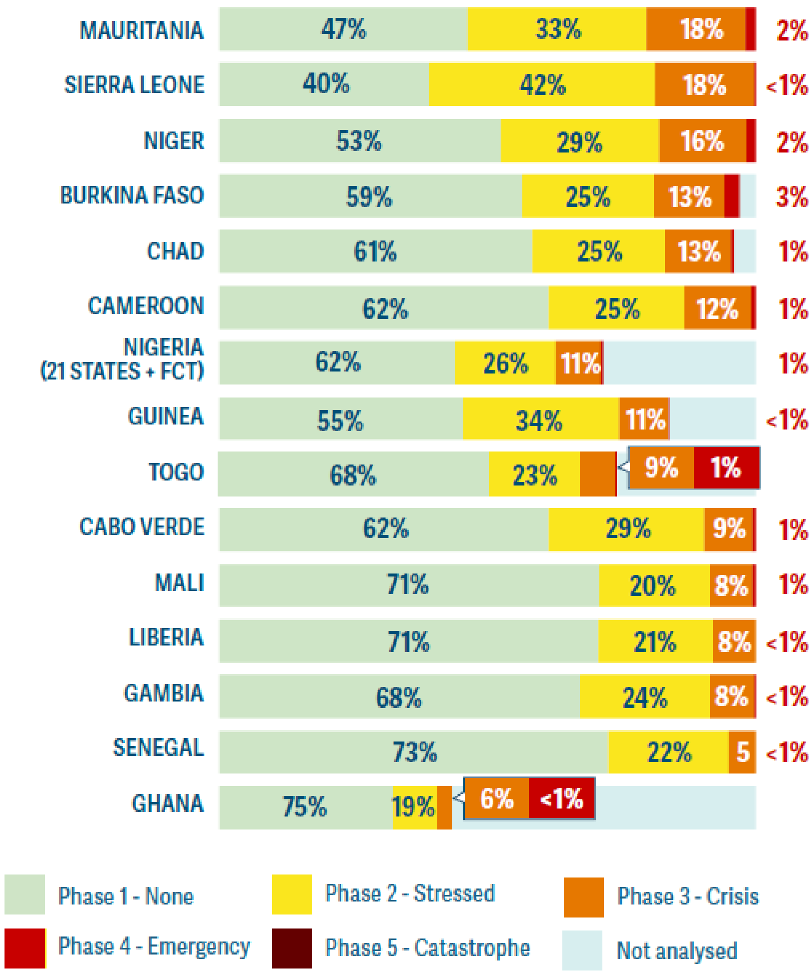

Figure 4. 7. Acute food insecurity in West African countries – 2022 peak. Source: Global Network Against Food Crisis & Food Security Information Network, 2023

In West African countries, approximately 41.2 percent of the population is engaged in agriculture-related activities (Molina-Flores et al., 2020). Most food production occurs on smallholder farms with poor yields, with the farmers themselves living below the official poverty line (Gassner et al., 2019) and struggling to achieve food self-sufficiency (Giller, 2020). This situation illustrates the vulnerability of smallholders and highlights the need for interventions that support and improve their livelihoods, strengthen their agency, and enhance their resilience and adaptation capacity to external shocks.

Despite smallholders' vulnerability, high expectations are placed on them to drive transformative change in rural areas, particularly regarding poverty alleviation and food security. Gassner et al. (2019) call for managing such expectations with caution, given that "while most smallholders would be capable of providing vital safety nets for the families that depend on them, few have the potential to generate substantial inclusive rural growth” (p. 312). In this sense, it is essential to recognize the heterogeneity among smallholders – in terms of capabilities, resources, potential, interests, and expectations – to design nuanced interventions and policies that promote their development, maximizing the benefits for them, their families, and society. Dorward et al. (2009) describe three types of livelihood strategies that shed light on the diverse pathways people follow to meet their requirements and aspirations in an evolving environment: maintaining livelihood levels in the face of adverse circumstances, increasing production and incomes to improve livelihoods, and investing in diversifying activities to support financial stability.

Livestock and poultry as livelihoods for rural households

In the agriculture sector, livestock production plays a crucial role in addressing trends such as population growth, urbanization, shifts in consumer preferences, and growing demand for Animal-Source Food (ASF) (Molina-Flores et al., 2020). ASF, due to its potential to improve the “nutritional adequacy of poor and vulnerable populations in most low-income countries and of population groups with limited food intake capacity” (FAO et al., 2021, p.69), can be a significant lever for enhancing food security in the region. Livestock production not only improves households’ access to diverse ASF but also serves as a source of financial security for smallholders facing vulnerable situations (Hetherington et al., 2017; Randolph et al., 2007; Smith et al., 2013).

For Senegalese households, livestock has economic and social importance (Habanabakize et al., 2022). According to the Global Center on Adaptation (2023), livestock farming is practiced by one in three households in Senegal while contributing to 3.4% of the country's GDP.

In Ghana, the livestock sector contributes to the food and nutritional security of the population and generates employment opportunities, particularly in rural areas (Ministry of Food and Agriculture, 2016). “It offers prospects for wealth creation, income enhancement, coping mechanism against crop failure, financial security and improvement in rural livelihoods” (Ministry of Food and Agriculture, 2016, p. 4).

Within the livestock sector, poultry farming plays a central role in West African countries, particularly in most rural and some urban areas, where it is adopted as a livelihood strategy to sustain or enhance food security (De Bruyn et al., 2015; Hetherington et al., 2017). While it may not be the primary economic activity, selling poultry products generates vital revenues that enable families to meet their basic household expenses (Molina-Flores et al., 2020). This dual function of poultry farming as a source of food and income underscores its relevance in West Africa, as it simultaneously addresses nutritional needs and provides economic support to rural communities.

Overview of the poultry sector in Ghana and Senegal

Table 4.1 includes a brief overview of the poultry sector in Ghana and Senegal, emphasizing the challenges and opportunities faced by small-scale and traditional/ backyard poultry farmers.

Table 4.1. Overview of the poultry sector in Ghana and Senegal

	Senegal	**Ghana**
Relevance of the poultry sector	The poultry sector in Senegal is an important source of employment, with over 500,000 people directly and indirectly employed (RVO Netherlands Enterprise Agency, 2021), and contributes to family incomes and rural development (Ly, 2020). Additionally, poultry farming plays an essential role in ensuring food security in Senegalese households (Ly, 2020) since "both chicken meat and eggs are gram-for-gram the second most affordable animal protein after sardines" (RVO Netherlands Enterprise Agency, 2021, p.3).	According to Hartley & Ardnt (2018), in Ghana, the poultry value chain is among the ten agricultural value chains with more significant positive impacts on economic growth, employment earnings, poverty reduction, and nutrition.
Evolution of poultry supply and demand	Poultry production in Senegal has increased exponentially since the importation ban of poultry products in 2005, reaching 51.4 million broiler chicks in 2019 (Ba et al., 2022). The growth in the poultry sector is not only	Demand for poultry meat in Ghana is ever-increasing. Meanwhile, domestic surplus remains almost stagnant, allowing imports to fill the gap. Imported chicken has filled the local demand gap since 2002, contributing to more than 50% of the national demand

	attributed to socioeconomic trends and import control but also to the modernization of poultry farming in Senegal (Ly, 2020).	annually (RVO Netherlands Enterprise Agency, 2019). The decline in domestic poultry production from early 2000 to the present is generally explained by high feed costs, subsidized foreign production, and the "dumping" of frozen chicken parts (Sumberg, Awo, & Kwadzo, 2017).
Types/ scales of poultry farming	Ly (2020) classifies poultry farming into three types - traditional, semi-intensive, and industrial. Although moving toward industrial poultry farming has been critical for the sector's growth, Ly (2020) highlights that traditional poultry farming accounts for 40% of national consumption and generates about 30% of modern/ industrial poultry farming's revenue.	Commercial poultry production can be categorized into large-scale (over 50,000 birds), medium-scale (10,000 - 50,000 birds), and small-scale (less than 10,000 birds). Large-scale farms are responsible for 20 percent of the poultry sector and produce mainly eggs. The medium-scale category also produces primarily eggs. Within the small-scale farms are backyard poultry producers, who mostly have broiler birds (RVO Netherlands Enterprise Agency, 2019).

Relevance of traditional/ small-scale poultry farming	Traditional poultry farming plays a significant role in households in rural areas, covering food needs and ensuring social functions with relatively low investments (Faye et al., 2022). However, it faces genetic, sanitary, technological, and organizational challenges that hinder its full potential, as noted by Ly (2020).	The backyard production system is the most common poultry production system in rural areas in Ghana. Revenues earned from this production system provide additional household income and occasionally satisfy the nutritional needs of farm households (Anang et al., 2013; Butler, 2016).
Challenges & Opportunities	The lack of appropriate slaughtering, chilling, and processing facilities and services in the Senegalese poultry value chain poses barriers for farmers to optimize productivity, as demand does not always keep pace with production cycles. This situation intensifies the competition in selling live birds in the fresh markets, negatively impacting small-scale/ traditional poultry farmers (RVO Netherlands Enterprise Agency, 2020). Strengthening farmers' access to appropriate slaughtering, chilling, and processing facilities and	Poultry farmers see broiler production as a non-profitable activity, as they cannot compete with imported and less expensive frozen chicken products (RVO Netherlands Enterprise Agency, 2019). Feed represents about 70% of the total production costs. Despite the government's efforts to enhance the domestic production of maize and soybeans, most maize used as poultry feed is imported and thus exposed to world grain price fluctuations (Sumberg, Awo, & Kwadzo, 2017). Besides the price and access to feed - which is a

services would allow them to control the production cycles, optimize productivity, and manage both production surplus and demand peaks (RVO Netherlands Enterprise Agency, 2020).

Large/ industrial poultry farmers work closely with independent traders or *bana-banas,* who sell their live birds almost exclusively in markets nationwide. In contrast, traditional and small-scale poultry farmers are constrained to rural weekly markets and direct sales to consumers in villages and small towns. This situation leads them to face regular market gaps and forces them to extend their production, reducing productivity levels (Ly, 2020).

In Kolda and Ziguinchor, where the case study was performed, traditional poultry farming predominates (Diédhiou et al., 2022; Faye et al., 2022), with supply and marketing circuits highly challenge shared by small, medium, and large-scale farmers - backyard producers face many other challenges related to the precarity of their farming systems and the appropriateness of husbandry practices and the sanitary and safety conditions on the farms, which makes them more vulnerable to disease outbreaks and prevent their compliance with Food Safety Standards (RVO Netherlands Enterprise Agency, 2019). Besides production-related challenges, poultry farmers - particularly the commercial type - need stronger linkages to the agro-processing sector to be more competitive in the markets (Sumbers, Awo, & Kwadzo, 2017).

Naggujja et al. (2020) sustain that for broiler producers in Ghana to survive in the broiler industry, it is essential to increase trade barriers to reduce imports while boosting the domestic broiler industry to cover the national demand for quality poultry meat products at dependent on Dakar, which prevents them from being more competitive in the market. In Ziguinchor, poultry farming is part of the informal economy for diversification and income generation to face unemployment, and as such, it is precarious and unsafety (Diédhiou et al., 2022). On the other hand, poultry farming in Kolda is slowly showing improvements in husbandry practices derived from project interventions, but they are still limited by their high implementation costs (Faye, 2022).

a competitive price. In the scenario of no significant change being made to the trade policy, any pathway for strengthening the domestic broiler industry should first assure access to high-quality, competitively priced inputs, to then improve husbandry and management practices on the farm to boost productivity (Sumberg, Awo, & Kwadzo, 2017).

4.3.2. Application of the PFSM framework on poultry systems on the national poultry system in Ghana

This section elaborates on the nuances of applying the PFSM framework in the Ghana case study. Figure 4.8 outlines the flow of activities carried out in each PFSM stage over time, indicating the results derived from each activity. The results of this application are shown in Chapter 5 of this thesis.

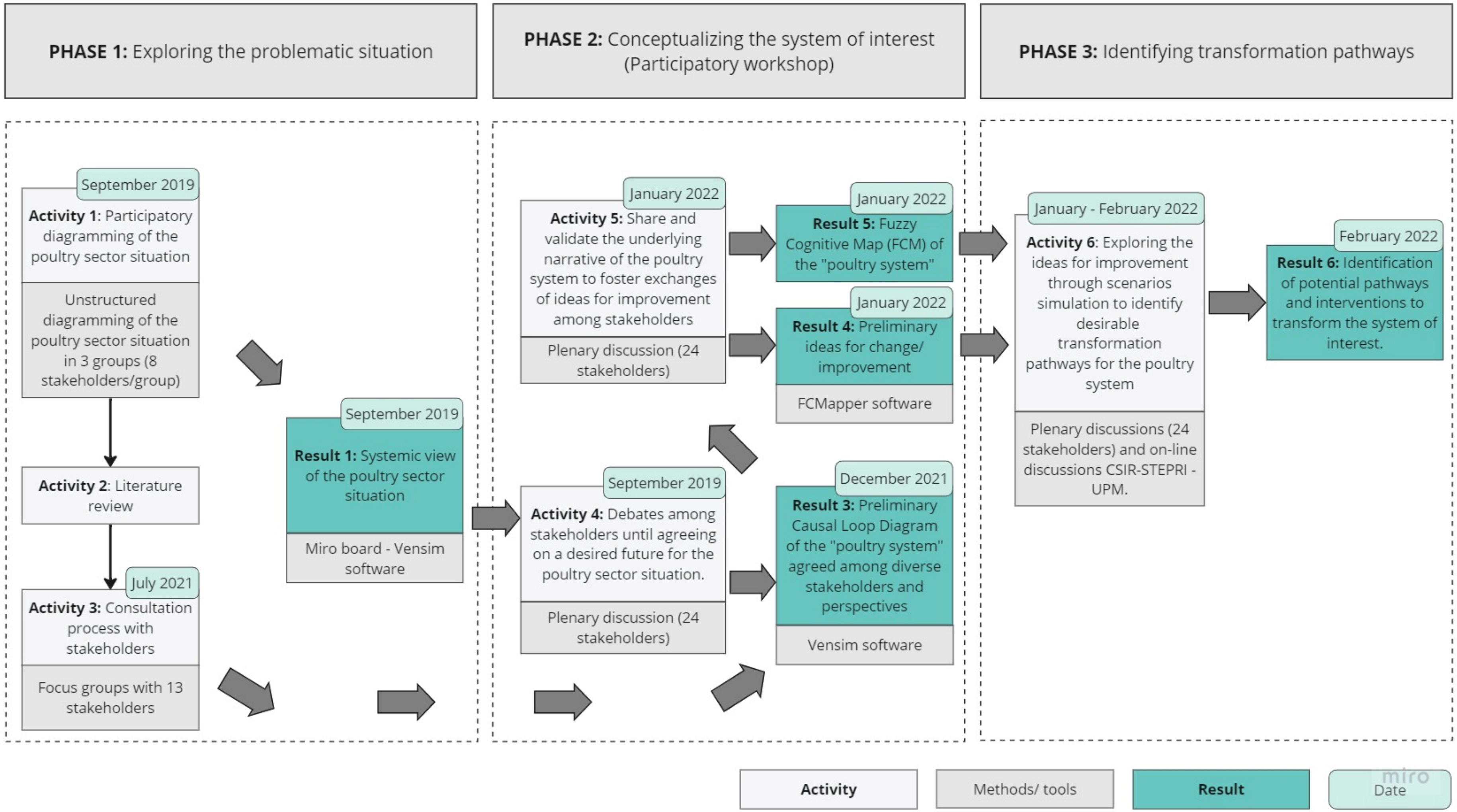

Figure 4.8. Application of the PFSM framework to poultry systems in Ghana

Phase 1: Exploring the problematic situation of the poultry sector.

A participatory workshop was scheduled to explore the poultry sector's situation before the onset of the COVID-19 pandemic (September 2019), allowing the engagement of diverse stakeholders and perspectives from the early stages of the research (Table 4.2).

Table 4.2. Workshop participants – Accra, September 2019.

Role / Group	**Number of participants**
Livestock and poultry farmers	3 females; 4 males
Feed processors	1 male
Meat marketers	1 male
Inputs supplier	1 female; 2 male
Consumers	1 female
Policymakers/ public officers	1 female; 2 males
Researchers	2 females; 6 males
Total	24 people: 8 females and 16 males

Workshop participants were divided into three groups and asked to diagram - in an unstructured manner and as comprehensively as possible – all the elements that they felt could help explain the poultry sector situation, including contextual factors, activities, agents involved, views and perspectives – whether similar, complementary, or opposite (Activity 1). The notion of food systems was shared in the workshop to foster a systemic analysis of the situation around poultry, paying attention to the different capitals that affect and are affected by how we produce, process, market, and consume food, as explained in the TEEBAgriFood framework (Eigenraam et al., 2020; TEEB, 2018).

The information gathered in the participatory workshop of September 2019 was organized around topics of interest, providing a first systemic view of the poultry sector situation (Result 1).

A literature review (Activity 2) and consultation processes with stakeholders (Activity 3) were conducted to delve into each topic. The consultation process was made with farmers, politicians, public officers, researchers, and technical experts in July 2021

(Table 4.3), when the incidence of COVID-19 and the restrictions to avoid massive infections lowered.

Table 4.3. Stakeholders consulted to delve into the poultry sector situation – Accra, July 2021.

Role / Group	Number of participants
Livestock and poultry farmers	2 females; 2 males
Feed processors	1 male
Veterinarian	1 male
Inputs supplier	1 male
Policymakers/ public officers	1 female; 3 males
Researchers	1 female; 1 male
Total	13 people; 4 females, 9 males

Phase 2: Conceptualizing the system of interest/ system to transform.

The collective exploration of the poultry sector situation at the September 2019 workshop laid the foundations for stakeholders – being more aware of the complexity of the situation and the diversity of ways of understanding it – to discuss and debate what needs to be transformed in the current situation to move towards a future that makes sense to all.

Although the proposed PFSM framework calls for a structured exploration of the diverse ways of understanding the problematic situation of the poultry sector, time limitations during the participatory workshop of September 2019 prevented this activity from developing as planned. As the activities scheduled for the workshop progressed, the lack of time to meet the objectives became evident, which led the research teams to dispense with the identification and exploration of perspectives to prioritize discussions and debates among stakeholders on what needs to be transformed from the poultry sector's current situation. This decision was based on what, at the time, seemed to be an alignment of worldviews among stakeholders.

For structuring debates, stakeholders were asked to collectively think about a future that makes sense to all, reflecting on the motivations behind such a transformation, the agents involved, and the contextual conditions that would enable it (Activity 4). The PFSM framework envisaged that stakeholders would share and discuss ideas for improving the poultry sector at this stage; however, once again, time was a constraint, and stakeholders ended up focusing more on what the transformation should look like and less on discussing how to support it.

Based on what stakeholders agreed as the desired future, a system of interest to all was conceptualized. The research teams of UPM and CSIR-STEPRI worked together to build a conceptual model of the system of interest to all – called the poultry system in this chapter – performing a Fuzzy Cognitive Mapping.

The first step in building a Fuzzy Cognitive Map involved creating a Causal Loop Diagram of the system of interest (Result 3). The development of the Causal Loop Diagram was an iterative process of several months, which started immediately after the September 2019 workshop in Accra, with the first information gathered on the poultry sector situation. After that, the CSIR-STEPRI and UPM research teams worked together to build, discuss, test, and improve the Causal Loop Diagram in an iterative process that ended in December 2021. It is worth noting that, far from being the work of the research teams exclusively, building the Causal Loop Diagram was nourished by the insights gathered in the consultation processes with key stakeholders in July 2021 (Activity 2), as well as from the literature review (Activity 3) and punctual consultations to key experts made to deepen and triangulate information. To create the Causal Loop Diagram, the elements making sense of the poultry system were expressed as variables interlinked through positive or negative linkages, and feedback loops were identified and categorized.

The Causal Loop Diagram illustrating the poultry system was shared at a second participatory workshop in January 2022 to establish a common language among stakeholders and facilitate the exchange of ideas and debates on possible ways to move the poultry system from its current situation to the desired future (Activity 5). Table 4.4 lists the participants of this second workshop.

Table 4.4. Workshop participants – Accra, January 2022

Role / Group	Number of participants
Researchers & technical experts	4 females, 6 males
Livestock and poultry farmers	1 female, 2 males
Farmers associations	2 females, 1 male
Civil Society Organization	1 male
Input supplier	1 male
Policymakers/ Public officers	1 female, 5 males
Total	24 people: 8 females, 16 males

Causal trees were generated from the Causal Loop Diagram created in Vensim PLE® software to offer a friendly visualization of the interrelations between poultry system elements. On the other hand, feedback loops were identified, categorized, and used to create a narrative that illustrates the system's dynamic behavior. Both causal trees and feedback loops were used to share with stakeholders the underlying narrative of the poultry system's conceptual model around six topics of interest:

i. Competitiveness of domestic poultry meat
ii. Poultry farming profitability
iii. Poultry farming productivity
iv. Access to quality inputs, services, and facilities
v. Adoption of good practices and technologies
vi. Design and enforcement of poultry value chain regulations.

The document used to this end is included in Annex D.

Once the underlying narrative of the poultry system conceptual model was shared, stakeholders in the participatory workshop of January 2022 were divided into three groups to – using the conceptual model as an inquiry device – share and discuss ideas to move the poultry system toward the desired transformation (Result 4).

One or more topics of interest were assigned to each group of stakeholders in consonance with their expertise, interests, or roles within the poultry sector. Thus, the first group discussed the access of poultry farmers to quality inputs and facilities for developing their activity; the second group discussed poultry farming performance and profitability; and the third group discussed conditions affecting the competitiveness of domestic poultry meat, including processing and marketing facilities, as well as policies and regulations guiding value chain activities.

As stakeholders shared and discussed ideas to improve the poultry system concerning the different topics of interest discussed in groups, the underlying narrative of the poultry system conceptual model was validated with them. The main objective of this validation process was to improve the poultry system conceptual model – being faithful to stakeholders' perspectives by incorporating their feedback – for use as an inquiry device to identify and explore transformation pathways.

The feedback provided by stakeholders as part of the validation process was incorporated by the UPM and CSIR-STEPRI research teams into the Causal Loop Diagram, thus setting the groundwork to build an enhanced conceptual model of the poultry system in a Fuzzy Cognitive Map (Result 5).

Performing a Fuzzy Cognitive Mapping involves qualitatively valuing the linkages between the poultry system's variables to obtain further information on its structure and shed light on its dynamic behavior. Research teams from UPM and CSIR-STEPRI qualitatively valued the linkages as soon as the first Causal Loop Diagram of the poultry system was created, based on the local knowledge shared in the participatory workshop of September 2019 and the consultation process of July 2021 with key stakeholders. To that end, a matrix for coding the interrelations between variables was created in an Excel file. After the participatory workshop of January 2022, the matrix was revisited to incorporate the feedback received while validating the conceptual model narrative.

Below is a description of how each relationship in the Causal Loop Diagram was valued.

- **+1:** A positive change in variable A very highly explains the positive change in variable B.
- **+0,75:** A positive change in variable A highly explains the positive change in variable B.
- **+0,5:** A positive change in variable A moderately explains the positive change in variable B.
- **+0,25:** A positive change in variable A slightly explains the positive change in variable B.
- **-1:** A positive change in variable A very highly explains the negative change in variable B.
- **-0,75:** A positive change in variable A highly explains the negative change in variable B.
- **-0,5:** A positive change in variable A moderately explains the negative change in variable B.
- **-0,25:** A positive change in variable A slightly explains the negative change in variable B.

It is noted that as participatory modeling is an iterative learning process, the insights emerging from exploring transformation pathways for the poultry system can lead to adjusting the Fuzzy Cognitive Map and its adjacent matrix for coding the interrelations between the variables of the poultry system.

Phase 3: Identifying potential pathways for transforming the system of interest.

The enhanced poultry system conceptual model – built in a Fuzzy Cognitive Map (Result 5) – was used as an inquiry device to explore the shared ideas for improvement (Result 4) and identify desirable and culturally feasible transformation pathways (Result 6).

The FCMapper® software was employed to analyze the complex structure of the poultry system and thus shed light on its overall dynamic behavior based on the values assigned to the connections between the variables. The indegree, outdegree, and centrality of the variables within the poultry system were calculated to show how connected each variable is to others and what the accumulated strengths of those connections are (Özesmi and Özesmi, 2004).

Calculating the indexes mentioned above helped identify the variables with the highest centrality within the poultry system. Considering centrality as a measure of significance within the overall system, the top third of variables with the highest centrality were regarded as potential entry points for creating scenarios that shed light on poultry systems' behavior and inform the exploration of transformation pathways.

Collaboration and engagement with stakeholders were fostered during the development and analysis of scenarios. Having an enhanced understanding of the poultry system structure, stakeholders participating in the January 2022 workshop used the ideas for improvement from previous discussions and debates (Result 4) to identify potential levers for the poultry system's transformation among the variables in the top third with the highest centrality. Then, "what-if scenarios" simulating changes in the identified potential levers were run to explore transformation pathways for the poultry system (Activity 6).

Five, ten, and twenty iterations of the Fuzzy Cognitive Map were conducted to explore the short--, mid-, and long-term implications of "what if" scenarios in moving the poultry system toward the desired future (Activity 6). These iterations capture the interactions between the poultry system's variables over time, illustrating how altering certain variables affects the system's future state or trajectories.

Building the conceptual model of the poultry system on the transformation agreed upon among stakeholders allowed for analyzing the outcomes and dynamics associated with different transformation pathways and identifying those that lead to the most favorable results to reach the desired future (Result 6). In that sense, the relative change in the variables that reflect the desired state of the poultry system – in terms of expected outcomes – was compared under different scenarios in the short, mid, and long-term timeframes to determine the level of the desirability of the scenario's resulting state in different timeframes.

It is worth highlighting that modeling scenarios do not fulfill a prediction role but work as inquiry devices to gain valuable insights into poultry system behavior in order to inform and support transformations.

4.3.3. Application of the PFSM framework on poultry systems on poultry system in Kolda and Ziguinchor, Senegal.

This section elaborates on the nuances of applying the PFSM framework in the case study in Kolda and Ziguinchor in southern Senegal. Figure 4.9 outlines the flow of activities carried out in each PFSM stage in this case study over time, indicating the results derived from each activity. The results of this application are shown in Chapter 5 of this thesis.

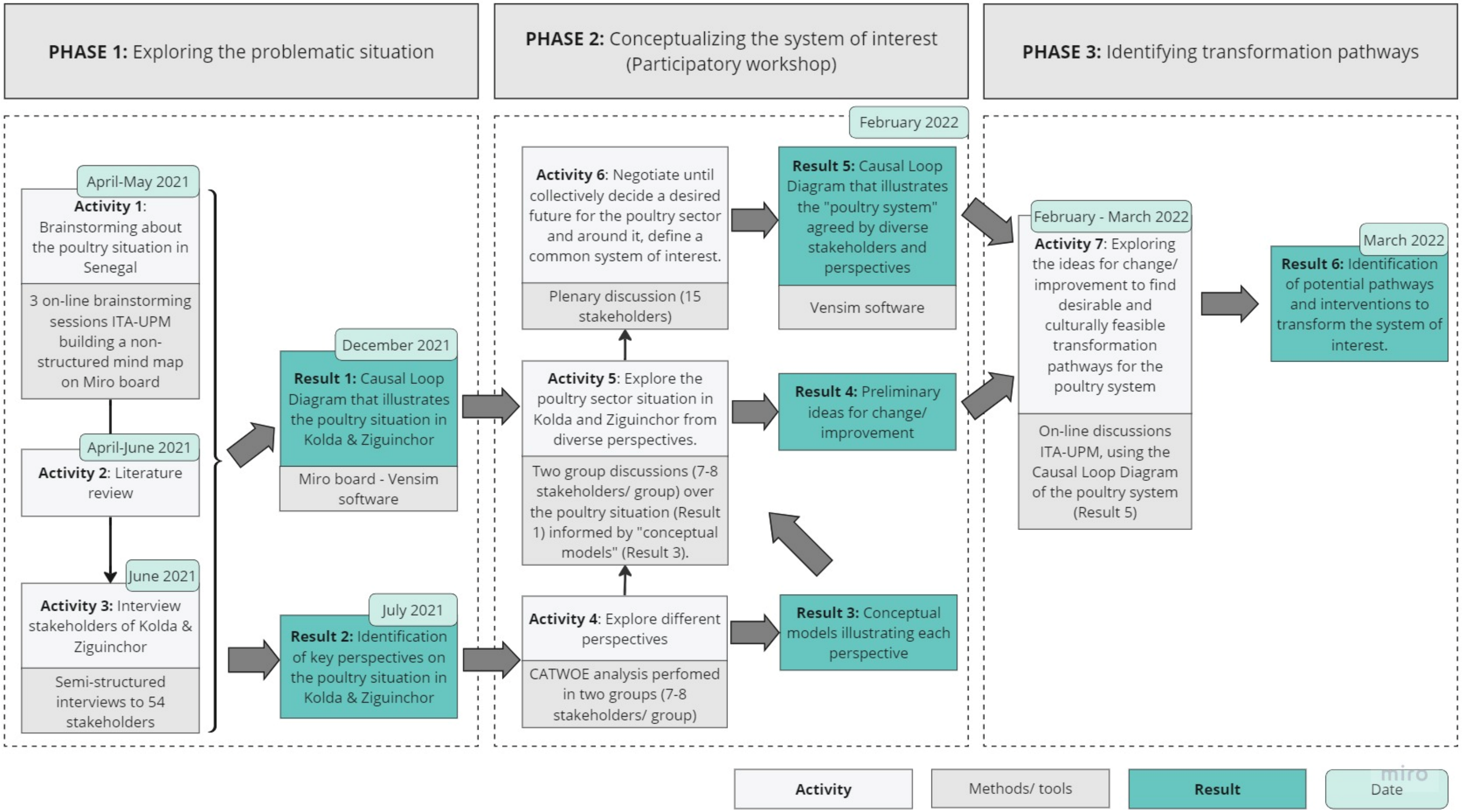

Figure 4.9. Application of the PFSM framework to poultry systems in Senegal.

Phase 1: Exploring the problematic situation of the poultry sector.

Unlike in Ghana, the first phase of the participatory modeling process in Senegal was impacted by the COVID-19 pandemic, as planned for the first quarter of 2020.

Considering the challenges posed by the COVID-19 pandemic to bring together diverse stakeholders in the same place, the poultry sector situation was explored through three online brainstorming sessions between UPM and ITA research teams between April and May 2021 (Activity 1). These sessions gave a preliminary view of the processes, elements, people, and activities shaping the poultry sector's current situation, expressed in a non-structured mind map using the Miro® visual and collaborative online platform.

Aware that this first view expressed exclusively the perspectives of researchers, key literature was consulted to delve into the poultry sector situation between April and June 2021 (Activity 2), contrasting and complementing the insights from the brainstorming sessions. Later, when the COVID-19 restrictions allowed for mobilizing within the country, key stakeholders were identified and engaged in the PFSM.

Once identified, stakeholders were consulted about their views concerning the poultry sector situation, delving into their interests, expectations, and concerns to obtain a closer-to-reality view of the challenges and opportunities in the poultry sector. Grounded on TEEBAgriFood's conceptual framework (Eigenraam et al., 2020; TEEB, 2018), semi-structured interviews were codesigned by the UPM and ITA research teams and conducted by ITA in Kolda and Ziguinchor during June 2021 as part of a systemic exploration of the poultry sector (Activity 3). As shown in Table 4.5, 54 stakeholders were interviewed.

Table 4.5. Stakeholders interviewed in Kolda and Ziguinchor

Role / Group	Number of participants
Small-scale farmers / Breeders	8 males
Breeders associated / Breeders	5 males
Transformers / Transformation	2 females; 6 males
Researchers and ITA's trainees / ISRA (online) Innovation	2 males
Veterinarians	4 males
Consumers / Consumption	5 females
Retailer and Seller/Consumption	6 females
Intermediaries	2 females; 8 males
Politicians / Politics	6 males
Total	54 people: 15 females and 39 males

The insights gathered from brainstorming sessions, literature review, and interviews with key stakeholders laid the foundation for creating a Causal Loop Diagram (CLD) depicting the poultry sector situation (Result 1). The CLD was built using the collaborative platform Miro®, which facilitated an iterative process of reflection and joint work between ITA and UPM research teams. This allowed us to continuously refine and update the model to ensure it effectively captures the richness of insights gathered from various sources and aligns with real-world dynamics. A final version of the CLD was obtained in December 2021.

The interviews, as made individually and in small groups of people that share stakes, facilitate them to share their worldviews more freely and openly than in a space shared with diverse stakeholders. As a result, interviews revealed that not everyone has the same interests, expectations, and concerns regarding the poultry sector; hence, they do not understand nor formulate their challenges and opportunities in the same way (Result 2).

Phase 2: Conceptualizing the system of interest.

All the activities related to the exploration of the poultry sector situation from different perspectives and the debates on possible ways to transform it were carried out in a participatory workshop in Dakar in February 2022 that brought together diverse stakeholders and perspectives and fostered dialogues, discussions, and negotiations among them to broaden both individual and collective knowledge. Fifteen stakeholders attended the participatory workshop, including small-scale farmers, associated farmers, processors, researchers, veterinarians, and politicians (Table 4.6).

Table 4.6. Workshop participants – Dakar, February 2022.

Role / Group	**Number of participants**
Small-scale farmers / Breeders	2 males
Breeders associated / Breeders	1 female; 1 male
Transformers / Transformation	1 female
Researchers and ITA's trainees / ISRA (online) Innovation	3 females; 6 males
Veterinarians / PVC regulations	1 male
Consumers / Consumption	-
Retailer and Seller/Consumption	-
Intermediaries	-
Politicians / Politics	1 female
Total	15 people: 5 females and 10 males

As identified in the first phase of the PFSM, not all stakeholders understand nor formulate the challenges and opportunities of the poultry sector in the same way (Result 2). A CATWOE analysis was conducted to delve into the different perspectives on the poultry sector situation (Activity 4) and obtain valuable insights into its complexity.

For performing the CATWOE analysis, stakeholders were asked to organize in groups and describe the envisioned transformation for the situation within the poultry sector that, from their perspectives, is understood as problematic, the motivation behind that transformation, the agents who benefit from it, and those who have the resources to enable it, other agents involved, and the influencing contextual factors (Checkland & Scholes, 1999; Checkland, 2000; Checkland & Poulter, 2010). The results from exploring each perspective were illustrated in “conceptual models” (Williams & Hummelbrunner, 2009, p. 249) (Result 3). As many conceptual models were constructed as perspectives identified.

As argued by Checkland & Poulter (2010), the conceptual models expressing each perspective were used as devices for stakeholders to explore the poultry sector situation as richly as possible. The CLD built to gain a comprehensive view of the poultry sector situation (Result 1) was shared with the workshop participants to explore it from different perspectives and gain valuable insights into its complexity (Activity 5). To ease the discussions and debates among stakeholders, the CLD was shared through a narrative supported by causal trees and feedback loops generated using Vensim PLE® software (Annex E). The causal trees show the interrelationships between the elements that make sense of the poultry sector situation, and the feedback loops shed light on its dynamic behavior to inform debates and discussions among stakeholders.

The main advantage of using conceptual models to explore the poultry sector situation was the richness of the insights gained, which revealed areas of synergy or contradiction between perspectives, suggesting strategies for improving the poultry sector situation (Result 4) (Williams & Hummelbrunner, 2009). Moreover, the discussions and debates among stakeholders increased their awareness of the diversity of interests, concerns, expectations, and values underlying diverse perspectives, setting a common language (Daniell et al., 2006) that eased them to agree upon a future for the poultry sector that is desirable, or at least acceptable, for everyone (Checkland & Poulter, 2010) (Activity 6).

Stakeholders' agreement on a desired future led to setting new boundaries for the situation identified as problematic in the poultry sector, thus defining a system of interest to all stakeholders. This system – referred to as the poultry system in this chapter – is one way of representing the poultry sector situation that expresses the values, interests, concerns, and expectations that stakeholders decide to prioritize. The poultry system was expressed in a new CLD, used as a tool to help stakeholders identify transformation pathways to move towards the agreed desired future (Result 5) (Checkland & Haynes, 1994; Checkland & Poulter, 2010; Eigenraam et al., 2020; TEEB, 2018).

Phase 3: Identifying potential pathways for transforming the system.

As detailed in the second phase, ideas for change and improvement emerged during the discussions and debates among stakeholders to explore the poultry sector situation from different perspectives (Result 4). Those ideas were explored at this phase through consultation processes between the UPM and ITA research teams to find transformation pathways for the poultry system that are both desirable and culturally feasible (Activity 7, Result 6). Desirable according to the model (CLD) of the poultry system – built around a desired future agreed upon among the perspectives engaged – and culturally feasible in the sense of being possible for the agents involved in the poultry system, considering the social norms, values, and power structures that guide their behavior and actions (Checkland & Poulter, 2010). The Causal Loop Diagram of the poultry system (Result 5) was the main device for exploring the ideas for change and, upon them, identifying transformation pathways.

4.4. Concluding remarks

The PFSM framework – comprising three phases with clearly defined objectives and outcomes – is proposed as an adaptable and flexible framework. The two case studies included in this chapter illustrate variations in the methodological application in terms of the specific activities developed, the methods and tools applied, and the temporal organization of the activities within each phase of the PFSM framework.

Below, the adaptations for each case study are discussed, as well as their implications in achieving the objectives of each phase of the PFSM and the ultimate goal of supporting and informing food systems transformations.

Regarding the *phase of exploration of the problematic situation in the poultry sector*, both case studies sought the engagement of a wide range of agents – with different roles and perspectives – to build a first understanding of the situation being explored. However, the COVID-19 pandemic led to adapting the participatory components differently in each case.

In Ghana, a participatory workshop was held in October 2019 to facilitate this exploration. This workshop provided an overview of the poultry sector situation, informed by primary sources. As the information obtained from the participatory workshop was processed, issues and topics for further exploration were identified, leading to the review of secondary sources and planning a consultation process with key stakeholders. In this case, COVID-19 impacted the work derived from the participatory workshop, especially the consultation with key stakeholders, since contacting them throughout 2020 and the first half of 2021 was impossible.

In Senegal, on the other hand, COVID-19 limited the performance of the activities within the first phase of the PFSM from its very beginning, preventing the organization of a participatory workshop. This forced the UPM and ITA research teams to look for alternatives to build an overview of the poultry sector situation in Kolda and Ziguinchor without bringing together stakeholders. Thus, at first, several brainstorming sessions were held between the research teams: ITA with the scientific-technical knowledge of the challenges and opportunities of the poultry sector in the study areas, and UPM with the scientific-technical knowledge of food systems approaches to explore problematic situations linked to agriculture and food from a systemic perspective, and with the methodological understanding of participatory modeling processes as instruments to inform and support transformations. These sessions allowed, on the one hand, the exchange of knowledge and capacity building among the research teams and, on the other hand, the identification of topics to be explored in order to build a comprehensive view of the poultry sector situation. Secondary sources were consulted to delve into the topics of interest, and interviews with key stakeholders in Kolda and Ziguinchor were held to complement the viewpoints of researchers and technical experts.

Regarding the *conceptualization of the system of interest* – the second phase of the PFSM – the use of conceptual models as inquiry devices to structure and inform debates among stakeholders was not the same for both case studies. Despite the nuances, both case studies encouraged the exchanges and discussions between agents with different perspectives to strengthen the awareness and respect for diversity as a groundwork to share ideas for improvement and agree on a future towards which to work collectively.

In Ghana, the participatory workshop of September 2019 aimed to meet the objectives set out in the first and second phases of the PFSM framework. However, time constraints and other challenges arising from implementing the methodological proposal for the first time meant that the planned activities did not unfold as expected. In this sense, based on what initially seemed to be an alignment between perspectives, it was decided to forgo the construction of conceptual models for each perspective and directly promote discussions and debates among stakeholders on what needs to be transformed from the poultry sector's current situation in order to move towards a future that makes sense to all. This decision made sense at the time since it allowed leveraging the participatory workshop to maximize the dialogue and discussions. However, it probably led to a loss of valuable insights from deepening the different perspectives, weakening the basis for debating and negotiating a future for the poultry sector that makes sense for the agents involved.

The activities of phases 1 and 2 of the PFSM framework were carried out simultaneously in the Ghana case study. In the participatory workshop of September 2019, stakeholders collectively built a comprehensive view of the poultry sector – Phase 1 – and debated and agreed on a future that makes sense to all – Phase 2. The first view of the poultry sector was further enhanced with secondary information and consultation processes with key stakeholders during 2020 and 2021, providing substantial information to, joint with the agreed-upon future for the poultry sector, set the groundwork for conceptualizing the system of interest.

The conceptual model of the system of interest – built through Fuzzy Cognitive Mapping – was then used as an inquiry device to foster discussions and debates among stakeholders with different perspectives on how to improve the poultry system to move towards the desired future. In line with Checkland & Poulter (2010), the assumption is that generating ideas for improvement without first going deeper into the different ways of understanding and formulating the problematic situation concerning the poultry sector led to a loss of insights.

In Senegal, four perspectives on the poultry sector situation in Kolda and Ziguinchor were identified and explored. The interviews with stakeholders and the online sessions for exchange and capacity building among UPM and ITA research teams developed in adaptation to the COVID-19 limitations played an essential role in this outcome.

On the one hand, doing the interviews through ITA researchers, in situ, individually, or in small groups, allowed stakeholders to share their interests, concerns, and expectations on the poultry sector more freely. On the other hand, the online sessions among ITA and UPM research teams allowed sharing and discussing the importance of identifying perspectives and jointly developing an interview guide that paid attention to valuable information for that purpose.

Once the different perspectives were identified, the participants of the February 2022 workshop were asked to model the desired transformation of the poultry sector from each perspective through a CATWOE analysis. These conceptual models helped structure the discussions on how to improve the poultry sector's current situation. Stakeholders proposed ideas for improving the poultry sector situation based on the revelations of synergies, complementarities, and divergences between perspectives. As Williams & Hummelbrunner (2009) and Daniell et al. (2006) suggested, valuable insights into the situation's complexity emerged from fostering collective learning based on recognizing and delving into different perspectives.

Unlike the case study in Ghana, the conceptual models of each perspective were used as inquiry devices to formulate questions and propose ideas to improve the problematic situation in the poultry sector. In order to establish a common language for stakeholders to discuss, the Causal Loop Diagram of the poultry sector situation – built from consulting diverse sources and agents in phase 1 – was shared. It should be noted at this point that in contrast to the case study in Ghana, only one participatory workshop was held in Senegal. In this workshop, the CLD illustrating the problematic situation as close to reality as possible was shared and validated to discuss and question it from different perspectives, thus giving rise to valuable ideas for improving the poultry system.

Another important nuance concerning the case study in Senegal is the negotiations to agree on a future for the poultry sector that is desirable – or at least acceptable – to all. Such negotiations, informed by the in-depth exploration of diverse perspectives, strengthen individual and collective awareness and learning about the complexity of the problematic situation. The system of interest to all was defined at this point and not before the generation of ideas for improvement, as in the case study in Ghana.

Concerning the modeling methods used in the second phase of PFSM, the main nuance is applying semi-quantitative modeling in Ghana and qualitative modeling in Senegal.

In Ghana, stakeholders in the poultry system show particular interest in performing quantitative modeling that allows the generation of scenarios to inform decision-making. Given the limitations in gathering some information, joined with the interest in exploring the behavior of qualitative variables and engaging diverse stakeholders in the modeling process, the UPM research team proposed semi-quantitative modeling, specifically Fuzzy Cognitive Mapping.

Although a Fuzzy Cognitive Map was built to model the poultry system in Ghana, a Causal Loop Diagram was created as the preliminary step to ease the sharing and validation of the conceptual model's narrative with stakeholders concerning the way variables connect to each other, forming feedback loops that determine the dynamic behavior of the whole system.

In Senegal, the modeling process focused on identifying suitable pathways to transform the poultry system in response to stakeholders' interests and concerns. In that sense, stakeholders show particular interest in actively engaging in the modeling process and propose doing it qualitatively. A Causal Loop Diagram was developed to illustrate the complexity of the poultry sector’s problematic situation and its dynamic behavior and, after discussions and negotiations on the desired future for the poultry sector, conceptualize the system of interest to all.

Finally, regarding *the identification of transformation pathways for the poultry system*, the nuances of the proposed methodology derive mostly from applying either qualitative or semi-quantitative modeling.

In Ghana, applying a Fuzzy Cognitive Mapping approach allowed for running short-, mid-, and long-term scenarios to explore the levels of desirability of pathways derived from intervening in variables identified as leverage points for transforming the poultry system. On the other hand, using Causal Loop Diagrams in Senegal informed the identification and categorization of feedback loops within the system. While the qualitative model did not facilitate scenario exploration, it provided valuable insights into the system's dynamics. These insights, in turn, informed the identification of leverage points for transformation, which played a pivotal role in informing collective discussions on potentially desirable and culturally feasible transformation pathways.

Having presented and discussed the nuances of the applications of the PFSM frameworks in the two case studies, Chapter 5 presents the corresponding results.

5. RESULTS OF APPLYING THE PARTICIPATORY FOOD SYSTEMS MODELLING FRAMEWORK TO IDENTIFY TRANSFORMATION PATHWAYS FOR POULTRY SYSTEMS IN GHANA AND SOUTHERN SENEGAL

This chapter presents the results of the application of the Participatory Food Systems Modeling (PFSM) frameworks – proposed in Chapter 4 – for the identification of desirable and culturally feasible transformation pathways in poultry systems in Ghana (Section 5.1) and the Kolda and Ziguinchor regions in Southern Senegal (Section 5.2).

To close the chapter, Section 5.3 concludes with the practical implications and potential contributions of the insights gained from these applications to advance food systems challenges in the West African region and beyond.

5.1. Results from the application of the PFSM in the case study in Ghana

This section presents the results of applying the PFSM framework in Ghana for each of the three phases described in detail in Chapter 4.

5.1.1. Phase 1: Exploring the problematic situation of the poultry sector

In the participatory workshop developed in September 2019, stakeholders from the poultry sector collectively described the situation of interest in an unstructured way. For that, they held discussions in three groups of eight people with diverse roles. Farmers (members and non-members of farmers-based organizations), researchers, input suppliers, policymakers, public officers, and consumers participate in collectively making sense of the problematic situation in the poultry sector.

The information shared in the three groups was expressed as comprehensively as possible in three diagrams to illustrate the poultry sector's problematic situation. Although stakeholders were asked to express their thoughts about the current situation in the poultry sector in an unstructured way, some made it more structured than others. Annex F includes the diagrams developed in the three groups to illustrate the poultry sector situation.

The results of the discussions held in each group were shared in plenary, revealing eight main topics of interest:

i. Breeding conditions and farm productivity.
ii. Availability and access to key inputs (feed, day-old chicks, veterinary products) in the right quality and quantity.
iii. Animal health
iv. Extension, training, and technology transfer
v. Funding and financial services
vi. Associativity and communication
vii. Sales and demand

viii. Formulation, enforcement, and evaluation of policies and regulations.

Scripts were prepared to interview agents who could provide information to delve into each topic as key pieces of the problematic situation. Thirteen agents – including poultry farmers, politicians, public officers, researchers, and technical experts – were invited into the consultation process carried out in a workshop in July 2021 to delve into each of the topics revealed by stakeholders when illustrating the poultry sector situation. Annex G includes the results of the consultation process, differentiating the responses given by poultry farmers from those of politicians, public officers, researchers, and technical experts.

5.1.2. Phase 2: Conceptualizing the system of interest

As described in the methodology, it was not possible to delve into the different perspectives on the problems of the poultry sector. In this sense, the debates on what needs to be transformed in the current situation and the underlying motivations and values for such transformation were carried out collectively without first delving into how the current situation is understood and framed.

Collective debates involve negotiations that lead stakeholders to conceptualize a future that makes sense to all. Or, in other words, that is desirable – or at least acceptable – to all. The envisioned future for the poultry system was the following:

> "A poultry system that provides an enabling environment to improve the competitiveness of domestic poultry products and thus maximize the positive impacts of poultry farming on the well-being of families whose livelihoods depend on it, allowing them to remain engaged in that activity."

With the future agreed upon among stakeholders in mind and having a comprehensive view of the poultry sector situation informed by diverse sources – including literature review and primary information from key stakeholders engaged in participatory workshops and consultation processes – a conceptual model was built to illustrate the agreed system of interest. The conceptual model was created through a Fuzzy Cognitive Mapping Approach.

The first step in building a Fuzzy Cognitive Map was to create a preliminary Causal Loop Diagram to share and validate the conceptual model's narrative with stakeholders. This Causal Loop Diagram is included in Annex H.

The Causal Loop Diagram was employed to share and validate the narrative of the poultry system's dynamics with stakeholders during the participatory workshop in January 2022. This narrative was informed by the causal trees depicting the interrelationships between elements and the feedback loops identified within the conceptual model. During validation, stakeholders provided feedback to enhance the poultry system's model.

The feedback from stakeholders has been summarized in Table 5.1, organized according to the six topics of interest defined by the CSIR-STEPRI and UPM research teams (as detailed on page 131). This feedback is linked to various sections of the narrative. It is important to note that only the narrative sections where stakeholders provided feedback have been included. The feedback is presented as additions or modifications to the narrative.

Table 5.1. Stakeholders' feedback on the Ghana poultry system conceptual model

Topics of interest	Narrative in the conceptual model	Additions/ modifications suggested by stakeholders
Competitiveness of domestic poultry meat	Production, storage, and processing conditions affect the quality of poultry meat. Production conditions leading to greater compliance with quality standards include access to quality feed, day-old chicks, animal health services and products, and appropriate housing conditions.	In addition to the conditions listed, farmers need to be aware of the quality standards for poultry meat and access to appropriate transport (for day-old chicks, birds ready for slaughter, and after slaughtering) to comply with the quality standards. New variables/ linkages in the CLD: - "Awareness of quality standards," positively affecting "Compliance with poultry meat quality standards." - "Access to appropriate transport," positively affecting "Compliance with poultry meat quality standards."

The product differentiation depends on access to appropriate processing and storage facilities.	Consider the packaging and branding as conditions affecting product differentiation. Modifications in existing variables/ linkages: - Consider packaging and branding as processes farmers can access when they have "access to storage and processing facilities."
Reducing the cost per ready-to-sell bird means reducing poultry farming costs. In addition, this value is affected by flock size: the larger the flock size, the lower the cost per bird due to economies of scale.	Show that poultry farming costs are affected by the type of production system, i.e., modernization level in poultry farming. Modernizing farms would increase the fixed costs in a short time and would reduce the cost of labor. New variables/ linkages in the CLD: - "Suitability of husbandry practices and housing facilities" (as a way to address modernization),

		negatively affecting “cost of labor” (variable cost), and positively affecting “cost of housing” (fixed cost).
Poultry farming profitability	The selling price is affected by poultry farmers' access to storage facilities - that allow them to wait for better prices - by their access to modern retail markets - which offer them better prices - and by the weight of broilers to sell, which is the primary determinant of price when you sell live birds.	The seasonality of poultry meat production and demand affects the selling price. This can be addressed by improving “farmers’ access to appropriate processing and storage facilities, " allowing them to wait for better prices without losing product.
	The mortality rate is affected by birds’ health issues. Having more health issues leads to higher bird mortality rates, which, in the end, will reduce the poultry farmers’ incomes.	Husbandry practices (temperature regulation, sanitary conditions, feed provision in appropriate quantity and quality, etc.) also affect the mortality rate in poultry. New variables/ linkages in the CLD:

	- "Suitability of husbandry practices and housing facilities," negatively affecting "birds' health issues."
Variable production costs, which include feed, day-old chicks, and animal health-related costs, are affected by the flock size and the growth rate of birds. The higher the growth rate, the lower the time of rearing poultry, leading to lower variable costs.	Another variable cost is the interest on loans. It is to be noted that small-scale farmers can only access loans if they are of low interest rates. Therefore, to express this variable cost in the poultry system model, participants propose directly linking farmers' access to loans with poultry production variable costs, considering that loans should have low interest rates to be accessible for small-scale poultry farmers. Modifications in existing variables/ linkages: - Modify the variable "access to loans" to "access to low-interest loans" and positively link it to "poultry production variable costs."

Fixed costs include the cost of housing and labor	Reclassify labor as a variable cost since it depends on the number of birds and the type of production system used. Modifications in existing variables/ linkages: - “Cost of labor” positively affects “poultry production variable costs.”
Processing and storage costs depend on the farm’s closeness to markets and product differentiation. Lowering the distance from farm to market reduces the cost of poultry meat storage; conversely, higher product differentiation leads poultry farmers to increase processing costs.	The processing and storage costs are affected by the farm's closeness to those facilities, which are usually located in urban centers. Modifications in existing variables/ linkages: - Modify the variable “farm’s closeness to markets” to “farm’s closeness to processing, storage, and market facilities.”

Poultry farming productivity	The growth rate of birds is affected positively by access to quality feed, access to quality day-old chicks – with better genetic conditions – and access to appropriate housing conditions.	Husbandry practices (temperature regulation, sanitary conditions, feed provision in appropriate quantity and quality, etc.) also affect the growth rate of birds. This goes beyond access to appropriate housing conditions and knowing how to use housing facilities and equipment appropriately. New variables/ linkages in the CLD: - “Suitability of husbandry practices and housing facilities,” positively affecting “birds’ growth rate.”
	The mortality rate of birds can be reduced by minimizing their health issues. In turn, birds’ health is affected by the quality of day-old chicks, husbandry conditions – including housing and feed – and access to veterinary services and products to prevent or control birds’ diseases and other health issues.	Husbandry practices affect the mortality rate in poultry and are affected in turn by farmers’ adoption of better practices and technologies. New variables/ linkages in the CLD:

		- "Suitability of husbandry practices and housing facilities" negatively affects "birds' health issues." - "Farmers' adoption of better practices and technologies" positively affects the "suitability of husbandry practices and housing facilities positively."
Accessing quality inputs, services, and facilities	The feed price could be reduced by increasing the availability of quality commercial feed or promoting self-formulation among poultry farmers, which generally involves lowering costs.	Small-scale farmers are not cost-efficient to produce their own feed. One option to address this challenge is to produce feed in associations or any other form of collaboration. Modifications in existing variables/ linkages: - Considering the cost efficiency of feed self-production, modify the variable "farmer capacity to formulate their own feed" to

		“farmers’ capacity to produce and formulate feed efficiently.” - “Farmers’ membership in associations” positively affects “farmers’ capacity to produce and formulate feed efficiently.”
	The availability of veterinary officers for poultry farmers is affected by the logistic support provided to public officers since, without facilities and a budget that allows them to travel, the veterinary officers cannot attend to all the poultry farmers around the country.	The availability of quality veterinary services and products is taken as a consequence of enforcing regulations aimed at controlling fake drugs and the quality of veterinary services. In turn, the enforcement of regulations is affected by the logistic support for public officers. Modifications in existing variables/ linkages: - Consider the availability of quality vet services and products within the “Enforcement of PVC regulations” (as an immediate consequence instead of as a new variable).

		- "Logistic support for public officers" positively affects "Enforcement of PVC regulations."
	Farmers' access to loans, reinvestment capacity, and membership in associations positively affect their access to key inputs and services. The first two assume that a better financial capacity would translate into greater access to quality inputs, services, and facilities. The third considers that by belonging to an association, poultry farmers will be able to make collective purchases, thus better access to quality inputs.	For accessing loans, farmers need to have guarantees. In that sense, housing structure should be considered, besides land. Moreover, another condition affecting access to loans is the farmers' management practices like cost-benefits record keeping, the use of business plans, etc. Within the variable "access to knowledge and technology transfer services," we could consider training in finance and business management, which translates into adopting better financial and management practices. Modifications in existing variables/ linkages:

- “Suitability of husbandry practices and housing facilities & equipment” positively affects “farmers’ access to low-interest loans.”
- “Farmers' adoption of better practices & technologies” positively affects “farmers’ access to low-interest loans.”

Feedback from stakeholders was incorporated into the conceptual model of the poultry system, resulting in an enhanced Causal Loop Diagram, shown in Annex I.

The linkages between poultry system variables were qualitatively valued as part of the Fuzzy Cognitive Mapping approach adopted to build the poultry system conceptual model. Annex J includes the latest version of the matrix UPM and CSIR-STEPRI, developed to code the interrelations between poultry systems variables to be translated into the Fuzzy Cognitive Map using the FCMapper® software. This version contemplates the variables and interrelations as illustrated in the enhanced Causal Loop Diagram (Annex I).

Figure 5.1 depicts a simplified version of the CLD presented in Annex I. Nine feedback loops were identified – seven reinforcing and two balancing loops – that shed light on the dynamics of poultry systems, providing valuable information to identify possible levers for transformation.

(R1) <u>Reinvestment - Farm Performance Reinforcement Loop:</u> Investing in quality inputs and better practices at the farm leads to improved performance rates, ultimately increasing profitability. This profitability allows for further reinvestment in poultry farming, reinforcing the cycle.

(R2) <u>Reinvestment - Quality Compliance Reinforcement Loop:</u> Investing in better farm practices improves compliance with quality standards, resulting in better prices and increased profitability. This reinforces farmers' ability to reinvest in poultry farming.

(R3) <u>Reinvestment – Access to Processing, Storage, and Retail Facilities Reinforcement Loop:</u> Investing in accessing appropriate processing, storage, and retail facilities allows farmers to comply with quality standards and obtain better prices for their products, improving profitability. Having a more profitable activity strengthens farmers' ability to continue reinvesting in processing, storage, and retail facilities, creating a reinforcing loop.

(R4) Competitiveness – Knowledge and Technology Transfer Reinforcing Loop: A more competitive domestic poultry sector drives tailored knowledge and technology transfer services. This positively impacts farmers' access to these services and the adoption of better practices and technologies, reinforcing sector competitiveness.

(R5) Competitiveness – Regulations Enforcement Reinforcing Loop: Improving the competitiveness of the domestic poultry sector leads to increased resources allocated to regulations supporting it. This, in turn, improves poultry farmers' access to quality inputs, services, and facilities, reinforcing the sector's competitiveness.

(R6) Flock Size – Access to Low-Interest Loans Reinforcing Loop: Increasing the flock size of poultry farms improves the conditions for farmers to access low-interest loans, enhancing their access to quality inputs, technologies, and facilities. This improvement leads to better farming performance and product quality, reinforcing their capacity to increase the flock size.

(R7) Adoption of Better Management Practices – Access to Low-Interest Loans: Adopting better management practices at the farm improves farmers' access to low-interest loans, enabling them to enhance their practices further.

(B1) Reinvestment – Total Costs Balancing Loop: Investing in the adoption of better practices and technologies leads to an increase in costs associated with improved husbandry practices, housing facilities, and equipment at the farm, as well as those related to processing, storage, and retail facilities. These costs balance the profitability of poultry farming and, therefore, the farmers' capacity to reinvest.

(B2) Competitiveness – Total Costs Balancing Loop: A more competitive domestic poultry sector drives tailored knowledge and technology transfer services and improves the enforcement of regulations that support the sector. These two conditions help farmers adopt better practices and technologies, leading to increased costs that balance domestic poultry meat's competitiveness.

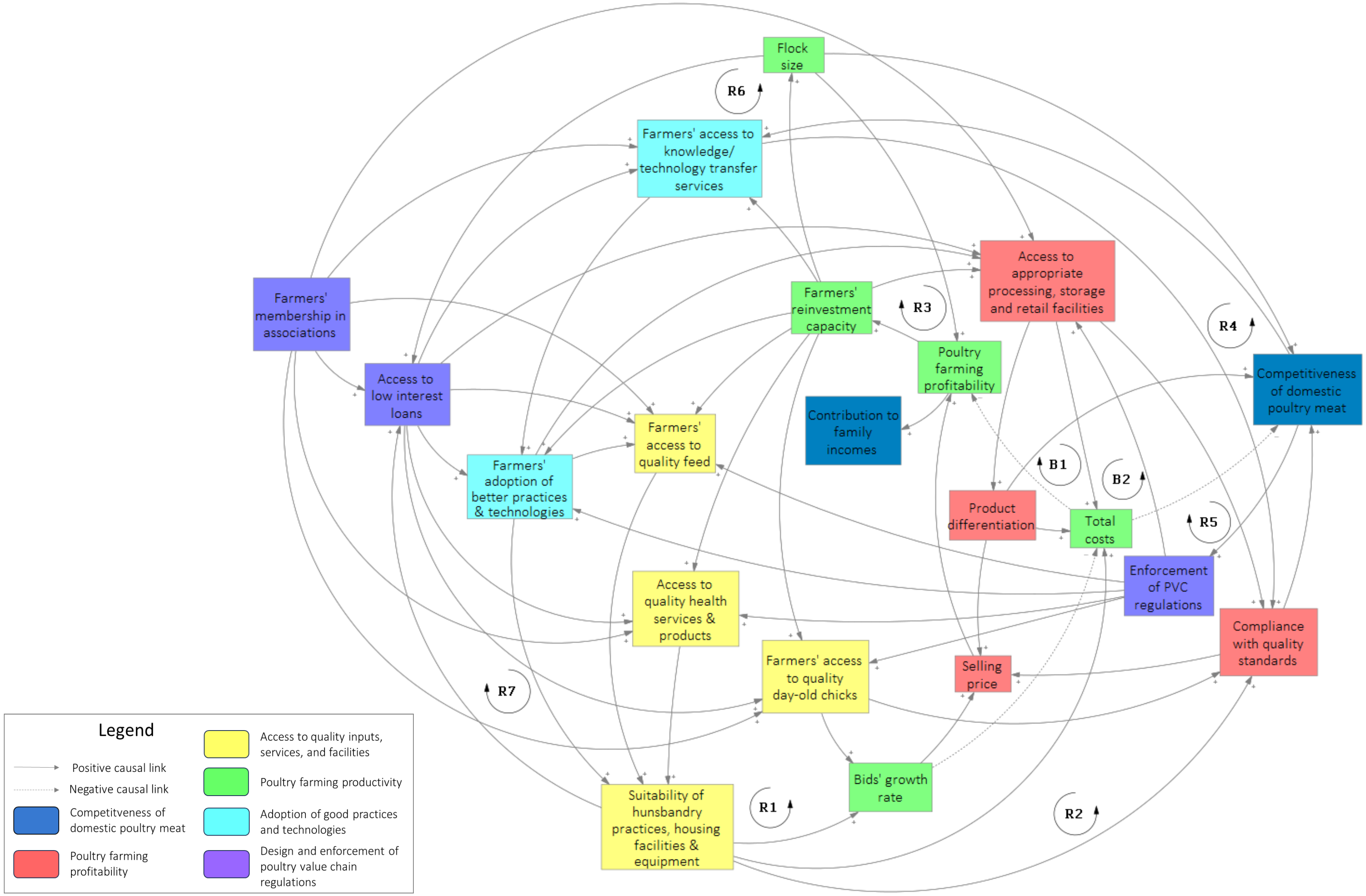

Figure 5.1. Causal Loop Diagram of the poultry system in Ghana incorporating the feedback of stakeholders (provided in January 2022)

During the review and validation of the poultry system’s conceptual, stakeholders discuss and debate how to move it from its current situation to the desired future. The narrative created with the support of causal trees and feedback loops was crucial to inform the debates among stakeholders, as they reveal potential levers or drivers for change within the system. The improvement ideas emerging from those debates are shared in Table 5.2.

Table 5.2. Ideas for improving the Ghana poultry system.

<table>
<tr><th></th><th>Ideas to improve the poultry sector situation</th><th>Justification</th></tr>
<tr><td>1</td><td>Facilitate the creation and registration of poultry farmers' associations.</td><td rowspan="2">It is advisable for farmers to join associations, cooperatives, or any other forms of collaboration to facilitate their connections with public and private organizations working in the poultry sector. These forms of cooperation can help farmers to (i) access inputs through collective purchase, which improves their bargaining power to get better quality, enough quantity, and/ or lower priced products; (ii) optimize processes such as feed self-formulation, storage, processing, transport; access to training on how to start and manage the poultry farming business, how to improve their husbandry conditions, how to set appropriate housing facilities, etc.; (iii) access to loans by giving farmers more credibility; (iv)</td></tr>
<tr><td>2</td><td>Promote poultry farmers' membership in associations by disseminating their benefits and/or providing farmers with some incentives.</td></tr>
</table>

		enhance farmers' agency to communicate their needs and influence on poultry system's governance.
3	Provide farmers with training on financial, technical, and management practices in the farm to either improve their eligibility to access loans or enhance their financial independence.	To either improve farmers' access to loans or enhance their financial independence, it is essential to professionalize poultry farming in order to make it a profitable activity. In this regard, becoming members of associations or cooperatives facilitates government, aid, and financial institutions to contact farmers and work with them to improve their technical, financial, and management abilities.
4	Create alternative channels for farmers to access loans.	For alternative funding channels like credit unions to work, it is essential to sensitize farmers so they feel part of and engage with the project. These alternative channels are especially suitable for small-scale farmers who do not have enough guarantees to access loans from traditional financial institutions.

5	Design and implement policies that promote lower interest rates for farmers to be able to pay (10-15%).	Farmers' profit margin goes between 20-25%, and the current interest rate in institutions that offer "easy" loans for farmers is 25% or more. This would be feasible in the frame of some projects that work with financial institutions (e.g., CARE, GPP, and GNAPF) or through public or private institutions specialized in the agri-food sector (e.g., Agriculture Development Bank). The work made in the Ghana Poultry Project (GPP) in collaboration with the Ghana National Association of Poultry Farmers (GNAPF) about utility grading for creating a risk assessment of poultry farmers helps banks access funds for providing loans for poultry farmers.
6	Enforce regulations aimed at controlling fake drugs and the quality of veterinary services while designing regulations to encourage the manufacturing of poultry drugs at the national level.	These policies aim to lower the costs of veterinary services and crucial medicines to improve farmers' access to them, avoiding the use of fake drugs or informal veterinary services.
7	Design and implement policies & regulations that promote the importation of subsidized feed products or subsidize local production.	These policies aim to lower the price of feed, improving farmers' access to it.

8	Attract foreign investors to operationalize national day-old chicks' hatcheries and thus avoid freight changes related to imported ones.	Only 10% of day-old chicks are locally produced, making farmers highly dependent on imported products, with freight charges increasing their costs and precluding farmers' access to quality day-old chicks. Participants proposed attracting investors to operationalize national day-old chicks' hatcheries with appropriate sanitary and safety conditions to produce quality day-old chicks at a competitive price.
9	Design policies & regulations that protect domestic poultry meat production (i.e., regulating the value or quality of importations of poultry meat products; subsidizing domestic production in terms of inputs).	
10	Design policies & regulations that promote building cold storage facilities to better face seasonality	Cold storage would allow farmers to have a buffer system and better face the market changes in price and demand. Having means to face seasonality better would minimize farmers' losses and allow them to wait for the right prices to sell.

11	Promote initiatives involving the private sector and R&D institutions for poultry farmers and other stakeholders to learn about new practices and technologies to process birds into semi-finished products and increase their shelf life.	Even if they are primarily focused on processing, the initiatives proposed will have a ripple effect in the value chain. There are examples of running interventions in this regard, such as the Government policy initiative One District One Factory 1D1F and the work of the Food Research Institute.
12	Creating learning platforms or carrying out demonstrations on the field to promote the adoption of good husbandry practices and technologies	Adopting appropriate husbandry practices and technologies would allow farmers to modernize their operations, positively impacting their competitiveness by reducing production costs in the long term and improving the quality of their products. Adopting appropriate husbandry practices involves making good use of housing facilities and equipment.
13	Offer farmers training on finance and business management.	Improving farmers' knowledge of finance and business management would improve management and financial practices on the farm.
14	Offer farmers training or share information that increases their awareness of quality standards for poultry meat.	

5.1.3. Phase 3: Identifying potential pathways for transforming the system

The ideas arising from discussions and debates among stakeholders on how to move the poultry system toward the desired future were explored using the Fuzzy Cognitive Mapping approach to gain insights into potential transformation pathways.

The conceptual model built on FCMapper® was analyzed in its structure – multiple variables, interrelations, and feedback loops –to understand the contributions of each variable to the systems' overall behavior. The contributions of each variable were analyzed calculating its centrality. As explained in the methodology, centrality shows how connected the variable is to other variables and the accumulated strengths of these connections (Özesmi and Özesmi, 2004). Table 5.3 lists the top third of variables with the highest centrality, indicating their indegree and outdegree to show whether the variable mainly influences other variables or if other variables influence it.

Table 5.3. Top third of poultry system's variables with the highest centrality

№	Variables	Centrality	Outdegree	Indegree
1	Suitability of husbandry practices, housing facilities & equipment	6,50	3,75	2,75
2	Farmers' adoption of better practices & technologies	6,50	2,50	4,00
3	Design and enforcement of poultry value chain (PVC) regulations	6,25	5,00	1,25
4	Access to low-interest loans	6,00	4,25	1,75
5	Competitiveness of domestic poultry meat	5,50	2,75	2,75
6	Farmers' access to quality day-old chicks	5,50	2,00	3,50
7	Reinvestment capacity	5,25	4,25	1,00
8	Poultry production variable costs	5,00	1,00	4,00
9	Farmers' access to quality feed	5,00	0,75	4,25
10	Farmers' membership in associations	4,75	4,50	0,25
11	Access to appropriate animal health services & products	4,75	0,75	4,00

12	Flock size	4,50	4,25	0,25
13	Growth rate	4,25	2,00	2,25
14	Farmers' access to appropriate processing, storage, and market facilities	4,25	1,75	2,50
15	Birds' health issues	4,00	2,50	1,50
16	Farmers' access to knowledge/ technology transfer services	3,75	1,50	2,25
17	Compliance with poultry meat quality standards	3,75	1,00	2,75
18	Incomes from poultry meat sales	3,75	1,00	2,75

In the January 2022 participatory workshop, stakeholders enhance their knowledge about the poultry system's structure by exploring the interrelationships and feedback loops within the conceptual model. Through discussions and debates on poultry systems' problematic situation and how to address it, they identified five of the 18 variables listed in Table 5.3 as leverage points for initiating transformations. These levers, when acted upon, set in motion changes at a systems level, ultimately contributing to a transformation toward the desired future.

The changes in the variables identified as levers represent transformation pathways for the system. These pathways open opportunities for the poultry system to align with the desired future.

The improvement ideas shared by stakeholders during discussions in the participatory workshop of January 2022 are illustrated below as interventions on the identified levers for change across social, financial, political, and technical dimensions. The aim is to show how acting on levers triggers changes at the system level in ways that contribute – or not – to the desired transformation.

Figures 5.2-5.5 illustrate potential pathways for enhancing the poultry system's overall performance measured in terms of competitiveness of domestic poultry meat and poultry farming profitability. Each figure represents a dimension and includes stakeholders' ideas for improving the system (Table 5.2) as interventions on the levers, which are included in black boxes.

Acting on the levers triggers system-level changes, impacting overall performance and expected outcomes. The expected outcomes – variables in bold – express the desired future stakeholders agreed upon. A short description of the system diagrams illustrating each group of transformation pathways is provided below.

Figure 5.2 illustrates the transformation pathways derived from enhancing the social dimension of the poultry system by improving farmers' membership in associations. Strengthening associativity among poultry farmers brings several positive changes within the system that affect its overall performance and expected outcomes. Firstly, it improves farmers' capacity to access quality farming inputs and services by bolstering their bargaining power through collective purchase. Secondly, it enables the aggregation of poultry products, simplifying farmers' access to processing, storage, and marketing facilities that may otherwise be economically or technically unfeasible for small quantities of products. Thirdly, belonging to associations facilitates farmers' access to knowledge and technology transfer services offered by public institutions or R&D institutions. Additionally, farmers' associativity increases their options to access low-interest loans, improving their access to quality farming inputs and services, processing, storage, and marketing facilities, and adopting practices and technologies to enhance their husbandry practices, housing facilities, and equipment.

Improved access to quality inputs and services and training and technology transfer services allow farmers to adopt more suitable husbandry practices, housing facilities, and equipment. These conditions positively impact birds' growth rates and the overall quality of poultry products.

Improving birds' growth rates reduces the total costs of production. This reduction is balanced with the increase in the expenses resulting from the adoption of new technologies and equipment on the farm. Any reduction in production cost positively impacts domestic poultry meat's competitiveness. On the other hand, meeting quality standards increases the competitiveness of poultry meat products, thereby positively impacting their selling price.

Furthermore, improving farmers' access to processing, storing, and marketing facilities contributes to product differentiation and compliance with quality standards, which directly impacts both the selling price and the total costs. Additionally, the access to storage facilities allows farmers to wait for the opportune time to sell their products, further improving selling prices.

Finally, price improvements derived from higher quality, product differentiation, and access to storage facilities positively impact the poultry business's profitability. It is worth noting that the increase in total costs derived from the adoption of new technologies and equipment for production, processing, storing, and marketing exert a balanced effect on the improvements coming from better selling prices.

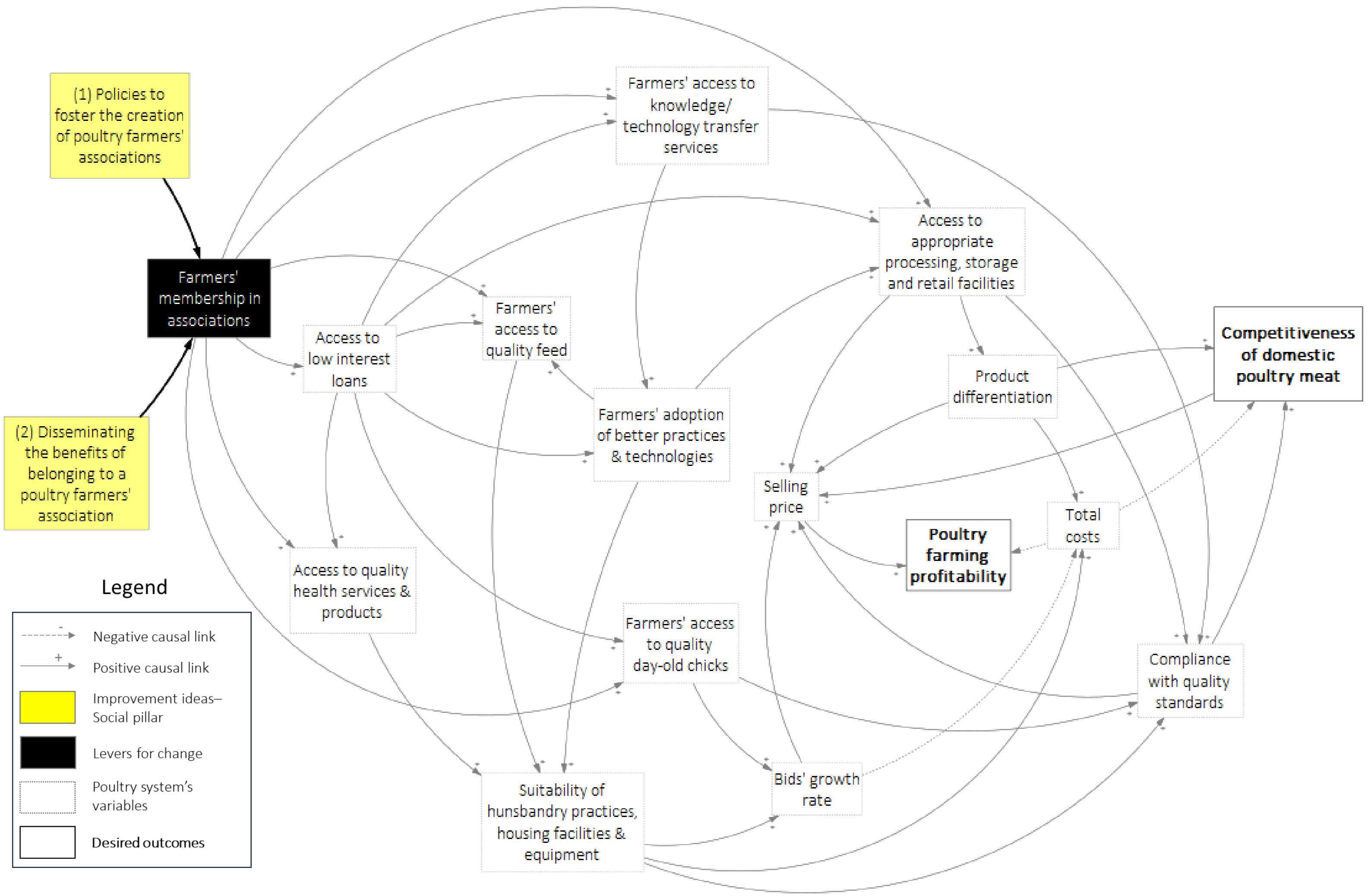

Figure 5.2. Transformation pathways derived from enhancing poultry farmers' membership in associations.

Figure 5.3 illustrates the transformation pathways derived from strengthening the financial dimension of the poultry system by improving farmers' access to low-interest rate loans. Improving access to loans among poultry farmers involves designing financial products adapted to the needs of the small-scale poultry sector.

Overall, improving farmers' access to loans leads to the same transformation pathways as enhancing farmers' membership in associations. A slight difference is that improving farmers' access to loans frees up funds to adopt better practices and technologies, directly impacting the suitability of husbandry practices, housing facilities, and equipment.

As already mentioned, improving these conditions on the farm will enhance both birds' growth rate and product quality, making poultry meat products more competitive in the market and poultry farming more profitable. Although accessing loans does not reduce the costs of farming inputs, it does help reduce the total farming costs by adopting husbandry practices, housing facilities, and equipment that improves birds' growth rate.

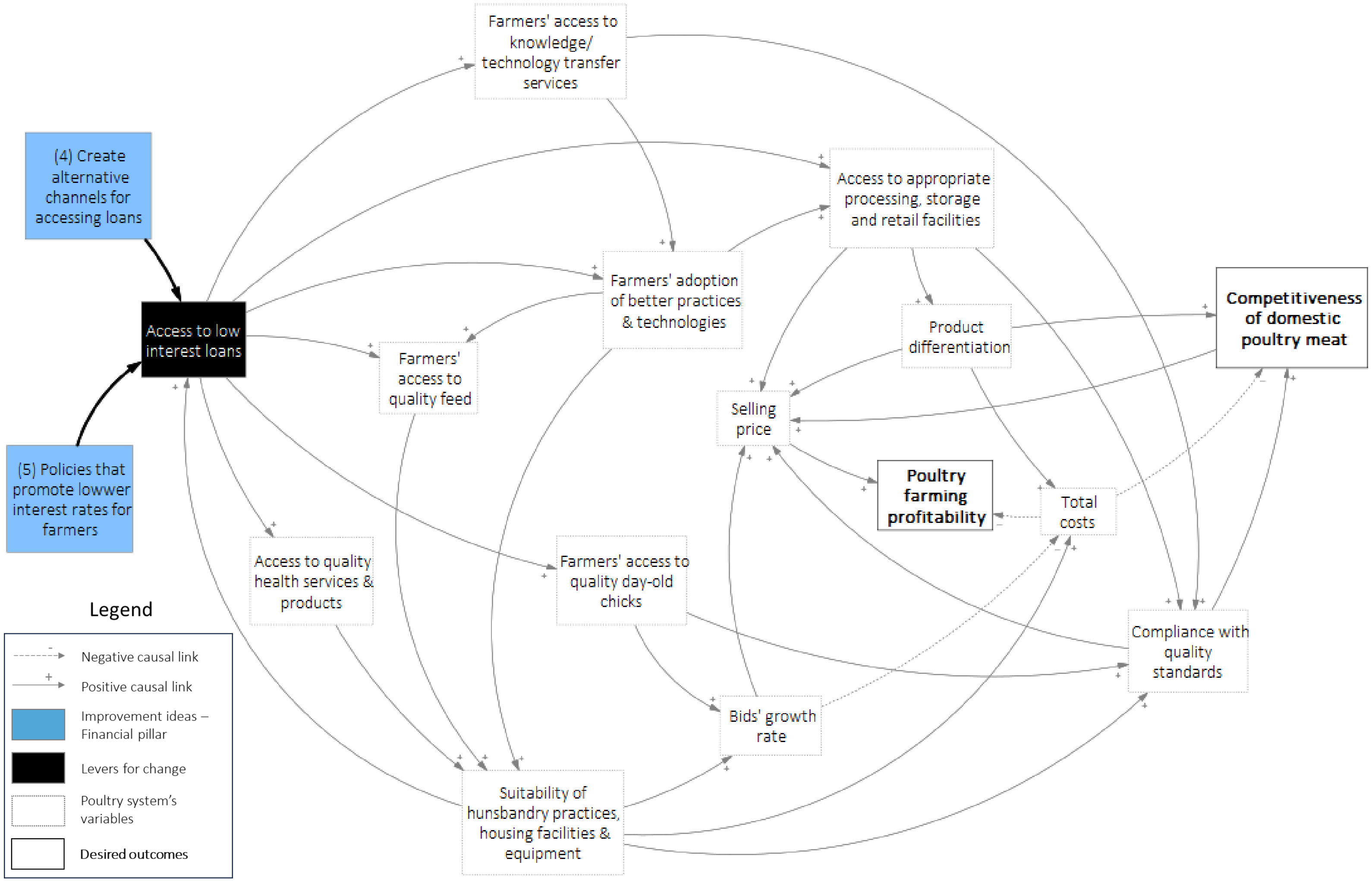

Figure 5.3. Transformation pathways derived from improving poultry farmers' access to low-interest rate loans.

Figure 5.4 illustrates the transformation pathways derived from enhancing the political dimension of the poultry system by promoting the design and enforcement of regulations to support their development.

Strengthening the design and enforcement of regulations related to the poultry system has the potential to trigger multiple benefits within the system. First, policies can minimize the costs of essential farming inputs (feed, day-old chicks, medicines/vaccines) through subsidies to improve farmers' access to them in the right quantity and quality. Second, policies can contribute to operationalizing/formalizing national hatcheries, feed mills, and veterinary practices to provide farmers with products and services of adequate quality and competitive price. Third, policies can foster the adoption of better practices and technologies along the poultry value chain. Finally, policies can promote building more storage and processing facilities for poultry products, making those services more accessible for poultry farmers nationwide.

From here on, the transformation pathways opened are the same as in the two previous figures, positively impacting both the competitiveness of domestic poultry meat and the profitability of poultry farming. It should be noted that a more competitive domestic poultry sector would reinforce the design and enforcement of regulations that further support its development.

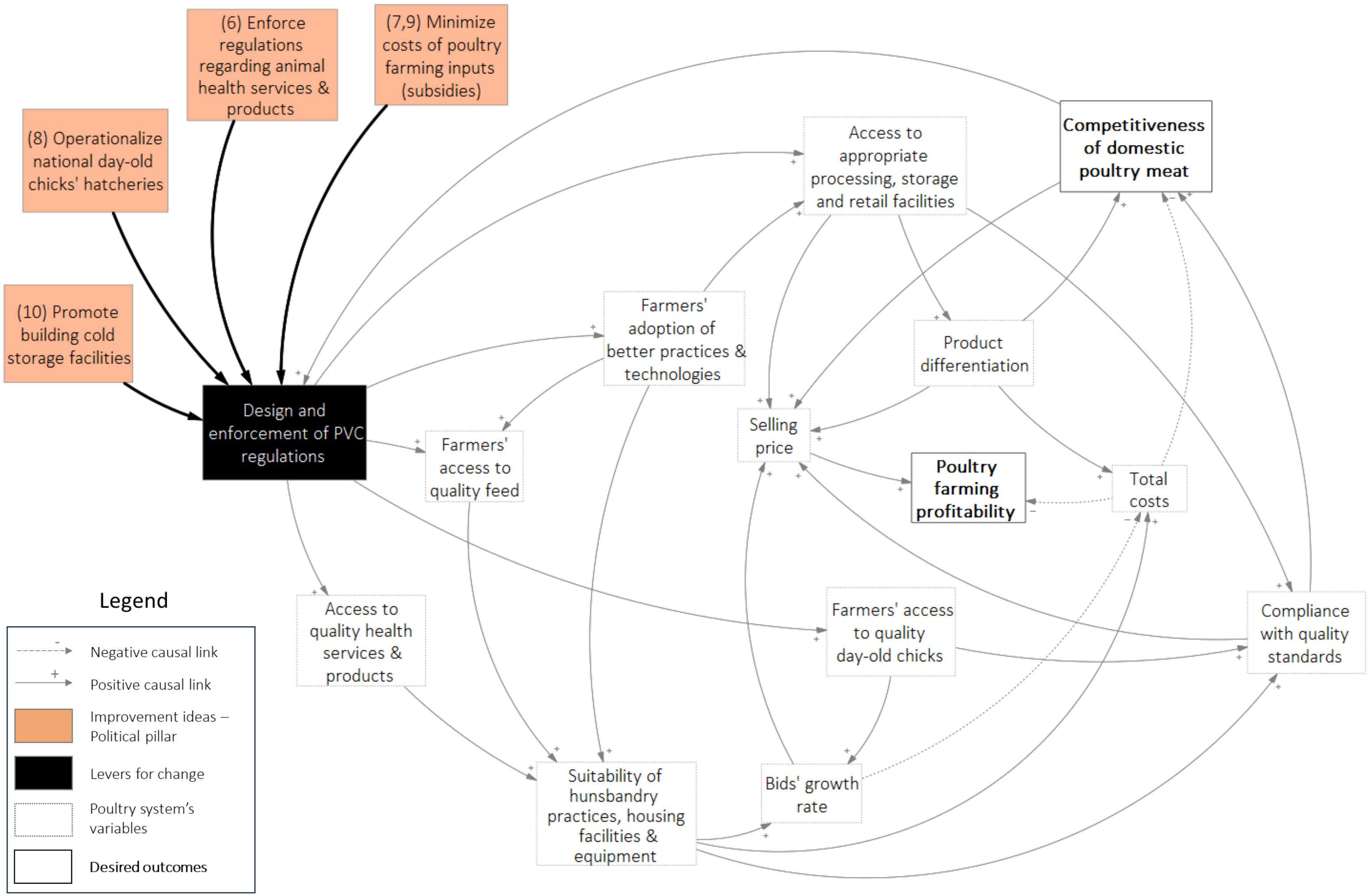

Figure 5.4. Transformation pathways derived from promoting the design and enforcement of regulations to support the poultry value chain.

Figure 5.5 illustrates the transformation pathways derived from improving farmers' access to knowledge and technology transfer services. Considering that training services contemplate sharing information about poultry-related quality standards and how to comply with them, farmers' access to them would enhance their awareness of quality standards related to poultry. This enhanced awareness will set the groundwork for improving farmers' compliance with poultry meat quality standards.

On the other hand, improving farmers' access to knowledge and technology transfer services fosters their adoption of practices and technologies that strengthen poultry production, process, storage, and retail, enhancing birds’ growth rate and the quality and differentiation of poultry products. As explained in the previous figures, the resulting quality and product differentiation improvements make poultry meat products more competitive and increase their selling prices. In the end, higher selling prices and lower production costs improve the profitability of poultry farming.

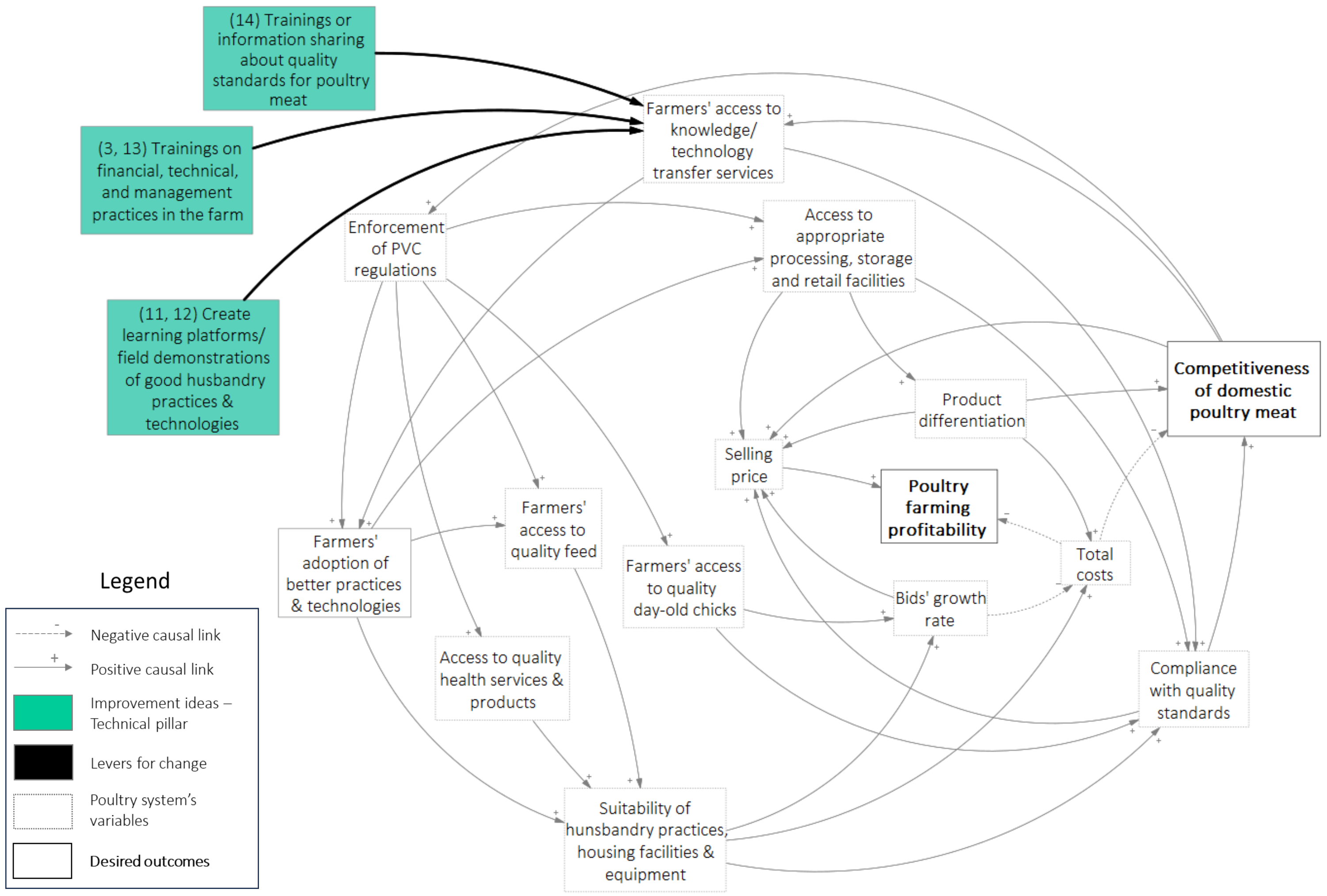

Figure 5.5. Transformation pathways derived from improving farmers' adoption of good practices and technologies.

To further assess the desirability of the transformation pathways illustrated above, five "what-if" scenarios were conducted, simulating changes in the variables identified as levers across social, financial, political, and technical dimensions (Table 5.4).

Table 5. 4. "What if" scenarios to explore potential pathways to transform the Ghana poultry system.

Dimension	Scenarios
Social	(i) Enhancing the poultry farmers' membership in associations
Financial	(ii) Improving the poultry farmers' access to low-interest loans
Political	(iii) Promote the design and enforcement of regulations that support PVC
Technical	(iv) Improving poultry farmers' adoption of better practices and technologies
	(v) Improving poultry farmers' access to knowledge & technology transfer services.

The Fuzzy Cognitive Map and its code matrix provided the foundations for exploring poultry system dynamics in the short, mid, and long term by running scenarios that simulate changes in the levers.

Figure 5.6 compares the five "what-if" scenarios in the relative changes they trigger in variables expressing the desired transformation for the poultry system.

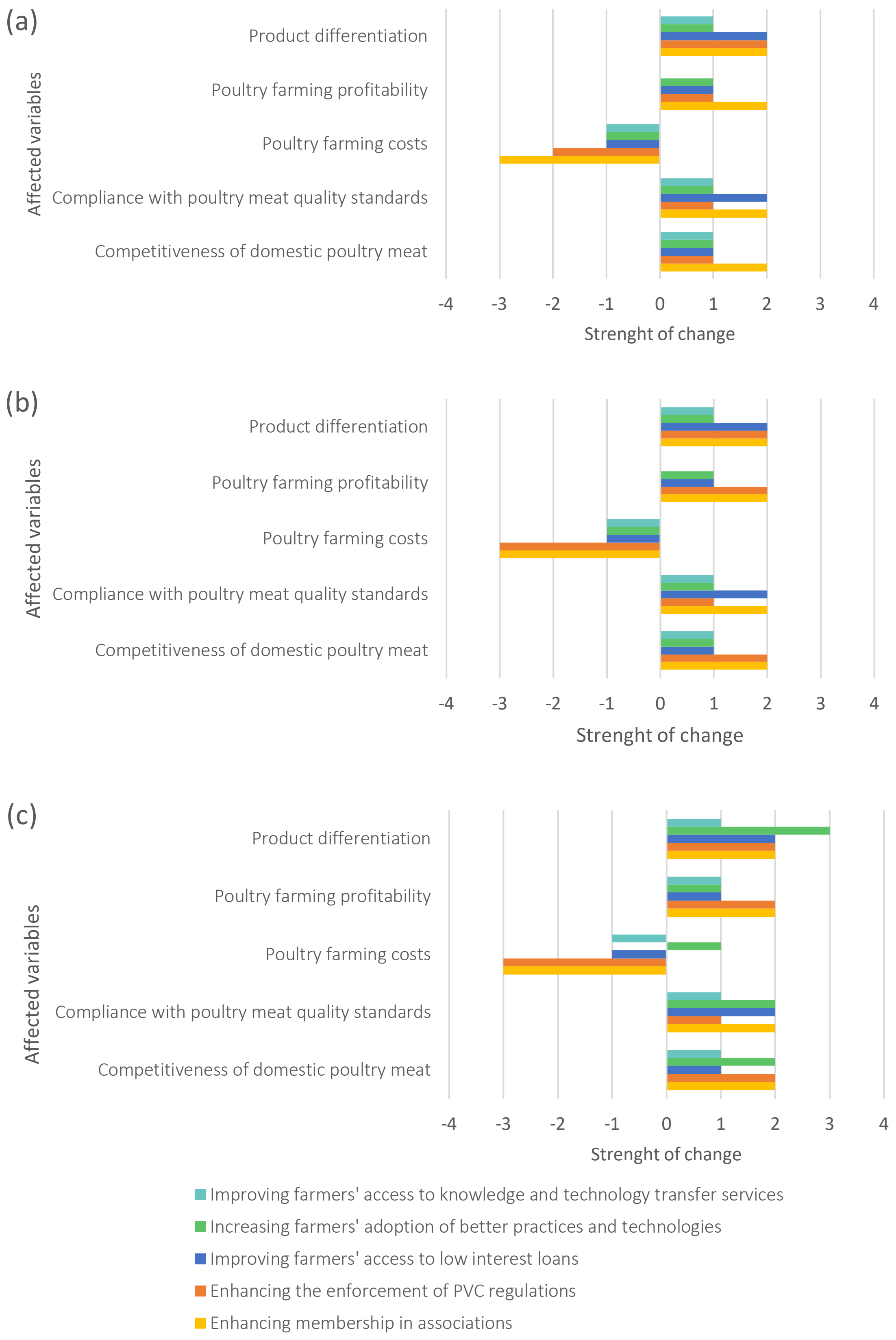

Figure 5.6. Scenarios for the poultry system in Ghana. (a) Short-term scenarios; (b) Mid-term scenarios; (c) Long-term scenarios

The “what-if” scenarios were compared in the three timeframes. For illustration purposes, the results of comparing mid-term scenarios are described below.

Regarding the competitiveness of domestic poultry meat, the scenarios with better results simulate interventions in the social and political pillar – enhancing farmers’ membership in associations and fostering the design and enforcement of regulations to support the poultry sector. These results are directly related to three affected variables included in Figure 5.6: poultry farming costs, compliance with poultry meat quality standards, and product differentiation.

Acting on the social and political pillars of the poultry system shows a significantly higher effect on the poultry farming costs than working on the financial and technical pillars. As illustrated in Figure 5.2, being members of associations provides farmers with better conditions to negotiate lower prices for farming inputs and to improve their husbandry practices and facilities, two conditions that impact production costs. On the other hand, promoting the design and enforcement of regulations that support the poultry sector – subsidizing key farming inputs and strengthening key services and facilities along the value chain – impacts both the cost of farming inputs and services and the suitability of husbandry practices, leading to a reduction in the cost per bird ready to sell (Figure 5.4).

Regarding farmers' compliance with poultry meat quality standards, the best results are shown when acting on the social and financial pillars, not on the political anymore. In both the social and financial pillars (Figures 5.2 and 5.3), the pathways contributing to compliance with quality standards go through strengthening the husbandry practices and facilities in the poultry farms and improving farmers' access to appropriate processing, storage, and marketing facilities.

Finally, concerning product differentiation, acting on the social (Figure 5.2), financial (Figure 5.3), and political pillars (Figure 5.4) yields similar results. Regardless of entry points, all the pathways contributing to product differentiation involve improving farmers' access to adequate processing, storage & marketing facilities, either by using services or facilities offered by third parties or by adopting practices and technologies that enable them to carry out these activities themselves.

The second main expected outcome for the poultry system is the profitability of poultry farming, which depends on the selling price and the cost per bird ready to sell. As for the competitiveness of domestic poultry meat, better results are obtained by acting on the social and political pillars. This makes sense considering that intervening in improving farmers' membership in associations and fostering the design and enforcement of regulations to support the poultry sector has a more significant impact on reducing the cost per bird ready to sell and improving the competitiveness of domestic poultry meat.

Besides facilitating a structured analysis of the desirability of different transformation pathways, running scenarios for the short, mid, and long term create awareness among stakeholders of the poultry systems' dynamic behavior over time and how it should be a critical consideration for decision making.

5.2. Results from the application of the PFSM in the case study in Kolda and Ziguinchor, southern Senegal

This section presents the results of applying the PFSM framework in Kolda and Ziguinchor for each of the three phases described in detail in Chapter 4.

5.2.1. Phase 1: Exploring the poultry sector situation

The insights gained from brainstorming sessions between UPM and ITA provided a preliminary view of the poultry sector situation in Kolda and Ziguinchor. The main result from this first exploration was a non-structured mind map (Annex K) revealing six topics of interest that were further explored through a literature review and interviews with stakeholders to have a view of the poultry sector situation that was as comprehensive as possible.

The six topics of interest were:

i. Processes, services, inputs, & facilities along the poultry value chain
ii. Poultry farming performance
iii. Research, development, and innovation
iv. Policy & regulations, economy, and finance
v. Social structures and stakeholders' engagement
vi. Access and consumption of domestic poultry meat

UPM and ITA research teams prepared scripts to interview key stakeholders in Kolda and Ziguinchor to delve into each topic of interest. Fifty-four stakeholders were interviewed by ITA between May and June of 2021 (Table 4.5). Annex L summarizes the results from the interviews, differentiating between the responses given by poultry farmers (mostly smallholders), intermediaries, agents involved in policy & regulations, R&D institutions, and technical experts providing these services, and retailers, supermarkets or other agents involved in the sale of poultry products to end consumers, and finally consumers.

The interviews revealed four different ways of understanding the poultry sector situation, focused on:

i. Improving poultry farming performance
ii. Enhancing the quality of domestic poultry meat
iii. Fostering favorable political, financial, and socioeconomic conditions for poultry farmers
iv. Adopt more efficient and sustainable poultry farming practices and technologies.

Finally, all the information gathered – regardless of the perspectives – was included in a Causal Loop Diagram, shown in Figure 5.7. In the process of building the CLD, periodical online meetings were held between the UPM and ITA research teams, who worked together in the Miro® collaborative platform to express the complexity of the poultry sector situation through the identification of key variables, the exploration of the linkages among them, and the identification of feedback loops that illustrate system's dynamics. The literature review was essential during this process, especially in translating all the information shared by stakeholders into variables and interrelations.

To facilitate the use of the CLD as an inquiry device to inform the coming discussions and debates between stakeholders, the variables making sense of the poultry sector situation were classified into four groups that correspond with the four perspectives identified, as detailed in the legend of Figure 5.7.

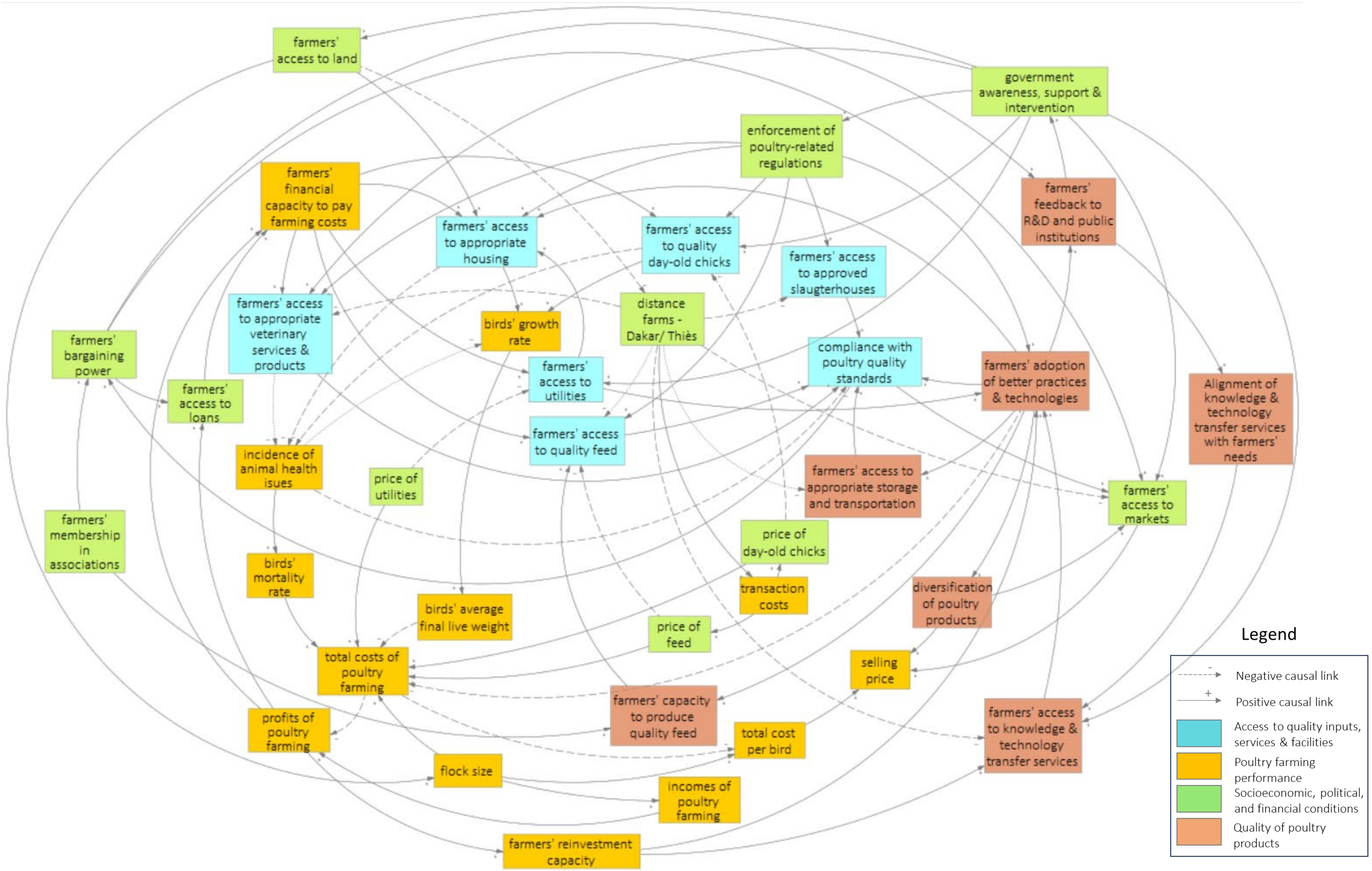

Figure 5.7. Causal Loop Diagram of the poultry sector problematic situation in Kolda and Ziguinchor

5.2.2. Phase 2: Conceptualizing the system of interest.

The participatory workshop organized in Dakar in February 2022 brought together stakeholders with different perspectives on the problematic situation of the poultry sector to promote dialogue, debates, and negotiations among them on what is failing in the current situation and how to improve it.

As explained in section 4.3.3, the CLD developed in phase 1 to illustrate the poultry sector situation was shared with the workshop participants through a narrative supported by causal trees and feedback loops. Sharing this narrative sets a common groundwork for stakeholders to explore the problematic situation from different perspectives and gain valuable insights into its complexity.

Once the poultry sector situation was shared by walking through the CLD, the workshop participants organized themselves into groups around the four perspectives identified to illustrate their worldviews through conceptual models about the transformation they envision for the poultry sector. Table 5.5 narrates the conceptual models resulting from stakeholders performing a CATWOE analysis of the four perspectives identified.

Table 5.5. Conceptual models illustrating the perspectives on the poultry sector situation in Kolda and Ziguinchor

Perspective	Conceptual model on the envisioned transformation for the poultry sector situation in Kolda and Ziguinchor
Improve poultry farming performance.	A poultry system that provides poultry farmers with access to inputs and facilities – from quality feed to appropriate slaughter facilities at farms or slaughterhouses – in a way that improves the performance of poultry farming activities in terms of birds' growth rate and mortality rate. This transformation would be enabled by companies supporting poultry farming (manufacturers, slaughterers,

	etc.) and R&D and governmental institutions providing knowledge, technical, economic, and material resources.
Enhance the quality of domestic poultry meat.	A poultry system that allows poultry farmers - especially small-scale farmers in rural areas - to progress in the prevention and control of disease outbreaks and animal health issues on the farm while procuring appropriate sanitary conditions for their products until selling, thus improving compliance with quality standards. To allow that to happen, governmental institutions should provide information to increase poultry farmers' awareness of regulations and standards, as well as economic and material resources to improve sanitary and safety conditions along the poultry value chain; on the other hand, R&D institutions should encourage research, provide technical advice, and transfer knowledge and technology to take both preventive and controlling actions.
Foster favorable political, socioeconomic, and financial conditions for poultry farming.	A poultry system that enables small-scale poultry farmers to boost their competitiveness in the domestic market, promoting political, socioeconomic, and financial-related measures. In achieving this, governmental institutions should design and enforce policies and regulations that strengthen the domestic poultry sector; on the other hand, financial companies should support poultry farming by providing conditions that enable small-scale farmers' access to funds. Finally, stakeholders' associations could also ease access to funding and training and be a platform to better communicate with R&D and governmental institutions, fostering improvements for the poultry sector.

Adopt more efficient and sustainable poultry farming practices and technologies.	A poultry system that enables small-scale poultry farmers to adopt more efficient and sustainable practices and technologies by improving their access to training oriented to their needs and interests. For these practices and technologies to be adopted, the participation of technical experts from R&D or governmental institutions to monitor and evaluate and financial institutions to provide access to finance. Stakeholders' associations (IPAS) also play a role in facilitating this transformation to happen.

Following what Checkland (2000) proposes, the conceptual models resulting from the CATWOE analysis (Table 19) were used as inquiry devices to help structure debates about the current situation of the poultry sector among stakeholders with different perspectives. The following illustrates how the discussions among stakeholders offered valuable insights into the complexity of the poultry sector situation (Williams & Hummelbrunner, 2009), revealing complementarities and divergences among perspectives.

The synergies and complementarities among perspectives suggested ideas for improving the poultry sector situation. Two of these ideas are described below.

The first idea underscores the significance of combining farmers' access to the rights inputs, services, and facilities with adopting appropriate husbandry practices. This integration enhances poultry farming performance (perspective 1) and elevates the quality of domestic poultry meat (perspective 2). The second idea focuses on decentralizing poultry value chain facilities and services to reduce farmers' need for long travel or sole reliance on large companies that may engage in price speculation, leading to shortages. Establishing local means of production and sales eases farmers' access to the required resources and services. This accessibility promoted the adoption of more efficient and sustainable poultry farming practices and technologies (perspective 4), resulting in an overall enhancement in the quality of domestic poultry meat (perspective 2).

Valuable insights also emerged from debates between divergent and contradictory perspectives. We found that acting on the price of poultry farming inputs is considered critical to improving the quality of domestic poultry meat (perspective 2) since reducing prices improves input's accessibility and thus promotes an appropriate use both in quantity and quality. However, from a perspective focused on improving poultry farming performance (perspective 1), the price of inputs is considered a contextual factor that stakeholders cannot directly control or change. In discussing and debating this point, stakeholders agreed that whether the focus is on poultry meat quality or poultry farming performance, it is critical to minimize fluctuations in input prices to create a more stable and predictable environment for all stakeholders along the poultry value chain.

Table 5.6 lists the ideas for improving the poultry sector situation that emerged from the debates and discussions among different perspectives. A concise summary of the reasoning behind the ideas is included, outlining key arguments or evidence presented during the debates among stakeholders with diverse perspectives.

Table 5.6. Ideas for improving the poultry sector situation in Kolda and Ziguinchor.

	Ideas to improve the poultry sector situation	Justification
1	Promoting small-scale poultry farmers' membership in associations/ cooperatives.	Cooperatives, associations, and other forms of collaboration between farmers can help them: (i) access quality inputs in the right quantity and to a fair price; (ii) access to training and information to improve their activities and better comply with quality standards; (iii) being more integrated into value chains; (iv) access more competitive markets.
2	Improving poultry farmers' access to information and training - particularly in husbandry practices - for better compliance with poultry/ poultry meat standards and regulations.	Improving farmers' access to training, knowledge, and information increases their awareness of good husbandry practices and technologies and promotes their adoption to sustainably enhance farm productivity and live birds/ poultry meat quality.
3	Enforcing sanitary and safety standards on local (usually small) slaughterhouses and transportation facilities.	Local slaughterhouses and transportation facilities usually do not comply with sanitary and safety standards, which increases the risk of contamination, affecting the quality of the final product.
4	Improving poultry farmers' access to appropriate storage and preservation facilities.	Access to storage facilities and refrigerated transport allows farmers to maintain the quality of the product and avoid losses,

		thus increasing their bargaining power by reducing their dependence on intermediaries.
5	Developing policies and regulations to improve domestic small-scale poultry farming competitiveness (e.g., adjusting taxation over profits and regulating prices of inputs, facilities, and services along the poultry value chain).	Production costs in small-scale poultry farming limit its competitiveness and leave it with a low-profit margin. The price volatility of poultry farming inputs severely impacts the costs of production. For feed – the main cost of poultry farming – price volatility is attributed to feed mills' speculation with price and availability.
6	Developing policies that offer decent opportunities for employment along the poultry value chain and contribute to its decentralization.	Poultry farmers - particularly smallholders - rely on few companies to access quality inputs, services, and facilities along the value chain. Those companies control the market and often speculate on the price and availability of key inputs.
7	Facilitating small-scale and young poultry farmers' access to non-repayable loans and subsidies to improve their activity and further integrate into the value chain (e.g., through egg hatching or feed self-formulation) to contribute to the decentralization of poultry-related activities.	Decentralizing value chain activities can reduce farmers' sole reliance on companies that may engage in price speculation. Moreover, decentralization opens job opportunities for smallholders and other local agents.

8	Developing policies and regulations that promote poultry farming reinvestment in diversifying products (e.g., reducing taxes over profits).	
9	Enforcing existing poultry-related regulations to procure accessible quality poultry products to Senegalese families (e.g., PRAVIS – Senegalese Poultry Recovery Plan).	Policies and regulations should promote sustainable growth and development in the poultry sector, benefiting farmers and consumers. This means enhancing poultry farmers' profitability while ensuring that poultry products remain accessible to a broader range of local households.
10	Generating knowledge, training, and technology transfer services focused on poultry farming needs.	Open channels of communication and feedback between poultry farmers, R&D, and public institutions are considered essential for farmers to access training, knowledge, and technology transfer services that enhance their awareness of good practices and technologies and promote their adoption.
11	Reinforcing management training for small-scale farmers to improve their administrative and financial abilities.	
12	Monitoring the results of training and technology transfer services in poultry farming performance and employability in the long term.	

Besides offering valuable insights into the current situation in the poultry sector, the debates among perspectives have also enabled them to broaden their knowledge and understanding of the various perspectives involved (Daniell et al., 2006). With enhanced awareness of the situation's complexity, stakeholders engaged in negotiations to envision a future for the poultry sector that is desirable – or at least acceptable – for all parties involved (Checkland & Poulter, 2010). The agreed future was the following:

> "A poultry system that, on the one hand, improves the incomes of poultry farmers and other agents within the poultry value chain, thereby providing them with sustainable livelihoods. And on the other hand, that increases the accessibility of quality animal protein for improving food security in Senegalese households".

With the agreed future in mind and having the CLD of the poultry sector's problematic situation as a foundation, stakeholders conceptualized the agreed system of interest to all, referring to it as the "poultry system." Figure 5.8 illustrates the agreed-upon poultry system conceptual model, offering a visual representation of the needed transformation to realize the future for the poultry sector in Kolda and Ziguinchor agreed upon among stakeholders. This CLD maintained the classification of variables applied when illustrating the poultry sector situation in Figure 5.7, adding one category for the outcomes the poultry system should deliver to reach the agreed-upon future.

Both reinforcing and balancing feedback loops are depicted in Figure 5.8. These feedback loops serve as a narrative tool, enabling us to articulate the dynamics of the poultry systems. This detailed understanding of food systems dynamics lays the groundwork for identifying potential levers or drivers for change within the system.

(R1) <u>Reinvestment – Access to TIMPs and Facilities Reinforcement Loop:</u> Investing in Technology, Innovations, Management Practices (TIMPs), and facilities enhances birds' performance rates and the quality levels of poultry products. These enhancements strengthen smallholders' bargaining power and market access, improving selling prices. Improved bird performance reduces farming costs and elevates the selling price of poultry products, enhancing poultry farming profitability. This, in turn, facilitates further reinvestment, creating a reinforcing cycle.

(R2) Reinvestment – Size of the Farm Reinforcement Loop: Increasing the flock size improves smallholders' access to approved slaughterhouses and storage facilities, enhancing bargaining power and market access. On the other hand, a larger flock size reduces the unitary costs of poultry products and positively impacts bargaining power. Improved selling prices enhance poultry farming profitability, reinforcing the reinvestment cycle.

(R3) Smallholders' Bargaining Power – Design & Enforcement of Regulations Loop: Strengthening smallholders' bargaining power fosters cooperation with R&D and government institutions, positively influencing the design, implementation, and enforcement of regulations supporting the poultry sector. Improved regulations and the development of tailored TIMPs and facilities enhance farm performance and quality of poultry products, reinforcing farmers' bargaining power.

(R4) Smallholders' Access to Low-interest Loans – Financial Capacity to Pay Farming Costs Reinforcing Loop: Enhancing smallholders' access to low-interest loans improves the affordability of poultry farming expenses, enabling the adoption of practices that enhance performance rates on the farm and product quality. These improvements in performance and quality improve farmers' access to markets and strengthen farmers' capacity to secure low-interest loans, reinforcing the loop.

(R5) Price Volatility of Key Inputs – Farmers' Financial Capacity to Pay Farming Costs Reinforcing Loop: Reducing price volatility of key inputs improves farmers' ability to cover farming costs and adopt practices that enhance product quality and reduce production costs. The quality improvements and expense reductions strengthen farmers' bargaining power and resilience to input price fluctuations.

(R6) Profits of Poultry Farming – Farmers' Financial Capacity to Pay Farming Costs Reinforcing Loop: Improving poultry farming profits boosts farmers' financial capacity to cover farm costs, fostering the adoption of husbandry practices that enhance birds' performance, compliance with quality standards, and market access, reinforcing farm profitability and farmers’ capacity to cover farming costs.

(B1) Size of the Farm – Total Costs of Poultry Farming Balancing Loop: Reinvesting in the farm, particularly in increasing flock size, introduces new production costs that balance farm profits and reinvestment capacity of poultry farmers, creating a balancing loop.

(B2) Farmers’ Access to Loans – Total Costs of Poultry Farming Balancing Loop: Improving farmers' access to low-interest loans has associated costs that balance farm profits, a crucial condition for evaluating access to low-interest loans.

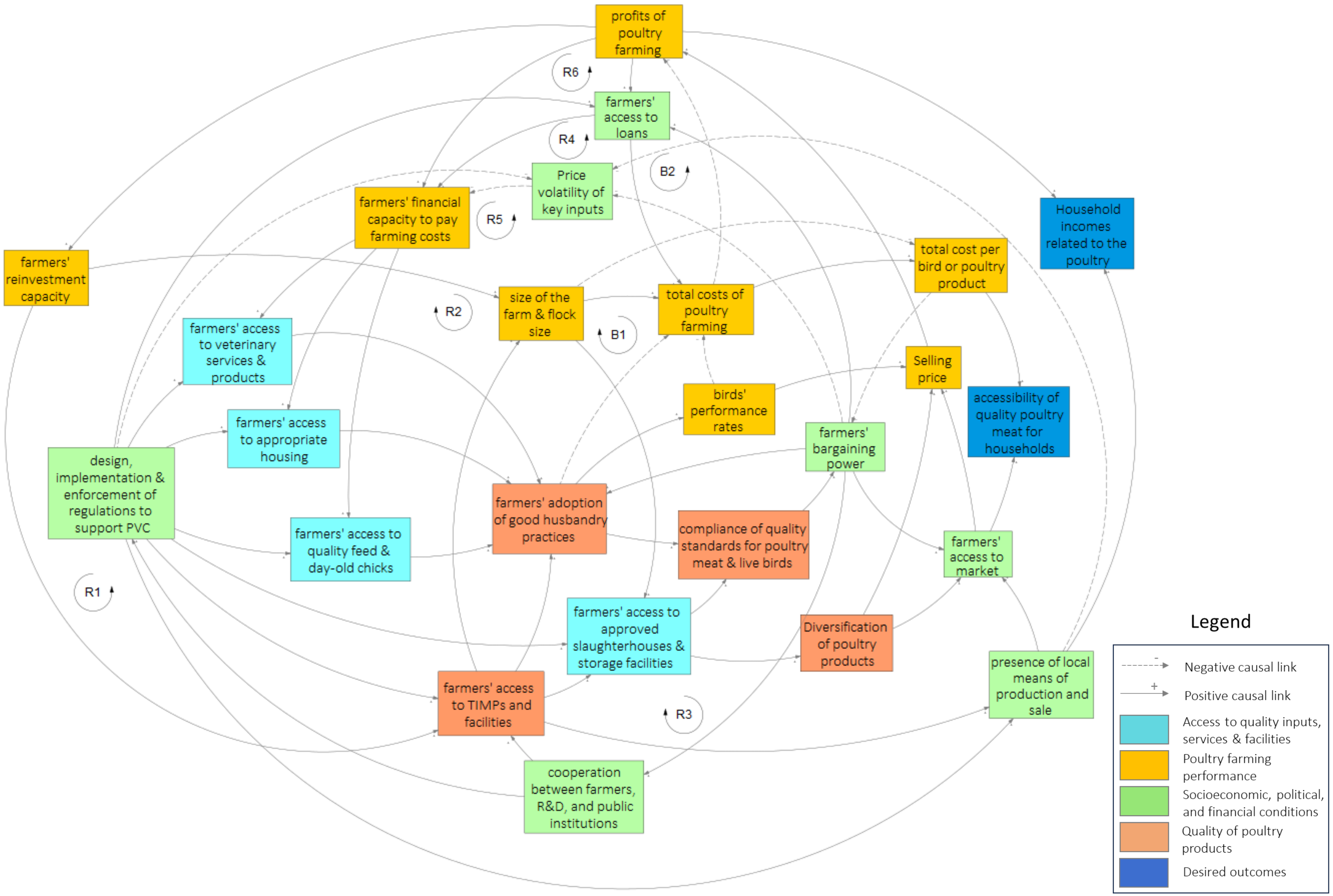

Figure 5.8. Causal Loop Diagram of the poultry system in Kolda and Ziguinchor

5.2.3. Phase 3: Identifying potential pathways for transforming the system.

To identify desirable and feasible pathways for transitioning the poultry system from its current problematic situation to the desired future agreed upon among stakeholders, the improvement ideas shared during the participatory workshop (Table 5.6) were explored using the Causal Loop Diagram of the agreed-upon poultry system (Figure 5.8).

These ideas, emerging from an enhanced understanding of poultry systems structure, complexity, and dynamics, informed the identification of levers of change within the system. Four levers were identified within the poultry system: “farmers’ financial capacity to afford farming costs,” “design, implementation & enforcement of regulations to support the poultry sector,” “membership in associations,” and “farmers’ access to TIMPs.” Addressing these leverage points through interventions such as those proposed by stakeholders in the participatory workshop sets in motion system-wide changes that ultimately contribute to progress toward the desired future agreed upon by stakeholders.

In this sense, identifying leverage points within the poultry system was the basis for exploring pathways for its transformation. These transformation pathways represent the changes triggered throughout the system when acting on the identified levers of change.

The desirability of transformation pathways is evaluated based on their contribution to progress toward the agreed-upon future for the poultry sector in Kolda and Ziguinchor, expressed in the variables “household incomes related to the poultry system” and “accessibility of quality poultry meat for households.”

Feasibility for the agents involved in the transformation was also critically discussed when exploring pathways to transform the poultry system. In this regard, the UPM and ITA research teams reflected on the livelihood strategies adopted by poultry farmers in Kolda and Ziguinchor to nuance the transformation pathways identified as desirable to their realities, requirements, goals, and aspirations. It is worth recalling that in Kolda and Ziguinchor, most poultry farmers are smallholders practicing traditional and often informal poultry farming, with the consequent challenges and barriers that this entails.

To analyze and describe the livelihood strategies adopted by poultry farmers, they were categorized into three groups – as shown in Table 5.7 – based on the types of livelihood strategies defined by Dorward et al. (2009) to shed light on the diverse pathways people follow to meet their goals and aspirations.

Table 5.7. Poultry farmers' livelihood strategies

Groups	**Poultry farmers' livelihood strategies**	**Related type of livelihood strategy (Dorward et al., 2009)**
Group I	Poultry farmers aiming to maintain the livelihood levels that poultry farming provides them in the face of a lack of financial and technical resources to improve it.	Maintaining livelihood levels in the face of adverse circumstances
Group II	Poultry farmers willing and with the means to adopt technologies and practices that enhance farm performance and comply with the quality standards that enable access to more competitive markets.	Increasing production and incomes to improve livelihoods
Group III	Poultry farmers willing and with the means to diversify activities within the poultry value chain, either through upstream or downstream vertical diversification (Barghouti et al., 2004; Heumesser & Kray, 2019).	Investing in diversifying activities to support financial stability.

Discussions and reflections on the desirability and feasibility of the pathways to transform the poultry system were informed by systems diagrams that were no more than simplifications of the poultry system's conceptual model (Figure 5.8).

Four systems diagrams (Figures 5.9 to 5.13) were created to illustrate the primary transformation pathways resulting from acting on the four identified levers of change within the system. The desirability of the four transformation pathways is mapped in their contributions to the outcome variables in bold: "household incomes related to the poultry system" and "accessibility of quality poultry meat for households." On the other hand, their cultural feasibility is depicted with Roman numerals indicating the paths that would be culturally feasible for each of the three groups of poultry farmers according to their livelihood strategies (Table 5.7).

Below is a short description of the system diagrams illustrating the four major transformation pathways for the poultry system.

Figure 5.9 illustrates the first primary pathway to transforming the poultry system, resulting from enhancing farmers' financial capacity to afford poultry farming costs. As depicted in Figure 5.9, this pathway is culturally feasible for farmers lacking the resources to invest in their farms (Group I), for those both able and willing to enhance on-farm activities (Group II), and for those interested in diversifying activities within the value chain (Group III).

By improving farmers' financial capacity – through measures such as subsidies, price regulations on poultry inputs, access to non-repayable loans, or other policies – a growing adoption of good husbandry practices is observed, positively impacting birds' performance rates and the quality of poultry products.

These enhancements in quality and performance rates subsequently translate into improved selling prices and lower production costs, rendering poultry farming a more profitable activity that improves incomes in farmers' households. Moreover, they contribute to enhancing the accessibility of quality poultry products for households.

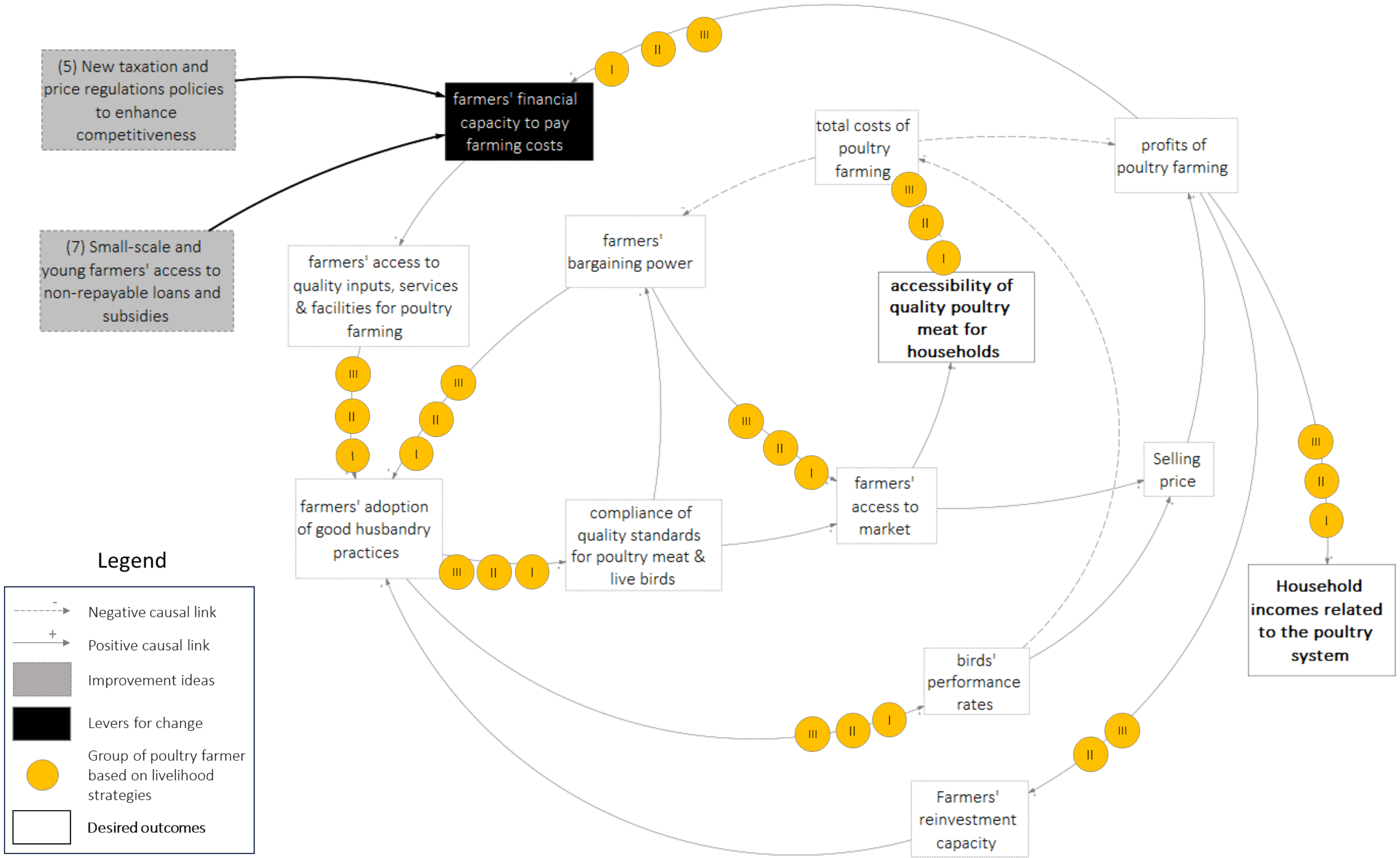

Figure 5.9. First primary pathway to transform the poultry system in Kolda and Ziguinchor

Figure 5.10 illustrates the transformation pathways resulting from the reinforcement of policies and regulations supporting the poultry system, delineating three distinct paths.

The first path begins with policies and regulations designed to improve farmers' access to quality inputs, services, and on-farm facilities, addressing the price volatility of key poultry inputs. These regulations also contemplate the creation or enhancement of local feed mills, hatcheries, storage facilities, slaughterhouses, and local markets, contributing to the reduction of input price volatility. As depicted in Figure 5.10, this pathway is culturally feasible for farmers lacking the resources to invest in their farms (Group I), for those both able and willing to enhance on-farm activities (Group II), and/or for those interested in diversifying activities within the value chain (Group III).

The second path focuses on policies and regulations that enable farmers to adopt technology, innovation, and management practices that improve on-farm performance, compliance with quality standards, and product diversification, resulting in better access to markets and selling prices. This path is feasible for farmers interested in diversifying activities within the value chain (Group III) as it contributes to decentralizing activities within the value chain by engaging farmers in the production and formulation of feed, establishing hatcheries, or managing storage facilities and slaughterhouses. It is also feasible for farmers who are able and willing to enhance on-farm activities (Group II) only in the sense it promotes the adoption of good husbandry practices that improve on-farm performance and the quality of poultry products.

The third path is shaped by policies and regulations fostering the decentralization of poultry activities and services, supporting the establishment of new businesses in the value chain, such as slaughterhouses, feed mills, hatcheries, and local markets. This pathway is culturally feasible for all poultry farmers (Groups I, II, and III), helping them to access markets with more competitive products. Furthermore, this path generates employment opportunities that improve the incomes of households with poultry-related livelihoods in the region.

Notably, by enhancing farmers' bargaining power, these three paths reinforce the design of policies supporting the sector and the development of training and technology transfer services tailored to poultry farmers' needs. In other words, farmers with more competitive products – in quality and price – have more agency to influence the poultry system's governance.

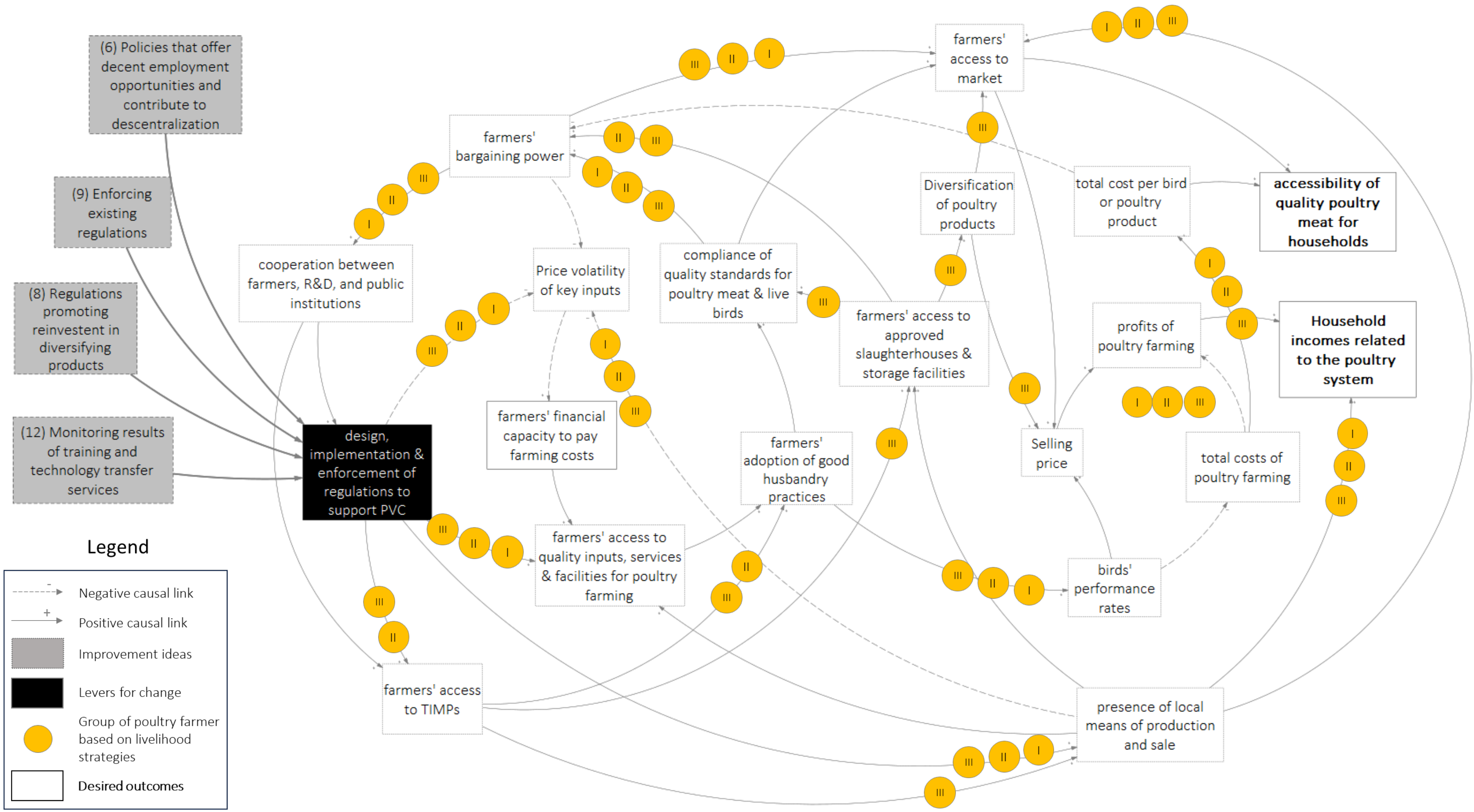

Figure 5.10. Second primary pathways to transform the poultry system in Kolda and Ziguinchor

Figure 5.11 delineates the transformation pathways resulting from reinforcing farmers' membership in associations. Two paths are identified, as described below.

Through the first path, membership in associations strengthens farmers' bargaining power, enabling them to negotiate favorable prices for farming inputs. This, in turn, enhances on-farm performance rates and the overall quality of poultry products, facilitating access to markets with better selling prices. As depicted in Figure 5.11, this path is culturally feasible for farmers lacking the resources to invest in their farms (Group I), those both able and willing to enhance on-farm activities (Group II), and those interested in diversifying activities within the value chain.

Through the second path, membership in associations improves farmers' access to technologies, innovations, and management practices (TIMPs). Accessing TIMPs can lead to adopting better husbandry practices or gaining access to approved slaughterhouses and storage facilities. Adopting good husbandry practices is culturally feasible for farmers both able and willing to enhance on-farm activities (Group II) and those interested in diversifying activities within the value chain (Group III), leading to improved on-farm performance and quality of poultry products. On the other hand, accessing approved slaughterhouses and storage facilities is culturally feasible for farmers interested in diversifying activities within the value chain (Group III), allowing them to diversify their products and access markets with better selling prices.

These two paths make poultry farming more profitable and poultry products more accessible to households, thus contributing to the desired transformation for the poultry system.

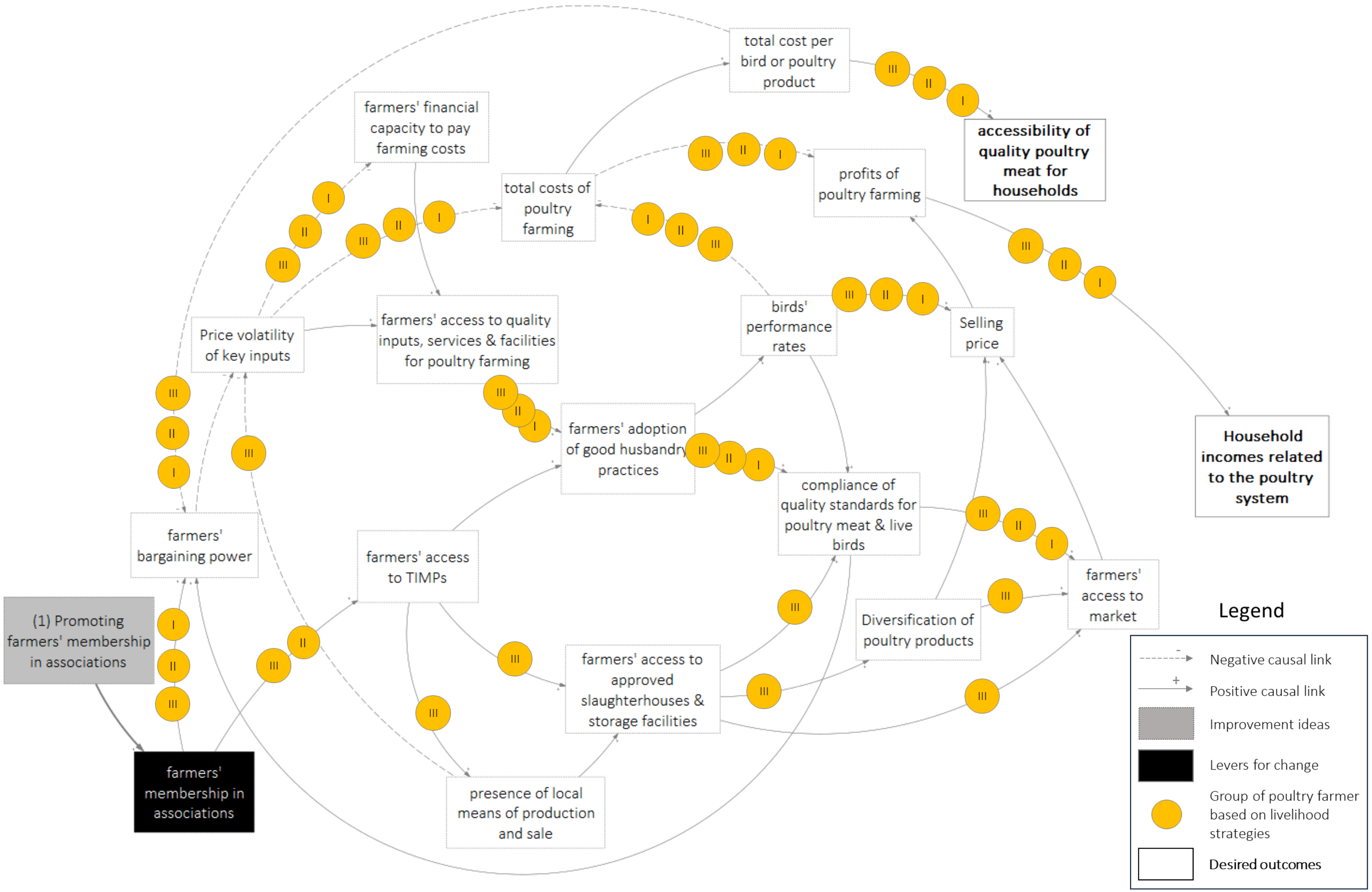

Figure 5.11. Third primary pathway to transform the poultry system in Kolda and Ziguinchor

Figure 5.12 delineates the transformation pathways resulting from the reinforcement of farmers' access to TIMPs, delineating three distinct paths.

Through the first path, accessing TIMPs triggers farmers' adoption of husbandry practices that significantly elevate on-farm performance rates and improve the quality of poultry products. This, in turn, facilitates entry into competitive markets with improved selling prices. This path is culturally feasible for farmers who are both able and willing to enhance on-farm activities (Group II) and those interested in diversifying activities within the value chain (Group III).

Through the second path, access to TIMPs encompasses access to approved slaughterhouses and storage facilities that enhance the quality of poultry products - adding them value through diversification – and allowing farmers to store their products until they see the appropriate time to sell.

Through the third path, accessing TIMPs empowers farmers to diversify activities downstream in the value chain by formulating their feed and own hatcheries, thus strengthening the local presence of local means of production. This strategy reduces farmers' dependence on the few companies currently controlling the market and speculates with prices and availability of key inputs. The ensuing reduction in the volatility of key input prices positively impacts farmers' access to these essential resources.

Both second and third paths, as they involve diversification of activities within the poultry value chain, are culturally feasible exclusively for farmers in Group III.

The enhanced adoption of good husbandry practices, the presence of local means of production, and access to approved slaughterhouses and storage facilities culminate in improved poultry farming profitability and increased accessibility of poultry meat products for households, contributing to the desired transformation for the poultry system.

Notably, the improvements in poultry farming profitability resulting from the enhanced adoption of good husbandry practices and access to approved slaughterhouses and storage facilities reinforce farmers' financial capacity to afford farming. Moreover, it strengthens farmers' ability to reinvest and supports their access to TIMPs.

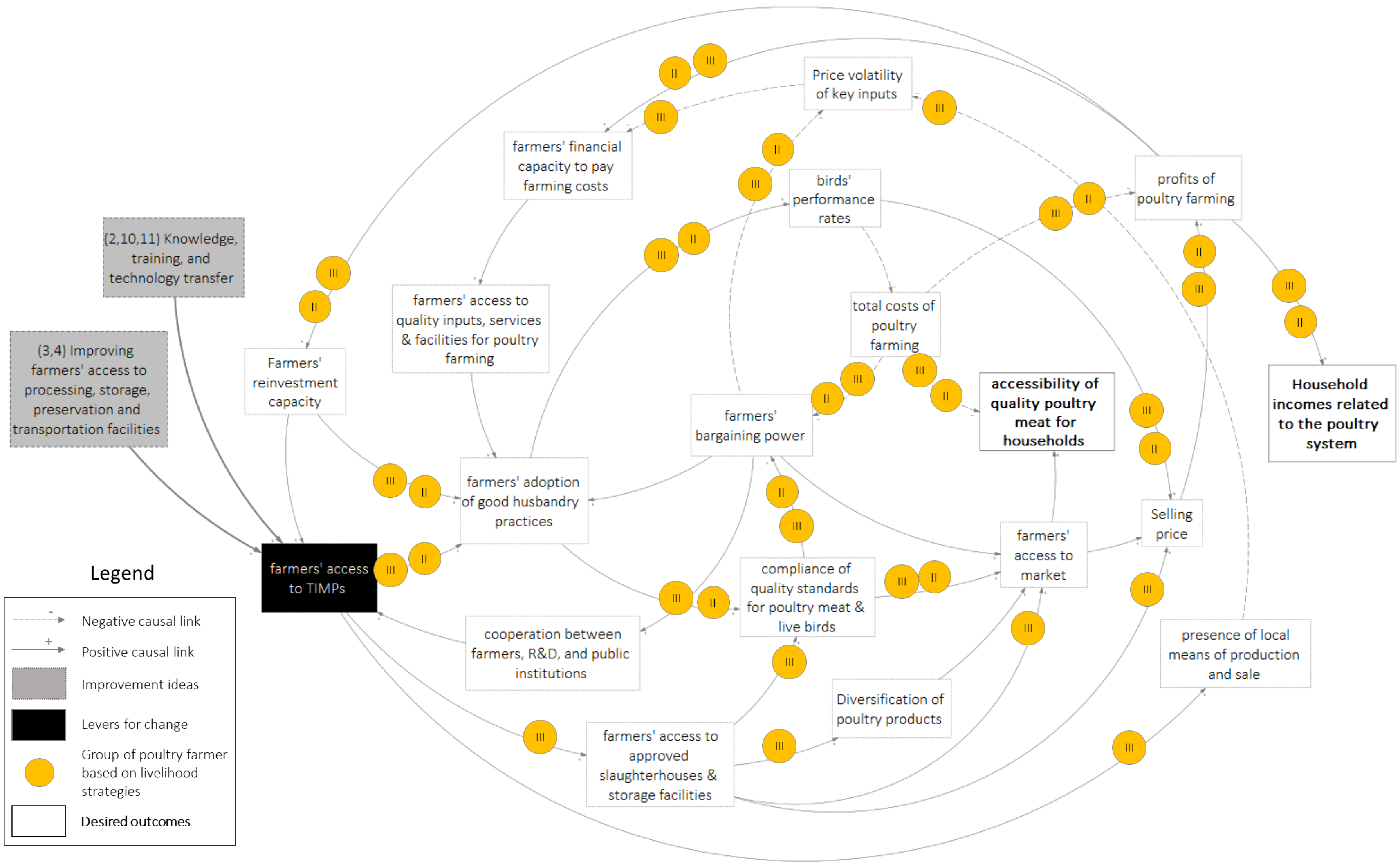

Figure 5.12. Fourth primary pathway to transform the poultry system in Kolda and Ziguinchor

As we delve into the intricacies of the four primary transformation pathways for the poultry system in Kolda and Ziguinchor through the lens of cultural feasibility, valuable insights emerge to guide the design of tailored interventions that align with the unique circumstances and aspirations of poultry farmers, expressed through the livelihood strategies they choose to adopt. Nuancing the interventions to poultry farmers' livelihood strategies aims to maximize the benefits for poultry farmers, their families, and society.

The nuances of each primary transformation pathway, categorized by the three distinct livelihood strategies adopted by poultry farmers, illustrate diverse opportunities and challenges to contribute to the desired transformation of the poultry system. For Group I, comprised of farmers with limited resources, sustaining or improving incomes and accessibility of poultry meat products remains feasible across three of the four pathways, though confined to their households. As farmers in this group may not be able to invest in adopting new technologies or better practices, interventions should provide enabling conditions for them to continue poultry farming in a way that sustains or improves their incomes and poultry meat self-consumption.

Group II, comprised of farmers both able and willing to invest in technologies and practices to improve their on-farm activities, can contribute to poultry systems transformation by strengthening the quality of their products while reducing production costs, thus improving profitability and accessibility of poultry meat products for their households and others in the region. To maximize this group's potential to contribute to the poultry system's transformation, interventions should focus on enabling their access and adoption of TIMPs that improve their on-farm activities. Additionally, creating an enabling environment that supports the development of the poultry sector, with particular attention to smallholders, is crucial.

Group III, comprised of farmers who are able and willing to diversify activities within the poultry value chain, can contribute to transforming poultry systems by improving the competitiveness of poultry meat products. This involves strengthening farmers' bargaining power to access markets with better selling prices, thus enhancing the accessibility of poultry meat products for households. Diversifying farmers' activities downstream in the value chain reduces their dependence on companies that control the market of key inputs, optimizing processes and production costs and maximizing the profitability of poultry farming. To maximize the potential of this group, interventions should focus on providing farmers with the appropriate conditions to diversify activities downstream and upstream in the value chain, either through policies or through the adoption of technologies and practices that allow this diversification.

As Checkland (2000) states, the process of identifying desirable and culturally feasible pathways for transforming the poultry system consists of a learning cycle in which debates and discussions among stakeholders with diverse perspectives shed light on the system's complexity and set the groundwork for identifying courses of action that are both desirable and feasible for the people involved, and that could lead to actions by informing the design of policies and interventions. Finally, the CLD expressing the poultry system stakeholders agreed to transform would inform further discussions, reflections, and exploration of potential interventions, including those described in this paper and those emerging from new exploration-learning cycles.

5.3. Concluding remarks

Implementing the Participatory Food Systems Modelling framework in case studies on poultry systems in Ghana and Senegal has been instrumental in gaining valuable insights and paving the way for transforming food systems in West Africa.

Applying the PFSM framework allowed for a systemic and collective exploration of the problematic situation in the poultry sector of both countries. By adopting a food systems approach, stakeholders explored the poultry sector situation systemically, sharing knowledge, impressions, and perspectives with each other to build a collective understanding (Garcia-Gonzales & Eakin, 2018). Engaging stakeholders with diverse perspectives in this participatory process provided a closer-to-reality view of the multidimensional issues involved in the poultry sector.

Stakeholders in both case studies agreed on a shared vision for the future of the poultry sector. In Ghana, the agreed-upon future prioritizes enhancing the competitiveness of domestic poultry meat and improving poultry farming profitability, particularly for small-scale/ backyard farmers who produce most broiler birds (Anang et al., 2013; RVO Netherlands Enterprise Agency, 2019). This vision aligns with the national goal of strengthening the competitiveness of the domestic poultry sector to meet the rising demand for animal-source protein that is currently covered by imported products (Nagguija et al., 2020; Sumberg et al., 2017). Similarly, in Senegal, the agreed-upon future focuses on the expectations and concerns of poultry farmers, especially smallholders, aiming to improve economic well-being and food security in their households (Ly, 2020; RVO Netherlands Enterprise Agency, 2021).

Recognizing the essential role of poultry farming in the households of both countries (Hartley & Ardnt, 2018; Ly, 2020; RVO Netherlands Enterprise Agency, 2019, 2021) and rural communities in the West African region (De Bruyn et al., 2015; Hetherington et al., 2017; Molina-Flores et al., 2020), the poultry systems' transformation holds great potential to enhance food security and provide economic support to rural communities and vulnerable populations (Anang et al., 2013; Butler, 2016; Hartley & Ardnt, 2018; Hetherington et al., 2017; Molina-Flores et al., 2020), particularly the rural poor (FAO-GIEWS, 2021).

Concerning the identification of transformation pathways, the application of semi-quantitative analysis in Ghana facilitated the exploration of different scenarios and their implications on poultry systems' trajectories and future states. This analysis identified transformation pathways within the social, technical, financial, and political pillars, assessing their desirability in different timeframes. In that sense, scenarios revealed that depending on the timescale, certain interventions would show more favorable results than others.

Notably, in the short term, interventions in the social lever – farmers' membership in associations – show more favorable results than interventions in the political, technical, and financial levers. These results indicate that fostering farmers' membership in associations shows better results on poultry farming profitability and competitiveness of domestic poultry meat in the short term than acting on any other lever in the system. In the mid-term, interventions in the social and political levers show similar results, and in the long term, so do interventions in one technical lever. This information supports decision-making for transforming the poultry system, providing insights into the timing and relative impact of different transformation pathways.

Conversely, in Senegal, the qualitative modeling approach within the PFSM allowed for discussions on the desirability and cultural feasibility of transformation pathways, acknowledging the diversity of stakeholders and the role of governance structures and power imbalances in shaping the feasibility of transformation pathways (Garcia-Gonzales & Eakin, 2018).

Besides identifying four key levers of change within the poultry system in Kolda and Ziguinchor – linked to the financial, political, social, and technical pillars as in Ghana – stakeholders highlighted the presence of a few large companies with vertical integration along the value chain that, besides being the biggest poultry farming producers, control the supply of key inputs and most of the formal processing and storage facilities in the country. During the participatory workshop, stakeholders reported speculative practices with feed that cause shortages and price instability, preventing traditional poultry farming from maximizing its potential as a livelihood strategy to sustain or enhance food security in rural areas and as a source of financial security for vulnerable groups (Hetherington et al., 2017; Randolph et al., 2007; Smith et al., 2014). As argued by Da Costa & McMichael (2007), power imbalances within the poultry systems are associated with the dominant market-and-corporate-led regime.

With growing awareness of the diversity of perspectives, heterogeneity within groups of agents, and governance structures within the poultry system that shape stakeholders' agency, the transformation pathways were nuanced to the livelihood strategies poultry farmers adopt to meet their requirements and aspirations. Being grounded on the dynamic livelihood strategies framework proposed by Dorward et al. (2009) allowed showing that the cultural feasibility of transformation pathways depends on both the particularities of the agents involved and on the specificities of the context and governance structures that condition their capacities to perform specific actions. In this sense, the analysis of transformation pathways for the poultry system in Kolda and Ziguinchor through the lens of cultural feasibility provided valuable insights to inform decisions that take into account the unique circumstances, goals, and aspirations of the agents involved, particularly those of the poultry farmers and their families.

The insights gained from these case studies are considered of value to foster a more sustainable poultry system in the West African regions for the benefit of all stakeholders involved.

5.4. Lessons learned for future research and practice

Implementing the PFSM in two case studies provides valuable insights and lessons for future research and practices. Below are the lessons learned regarding adaptations to the PFSM framework, stakeholders' engagement strategies, the importance of fostering debates and negotiations while dealing with power imbalances, and the implications of the different modeling methods applied to gain insights to identify food systems' transformation pathways.

Lesson 1: Adaptations to the PFSM framework due to the COVID-19 pandemic

As detailed at the beginning of this section, the PFSM framework encountered several limitations in its implementation in both case studies, most of which derived from the COVID-19 pandemic. These limitations led to adaptations to avoid compromising the participatory components of the proposed methodology. Regular online work sessions were established between the research teams of UPM in Spain and the CSIR-STEPRI and ITA in Ghana and Senegal to carry out the PFSM in light of the mobility restrictions. These working sessions involved capacity building and knowledge transfer between the teams, allowing them to prepare the PFSM activities without the UPM being able to attend in person. The additional efforts required, which involved developing materials and training sessions that were not initially planned, strengthened the research teams' capacities regarding PFSM. Additionally, adaptations were made in terms of participatory methods and tools in response to the mobility and meeting limitations caused by COVID-19. Consequently, interviews and consultation sessions were held with key stakeholders as alternatives to participatory workshops, which implied bringing together many people in closed spaces.

Lesson 2: Stakeholders' engagement strategies

Regarding stakeholder engagement throughout the PFSM, the implementation of the case studies revealed that conducting interviews or small focus groups before participatory workshops facilitated gathering more diverse information and obtaining a more accurate picture of the situation's complexity to explore. Having a picture of the problematic situation that expresses the diversity of knowledge and perspectives lays the foundations for fostering discussions and debates informed by a broadened individual and collective knowledge. The case study in Kolda and Ziguinchor in Senegal illustrated this well, as interviews conducted with stakeholders revealed different perspectives on the poultry sector's problematic situation, providing valuable information that captured its complexity.

Attempting to obtain a closer-to-reality picture of problematic situations solely through information gathered in participatory workshops is not advisable, as such spaces may limit the participation of the most vulnerable and marginalized groups, resulting in more partial views of the real issues. While generating participatory spaces is essential to fostering debates and discussions among stakeholders, having a prior image reflecting different perspectives and knowledge of the problematic situation is crucial to facilitating meaningful discussions during workshops. For informing debates and discussions on the desired future and the needed transformations, it is essential not only to have a comprehensive picture of the problematic situation but also to delve into the different perspectives on what is problematic to whom, why, in which ways, and how to address it. In this regard, it is crucial to explore and be aware of power relations, imbalances, and governance structures in order to plan the exploration of different perspectives involving stakeholders in a way that encourages open and free expression of their worldviews and reflections on the values, interests, and concerns that underlie them. Facilitators who create spaces of trust among participants are also vital to lead this process effectively.

Sharing and reflecting on different perspectives through dialogue and discussions among stakeholders strengthen individual and collective awareness of the complexity of the situation to be addressed. This facilitates negotiations between stakeholders to build a joint vision and define a system of interest to all, focusing on similarities and complementarities while recognizing and addressing divergences among perspectives.

Lesson 3: Insights from qualitative and semi-quantitative modeling

Both qualitative and semi-quantitative modeling processes provide valuable insights into the potential transformation pathways for poultry systems.

In applying the PFSM in the poultry system in Kolda and Ziguinchor regions in Senegal, qualitative modeling served as a device to foster debates on the desirability and cultural feasibility of different transformation pathways. Transformation pathways were considered desirable if they contributed to the agreed-upon future. Regarding cultural feasibility, discussions focused on identifying which transformation pathways were best suited to each type of poultry farmer, considering the livelihood strategies they adopted.

Conversely, the semi-quantitative modeling applied in Ghana focused more on the different degrees of the desirability of different transformation pathways and their implications for the future state and trajectories of the poultry system in the short, mid, and long term.

Both modeling processes provide valuable insights to inform decision-making in support of transformations, but in different ways. Qualitative modeling emphasizes the need to design tailored interventions, considering the agents' capacity at a given time to perform specific actions and the governance structures that shape their agency. As such, the application of the PFSM framework in Kolda and Ziguinchor in Senegal nuanced the four primary transformation pathways identified considering the livelihood strategies adopted by smallholder poultry farmers in these two regions to determine which pathways will be feasible for whom, thus maximizing the contributions to the transform the poultry system in benefit of the poultry farmers, their families, and the society. On the other hand, quantitative modeling allowed comparing the relative effect of different interventions in the behavior and the results of the poultry system over time, giving valuable insights into their desirability levels. In Ghana, running different scenarios provides interesting information about the desirability of transformation pathways resulting from interventions in the poultry system's social, political, financial, and technical pillars.

In both case studies, stakeholders participating in the PFSM modeling used the modeling results to explore ideas for improving the poultry system that emerged from discussions and debates among them and discuss their desirability and feasibility in a structured and systemic way.

As illustrated by the results and use of modeling tools in both case studies, understanding the limitations of each specific case and context is crucial to adapting the proposed PFSM for future applications.

6. CONCLUSIONS

Amidst the increasing awareness of the complexity of food systems challenges and the need for systemic approaches to address them, this thesis aims to contribute to the ongoing efforts to inform and support the needed transformations. The main conclusions of the thesis are outlined below in response to each of the three specific objectives set.

- **Conclusion 1:** *This thesis sets the foundations for fostering a meaningful engagement with Systems Thinking and Complexity Science among agents involved in shedding light on and addressing complex issues by synthesizing the key insights offered by these fields of knowledge in a principle-based framework that offers actionable guidance and inspiration.*

In view of the growing awareness of the complexity of global challenges over the last decades, there has been a paradigm shift toward increasingly systemic approaches across disciplines and in different spheres (Burns & Worsley, 2015; Reynolds et al., 2016; Reynolds & Holwell, 2010; Walton et al., 2021; Williams & Hummelbrunner, 2009). This shift is demonstrated by a growing interest in Systems Thinking and Complexity Science (Gates, 2016; Gates et al., 2021; Walton et al., 2021), two fields of knowledge that emerged to transcend the traditional, linear thinking to make sense of complex issues and support transformative processes (Gates et al., 2021).

In order to offer actionable ways to make sense of and promote substantial engagement with the broad wealth of insights provided by STCS for dealing with complex challenges, Chapter 2 proposes a principles-based framework informed on a comprehensive literature review of Systems Thinking and Complexity Science in evaluation. It is important to note that making sense of the theories, concepts, methods, and tools from STCS as part of traditions or schools of thought with different philosophical assumptions was critical to creating a principles-based framework that offers an "in-depth" look at both fields and their contributions to understanding and addressing complex challenges. In this regard, a multi-methodological approach was adopted to formulate the principles-based framework, presenting the ideas and practices from traditions and schools of thought with different philosophical assumptions as complementary.

The principles were developed transparently and structured around key STCS insights, bringing to the table features inherent to real-world situations to which attention must be paid to design interventions that support the transformations needed to address complex challenges. Three significant considerations to deal with complex issues were fleshed out through the principles: (i) exploring the big picture as comprehensively as possible, (ii) understanding the dynamic behavior of the system, and (iii) acknowledging the role of agents in framing problematic situations and proposing ways to improve them.

Applying the STCS principles in evaluating the TEEBAgriFood framework illustrated how STCS ideas and practices have been informing the exploration and address of complex food systems challenges in practice.

- **Conclusion 2:** *This thesis contributes to strengthening and leveraging frameworks aimed at informing and supporting food systems transformations by guiding and inspiring agents involved in their design and application to dialogue and engage with Systems Thinking and Complexity Science. This is done by highlighting opportunities for cross-learning and collaboration within the food systems practice and with Systems Thinking and Complexity Science.*

The complexity of food-and-agriculture-related challenges and their strong relationships with other sustainability challenges support the global claim for transforming food systems. This call for transformations goes hand in hand with the adoption of systemic approaches to shed light on the complexity of food-and-agriculture-related challenges and inform debates and agendas worldwide (Béné et al., 2019; Burns & Worslet, 2015; HLPE, 2020a). While there is a clear evolution in this direction with the growing adoption of food systems approaches and frameworks, the efforts undertaken so far do not translate into substantial support for transformations.

According to Leeuwis et al. (2021), barriers to transformation are rooted in features inherent to the complexity of food systems. In this sense, they call for accounting for food systems' complex and systemic nature to inform and support their transformations. Under this premise, Chapter 3 delved into the meaningfulness of the STCS principles for informing and supporting food systems transformations, revealing that most barriers to transformations are linked to systems-and-complexity-related features.

Some of these barriers are the undesirable trade-offs between food systems outcomes that prevent their sustainability (Abson et al., 2016; Béné, 2022; Ruben et al., 2021); difficulties in identifying leverage points for transformations derived from a poor misunderstanding of food systems' emergent properties and patterns of behavior (Abson et al., 2017; HLPE, 2017; Leeuwis et al., 2021; Oliver et al., 2018); divergent perspectives among stakeholders (Béné, 2022; Hubeau et al., 2019; Leeuwis et al., 2021); and governance-related issues that constrain the agency of certain groups while enhancing power imbalances (Brouwer et al., 2021; Lam et al., 2020; Leeuwis et al., 2021; Ruben et al., 2021).

Having proven the significance of STCS principles in addressing barriers to transformations, these were used as evaluation criteria to analyze 20 food systems frameworks developed over the past two decades. This is to transparently and robustly analyze their contributions to food systems transformations from the progress made in understanding and addressing features inherent to their complex and systemic nature.

Assessing food systems frameworks from an STCS perspective allowed showcasing and highlighting practices with the potential to address barriers preventing transformations, revealing complementarities among the frameworks to leverage by fostering dialogue and knowledge exchanges within the food systems research field. Special attention was placed in Chapter 3 to practices that improve the understanding of food systems dynamics, encourage the engagement with diverse perspectives while trying to deal with power imbalances that prevent challenging the status quo to foster food systems' transformations, and promote conscious reflections on the boundaries that support the current regime. By emphasizing practices that address the systems-and-complexity features less developed in the analyzed frameworks, the aim is to give them greater visibility by promoting exchanges and learning in their regard.

On the other hand, the assessment of frameworks revealed areas for improvement where ideas and practices from STCS could strengthen the guidance offered by food systems frameworks to address the barriers hindering their transformations. In this sense, the assessment laid the groundwork to promote greater engagement to STCS among food systems frameworks as a way to contribute to the ongoing efforts to inform and support the necessary transformations toward sustainable food systems.

- **Conclusion 3:** *This thesis contributes to identifying desirable and culturally feasible pathways for food systems by proposing a Participatory Food Systems Modeling (PFSM) framework that engages stakeholders with different perspectives in making sense of current challenges, negotiating a desired future, and thinking together on how to move towards it. Through real-world applications in Ghana and Southern Senegal, PFSM has demonstrated its value in informing decision-making to advance the transformations of food systems.*

According to Chapter 3, one of the barriers to food systems transformations being least addressed by the analyzed frameworks derives from power imbalances and agency limitations among food systems agents, which prevents challenging the governance structures that hinder food systems from moving away from their current unstainable trajectories (Blesh et al., 2019; Garcia-Gonzales & Eakin, 2019).

In that sense, several authors highlight the importance of promoting processes of exchange and reflection among stakeholders with different perspectives and types of knowledge to facilitate informed and conscious exploration and negotiation on what is failing in the system, what would be its desired state, and how to move from the current problematic situation to the desired future (Checkland, 2000; Checkland & Haynes, 1994; Checkland & Poulter, 2010; Checkland & Scholes, 1999). Along the same line, the HLPE (2020) highlights the need to reflect on the interests and values underlying the decisions shaping food systems' current and future state to inform debates that openly question the boundaries that prevent interventions challenging the status quo and fostering the needed transformations from prospering (IPES-Food, 2017; Leeuwis et al., 2021).

The Participatory Food Systems Modeling framework proposed in Chapter 4 aimed to address the considerations above in order to inform the identification of desirable and culturally feasible pathways to transform food systems. In this sense, it is proposed as an iterative process that engages stakeholders with different perspectives along three phases aimed to (i) explore as comprehensively as possible what is failing, (ii) discuss and negotiate on what the desired future looks like, upon an enhanced awareness on the diversity of perspectives involved, and (iii) think and discuss on potential ways to move the system from the current to the desired state.

The PFSM was designed to be easily adaptable and flexible to be used in different contexts and under different conditions. In that sense, Chapter 4 discusses the adaptations made when applying the PFSM frameworks to analyze poultry systems in Ghana and Senegal. The applications show that there is flexibility in the type of activities and methods used in each phase of the participatory modeling process as long as they contribute to the three objectives described in the previous paragraph, which, according to Schot & Steinmueller (2018), are essential to inform food systems transformations.

Chapter 5 illustrates how the PFSM framework has been instrumental in gaining valuable insights and paving the way for transforming poultry systems in the case studies in Ghana and Southern Senegal. Moreover, it highlights the relevance of the applications in fostering a more sustainable poultry system in the West African regions for the benefit of all stakeholders involved, particularly the rural communities and vulnerable populations where poultry systems transformation holds great potential to enhance food security and provide economic support (Anang et al., 2013; Butler, 2016; Hartley & Ardnt, 2018; Hetherington et al., 2017; Molina-Flores et al., 2020).

The case studies proved the value of the Participatory Food Systems Modeling framework in supporting transformations by engaging stakeholders to collectively make sense of what is failing in food systems, envisioning an agreed-upon desired future, and identifying desirable and feasible pathways to move toward it (Checkland & Poulter, 2010; Checkland & Scholes, 1999; Schot & Steinmueller, 2018). Moreover, it demonstrated the value of using modeling tools as inquiry devices that, by fostering exchanges and informing debates among stakeholders with different perspectives, create learning cycles that broaden individual and collective understanding of the food systems' complexity (Daniell et al., 2006; Williams & Hummelbrunner, 2009). This increased awareness of diversity and complexity set the foundations for stakeholders to agree upon a desirable future for the food system and identify desirable and culturally feasible pathways for moving from the current situation to the envisioned one (Checkland & Poulter, 2010).

Overall, the contributions of this thesis unfold in three dimensions, progressing from a foundational theoretical exploration to methodological proposals and closing in practical and political implications.

Theoretically, Chapter 2 synthesizes STCS insights into actionable principles, guiding agents within food systems evaluation to navigate complexity and support transformational processes through a deeper engagement with STCS. Building upon this theoretical groundwork, the thesis extends methodologically into the domain of food systems frameworks in Chapter 3, evaluating their capacity to address barriers hindering transformations through an STCS lens and revealing actionable ways to improve their potential to inform and support the needed transformations. The findings derived from assessing food systems frameworks set the groundwork for designing a Participatory Food Systems Modeling (PFSM) framework in Chapter 4 to identify desirable and culturally feasible transformation pathways. Chapter 5 elevates this methodological contribution to a practical/ political realm with the results of implementing the PFSM framework to identify transformation pathways in poultry systems in Ghana and Southern Senegal. This empirical validation of the value of the PFSM framework in fostering collective exploration, negotiations, and discussions among agents with diverse perspectives to identify suitable pathways to transform food systems underscores its practical significance in informing decision-making to support transformations. Lastly, it is worth noting that a potential transformation in the poultry system of both case studies can resonate on national and regional agendas concerning food security and poverty alleviation, particularly in rural communities.

In essence, this thesis contributes to meaningfully bringing STCS into practice by providing solid theoretical foundations, fostering methodological enhancements, and testing them through practical implementations to move toward more productive and prosperous, equitable and inclusive, empowering and respectful, resilient and regenerative, and healthy food systems. Furthermore, it holds promise for addressing other complex global challenges and contributing to the global sustainable development agenda by integrating Systems Thinking and Complexity Science principles in scientific, practical, and political spheres.

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ANNEXES

ANNEX A

Summary of information coming from the Systems Thinking and Complexity Science literature review

N.	Title	Authors (Year)	Field	Focus and propose	Operating Principles	Key considerations to deal with complex situations: Exploring the big picture	Key considerations to deal with complex situations: Understanding the dynamics of the system	Key considerations to deal with complex situations: Acknowledging the role of agents in framing systems
1	Navigating Complexity in International Development	Burns & Worsley (2015)	CS	Three chapters of the book were explored. The second chapter shows how systems thinking and complexity theory allow a better understanding of how and why changes happen, which is crucial to improve decision-making in complex situations, like the ones addressed on most international development interventions. The third chapter presents a framework for catalyzing large-scale and sustainable changes. Finally, the fourth chapter presents a participatory systems inquiry.	2.1, 2.2, 3.1, 5.2, 6.1, 10.1, 10.2	Systems elements are interconnected among them, and with the environment or wider system. The non-linearity of these interrelations might result on unintended consequences and unpredictable results (OP 2.1, OP 3.1). The authors propose systemic issue mapping process to see the complex interdependencies among systems elements and understand the system as a whole (OP 2.2, OP 3.2). Feedback loops and non-linearity characterize complex systems, and explain why it is crucial to look beyond simple causalities to explore the whole system dynamics and patterns Emergence, on the other hand, can be understood as the arising of novel and coherent structures and patterns from interrelations in lower levels in complex systems (OP 3.1).	Systems dynamics can be partially explained by movements between equilibrium points, also known as attractors. These attractors are not always static, and can shift, appear, or disappear when a "tipping point" is reached. It is important to note that the patterns of change are non-linear, to understand how attractors work (OP 5.2). Complex systems are sensitive to initial conditions, and their behavior is highly context specific, therefore is not possible to easy transfer something that works in one place to another that has different conditions (OP 6.1).	Authors take an epistemological perspective under which the system is seen as perceived sets of relationships within a boundary that have sense to those looking at them (OP 10.1). To catalyze sustainable and systemic changes, the authors propose a framework focused on involving and engaging stakeholders with different perspectives in the inquiry and decision-making process, in a way that enable learning processes and relationships development. Ass result, appropriate interventions with a high level of ownership can be designed, leading to sustainability and scaling of outcomes (OP 10.2).
2	Complexity Theory and the Social Sciences: the state of the art	Byrne & Callaghan (2014)	CS	This book seeks to establish the state of art of complexity-informed social sciences. We focused our review on the key issues in complexity theory (Part I) and its implications for social theory (Part II).	2.1, 3.1, 4.1, 5.2, 6.2, 10.1	Non-linearity is linked with unpredictability, since effects are diproportionate to changes in the causal elements (OP 2.1, OP 3.1). The multiple linkages and relations among systems components build the system as a whole, and are constitutive of properties of the system as the emergence. Authors mention three levels of emergence: higher properties of the system -more that the sum of the parts; at the level of self-organization capacity, and at the level of history of interrelations (OP 3.1).	The Phase space contains all the possible states in which the system might exist theoretically, considering all the possible values that variables can take (OP 4.1). States or phases of the system are determined by a small number of those variables known as control parameters, and the ways they are interrelated. Movements through the phase space occur when the system swap attractor. These phase shifts are trigger by internal fluctuations or external perturbations coming from the relation between the system and its environment (OP 5.2). Systems structure can be seen as product of part interactions, therefore is crucial to map the path history to understand systems dynamics and evolution (OP 6.2).	Boundaries are social constructions made from and shaped by reality, which allow us to frame the situation in a certain way and answering to certain reasons, establishing a connection between the system and its environment (OP 10.1)
3	Evaluating complex social interventions in a complex world	Byrne, D. (2013)	CS	This paper describes complex systems features and focus the analysis on the implication that have complexity for evaluation of complex social interventions.	3.1, 4.1, 6.1	Emergence condition involves thinking about the parts and wholes, acknowledging the causal implications that these parts and interactions among them have in the whole, as well the causal implications that the whole have in the parts (OP 3.1).	The phase space is a multi-dimensional mathematical space, where each dimensions is a quantitative variable to explain the state of the system. The state of the system in this phase space is determined by the values taken by those variables (OP 4.1). The states where the system can possibly move are determined in part by system history, due to the condition of path dependence (OP 6.1)	

4	Systems thinking	Cabrera, Colosi & Lobdell (2008)	ST	This paper seeks to address some of the amiguity of what constitutes systems thinking in evaluation field. It draws on a concept theory (Cabrera, 2006) comprised of four component rules or patterns: Distintions, Systems, Relationships, and Perspectives (DSRP), that apply to all human thinking.	1.1, 2.1, 8.1, 10.1	A systems can be understood as a collections of interrelated parts, that changes in time (OP 1.1). Relationships are comprised of two relations and four interrelations - affect and effect. (OP 2.1)		All concepts and definitions carry with them a human perspective or view point, which have the potential to transform the definition of the system, rearrange boundaries and modify interrelationships (OP 8.1). To stablish an entity, we need to place boundaries that distinguish what is in and what is outside the set boundary (OP 10.1).
5	Complexity evaluation Framework	CECAN (2019)	CS	This report oulines a complexity evaluation framework that comprise two key parts: (1) Introduction to core principles of complexity-appropiate evaluation; (2) framework of considerations to ensure that complexity thinking is embedded into evaluation design.	1.1, 2.1, 3.1, 5.1, 5.4, 5.5, 6.1, 7.1, 8.1, 8.2, 10.1, 10.2	Complex situations are shaped by multiple and diverse elements and interrelations (OP 1.1). Interrelations among systems elements are characterized by feedbacks, and non-linear behavior (OP 2.1) From the multiple interactions can arise emergent higher-level properties that cannot be predicted or explained from the properties of systems components (OP 3.1).	Systems have the capacity to change dramatically their behavior when they reach a tipping point that trigger a phase shift (OP 5.1). These changes happen inevitably over time, due to the interconnectedness and adaption of the systems (OP 5.4). To cope with the dynamics and changing behavior of complex systems, the evaluation purpose should be rethinked and revised constantly, and the results should be taken as indicative rather than definitive (OP 5.5). Systems future behavior and states are dependent of its history path, and also context sensitive, therefore the findings may not be transferable across contexts (OP 6.1).	Self-organization is a higher-level property that can arise form interactions of lower-level systems components (OP 7.1). Stakeholders may have different perspectives about the system, the expected outcomes, and the best way to reach them (OP 8.1); for that reason, it is crucial to involve a diversity of stakeholders and therefore perspectives actively in the evaluation (OP 8.2). Placing boundaries is considered crucial to define what and who will be included in the system to analyze, having in mind the big picture (OP 10.1). To define the evaluation purpose and system's boundaries, is important to include and build trust between different perspectives (OP 10.2).
6	Softs Systems Methodology. In Reynolds & Holwell (Eds), *Systems Approaches to Managing Change: A Practical Guide*	Checkland & Poulter (2010)	ST	This chapter presents the Soft Systems Methodology (SSM) as an action-oriented process of inquiry into problematic situations and gives an account of this approach by including its fundamental concepts and techniques.	1.2, 8.1, 8.2, 9.1	Soft Systems Methodology includes developing a rich picture as a first step to make sense of the situation, since it shows the multiple entities, structures, and viewpoints of the situations, and the relationships among them (OP 1.2).		Complex problematic situations always have people who act purposely (OP 7.1) as well as multiple interacting perceptions of reality that came from the different perspectives sustained by stakeholders, which should be surfaced and examined to tackle situation's complexity (OP 8.1). Soft Systems Methodology (SSM) is a highly participative process where a problematic situation is explored through models. These models represent different purposeful wholes - that answer to different perspectives (OP 8.2) - used as tools to discuss and debate in an organized way about the situation and how can be improved or changed. Following the iterative process by which the "real" situation is explored through models, based on different perspectives, it is possible to seek accommodations between perspectives to find desirable and culturally feasible changes (OP 9.1).

7	Systems Evaluation Protocol	Cornell Office for Research on Evaluation (2009)	ST	The Systems Evaluation Protocol provide an overview of "systems perspective" as theorethical underpinning of the protocol, and attempts to guide evaluators to integrate systems evaluation perspective into their work.	1.1, 1.2, 5.5, 8.2, 9.1, 9.3, 10.1, 10.2	Complex systems are composed of parts, wholes, and their interrelationships. Systems have a nested structure, which means that are systems embedded within another systems (OP 1.1). The Protocol include a list of questions aimed to gaining understanding of the systems parts and structure, including how it operates and whom it serves. This description should be as comprehensive s possible (OP 1.2).	Dynamic systems are composed by evolving relationships. To cope with systems dynamic behavior, evaluation need to change and adapt (OP 5.5).	A same situation can be understood very differently from different perspectives. This makes crucial to explore perspectives from diverse stakeholders to obtain a "complete picture" comprising everything and everyone involved or interested in the situation (OP 8.1). A key task of evaluators is to bring perspectives together and promote the dialogue and sharing among them to enable a common and deeper understanding of the situation (OP 9.1). The Protocol include some guidelines for thinking what the program is, and developing a comprehensive description through highly participatory process where stakeholders can share appreciations and statements, and reflect upon them (OP 9.3). Boundaries are artificial human constructs. It is important to note that there is no correct way to draw situations boundaries but to be drawn according to the according purpose (OP 10.1). Different stakeholders often draw systems boundaries quite differently, and often in divergent ways. The Protocol includes a step aimed to determine what is in the program and what is outside. This boundary analysis asks participants to clarify their perspectives regarding the situation under analysis (OP 10.2).
8	Applying Complexity Theory to New Zealand Public Policy. Principles for Practice	Eppel, Matheson & Walton (2011)	CS	This paper aims to provide an introduction to complexity theory for policy practitioners and researchers, highlighting principles of complexity theory relevant to improving policy practice and the positive impact of interventions.	1.1, 2.1, 3.1, 5.1, 5.2, 5.5, 7.1, 7.2, 9.1	Complex systems have a hierarchical structure, where lower levels of organization are nested within and interacting as parts of the whole. Systems elements are interrelated and interdependent (OP 1.1). Patterns of interactions between parts of the system are non-linear, characterized by feedback loops (OP 2.1). Complexity emerge from the interactions of parts whitin the system as a whole, which are capable to self-organize, adapt to each other, and evolve over time (OP 3.1).	Complex systems can easily be disturbed and change (OP 5.1). Those changes occur when feedback loops are disturbed and attractors change (OP 5.2). To cope with the dynamic and unpredictable character of complex systems, evaluations should support the implementation-learning-development process by being ongoing, reflexive, and "real-time" (OP 5.5). Systems history and contextual conditions also influence systems behavior, and therefore need to be explored and taken into account (OP 6.1).	Much valuable information on social-human systems comes from the social agents involved, therefore it is crucial to involve stakeholder with different perspectives and expertise to have a broader and closer to reality picture of the situation, through participative and collaborative approaches (OP 9.1). The boundaries of complex systems are human constructs that should be explored from multiple perspectives through sense-making and boundary critique (OP 10.2).
9	Putting the system back into systems change: A framework for understanding and changing organizational and community systems	Foster-Fishman, Nowell & Yang (2007).	ST	This paper provides a framework focused on systems structure and interactions among its elements, which purpose is to improve the understanding of systems functioning and leverage systems change. The framework is grounded in the fields of systems thinking and organizational change.	1.1, 2.1, 2.2, 3.2, 8.1, 8.2, 9.1, 9.3, 10.2, 10.3	Systems are a set of elements that are perceived to influence in or be affected by a given problem situation, and that interact with each other, functioning as a whole (OP 1.1). Attention to reinforcing and balancing interdependencies, and well as delays (OP 2.1) can shed light on the patterns of system behavior because these patterns are maintained with these interactions (OP 3.1). System dynamics approach, methods, and tools focus on the characteristics of interrelations, the role of feedbacks, the implications of delays (OP 2.2) and the role of unexpected and emergent outcomes on the non-linear behavior of the system (OP 3.2).		Problem situations and desired states reflect a given world rather than an objective reality, because different stakeholders perceive and value differnt aspects of the situation (OP 8.1). Multiple stakeholders should be engaged to ensure the inclusion of diverse perspectives (OP 8.2). Dialogue should be encouraged among stakeholders to share and accomodate their perspectives to finally build a problem statement (OP 9.1). The framework proposed in this paper incorporates some ideas of Soft Systems Methodologies: to engage multiple stakeholders to gain insights into different interpretations of the problem-situation; to acknowledge that the feasibility of interventions depends on which perspective(s) or ways of understanding the situation is selected; to attend both "realities" and desired states of the situation to identify levers for needed change (OP 9.3). From the negotiated process among stakeholders arise informed arguments to define the boundaries of the situation, in a way that agents are aware of the consequences of leaving outside the scope certain elements, and including others to achieve the desired changes in the problem situation (OP 10.2). Boundaries have values associated with them, that explain why something is inside or outside and how that decision is linked with the perspectives that are considered critical and valued within the system (OP 10.3).

10	Making sense of the emerging conversation in evaluation about systems thinking and complexity science	Gates (2016)	STCS	This papers reports on some of the major implications of STCS in the following aspects of evaluation practice: 1) supporting social problem solving, 2) framing interventions and contexts, 3) selecting and using methods, 4) engaging in valuing, 5) producing and justifying knowledge, and 6) facilitating use.	2.1, 2.2, 5.5, 9.3, 10.1, 10.2, 10.3	In complex systems, causality is conceptualized as recursive. Causal processes are comprised of multiple, interdependent factor that influence one another through non-linear, cyclical feedback processes (OP 2.1). Methodologies and models such causal loop diagrams and systems dynamics helps to make a causal analysis that shed light on systems behavior (OP 2.2: OP 3.2).	To solve complex social problems an iterative process of learning and adaptive management is needed (OP 5.5).	Soft systems methodology and Critical Systems Heuristics are approaches focused on exploring multiple perspectives on a situation, which can help to enhances the quality of knowledge generated regarding system's behavior (OP 9.3). Any way of framing an intervention requieres some boundaries judgments to decide what is included and excluded in the evaluation (OP 10.1). Boundaries in a problem-situation depend on the perspective under which it is explored, and therefore there is more that one way to bound it, define it, and find optimal solutions (OP 10.2). Boundary decisions require making value judgments about what is considered relevant and therefore should be included (OP 10.3).
11	Systems thinking and evaluation	Hummelbrunner (2011)	ST	This paper present systems thinking as an approach to assess and deal with the complexity of interventions in the field of international development.	1.1, 2.1, 2.2, 5.5, 6.1, 7.1, 8.2, 9.2, 9.3, 10.1, 10.2	A system consists of elements interrelated in certain way to each others to form a whole, and that is embedded in a broader context or environment determined when boundaries are placed to define the system (OP 1.1). Complex situations are characterized for a high level of uncertainty (OP 3.1) and non-linearity, where relationships between cause and effect can only be understood in retrospect and depend heavily on initial conditions (OP 2.1). There are various techniques for modelling interrelations, one group aimed to provide insights, while the other is designed to prediction (OP 2.2).	Relationships and therefore systems behavior depends heavily on system's initial conditions and the context, wich makes that a same intervention in different situations leads to different results (OP 6.1) To cope with the complexity of situations, evaluation require recursive and reflective design, and flexibility in its implementation (OP 5.5).	Agents and elements within the social systems adapt to and co-evolve with their context. Self-organization capacity arises from those interrelations, making it possible that the system develops new structures and patterns to deal with external changes (OP 7.1). Systems are considered mental constructs or representations of reality that depend on the purpose and the actors involved in their definition; in consequence, there are several ways to define a system (OP 8.1). System approaches provide methods and tools that bring together different perspectives by promoting sharing and exchanges between stakeholders to improve mutual understanding and achieve consensus (OP 9.3). Power issues are involved in defining the boundaries of a situation, therefore is important to study boundaries and critique boundary decisions (OP 9.2).
12	Introduction. In B. Williams, I. Iman (Eds.) *Systems Concepts in Evaluation: An Expert Anthology*	Iman, LaGoy & Williams (2006)	ST	This chapter provides an introduction of systems field in evaluation.	1.1, 9.1, 9.2, 10.1, 10.2, 10.3, 10.4	Systems can be described as product of its elements and the dynamic relationship between them. Systems are entangled with other systems, therefore is important to explore interrelations among them to decide how to frame it, and if it is necessary, rethink the boundaries choices (OP 1.1).		Stakeholders share their understandings of the situation under analysis, which usually implies divergent purposes, as starting point for debates around systems description and boundaries (OP 9.1). To find a course of action, issues of coercion and power relations should be addressed (OP 9.2). In systems inquiry, boundaries are crucial to determine what is relevant to those affected by the evaluation, and therefore should be included since it is not possible to be totally comprehensive (OP 10.1). Bringing together diverse perspectives regarding systems framing create different alternatives to reform the situation, and allow agents to reflect on consequences of taking ones reality over the others to inform boundary decisions (OP 10.2). It also allow them to reflect on the values that are being priviledge by taking determined decisions (OP 10.3). Finally, systems-influenced evaluations should acknowledge beneficiaries and victims of boundary decisions and take efforts to mitigate or treat their consequences (OP 10.4).
13	Capturing the complexity of evaluations of health promotion interventions. A scoping review	Kania et al. (2012)	CS	This paper deconstruct complexity concepts in a way that can support the design of complexity-informed evaluations, and developed Complexity Adaptive Systems (CAS) indicator questions regarding the following properties: Agents, relationships, self-organization, co-evolution, and emergence.	1.1, 2.1, 3.1, 5.5, 7.1	Relationships between agents, systems elements and the broader context are very important in CAS (OP 1.1). They are often nonlinear, and include amplifying and condensing feedback loops (OP 2.1). Relationships between agents and their context can be explored using different sources and types of information, and through different analytic approaches or techniques (OP 2.2). The evaluation should capture patterns of change by exploring systems behavior at multiple points through a time horizon, in order to see emergent or unpredictable outcomes. The patterns emerge from the relationships between agents and the system and can be unpredictable and dynamic (OP 3.1).	CAS has a dynamic nature and the ability to evolve and adapt within their changing environment, therefore, the evaluation design should be flexible and aptable to cope with the characteristics of the system and its agents (OP 5.5).	CAS are characterized by the presence of adaptive agents, who can learn and modify their behavior to adapt the changes. Self-organization refers to spontaneous development of structures of behavior that emerge from the interactions among adaptive agents and the system (OP 7.1). The evaluation should gather information from multiple agents, their processes of learning and behavioral change, and assess the interrelations among them and with the context (OP 7.2).

14	Systems Thinking for Evaluation. In B. Williams & I. Iman (Eds.) *Systems Concepts in Evaluation: An Expert Anthology*	Midgley (2006).	ST	This chapter outlines the development of the systems field in three waves.	1.1, 2.1, 2.2, 3.1, 5.1, 5.5, 7.1, 8.1, 8.2, 9.2, 10.1, 10.2, 10.3	Open systems have a hierarchical structure build of organized and interrelated subunits, which exchange matter and energy with the wider systems where is embedded. The system as a whole can enable or constrain their parts, and the parts contribute to/ challenge the stability of the whole (OP 1.1). To understand interrelations and causality is important to explore feedback loops and interdependencies. Feedbacks can function in two ways: to maintain a relatively stable state in the system, or to prompt the system to move it in a particular direction (OP 2.1). To understand causality can be useful to model feedback processes applying mathematical modeling tools like systems dynamics (OP 2.2, OP 3.2). Seeing the system as a whole - in terms of nested systems and networks - can help to understand its dynamics and behavior. The way system's elements are organized and interrelated gives rise to emergent properties that shape system's dynamics and determine their unpredictable behavior (OP 3.1).	Complex systems can easily be disturbed by the tiniest perturbation and change in unpredictable ways (OP 5.1). Due to the emergence phenomenon and dynamic behavior of the system, evaluation design should be continuously rethought and adaptable to changes (OP 5.5).	Social systems are very resistent to change, because they can self-organize to maintain a relatively stable state (OP 7.1). Systems are seeing as constructs of complex issues that aid their understanding (OP 8.1). To obtain a closer-to-reality picture and ensure a higher degree of ownership, diverse stakeholders and perspectives should be engaged in framing the situations, defining its desirable state, and proposing pathways to reach it (OP 8.2). Promoting participatory approaches is not enough to ensure that all perspectives are equally shared and taken into account. For that reason, special attention should be put on power relations that shape and influence the behavior of social groups (OP 9.2). Boundaries should be placed to determine the knowledge that is pertinent in the analysis and ensure practicality in the inquiry (OP 10.1). Dialogue, mutual appreciation, search for accomodations between perspectives, and critique the assumptions that underpin perspectives are especially encouraged to better understand and frame complex situations. Critical Systems Heuristics is a methodology that can be used to explore and justify boundaries through debate between stakeholders (OP 10.2). The values adopted by people involved in the situation direct the drawing of boundaries, therefore is important to explore the way are linked with boundary decisions (OP 10.3).
15	Exploring the science of complexity. Implications for development and humanitarian efffforts	Ramalingam, Jones, Reba & Young (2008)	CS	This report details ten key concepts of complexity science, using real world examples, and examines the implications of each concept in the aid world.	1.1, 2.1, 3.1, 4.1, 5.2, 6.1, 7.1, 8.1	Systems are comprised of multiple interrelated and interdependent elements, dimensions and levels (OP 1.1). The degree of conectivity determines the changes in the system, therefore is important to explore the interrelations (OP 2.1, OP 3.1). Changes in system's elements and dimensions are non-linear, characterized by feedback processes that can amplify changes in some direction and supress changes in others (OP 2.1). From interrelations within the system arise emergent properties that determine the dynamic and unpredictable behavior of the system as a whole (OP 3.1).	The phase space in a system is defined by the values that all its relevant dimensions can take. By knowing it, it is possible to map and characterize how the system changes over time (OP 4.1). The movements made by the system form recognisable patterns, known as attractors (OP 5.2). Systems behavior is highly context-specific and sensitive to initial conditions - a very small change in these conditions can lead to larger effects on a system's evolution - therefore, generalization is not entirely possible among different contexts (OP 6.1).	Complex systems are made up of adaptive agents, who act for their own purposes and have their own perspectives of the situation. Agents perspectives dynamically influence and are influenced by events and changes within the system and its environment. Their ability to retain knowledge and learn over time, as well as their interests and desires, also shape their behavior. Self-organization is a macro-scale pattern of behavior that result from the interactions between adaptive agents. Co-evolution occur among agents, other elements within the system, and their environment. Through this process, the agents perspectives and behavior may be shaped by its interactions with others or the wider environment (OP 7.1). There are different perspectives on what the system is, which should be bringed together to gain a rich picture of the constraints and opportunities (OP 8.1)

16	Introducing systems approaches. In M. Reynolds & S. Holwell (Eds.) *Systems Approaches to Managing Change: A Practical Guide*	Reynolds & Holwell (2010)	ST	This chapter examines the nature of the complex situations that systems approaches aim to improve, describes how systems thinking might help to manage them, and explores some perspectives on the nature and development of systems thinking underpinning systems approaches.	2.1, 2.2, 3.1, 8.1, 8.2, 9.2, 9.3, 10.2	By exploring relationships, it is possible to understand how something works by its effects on what surrounds it (OP 2.1, OP 3.1). Systems Dynamics is an approach to understanding the non-linear behavior of complex systems over time, dealing with feedback loops and time delays (OP 2.2). Systems thinking is based on understandng a situation as a whole, rather than focusing on its parts, because in that way is possible to observe properties that emerge from interactions, and that are not the same as the properties of individual parts or components (OP 3.1).		Systems are ultimately conceptual constructs used for engaging with and improving situations of real world complexity. Establishing what the problem is involves dealing with multiple human interests, therefore the systems processes of inquiry include searching for relevant wholes organized around particular purposes (OP 8.1). The diversity of perspectives associated with complex situations should be engaged in the evaluation process. Cognitive mapping is a technique for revealing and actively shaping mental models that people use to make sense of complex problems, and is based on a process of building a common understanding to facilitate negotiation and arrival at some agreed plan of actions (OP 8.2). Power relations, boundary issues and potential conflicts among perspectives should also be explored to provoke a new thinking that respond to the complexity of the problem-situation (9.2). Soft Systems Methodology main use is in the analysis of complex situations that involve divergent views of the problem-situation, where the system is used as an interrogative device that enable debate among agents (9.3). Critical Systems Heuristics main idea is to handle boundary judgments critically, which determine what is considered relevant and what less important . It is about assessing the meaning and mertis of a claim (10.2).
17	Complexity, systems thinking and evaluation - an emerging relationship?	Reynolds, et al. (2012)	STCS	This paper sums up a discussion among the relationship between complexity, systems thinking and evaluation, outlining paths of convergence and divergence.	2.1, 2.2, 3.1, 5.5, 8.1, 8.2, 10.2, 10.3	It is important to explore causality and interrelationships between systems elements (2.1) to understand emergent properties and changing behavior of complex systems (OP 3.1). Some methods associated with exploring dynamic interrelationships are Causal Loop Diagramas, Stock Flow Diagrams, Agent Based Modelling, or Social Network Analysis (OP 2.2, OP 3.2).		Encouraging a dynamic perspective in the evaluation design to cope with the changing behavior of the system (OP 5.5).	Inclusivity should be promoted by incorporating and engaging with multiple and often contrasting perspectives (OP 8.1). Soft Systems Methodology can be used to clarify perspectives and methods that work with divergent opinions can help to improve understanding anc achieve consensus among perspectives (OP 8.2). Diversity of perspectives is crucial to reflect on boundary judgments (10.2).Critical systems tradition involve a critical analysis and reflection on the power issues that are often associated with boundaries, which determine what is relevant, legitimate or ignored to the analysis (OP 10.3).
18	Towards systemic evaluation	Reynolds, et al. (2016)	STCS	This paper offers key perspectives regarding the uptake of Systems Thinking and Complexity Science in the world of institutionalized evaluation.	1.1, 2.1, 3.1, 5.5, 7.1, 8.1, 8.2, 9.2, 9.3, 10.1, 10.2, 10.3, 10.4.	Real world situations involve multiple elements and actors that are interrelated with their environment (OP 1.1). Interrelations are about how things are connected and with what consequences. They always non-linear and comprise multiple feedback loops (OP 2.1). Only delving into the broader picture that comprises social, economic, political, and institutional systems will be possible to examine the way the interrelations and causation chains within real world situations work. Acknowledging and exploring emergence phenomenon can help evaluators to identify how systems elements can produce new elements, changing the systems structure (OP 3.1).		Real-world situations are subject to ongoing changes with uncertain effects, therefore, evaluation designs need to somehow reflect, accommodate, and adapt to such ongoing change (OP 5.5).	Diverse agents learn, self-organize, and co-evolve with their environment. To detect self-organization patterns in the system is important to understand the way agents interrelate, influence and are influenced by their environment (OP 7.1). A situation ussually has diverse perspectives involved, consequently there are different ways to understand the situations and the interrelations among its elements (OP 8.1). Soft Systems Methodology helps to explore the implications of taking into account different perspectives (OP 8.2). Systems boundaries determine what is relevant and included, and what lays outside (OP 10.1). Involving diverse perspectives not necessarily mean being neutral, due to power and marginalization issues (OP 9.2) Approaches like critical systems thinking aim to deal with these issues by critiquing and judging boundary decisions (OP 9.3). To address the challenge of determining the interests that the evauation should serve, Critical Systems Heuristics (CSH) and Boundary Critique (BC) aimed to facilitate participative processess of reflection and discussion about the consequences of attending to some interests, while others are excluded and marginalized in an evaluation (OP 10.2). Prioritizing facts involves considering some values more relevant than others, for that reason the process of critically assess the implications of boundaries involves reflecting at values level (OP 10.3). CSH and BC also call attention to the potential consequences of boundary placement (OP 10.4).

19	A simple guide to chaos and complexity	Rickles, Hawe & Shiell (2007)	CS	This paper provides a glossary of complexity science terms that attemps to provide a simple guide to key concepts in chaos theory and complexity science.	1.1, 2.1, 3.1, 4.1, 5.1, 5.2, 6.1, 7.1	Complex systesm are built up from a large number of mutually interacting subunits (OP 1.1). Systems interrelations are non-linear, where the inputs are not proportional to outputs or expected outcomes. They are characterized by feedbacks loops between elements, dimensions and levels (OP 2.1). Interactions between systems elements result in emergent behavior at systems level that feedbacks into the behavior of individual elements. This contributes to system's unpredictable behavior (OP 3.1).	Systems dimensions are defined by variables that have a range of possible values. The values taken by these variables at an instant of time describe a system's state that represents a point in a geographical space known as phase space (OP 4.1). To explain unpredictable changes in the system is important to explain two concepts. Systems robustness refers to the capacity to remain stable under external changes, while criticality refers to the capacity to change dramatically under a small input (OP 5.1). Systems criticality is explained by the control parameters, which are external inputs that can change systems between phases when they reach a certain critical point. Systems movements between states define the trajectories through the phase space. These movements are influenced by attractors, which are points in the phase space where the system moves after it passes the transient stage (OP 5.2). Systems evolution also depend on its initial conditions, because a small difference in the initial state can end in a very different trajectory (OP 6.1).	Self organization occur when systems order themselves without external influence of a control parameter (OP 7.1).
20	Principles for Effective Use of ST in Evaluation	Systems in Evaluation TIG (2018)	ST	These principles aimed to support evaluators in the use of systems concepts in evaluation.	2.1, 4.2, 5.5, 8.2, 9.2, 10.2	A system's evaluation should identify, capture, map and track interrelationships that influence or result from the situation to the evaluated and the evaluation itself (OP 2.1)	A system's evaluation should consider how systems elements and agents interact, behaves and change to create patterns that are non-linear to shed light on how dynamics shape the system (OP 4.2). Evaluation design should be responsive to emergent developments, collect information about changes, and incorporates learning and respond to dynamics. (OP 5.5).	A system's evaluation should identify and represent diverse perspectives and the values on which they are based. It should also explore how agents worldviews and judgments about systems behavior influence its conceptualization (OP 8.2). It should also attend to the types of power associated with each perspective, and consider the consequences (OP 9.2). Finally, it should identify key boundaries that influence the situation being evaluated, to then deliberate on a range of critical boundary choices along with potential consequences (OP 10.2).
21	Complexity Theory: An Overview with Potential Applications for the Social Sciences	Turner & Baker (2019)	CS	This paper differentiates between General Systems Theory and Complexity Theory, as well as identifies advantages for the social sciences in incorporating complexity theory as a formal theory.	1.1, 2.1, 3.1, 3.2, 6.1, 7.1, 10.1	Complex systems are composed of interrelated and interdependent parts or subsystems that make up the whole (OP 1.1). Non-linearity in complex systems makes their behavior and future states unpredictable. A comprehensive approach is needed to explore the unpredictable behavior of systems, taking into account that, from the interrelations among systems elements, and their capacity to adapt to external forces, can emerge properties and behaviors that trigger system's changes to a new state (OP 3.1). Complex Adaptive Systems (CAS) is proposed as a framework that could help in this understanding (OP 3.2).	CAS are sensitive to small changes in their initial conditions due to path dependence characteristic, so the results of a same interventions in different systems will depend on their histories (OP 6.1).	Complex Adaptive Systems (CAS) generally refers to a system that is able to self-organize its structure through transforming resources exchanged with the environment to support a determined action; the collective patterns that emerge via self-organizations in CAS are known as emergent properties. The balance that CAS found between operating betwen chaos and order is self-organizing and allows the system to evolve into new emergent states (OP 7.1). To clarify the level of analysis, boundaries should be placed. This task is specially difficult with social systems, where boundaries depend on human perspectives (OP 10.1).

22	Critical systems heuristics. In B. Williams & I. Iman (Eds.) *Systems Approaches to Managing Change: A Practical Guide*	Ulrich & Reynolds (2010)	ST	This chapter offers a systematic introduction to the idea and use of boundary critique.	9.2, 10.2, 10.3, 10.4			Critical Systems Heuristics provides a set of questions that try to make sense of a situation by making explicit the boundaries that inform stakeholders' perspectives. These questions reveal different and often contrasting judgments regarding what is relevant and should be part of the picture, by offering a way to examine the multiple perspectives that stakeholders bring to the situations (OP 10.2) . It aims to raise awareness regarding what the knowledge basis that defines that is relevant in the situation (OP 10.2), the power structures that influence how the problem-situation is understood (OP 9.2), the values and motivations that underpin the different perspectives (OP 10.3), and the moral basis under which we decide who or what bear the consequences of boundary placement (OP 10.4).
23	Insights from Complexity Theory for the Evaluation of Development Action	Vincent (2012)	CS	This paper reviews how complexity theory insights have been applied to explore and evaluate social changes. Complexity is explained like two faces: Macro-patterns of behavior, and participatory approaches.	1.1, 3.1, 3.2, 5.1, 5.2, 5.3, 6.1, 6.2, 7.1, 8.1, 8.2, 9.2	Complex systems are built of multiple elements and interrelations between them (OP 1.1). These interrelations can produce emergent properties that cannot be predicted from, or reduced to, the characteristics of individual elements (OP 3.1). Emergent patterns can be explored by looking retrospectively to systems behavior. Some approaches like Qualitative Comparative Analysis and Realistic Evaluation and Systemic Review are focused on exploring how patterns of outcomes emerge from the interrelations among systems elements and social agents, by looking to the picture and its evolution in time, to have a cumulative picture of what works and in what circunstances (OP 3.2).	Complexity does not mean complete unpredictability.To explore systems behavior is important to acknowledge that systems can perform in the same way under changing conditions, but are also capable of undergoing structural changes to adapt to extreme external changes (OP 5.1).Structural changes refer to changes between states, which are triggered when control parameters reach a tipping point. These different states are known as attractors (OP 5.2). Some approaches like Qualitative Comparative Analysis explores and identifies control parameters that influence the character of outcomes (OP 5.3). Development Evaluation is a particularly useful approach to deal with complex situations characterized by emergent and dynamics behavior, because is foucsed on ongoing ans systematic reflection that attend to these characteristics (OP 5.5). Emergence is influenced by system's history and initial conditions, as well as by the context. Path dependence explains the role that history has in the evolution of complex systems (OP 6.1).	Self-organization is an emergent property of the system as a whole that arises from the interrelations among its elements, which enables the system to develop or change internal structure spontaneously and adaptively to cope with or change its environment. Self-organized criticality is a systems' condition through which the system tends to organize itself towards a critical point where a small change can lead to bigger changes in the system; is in this way how systems interrelations and dynamics drives it evolution into new states (OP 7.1). Different stakeholders bring to the table different perspectives and interests, which should be explored to gain an understanding of the situation of interest (OP 8.1). Evaluation should contribute to understand these different perspectives and to enable processes of co-creation through participatory approaches. Whole Systems Action Research is an approach specially focused on participation, understandings, and "sense making" of multiple stakeholders (OP 8.2). Finally, it is also important to understand the negotiated order in a particular intervention, drawing attention to sstructural conditions, power relations and communication processes (OP 9.2).
24	Applying complexity theory: A review to inform evaluation design	Walton, M. (2014)	CS	This paper reviews both practical examples and theoretical discussions of evaluation approaches using a complexity theory frame of reference, with the aim of identifying themes to be considered in applying a complexity frame of reference to evaluaiton.	1.1, 3.1, 3.2, 5.2, 5.3, 8.1, 8.2, 9.1, 10.2, 10.3	Complex systems are made up of multiple and interacting elements, dimensions, and levels (OP 1.1). The interactions within the systems and with its environment gives rise to emergent outcomes which are of interest to evaluation (OP 3.1). To understand the emergent properties arising at the system level, it is important to acknowledge the big picture comprised of systems elements, its environment, and the interrelations among them (OP 3.1). In that sense, the evaluation should be focused on systems multiple levels, applying both micro and macro views (OP 3.2).	The points of stabiity in a system are represented by attractor states, which depict a pattern of systems behavior. When the system changes from one stability state to another, a qualitative shift is produced in the system, impacting on emergent phenomena (OP 5.2). Non-linearity and emergence in systems behavior call for long evaluative time frames (OP 5.3).	Boundaries are constructs that reflect the position of the stakeholders involve in deciding what to include or exclude from the system (OP 8.1). Participatory approahes should be used to gather perspectives of stakeholders across the system (OP 8.2; 10.2), to co-develop systems descriptions (OP 9.1) making explicit value claims of actors across the system (OP 10.3).

25	Using complexity-consistent theory for evaluating complex systems	Westhorp (2012)	CS	This paper introduces the concept of "complexity-consistent" theories and suggest that are useful for evaluation of complex adaptive systems.The goal is to list common features between realist philosophy with complexity theory, to compare the understanding of causation between complex adaptive systems and realist evaluation.	1.1, 2.1, 2.2, 3.1, 3.2, 5.1, 5.2, 6.1, 7.1 10.1.	Complex adaptive systems are comprised of multiple elements and levels, are embedded within larger systems, and open to change information and energy with its environment (OP 1.1). The interrelations among systems elements and levels are characterized by multiple causation, non-linearity, and feebacks that operate to constrain or support change (OP 2.1). To better understand how systems work, evaluation shift attention from the structure of the system to the processes by which it works, and suggest collecting data about the nature and frequency of the interrelations (OP 2.2). The interactions of local elements following local rules at one level of a system generates complex patterns of outcomes at other systems levels (OP 3.1). Layering theories provide a structure and conceptual framework to examine the ways that multiple mechamism operate in multiple levels of systems to generate outcomes (OP 3.2).	Major system level change happens when the system reach a tipping point where it oscillates and then chooses between two possible trajectories (OP 5.1). This choice is made on the basis of very small differences in the values of control parameters at the point of change (OP 5.2). The nature of initial conditions, as well as the context, affect interactions within systems at the operation of the whole (OP 6.1)	Complex adaptive systems are comprised of multiple autonomous agents that make decisions - shaped by their preferences, interests, and desires - in response to information in the local environment. As systems evolve, the rules of behavior became more complex, making possible to the system to self-organize in response to external changes (OP 7.1). Determining the constituent elements of systems requires drawing conceptual boundaries around the system, which should be make through decisions of what to include and exclude in each case. Boundary decisions should be justified, because it specifies which elements in the system are important for promote the desired changes (OP 10.1).
26	About Systems, Thinking Systemically, and Being Systemic. In *Systems concepts in action: A Practitioner's Toolkit*	Williams & Hummelbrunner (2009)	ST	This chapter present systemic approaches as a way to describe and make sense of complex situations by thinking and being systemic.	1.1, 2.1, 2.2, 3.2, 8.1, 8.2, 9.2, 9.3 10.2, 10.4	A system is described as a set of embedded and interrelated parts that together make up the whole. Thinking systemically involves making sense of the big picture that involves the situation of interest and the context where it is embedded (OP 1.1). Interrelationships refer to the way systems elements are connected and with what consequences. They have a dynamic and non-linear character where feedback loops predominate (OP 2.1). Exploring interrelations involves making sense of their nature, the process between them and the patterns that emerge from those processes as well their consequences. Systems dynamics is a very known approach to explore interrelations (OP 2.2, 3.2).		A system is necessarily a simplification of reality, where specific aspects have been captured concerning a specific purpose or issue. Where people observe a situation, they will see it, interpret it, and make sense of it in different ways. There are many cognitive, social, cultural, pragmatic, and conceptual reasons why different people describe the same situation differently (OP 8.1). It is important to explore the different ways under which a situation can be understood by stakeholders, to identify key perspectives. From that, it is possible to explore the way these perspectives shape the framing of the situation, its behavior, and the success of the actions implemented to improve it. By seeing the system as a human construct, it is possible to explore perspectives concerning alternative scenarios - what the system might be like, could be like, or should be like - opening different paths for reflection and discussion (OP 8.2). Thinking about perspectives enables us to identify motivations - which can contribute to understand and sometimes predict behavior at agents and systems-level - and be aware of the assumptions made when we make sense of the situation (OP 8.2). Boundaries make the situations manageable by determining what is relevant and important to be considered inside the system (OP 10.1). Boundary decisions determine how to approach a situation, what to expect from it, and how to manage it, being aware of what purpose and whose interest is being privileged, who benefits, who is disadvantaged, and what is left outside (OP 9.2, 10.2). Power issues are often involved in deciding which perspective and interest to privilege in the framing of a situation (OP 9.3). The critical systems approach highlights the importance of reflecting on the marginalization that results from setting a boundary; it also highlights the ethical and practical aspects of setting boundaries, the first related to exacerbating injustices, and the second related to the practical consequences of excluding perspectives (10.2, 10.4).

ST: Systems Thinking; CS: Complexity Science; STCS: Systems Thinking and Complexity Science

ANNEX B

Summary of the information provided by food systems frameworks concerning the systems-and-complexity key features addressed in the STCS principles

		Exploring the big picture		
№	Authors (year)	**1. Acknowledge multidimensionality and hierarchical structure of complex systems**	**2. Engage with interrelations and interdependencies**	**3. Address emergent properties and unpredictable behavior**
1	Dury, S., et al. (2019)	The **value chain activities and actors** are interconnected but can be also considered as **sub-systems** with specific interactions with other activities and actors that are not part of agriculture or food (Pothukuchi and Kaufman, 2000). Taking a system approach acknowledge the **hierarchical structure:** subsystems with different purposes, and activities that are part of a larger bioeconomy. It also take into account the **interrelations between dimensions and across levels.** There are three **objectives** for food systems, which are interrelated: (a) food security and improved nutrition; (b) inclusive development; (c) creation of a sustainable environment and the fight against climate change. The **drivers which shape food systems** are: demographic, biophysical and environmental; innovation, technology and infrastructure; socio-cultural, economic, and political.	Taking a system approach take into account the interactions, influences and feedbacks between different activities, actors and institutions.	Taking a system approach take into account the interactions, influences and feedbacks between different activities, actors and institutions. Each sub-system includes actors whose sole purpose is not only food. Chanfes in these sub-systems have an influence on food systems. Nothing is static in food systems: there are strong dynamics at work in an innovative context, resulting in an ever-evolving mixture of different models of production, processing, distribution, consumption and waste management.
2	Nguyen, H. (2018)	Food system structure: - Focus on poverty, food security and nutrition. - Core system consists in a layer of activities through which food products flows and a layer of services supporting the flow. - Embedded in a broader societal (policies, laws and regultations, socio-cultural norms, infrastructures and organizations) and natural environment (water, soils, air, climate, ecosystem and genetics).	Food system challenges result from interactions across different scales and levels. Food systems changes over the past decades, bringing complex interactions and feedback loops that impact food security and nutrition in many different ways. These interactions and feedbacks mean that direct interventions in one are risk creating or excacerbating problems in another. The framework describes five pathways to value creation, and four feedback loops that relate to economic, social and environmental sustainability, and directly impact poverty, hunger and nutrition.	"Holistic thinking" - It considers the food system in its totality, taking into account all the elements, their relationships and related effects. It broadens the framing and analysis of a particular issue as the result of an intricate web of interlinked activities and feedbacks. It considers all the relevant causal variables of a problem and all social, environmental, and economic impacts of the solutions to achieve transformational systemic changes. This holistic vision allows us to use potential synergies and to reveal often hidden trade-offs, to ensure that while our targeted impact is positive, the net overall impact on the value added of the food system activities will also be positive. ex. Self organization. The "Structure-conduct-performance" paradigm offers some guidelines to explore this emergent property.

4	HLPE on Food Security and Nutrition (2017)	Three interacting elements of food systems: food supply chains, food environments and consumer behavior. These elements, which are influenced by the drivers, shape diets and determine the final nutrition, health, economic and social outcomes of food systems. Food systems, their drivers, actors and elements do not exist in isolation but interact with one another and with other systems.	Food systems, their drivers, actors and elements do not exist in isolation but interact with one another and with other systems. Food systems are interlinked n continual adaptive cycles of growth, restructuring and renewal.	To achieve the expected outcomes of "end hunger, achieve food security and improved nutrition and promote sustainable agriculture", the authors highlight that an integrated approach is required. Food systems are intelinked in continual adaptive cycles of growth, restructuring and renewal. More than food system constituents themselves, this framework underlines these interactions as they determine the complex links between food systems and their final outcomes.
5	IPES FOOD (2015)	A holistic food systems lens is concerned with how value chain processes interact with one another, and with the environmental, social, political and economic context (Ericksen et al, 2014). Food systems refer also to the web of institutional and regulatory frameworks that influence those systems. Domains that go from social policies and subsidies to policies to influence consumers behavior. Single discpline approaches are inappropriate for social-ecological systems, because of the combinations of factors - natural, institutional, and regulatory, linked to individual choices and socio-cultural relations - that play a role in shaping such systems.	The food systems lens also brings to light reinforcing and balancing feedbacks, tensions between the different components and flows of food systems, and interactions that are cyclical, multilayered and muti-scale.	The different components of modern food systems have co-evolved so as to become mutually reinforcing: each component is difficult to reform alone, and collectively, these intertwined and entrenched interests represent an increasingly powerful roadblock to reform.

6	IOM & NRC (2015)	The framework revolves around four key principles: (1) Recognize effects across the full food system; (2) Consider all domains and dimensions of effects; (3) account for system dynamics and complexities; (4) and choose appropriate methods for analysis and synthesis. Regarding the second principle, the framework includes a description of each dimension of effects (quantity, quality, distribution and resilience), and a set of examples that illustrate ways in which all four dimensions touch upon the broad effect domains (health, environment, social and economic). In the second step of the **methodological framework** - scoping - the framework recognize effects across the full system, considering all domains (health, environmental, social, and economic) and dimensions of effects (quantity, quality, distribution, and resilience), as well as the trade-offs among the different, both within each domain and across them. There are two requirements for understanding what causes food system effects: first the construction of a conceptual model containing all possible causes of the relevant effects, and second is to use good metrics. Assessing quantity and quality effects in the current food system centers on (1) describing the system and (2) explaining what causes it to function as it does.	It uses Complex Adaptive System approach to describe food systems, acknowledging feedback and interdependence as one of its main characteristics. Multiple interacting mechanisms across levels of scales can lead to interdependence among actors, sectors, or factors. Feedback can also arise, through which initial changes to one component that affect a second component, may "feedback" to further alter the first component after a time lag. Assessing quantity and quality effects in the current FS centers on describing the system and explaining what causes it to function as it does. A conceptual models can reduce the odds of confusing cause and effect, which only occur if the conceptual model is informed by realiable metrics measuring the current food systems. Statistical methods are well suited to describing effects from the current food system. Ex. Multiple regression models. For alternative food systems configurations, simulations modelling may be the best tool to predict certain effects of the food system. Ex. Agent-based modelling.	The presence of feedback, interdependence, and adaptation can produce dynamics in the food system with characteristics such as nonlinearity (a small change yielding a large effect), emergence (system-level behavior that differ from what might be expected from the sum of behaviors of individual components of the system), path dependence (dynamics strongly shaped by early events), and resilience (the ability to bounce back after a shock to the system). Given the tendency of complex interactions to trigger dynamic repercussions, assessment should also acknowledge the potential role of underlying drivers and interacting pathways. An intervention can generate multiple and often invisible or unintended consequences. That is, what might appear as a small intervention may have disproportionately large consequences in various domains across time and space. There are two requirements for understanding what causes food system effects: first the construction of a conceptual model containing all possible causes of the relevant effects, and second is to use good metrics. In alternative food system configurations direct measurement and indicator measures typically are either not feasible or not sufficient to anticipate their effects on a larger scale. **Simulation modelling** that are connected across domains of the food system can capture feedbacks between human choices and associated repercussions for envrionmental and health effects. These models can be particularly useful for assessing multiple outcome effects from scenarios describing possible conditions that cannot currently be observed. Ex. Agent-based modelling.
7	Bortoletti, M. & Lomax, J. (2019)	Food systems incorporate not only the activities of producing and consuming food, but also the social norms and cultures in which those activities are embedded, as well as the environment and natural resources which they depend upon to function. Moreover, the food systems include people who depend on the food and also additional actors who influence the food sector both indirectly and directly. The assessment should strengthen understanding of the elements, linkages, drivers, and outcomes of the current food system. It should analyze food and agriculture impacts systemicaly, including environmental, social, health and economic impacts. It also seek to understand the hidden aspects of food systems (externalities and environmental costs).	As well as the diversity of elements, a sustainable food systems approach takes into account the interconnection and trade-offs among the different elements. Food systems outcomes can have both positive and negative impacts on socioeconomic conditions, the environment, and food security and nutrition. Food systems present a "feedback loop mechanism", where activities and outcomes result in processes that feed back to the environmental and socioeconomic drivers.	In order to generate the most comprehensive diagnosis of the food systems, the assessment should not focus solely on food system sub-sectors or on a narrow problem. If the system analysis is fragmented, it will be difficult to examine the overall outcomes related to food security and nutrition or consumer behavior and preferences, or to set a plan that can effectively address food systems' interconnected issues.

8	TEEB (2018)	TEEBAgriFood acknowledges the multidimensional and hierarchical structure of the eco-agri-food system – value chain elements embedded in and interrelated with a multidimensional context comprised by human, social, produced, natural capitals – and provides system associated methodologies like Causal Loop Diagrams, Bayesian maps, and Mind maps, to map all that complexity .	It develops a conceptual framework that helps understanding interrelations and interdependencies between eco-agri-food systems elements, by describing the linkages between the value chain and the four capitals; however, it lacks guidance on how to address feedbacks and delays when exploring interrelations.	It provides methodologies like life cycle assessment and propensity scoring methods, to map the complexity of eco-agri-food systems and modeling approaches that explore interrelations, like systems dynamics, to identify and anticipate emergent behavior.

8	Eigenraam, M. et al. (2020)	The first step to **frame the situation** under analysis is to outline your interest as comprehensive as possible. Then, the eco-agri-food system relevant to your issue of interest is described through a **multiple capitals-based approach**, which enables you to articulate and explore the full range of visible and invisible connections that agricultural and food systems have with humans and the environment in eco-agri-food systems. It is important while describing to look as broadly as possible (within available time and resources) to ensure you have captured all relationships in the eco-agri-food system relevant to your assessment The outline completed in this first step provides a basic description that can be improved by including information about the actors, agency, and relationships within the system and its context.	**Flows** are a cost or benefit derived from the use of capital in the agri-food vale: Inputs that flow from stocks of capital into the agri-food value chain can be described as a dependency; outputs are the products and by-products of the production process in the value chain (agricultural and food outputs, and residuals). The changes in the extent and/or condition of stocks of capitals are **outcomes**. These changes can result from the employment of capital and the management of capital. These can be direct (resulting of the activities) or indirect (result of a change in capital). Finally, the **impact** are changes in well-being that are connected to outcomes. These can be measures by valuing the changes associated with an intervention. The aim of impact description is to list all potential impacts associated with the outcomes.	Implementing the describe phase of the assessment enables the systematic mapping of systemic connections and effects that may not be transparent if a narrow approach were used. Following the causal links between capital stock inputs, the flows of capital through to the outcomes or changes in capital, and the impacts that those changes have, reveals the impact pathways and dependency pathways that can be used to assess materiality (Scope section). At the end of this section we will have a comprehensive and systemic understanding of the activities related to the issue of interest and their impacts on the four capitals.
9	UNEP (2016)	The food system concept can be thought of as a combination of the activities ("what we do") and the outcomes of these activities ("what we get"). The food systems approach frames the food system activities as dynamic and interacting processes embedded in social, political, economic, historical, and environmental contexts (Ericksen, 2008). The systems approach implies the feedback and two-ways linkages – food chain activities with the social and environmental welfare – are taken into account.	Dynamics and feedbacks need to be analyzed as the result of a mix of factors. Non-linearity of feedbacks means that even a small change may have unpredicted effects across the system. Ex. Food system activities are fundamentally underpinned by natural resources, and their use have an impact on the environment. The environmental impacts usually feedback on the renewable resources as needed for both food system and other, non-food system activities. The feedbacks are sometimes very local and can act within a short timeframe, whereas in other cases the feedbacks are through global systems with a time horizon of decades.	The use a food systems lens provides a more complete description of the food interaction with both socio-economic and natural resource implications. Implications of food systems complexity include (i) dynamics and feedbacks that need to be analyzed as the result of a mix of factors, and (ii) non-linearity of feedbacks that means that even a small change in some elements may have unpredicted effects across the system.

10	van Berkum, S., Dengerink, J., & Ruben, R. (2018)	The food system is made up of activities whose primary aim is to increase food security (activities within the **value chain, service organizations and the enabling environment**). Factors influencing activities at consumer level are also included (**food environment and the characteristics of individual consumers**). These activities contribute to **outcomes at the socioeconomic level, and in the areas of the environment and food security.** These outcomes interact with one another. On the other hand, there are also **trade-offs** between environmental, socio-economic and food security outcomes. Lastly, **socio-economic and environmental conditions (drivers)** in turn affect the functioning of the system. Food systems approach provides a checklist for the topics that should in any event be addressed in order to improve food security, and identifies the actors and other parties who should be involved.	The food system approach helps to shed light on non-linear processes and feedback loops in the food system. Food systems activities at the first stages are influenced by service organizations and the enabling environment; on the other hand, activities at consumer level are influences by the food environment and the characteristics of invidual consumers. These food system activities contribute to outcomes at the socio-economic level, and in the areas of the environmet and food security. These three outcomes interact with one another. On the other hand, there are also trade-offs between environmental, socio-economic and food security outcomes (Ericksen, 2007). Lastly, socio-economic and environmental conditions in turn affect the functioning of the food system. The conceptual framework detail the way each group of drivers interact in both ways with the food systems activities.	A defining feature of systems thinking is that it views the behavior of a system as an interplay of interacting subsystems, in which feedback plays a key role. The food system approach helps to reveal the underlying structures of and relationships within the food system. Cause-effect patterns are enriched by feedback from other parts of the system that might otherwise be overlooked in the absence of a systematic approach. By mapping out the interactions between different subsystems, food systems thinking can contribute to an integrated approach that makes smart use of solutions at other levels of scale. By looking at how different subsystems complement one another, optimum use can be made of existing feedback mechanisms and multiplier effects.
10	Posthumus et al. (2018)		Systems dynamics focuses on the patterns and systemic structures, mapping the mechanisms of system behavior as **Casual Loop Diagrams (CLD)** - modelling technique that elicits variables and relations that describe the behavior of the system, represented in a conceptual model.	In self-organizing systems, properties cannot be analyzed by studying its components separately. Systems dynamics focuses on the patterns and systemic structures, mapping the mechanisms of system behavior as **Casual Loop Diagrams (CLD)** - modelling technique that elicits variables and relations that describe the behavior of the system, represented in a conceptual model.

11	Allen, T. & Prosperi, P. (2016)	**Food system as a complex social-ecological systems (SES)**: Human and natural components acting like drivers that interact to influence activities and outcomes of the food system. This paper consider food and nutrition security as the principal outcome of food systems. These outcomes are also determined by decisions and action taken along the activities of the food system, but also by global socio-economic, political, and environmental drivers through their impacts on the food system (Ingram et al. 2010). Such drivers might also impact food security directly. The vulnerability/ resilience framework can provide us concepts that allow us to clarify what we would like to proxy and can help articulate the different elements of the system of interest, i.e., categorize variables with regard to others, and construct a composite indicator. To identify drivers of change affecting food systems outcomes, the authors propose answering the question "vulnerability/ resilience of what to what", and to formalize the hypothesis to be explored ("what is vulnerable").	Elements within the system and the ones in embedding environment function together; changes in one variable will impact others, with possible lagged and multi-scale effects. Outcomes thus emerge from the complex interactions among system elements. **Modelling approaches:** Modeling dynamic systems is about representing matematically the dynamics between the inputs and outputs of the system of interest. Output functions are commonly used to characterize the input-output relationships.The dynamics of the system are usually represented using transition functions that map the state of the model today into the state tomorrow. Further two equations can be added to the usual differential equation to map the feedback to inputs (Ionescu et al. 2009).	**SES approaches** allows us to move away from focusing on isolated events, and to look at systems made up of interacting parts. It is essential to see the system as a whole to assess sustainability - understand dynamics to gauge the ability of the system to mantain or enhance its essential outcomes. A crucial challenge is to **manage the dynamics** originating from both external and internal changes, and their **synergistic impacts on systems' outcomes.** Only a better understanding of these processes will help us to estimate and forecast trade-offs between human well-being and ecosystem services, economic performances, and environmental impacts. **Modelling approaches:** Modeling dynamic systems is about representing matematically the dynamics between the inputs and outputs of the system of interest. Output functions are commonly used to characterize the input-output relationships.The dynamics of the system are usually represented using transition functions that map the state of the model today into the state tomorrow. Further two equations can be added to the usual differential equation to map the feedback to inputs (Ionescu et al. 2009). **Resilience and vulnerability**, as descriptive concepts, characterize the dynamic properties of a system and can thus define societal goals related to sustainability. Both answer questions about mechanisms that operate to produce outcomes under specific conditions. As such, these two properties provide policy makers with a model of highly formalized predictions of the effects of a limited set of variables (Epstein et al., 2013) that can be teste recursively and provide insights into possible feedbacks.

12	Béné, C. et al. (2019)	A food systems approach recognizes activities and outcomes across the whole food system, and focuses on the full range of interactions, feedbacks and tradeoffs, rather than on characteristics of separate pieces of the system (Chase & Grubinger, 2014; Grant, 2015; Pinstrup-Andersen & Watson, 2011). There is also a more explicit recognition of the multi-dimensional nature of the concept sustainabiity. *Expected outcomes:* Delivering food and nutrition security in a way that contributes to human health; improving diet; maximization of positive environmental and socioeconomic feedback loops; becoming resilient to impact of global environmental problems.	The shift towards sustainable food systems should be accompanied by a conceptualization of a food system as complex, heterogeneous over space and time, and replet with linear as well as non-linear feedbacks. This conceptualization emphasizes the multi-causality of food systems resulting from interactions among interdependent components.	As a multi-dimensional objective, sustainability is likely to be achieved only through trade-offs between the different dimensions (Liu eta al., 2013). More information and clarity are necessary on the potential solutions, and more guidance needed on how those choices and trade-offs could be navigated by societies in a fair and equitable way. Information, communication, governance, cultural dynamics and transforming food politics, all interact with each other and have impacts on food systems' dynamics, leading to **uncertainty and even unanticipated/ unintended consequeces** as the long-term implication of choices and actions cannot always be foreseen. The possibility of those unintended consequences needs to be better acknowledged and taken into consideration when evaluating impacts.
13	Connolly-Boutin, L. & Smit, B. (2016)	**The climate change, food security, and livelihoods framework** serves, in part, as a "checklist" of relevant variables to consider in an analysis. In terms of food security, adopting a livelihood approach allows for a more thorough analysis of the forces that shape food insecurity at the household and individual level. This approach is useful to capture the processes and contextual factors that shape adaptive capacity (Scoones,1998: Carney, 2003; Scoones, 2009). * Sustainable livelihood approaches emphasizes how people use a range of assets (natural, physical, social, human and financial capitals) to devise livelihood strategies with the goal of achieving positive livelihood outcomes. In the framework, assets exist within a context of vulnerability, which is composed of the trends, shocks, and cultural practices that affect livelihoods. Structures and processes influence people's access to assets (Moser et al., 2001; Carney, 2003).	The framework indicates key connections and interactions that represent important features of any assessment of the dynamic nature of a community's food security. Livelihood outcomes include changes in human well-being, income, health, and food security. Natural resource outcomes include changes in water, air or soil quality, and biodiversity. Both groups of outcomes are not independent of each other. Furthermore, the outcomes can change the system's vulnerability through feedbacks to its adaptive capacity.	In the "Climate change, food security, and livelihoods framework", the **vulnerability of a community** is a function of the multiple and interrelated bio-physical and socioeconomic drivers. Vulnerability is seen to have two interconnected elements: one related to **external risks**, shocks, drivers, and stresses to which communities are subject, and one relating to the means of coping or **capacity for adapting.** These interactions occur at different scales and can result in unexpected livelihood outcomes (O'Brien et al., 2009). **Adaptive capacity** at community level refers to the potential of a system to adjust itself to change (Watts and Bohle, 1993; Smit et al., 2000; Turner et al., 2003; Füssel and Klein, 2006) through the use of their assets or capitals. Access to livelihood assets is shaped by characteristics of the community and by the multiple and interacting biophysical and socioeconomic drivers. Transformations and adaptations are reflected in outcomes. **Livelihood outcomes** include changes in human well-being, income, health, and food security. **Natural resource outcomes**, also referred to as ''ecosystem services'' (Fisher et al. 2013), include (but are not limited to) changes in water, air or soil quality, and biodiversity. Both groups of outcomes are not independent of each other. Furthermore, the outcomes can change the system's vulnerability through feedbacks to its adaptive capacity.

14	Ericksen, P. (2008)	A comprehensive and holistic analysis of how the current organization of food production, processing, distribution and consumption contributes to food security requires broadening the concept of a "food system" beyond only those activities, by including: the interactions between and within bio-geophysical and human environments, which determine a set of activities; the activities themselves (VC); outcomes of the activities - contribution to food security, environmental security, and social welfare; other determinants of food security. Food systems as complex, heterogeneous over space and time, and replete with non-linear feedbacks. Treating food systems as a multi-scale and multi-level systems will facilitate the identification of critical drivers and determinant outcomes as well as the evaluation of trade-offs. The proposed framework aims to study the interactions of food systems with global environmental change and evaluating the major societal outcomes affected by these interactions: food security, ecosystem services, and social welfare.	Food systems are replete of non-linear feedbacks. "Cross-scale" interactions, between processes and actors in different arenas and at different levels, introduce even greater complexity and uncertainity (Cash et al., 2006).	Food systems as coupled and co-evolved social-ecological systems, with mutually dependent and interacting social and ecological components and highly uncertain and unpredictable outcomes. Systems approaches help in understanding the critical factors that lead to particular outcomes or the interactions that govern a specific behavior of interest. The framework can be used to identify and describe the determinants of any outcome and link them to the broader food system. In other words, it allows the identification of entry points for changing undesirable outcomes, through an analysis of the drivers and activities that have resulted in these outcomes. A goal of the system's description is to explain the patterns of interactions among the activities, external drivers, and the outcomes, so as to fully assess any emergent properties, as well as cause and effect.
15	Halbe, J. & Adamowski, J. (2019)	Conceptual modelling allows for the analysis of the system structure including the elements and their relationships. Functional analysis is a key approach to bridge requirement analysis with systems design. The objective of this analysis is to "define the set of functions that need to be included in the system design in order to satisfy the user's needs" (Cole, 1999, p.355). The Functional Organizational Analysis (FOA) method allows for an analysis of the linkages between primary functions and sub-functions as well as the underlying structures and processes that provide these functions. The hierarchy of functions is examined in a participatory process by using the conceptual modelling tool CMaps (Novak and Cañas, 2008).	Modelling approaches allow for the investigation of dynamics in complex systems - multiple causality, feedback processes and delays. Conceptual modelling allows for the analysis of the system structure of a vision including the elements and their relationships.	A vision model focuses on answering the question of whether a future system state is really desirable by analyzing sustainability benefits, potential contradictions, unintended side-effects or surprising system behaviors. Dynamic vision models build upon conceptual models and allow for quantitative analysis of the dynamics of a future vision by specifying relationships and parameters. - Systems dynamics: Approach that can handle relationships and variables that are challenging to quantify. Even with this method, resources and data are required to build a reliable simulation model. - Fuzzy cognitive mapping: Semi-quantitative method that does not depend upon the availability of empirical data for quantification of causal models and allows for the analysis of feedbacks and multi-causalities. The results of this exercise are quantitative in nature but need to be interpreted qualitatively.

16	Hubeau, M., et al. (2011)	Agri-food systems are shaped through the interaction of different systems such as natural systems, institutional systems, and social systems (Fracis et al., 2003; Lamine, 2011). Therefore, we need a systems approach to apply holisitic system thinking since it allows multilevel, multiscale and multi-actor approaches to understand the dynamics of the agri-food system and its interdependencies with other systems (Binder et al., 2010; Darnhofer et al., 2010b; Haberl et al., 2009; Lamine, 2011; Sutherland et al., 2015). *Four capital framework* (Ekins, 1992; Ekins et al., 2008) states that net-psychic income of human well-being depends on the service flows of four capitals - natural, human, social, and manufactured - which need to be maintained over time for future generations. AFFSA framework includes a set of indicators based on capital assets and linked to the categories of the DPSIR framework. This are multilevel indicators that describe the agri-food systems and its broader context, comprising all sustainability dimensions. *System knowledge:* Encompass the concepts i.e, the indicators that allow to understand the system.	Cause-effect interrrelationships are identified between agri-food system's indicators. *Driver-Pressure-State-Impact-Response DPSIR framework* (EEA, 1999). Drivers (D) are environmental conditions or human activities that put direct or indirect pressure (P) on the state (S) of the socio-ecological environment in terms of quality and quantity. This results in an impact (I) on the current state which induces societal responses (R)	A sustainable agri-food system is a complex adaptive system evolving through time i.e self organizing system that has to be analyzed as a whole and is formed by various actors (Folke et al., 2005; Klerkx et al., 2010; Liu et al., 2007) . Driver-Pressure-State-Impact-Response DPSIR framework (EEA, 1999). Drivers (D) are environmental conditions or human activities that put direct or indirect pressure (P) on the state (S) of the socio-ecological environment in terms of quality and quantity. This results in an impact (I) on the current state which induces societal responses (R)

17	Jackson, G., McNamara, K., & Witt, B. (2020)	Food systems as socioecological systems consist of multiple subsystems, internal variables, and reciprocal feedback mechanisms between human and bio-geophysical systems, including cross-scale and cross-level interactions. It draws on Ericksen's (2008) conceptualization of food systems, which desired normative outcome is providing food security (Hodbod & Eakin, 2015).	Food systems as socioecological systems consist of multiple subsystems, internal variables, and reciprocal feedback mechanisms between human and bio-geophysical systems, including cross-scale and cross-level interactions.	Food security as the key expression of food system vulnerability (e.g., Barrett, 2010; Maxwell and Slater, 2003; Jacobi et al., 2018; Moragues-Faus et al., 2017; Zavaleta et al., 2018). **Causal vulnerability** relates to processes, factors and actors that undermine the capacity of people, societies, economies, and ecosystems to provide food security and social and cultural welfare. Causal vulnerability is contextual and driven by multidimensional stressors and actors interacting many temporal and spatial scales (Gaillard and Mercer, 2012; Kelman, 2010; Sinclair and Fryxell, 1985). Understanding the root causes of vulnerability such as exposure to hazards coupled with factors which increase susceptibility such as geographic, economic, and political marginalization is critical (Birkmann et al., 2013; Gaillard and Mercer, 2012). Authors have suggested **resilience** relates to absorptive, adaptive, and transformational capacities (e.g., Béné et al., 2015; Mallick, 2019). However, these capacities are framed and dependent on the concept of "livelihood resilience" which includes, knowledge, capabilities, assets, power and participation, and social capital (Jackson et al., 2017; Mallick, 2019; Tanner et al., 2014). Therefore, resilience interacts with exposure and susceptibility and can either reduce or increase vulnerability (Jackson et al., 2017; Mallick, 2019). The authors introduce the main themes for each resilience indicator.
18	Paloviita, A. (2017)	Food system can be defined as a productive system that is capable of responding to changing demands, which requires minimization of vulnerability (Fresco, 2009). There are exogenous natural drivers and endogenous social drivers that increase vulnerability of the food system (Khazai et al., 2014). These drivers have social and ecological outcomes, which may also be seen as vulnerability of intertwined social-ecological systems (Ericksen et al. 2010: 67-70). Supply chain vulnerability assessment (Peck, 2005) contribute to supply chain resilience (Ponis & Koronis, 2012) since they facilitate the proactive planning and design of food supply chain networks that anticipate unexpected and disruptive events.	**Food security framework for upstream SCM:** Moderated by ecological and environmental thinking; by social injustice and inequalities; by supplier diversity; by vulnerability of farms and SME's. **Food security framework for downstream SCM:** Moderated by food waste along the supply chain; by human health; by food insecure areas; by cost internalization.	Focus on sustainable food systems in response to emerging societal needs.

20	Raza, A., et al. (2020)	*Food system drivers:* Processes and structural factors that affect the functioning of food systems in delivering safe, affordable, accessible and nutritious diets. They includes aspects of demographic change, political and economic environment, technological advances, natural resource management and social and cultural norms, all of which function in an integrated manner and could have endogenous and exogenous impacts on the food systems. *Food supply chains and influencers:* Comprise all activities and actors involved in the production, post-harvest management, retail, marketing, consumption and the disposal of food (Hawkes and Ruel, 2012). *Food envrionments:* Refer to the physical, economic, political and socio-cultural contexts through which consumers interact with food systems to purchase, prepare and consume food (HLPE, 2017). Are divided in external food environments and influencers (availability and accessibility of food, price of food, food quality and safety, and marketing and regulation) and personal food environments (accessibility of food, affordability of food, convenienve). *Behaviors of caregivers, children and adolescentes:* Intra-household dynamics inform the diets of children and adolescentes. Food preparation directly feeds back to food choices in the food environment. Desirability and acceptability of food are often directly linked to social and cultural norms. Eating patterns and appetite are influenced by various factors, such as physical activity, routines, taste preferences and social aspects of eating. *Diets of children and adolescentes:* Expected outcomes is to improve the quality of diets.	Employing a systems approach involves analyzing the system as an interplay of subsystems through feedback loops (Ericksen, 2008; Bene et al., 2019a). The interactions between multiple determinants are represented in the Innocenti framework by arrows that highlight feedback loops and reflect the dynamic nature of food systems.	It is critical to consider the interactions and feedbacks loops between and among food system drivers, determinants and influencers when designing policies and programs that aim to improve diets of children and adolescents. Attention to these interactions is important as effects in one part of the system can amplify or dempen effects in another, and following this dynamic process helps to anticipate unintended consequences in the evolving food system (Pinstrup-Andersen and Watson, 2011; Tendall et al., 2015).
21	Vallejo-Rojas, V., Ravera, F., &; Rivera-Ferre, M. (2016)	Integrated framework that links the agroecological context and the social function of agriculture --> **Food systems as SES under food sovereignty.** Food systems as SES are composed of multiple subsystems and internal variables within these subsystems at multiple levels, where these subsystems are relatively separable but interact to produce outcomes at the SES level, which in turn feed back to affect these subsystems and their components, as well other larger or smaller SESs. INTEGRATED FRAMEWORK: (i) Identify the boundary and the ecological and social components, taking into account scales and levels. *Boundaries* set the conditions for agri-food system activities; *units* are the inputs to perform the agri-food system activities; *governance* arragements set conditions for the agri-food system activities; and finally the *actors* that participate in the performance of agri-food activities. (ii) Define the scales (spatial, temporal, institutional and networks) that allow the study of each subsystem (component) and the levels as the units of analysis located at different positions on a scale.	INTEGRATED FRAMEWORK: (iii) Cross-level and cross-scale interactions occur when actors perform the agri-food activities. Focal action situation is when interactions occur producing certain outcomes (McGinnis and Ostrom, 2014). (iv) As agri-food activities result from interactions within and between the agri-food subsystems, each pillar of food sovereignty has relation with one or more agri-food activities.	Food systems as SES are composed of multiple subsystems and internal variables within these subsystems at multiple levels, where these subsystems are relatively separable but interact to produce outcomes at the SES level, which in turn feed back to affect these subsystems and their components, as well other larger or smaller SESs. Adger (2006) conceptualized vulnerability as a characteristic of a system, which is a function of exposure, sensitivity, and adaptive capacity, where exposure is the nature and degree to which a system experiences social, economic, political, and/or environmental changes; sensitivity is the degree to which a system is modified or affected by changes; and, adaptive capacity is the ability of a system to evolve in order to accommodate changes and to expand the range of variability with which it can cope (Adger 2006: 270). For the assessment of agri-food systems' transformation, the authors adapt the analysis of multidimensional agri-food systems' vulnerability (Faser 2007, 2011): (1) agro-ecosystem resilience that measure the extent to which the agro-ecosystem (Boundaries and Units) can tolerate climatic shocks and remain productive; (2) individual capacity that measures the socioeconomic attributes of actors (A) to be sensitive to and to be able to adapt to global changes, and (3) collective capacity that measures the extent to which the multilevel institutions (GS) respond and/or adapt to changes. This analysis is combined with participatory scenario analysis.

22	Zurek, M., et al. (2018)	**Food systems are complex entities:** Different actors, activities and interactions, the driving forces that shape these activities, and the outcomes produced at the invidiual and system's levels. The conceptual framework was created with inputs of scientific partners, to ensure that all important elements of the system are included. **Basic components:** The diverse sets of *actors* that are connected to the EU food system; the direct and indirect factors driving the behavior of food system actors and therefore influencing change within the food system (*drivers of change*); the *outcomes* that are related to the EU food system and its activities; the *goals* at the EU level that are shaping the drivers and the EU wide and national policies affecting the food system; the *interactions and feedback loops* that take place among the aforementioned food system components.	Among the basic components of food systems are the interactions and feedback loops that take place.	**Food systems approach:** Focusing on impacts and leverage points in the different domains it allows for an integrated assessment. A Conceptual framework is a prerequisite for a proper analysis of a food system. It provides a logical structure for analysis, and it helps to identify possible entry points for improving system's performance and outcomes. The framework is intended to highlight the dynamic aspects of the system by laying out the system's drivers as well as the system's interaction and various feedback mechanisms.

		Understanding the dynamics of the system		
№	**Authors (year)**	**4. Map the system's movements through the phase space to identify underlying patterns of change**	**5. Understand how a system changes between phases or states**	**6. Acknowledge the path dependence and context sensitivity of complex systems**
1	Dury, S., et al. (2019)			Just as food systems face locally specific combinations of risks, they also have to meet locally specific objectives of food security and nutrition, decent job creation and inequality reduction, as well as environmental integrity.
2	Nguyen, H. (2018)		The structure of the food system is dynamic and driven by complex and varied trends.	
4	HLPE on Food Security and Nutrition (2017)	The conceptual framework describes the three interacting elements of food systems - food supply chains, food environments, and consumer behavior - and the five set of drivers that influence those elements - biophysical ad environmental; innovation, technology and infrastructure; political and economic; socio-cultural; and demographic drivers. It details variables for each set of elements.	Food environments are constantly changing, with consequences for diets, nutrition and health. They need to be monitored in a systematic way (Swinburn et al., 2013). There is a need for a "data revolution" and more metrics to be able to understand how food environments are changing (UNSCN, 2016a).	Typologies of food systems are useful because they illustrate the complexity of food systems and allow researchers and policy-makers to consider the diversity of systems when designing policies and interventions adapted to a given context (Ericksen et al., 2010).

5	IPES FOOD (2015)			Proposals must be based on context-specific and adaptive knowledge in order to succeed.
6	IOM & NRC (2015)	The assessment consider all domains (health, environmental, social, and economic) and dimensions of effects (quantity, quality, distribution and resilience). Prevailing standards of evidence govern the choice of metrics and methods. They vary across health, environmental, social, and economic effects because of measurement challenges specific to each domain. Given the tendency of complex interactions to trigger dynamic repercussions, assessments should, to the extent feasible, account for effects across time, space, and heterogeneous populations. **Simulation models to measuring quantity and quality in alternative FS configurations:** - Descriptive: Help to understand systems by describing their components and processes. - Predictive: Forecast future system performance. - Postdictive: Help to diagnose past system performance. - Prescriptive: Recommendations for actions to achieve desired outcomes. *Statistical models used for descriptive and postdictive purposes. * Dynamical simulation models to generate predictions. *Agent-based modelling to represent interactions among individual actors and their environment. *Mathematical model to prescript an optimal strategy. **Measuring Distribution and Resilience**: Is more difficult to measure because they refer to a range of possible effects over space and time. Some of the variability of what happened and might have happended is driven by underlying processes that can be more or less understood. *Simulation models.	Given the tendency of complex interactions to trigger dynamic repercussions, assessment should account for effects across time, space, and heterogeneous populations. Distribution and resiliency dimensions refer to the range of possible effects over space and time. In "what if" scenarios, some of the variability is driven by underlying processes that are not well understood. If the underlying processes are changing it may be difficult to measure these dimensions. Some food system effects occur under extreme conditions. To capturing these situations will requiere measuring the probability that a given effect exceeds a threshold level. Exceding certain threshold levels can trigger extreme outcomes with irreversible consequences that matter not just in a distributional sense but, more importantly, because they can alter the resilience of a system. Ex. Rain-generated spikes in soluble phosphorus that can causes lakes to become eutrophic (Langseth and Brown, 2011). With simulation models, as with datasets, the assessment team must decide whether to build a new one or to draw on an existing model. The choice of an appropriate time horizon for the assessment shapes the type of health, environmental, social, and economic effects that can be considered. The time horizon should match the research goals and system boundaries because, in effect, the time period is an additional boundary.	Socioeconomic, spatial, and cultural heterogeneity can lead the impacts of food system changes to differ significantly for different sub-groups. Among the basic component of food systems, the frameworks describe contextual variables: - Biophysical Context: It is an integral component of the food system, both as a source of critical inputs and a recipient of the waste stream and by-products of farm and food production. Its quality and condition is critical to the long-term sustainability of the food system. - Social/ Institutional Context: (i) Markets, (ii) policies, (iii) Science and technology, (iv) Social organization. Given the tendency of complex interactions to trigger dynamic repercussions, assessment should account for effects across time, space, and heterogeneous populations. Distribution and resiliency dimensions refer to the range of possible effects over space and time Modeling approaches are proposed to measure the four dimensions - quantity, quality, distribution and resilience - the last two referred to a range of possible effects over space and time.

7	Bortoletti, M. & Lomax, J. (2019)	The conceptual framework describes the main sets of drivers, outcomes and food systems activities, listing some variables for each set.	The framework needs to be used flexibily and should not be seen as a rigid sequence of steps.	
8	TEEB (2018)	To understand the dynamics of the eco-agri-food systems, TEEBAgriFood maps the patterns of change that emerge from the interrelationships between the system and its context across the phase space, which is indirectly delimited by considering the variables that describe changes in the four capitals that support the eco-agri-food systems. While the proposed methods focus on understanding the interrelations at the time of analysis, they do not pay special attention to the historical trajectory of the system through the phase space, which is crucial for exploring and understanding patterns of change. Systems Dynamic modelling is presented as a methodology that allows analysts to identify and anticipate the emergence of potential side effects, leading to the formulation of complementary policy interventions for improved resilience and sustainability. It defines causal relations, feedback loops, delays and non-linearity by running differential equations over time (representing time explicitly). Can capture new and emerging trends or patterns of behavior.	To identify what triggers that the eco-agri-food system changes, TEEBAgriFood measures the changes in system resilience, which is the capacity of capital stocks to provide goods and services. It proposes simulation methodologies and models aimed to explore how interrelations across the system change over time, and it contemplates making regular and ongoing measurements through time to cope with the dynamic behavior of the system; however, it does not acknowledge the significance of identifying the control parameters that trigger phase shifts to understanding systems behavior. "Outcomes are fully reflected as changes in the extent or condition of the stocks of capital due to value-chain activities and hence can be described in terms of the changes in the four capitals. The role of the framework is to provide means by which all outcomes can placed in a common context. Thus, through regular and ongoing measurement it is possible to establish a dynamic picture of change in eco-agri-food systems that allows deeper understanding of the many and varied relationships within the system. An important consideration in understanding eco-agri-food system is the extent of their vulnerability and resilience to systemic change and shocks. In TEEBAgriFood Framework, concepts such as vulnerability and resilience are embedded in the concept of capital and the underlying stock. Thus, the resilience of a specificeco-agri-food system will be reflected in the condition of its stocks and their balance or composition. In turn, changes in resilience will be reflected in the measurement of outomes. Thus, measures of outcomes will embody the non-linear and dynamic descriptions of the state of eco-agri-food systems". Systems Dynamic modelling is presented as a methodology that allows analysts to identify and anticipate the emergence of potential side effects, leading to the formulation of complementary policy interventions for improved resilience and sustainability. It defines causal relations, feedback loops, delays and non-linearity by running differential equations over time (representing time explicitly). Can capture new and emerging trends or patterns of behavior.	By using a framework based on four capitals to describe eco-agri-food systems, TEEBAgriFood indirectly recognizes the sensitivity of these systems to context. Despite path dependence is acknowledge in theoretical terms, it not well referenced on the TEEBAgriFood conceptual and methodological framework. Systems Dynamic modelling is presented as a methodology that allows analysts to identify and anticipate the emergence of potential side effects, leading to the formulation of complementary policy interventions for improved resilience and sustainability. It defines causal relations, feedback loops, delays and non-linearity by running differential equations over time (representing time explicitly). Can capture new and emerging trends or patterns of behavior. TEEBAgriFood acknowledge path dependecy and the role it plays to explain how different polivies open up or close down pathways for future development.

8	Eigenraam, M. et al. (2020)	The four capitals approach, and the detail of stocks and flows, provides a basis to identify the "phase space" of the food system. The **Describe** phase of the methodological framework makes use of the four capital approach because it enables to articulate and explore the full range of visible and invisible connections that agricultural and food systems have with humans and the environment in eco-agri-food systems. (i) Describe the value chain (ii) Describe the activities related to the issue of interest, acknowledging the links to other stages of the chain that are not measured. Keep in mind the actors, agency and relationships within the system and context. (iii) Describe the capital stocks (iv) Describe the flows (v) Describe the outcomes (vi) Describe the impacts **Measure and Value:** When assessing impact pathways, you may measure one or all variables, depending on prior knowledge and the temporal aspect of the assessment. You should always measure activities, as this establishes the causal links between activity, outcomes and impacts. You should also consider the type of measurement suited to the different variables (Quantitative, qualitative, and monetary measurement).		
9	UNEP (2016)		The food systems approach frames the food system activities as dynamic and interacting processes embedded in social, political, economic, historical, and environmental contexts (Ericksen, 2008).	Food systems are globally very diverse as well as complex and dynamic. This implies there are no universal solutions. The food system description is generic and independent of spatial scale. How it manifests in a given situation is however highly context-dependent. Food systems differ regionally in terms of actors involved and characteristics of their relationships and activities. In all cases they need to be "sustainable". The identification of options towards environmentally sustainable food systems which are likely to be adopted and successful requires an understanding of the context in which food system actors operate. It should be stressed, however, that understanding the role of actors and institutions in food systems requires specific diagnostics at the country, region, or landscape level (Lieshout van et al., 2010, North, 1990).

10	van Berkum, S., Dengerink, J., & Ruben, R. (2018)	The conceptual framework offers detail to the food systems elements, listing some key contextual variables used for decribing biophysical and socio-economic drivers and impacts, as well as food systems outcomes.	The food systems approach reveals the non-linear nature of many cause-effect pathways. This means that once a tipping point is reached, an increase in one variable can sometimes lead to a disproportionally large increase in another (e.g. GHG emissions and climate change). it is essential to study these tipping points when we explore the interactions between different subsystems, which occurs outside the food system but which will have a direct impact on food system outcomes. However, the balance within the food system can also be disrupted by internal processes (specialization, monoculture) with their attendant risks. *Need of the food system to be not only sustainable but also resilient enough to cope with threats and uncertainties. Concepts like "adaptability" and "transformalbility" play a key role in enhancing the resilience of the food system. Adaptations that enhance the system's resilience to external shocks may be of a technical, organisational, political policy or socio-economic nature.	
10	Posthumus et al. (2018)	Common systemic patterns of behavior are called archetypes. Some archetypes are well understood, yet the same mistakes in decision making continue to occur (Kennedy et al. 2018). This is because systemic structures are often invisible until someone points them out. Systemic structures reveal how patterns and system components relate to and affect each other. Interventions at this level aim to (re)design the system structure. Building on hard systems thinking, food systems metrics and indices are proposed as monitoring tools to describe the state of food systems at regular intervals, in a way that can track system performance and compare. *CLDs.	Systems thinking helps to understand deeper system structures that are at the root of the problem (Kennedy et al., 2018), and identifying leverage points for systemic change. Leverage changes are "the right places in a system where a small, well-focused actions can sometimes produce significant, enduring improvements" (Senge 2006, p. 64).	
11	Allen, T. & Prosperi, P. (2016)	***Mathematical representation:** Modeling dynamic systems is about representing mathematically the dynamics between the inputs and outputs of the system of interest. In addition to an observed set of variables internal to the system that can be levers of action, external drivers can enter the model as inputs (Ionescu et al. 2009). Dynamic systems can also be perturbed by unobserved forces or noise. The dynamics of the system are usually represented using transition functions that map the state of the model today into the state tomorrow. The system state at any instant may be interpreted as a point in a multidimensional state-space, and the dynamic state response can be interpreted as a trajectory traced out in the state-space (Rowell, 2002). They also look for the essential variables describing the system and the variables that they can act upon to redirect food systems toward regarded objectives. These are the essential features of the system that determine the trajectory of the system and characterize its sustainability. The vulnerability/ resilience framework can help articulate the different elements of the system of interest, i.e., categorise variables with	**Vulnerability and resilience** assessment to explore sustainability. A common thread of almost all approaches to vulnerability is the consideration that it is an "intrinsic characteristic of a system" that is in risk. The conditions and properties of the exposed system - or elements - are then the crucial features to be identified and assessed (Birkmann, 2016). In the mean time, vulnerability deals also with features linked to capacities of the system to anticipate and cope with the impact of a change or hazard (Bohle, 2001). Resilience is central to visualize the dynamics of the SES. It is recognized as a multi-attribute concept composed of (i) an ability to cope with disturbance or change and retain control of function and structure; (ii) a capacity to self-organize; (iii) a capacity to learn and adapt (Walker et al, 2002; Berkes et al., 2003; Walker et al., 2004). The challenge is to identify the pathways leading to vulnerability, and the characteristics and opportunties ensuring resilience, to understand the mecahisms likely to affect activities within the system. ***Mathematical representation:** Modeling dynamic systems is about representing mathematically the dynamics between the inputs and outputs of the system of interest. In addition to an observed set of variables internal to the system that can be levers of action, external drivers can enter the model as inputs (Ionescu et al. 2009). Dynamic systems can also be perturbed by unobserved forces or noise. A set of equations can be used to describe the behavior of the system. Output functions are commonly used to characterize the input-output relationships. The dynamics of the system are usually represented using transition functions that map the state of the model today into the state tomorrow. The system state at any instant may be interpreted as a point in a multidimensional	**Mathematical representation:** Modeling dynamic systems is about representing mathematically the dynamics between the inputs and outputs of the system of interest. In addition to an observed set of variables internal to the system that can be levers of action, external drivers can enter the model as inputs (Ionescu et al. 2009). Dynamic systems can also be perturbed by unobserved forces or noise. The dynamics of the system are usually represented using transition functions that map the state of the model today into the state tomorrow. The state of a system at a given time is a extra piece of information needed, so that given the input trajectory, it is possible to determine the behavior of the system over time. The system state at any instant may be interpreted as a point in a multidimensional

		regard to others, and construct a composite indicator.	state-space, and the dynamic state response can be interpreted as a trajectory traced out in the state-space (Rowell, 2002). ***Categorizing variables:** Search for variables describing the system and variables we can act upon to redirect food systems towards regarded objectives (state and control variables). These are essential features of the system that determine the trajectory of the system and characterize its sustainability. The concepts from the already existing vulnerabiity/ resilience framework can allow us to clarify what we would like to proxy, since can help articulate the different elements of the system of interest and construct a composite indicator. The three components of vulnerability are intrinsic features of the system that mediate the impact of the drivers of change on the food system's outcomes, anc can be either state or control variables.	state-space, and the dynamic state response can be interpreted as a trajectory traced out in the state-space (Rowell, 2002).
12	Béné, C. et al. (2019)			<u>Challenge</u>: Need to acknowledge more explicitly the local-specific nature of food systems, because this raises challenges on how to identify adequate indicators for the sustainability of food systems, or how to find indicators that can capture local-specificity and yet remain universal at the same time. This local-specific nature of food systems also raises issues at the conceptual level as it highlights the importance of including the ‘‘cultural acceptability” dimension as a core element in discussions about food systems.
13	Connolly-Boutin, L. & Smit, B. (2016)	In this framework, the vulnerability is a function of the multiple and interrelated biophysical and socioeconomic drivers that act upon the community and shape its adaptive capacity. The goal of vulnerability research is to understand the adaptation process: how people have adapted to past changes, and what changes or conditions are relevant and can provide insight into how they will adapt in the future. The focus on the assets or capitals helps to establish what resources are available and accessible to aid in adaptation.	Food insecurity results from complex interactions of multiple stressors (socioeconomic and environmental) over long time periods and with sudden shocks (Swift 1989; Misselhorn 2005; Devereux 2007; Akrofi et al. 2012). In this framework, the vulnerability is a function of the multiple and interrelated biophysical and socioeconomic drivers that act upon the community and shape its adaptive capacity. Vulnerability is seen to have two interconnected elements: one related to external risks, shocks, drivers, and stresses to which communities are subject, and one relating to the means of coping or capacity for adapting. The goal of vulnerability research is to understand the adaptation process: how people have adapted to past changes, and what changes or conditions are relevant and can provide insight into how they will adapt in the future. Adaptive capacity is the ability of a person or community to use their assets or capitals in order to deal with or adapt to chaning conditions. Access to livelihood assets is shaped by characteristics of the community and by the interacting drivers. Adjustments to stresses may occur via: (i) Incremental adaptations: Actions taken by people to adjust to changing conditions in order to maintain or improve their well-being. (ii) Transformational changes: Reflect higher-level adjustments in policies, programs, and institutions, or when thresholds are crossed in sociocultural or political economy systems (e.g., Nelson et al. 2007). Both are reflected in livelihood and natural resource outcomes. which are interrelated.	

14	Ericksen, P. (2008)	The framework detail the food systems outcomes and their determinants. - *Food security:* The three major components are access, availability, and utilization. - *Environmental outcomes and determinants:* Food system activities contribute to environmental outcomes, and food security is determined in part by environmental factors independent of the FS activities. Natural capital comprises the land, water, and biological resources that people use for various activities (Ellis, 2000). Determinant of natural capital and ecosystem services are both a function of geography and management. - *Social and economic outcomes and determinants:*		System variability across scales results in heterogeneous outcomes, so a given pattern of outcomes will be context specific.
15	Halbe, J. & Adamowski, J. (2019)	Dynamic vision models build upon conceptual models and allow for quantitative analysis of the dynamics of a future vision by specifying relationships and parameters. - Systems dynamics: Approach that can handle relationships and variables that are challenging to quantify. Even with this method, resources and data are required to build a reliable simulation model. - Fuzzy cognitive mapping: Semi-quantitative method that does not depend upon the availability of empirical data for quantification of causal models and allows for the analysis of feedbacks and multi-causalities. The results of this exercise are quantitative in nature but need to be interpreted qualitatively.		

16	Hubeau, M., et al. (2011)	AFFSA should be able to capture the complexity of the agri-food system and its environment using systems thinking --> Multi-level approach to describe current state of sustainability and its potential to transform, as well as multilevel indicators with causal links between the agri-food and socio-ecological system level. To capture real-world complexity - which involves dynamics and trends - the AFFSA framework includes a combination of quantitative and qualitative indicators based on capital assets and linked to the categories of the DPSIR framework. This are multilevel indicators that describe the agri-food systems and its broader context, comprising all sustainability dimensions. AFSSA framework could be a useful tool for an iterative process continued in the future. In this way, AFSSA could be able to capture the dynamics of the agri-food system and further improve the recommendations for decision making (Darnhofer et al., 2010a).	AFFSA should be able to capture the complexity of the agri-food system and its environment using systems thinking --> Multi-level approach to describe current state of sustainability and its potential to transform, as well as multilevel indicators with causal links between the agri-food and socio-ecological system level. To capture real-world complexity - which involves dynamics and trends - the AFFSA framework includes a combination of quantitative and qualitative indicators based on capital assets and linked to the categories of the DPSIR framework. This are multilevel indicators that describe the agri-food systems and its broader context, comprising all sustainability dimensions. As every phase of AFFSA raises questions about previous ones, it was neccessary to organize the different phases in an iterative process until a shared agreement was reached.	Use of four capitals and DPSIR frameworks to describe the current state of sustainability of agri-food system.
17	Jackson, G., McNamara, K., & Witt, B. (2020)	**Causal vulnerability** relates to processes, factors and actors that undermine the capacity of people, societies, economies, and ecosystems to provide food security and social and cultural welfare. Causal vulnerability is contextual and driven by multidimensional stressors and actors interacting many temporal and spatial scales (Gaillard and Mercer, 2012; Kelman, 2010; Sinclair and Fryxell, 1985). Understanding the root causes of vulnerability such as exposure to hazards coupled with factors which increase susceptibility such as geographic, economic, and political marginalization is critical (Birkmann et al., 2013; Gaillard and Mercer, 2012).	Food security as the key expression of food system vulnerability (e.g., Barrett, 2010; Maxwell and Slater, 2003; Jacobi et al., 2018; Moragues-Faus et al., 2017; Zavaleta et al., 2018). **Causal vulnerability** relates to processes, factors and actors that undermine the capacity of people, societies, economies, and ecosystems to provide food security and social and cultural welfare. Causal vulnerability is contextual and driven by multidimensional stressors and actors interacting many temporal and spatial scales (Gaillard and Mercer, 2012; Kelman, 2010; Sinclair and Fryxell, 1985). Understanding the root causes of vulnerability such as exposure to hazards coupled with factors which increase susceptibility such as geographic, economic, and political marginalization is critical (Birkmann et al., 2013; Gaillard and Mercer, 2012). Authors have suggested **resilience** relates to absorptive, adaptive, and transformational capacities (e.g., Béné et al., 2015; Mallick, 2019). However, these capacities are framed and dependent on the concept of “livelihood resilience” which includes, knowledge, capabilities, assets, power and participation, and social capital (Jackson et al., 2017; Mallick, 2019; Tanner et al., 2014). Therefore, resilience interacts with exposure and susceptibility and can either reduce or increase vulnerability (Jackson et al., 2017; Mallick, 2019). The authors introduce the main themes for each resilience indicator.	

18	Paloviita, A. (2017)	There are exogenous natural drivers and endogenous social drivers that increase vulnerability of the food system (Khazai et al., 2014). These drivers have social and ecological outcomes, which may also be seen as vulnerability of intertwined social-ecological systems (Ericksen et al. 2010: 67-70).		
20	Raza, A., et al. (2020)	The framework detail the indicators to food system drivers, determinants and influencers.		
21	Vallejo-Rojas, V., Ravera, F., &; Rivera-Ferre, M. (2016)	The vulnerability approach has a contextual interpretation that allows focusing on the institutional, social, economic, technological, and biophysical conditions that affect the extent of exposure of the system to changes and the ways in which the exposed system can respond (O'Brien et al., 2007).	Adger (2006) conceptualized **vulnerability** as a characteristic of a system, which is a function of exposure, sensitivity, and adaptive capacity, where exposure is the nature and degree to which a system experiences social, economic, political, and/or environmental changes; sensitivity is the degree to which a system is modified or affected by changes; and, adaptive capacity is the ability of a system to evolve in order to accommodate changes and to expand the range of variability with which it can cope (Adger 2006: 270). For the assessment of agri-food systems' transformation, the authors adapt the analysis of multidimensional agri-food systems' vulnerability (Faser 2007, 2011): (1) *agro-ecosystem resilience* that measure the extent to which the agro-ecosystem (Boundaries and Units) can tolerate climatic shocks and remain productive; (2) *individual capacity* that measures the socioeconomic attributes of actors (A) to be sensitive to and to be able to adapt to global changes, and (3) *collective capacity* that measures the extent to which the multilevel institutions (GS) respond and/or adapt to changes. This analysis is combined with participatory scenario analysis.	The contextual interpretation taken in this vulnerability approach allows focusing on the institutional, social, economic, technological, and biophysical conditions that affect the extent of exposure of the system to changes and the ways in which the exposed system can respond (O'Brien et al., 2007). The constructivist perspective points out that human agency and culture make some people and places more vulnerable than others, even when they confront seemingly identifical risks (Tansey and O'Riordan, 1999).

22	Zurek, M., et al. (2018)	A prerequisite for a proper analysis and assessment of food system status is a conceptual framework that ensures that all the **important elements of the food system** are included. (set of actors, factors that drive the behavior of food systems, outcomes, goals, interactions and feedback loops. **Hierarchical approach** for assessing food systems performance: individual variable, derived variable, aggregate indicator, performance indicator, performance metric. **Modeling strategy for quantifying performance metrics**: Model build on existing models with different purposes. Using the models in combination allows a consistent assessment across the different domains covered by each individual model. Ex. MAGNET, DIET, CAPRI, GLOBIOM, SHARP.		

		Acknowledging the role of agents in framing systems			
№	**Authors (year)**	**7. Understand adaptive agents and the self-organization capacity that arises from the interactions among them**	**8. Acknowledge diverse perspectives as part of a same big reality**	**9. Promote dialogue and mutual appreciation among perspectives to decide how to frame the situation**	**10. Place boundaries to manage complexity**
1	Dury, S., et al. (2019)				
2	Nguyen, H. (2018)	Food systems performance is determined by the behavior and conduct of diverse actors (people centric). Conduct taking place and shaped by the structure of the system (core system, societal elements and natural elements). *Theory of change: Structure-conduct-performance* The dynamic structure of food system generates incentives for actors and influences their capacities, which ultimately determine their conduct. Actors are also interdependent on each other and can impact each other's incentives and capacities to act. Finally, the overall performance of the food system, measured in terms of sustainability, is the result of the intertwined conduct of all actors in the system. Actors have the power to influence food system performance and initiate change. Such performance, in turn, will generate positive and/or negative feedback that influences the conduct of actors and the structure of the system in an evolutionary process.	Addressing complexity of food systems requires a synergetic merging rather than a destructive clashing emerging from various angles (diverse stakeholders - both public and private).	Addressing complexity of food systems requires a synergetic merging rather than a destructive clashing emerging from various angles (diverse stakeholders - both public and private). Encouraging development practitioners and policymakers to see the bigger picture will also help facilitate multi-stakeholders collaborations to address future challenges. The systems approach allow to asses the governance mechanisms that underlie the power relations among stakeholders , determine the benefits they extract from conducting food system activities and thus drive their behavior.	

4	HLPE on Food Security and Nutrition (2017)	- The decisions made by one group of actors at one stage of value chain have implications on the other groups of actors and impact on the other activities, impacting the four dimensions of food security and nutrition. - The key elements of the food environment - such as proximity and affordability, food promotion, advertising and information, and food quality and safety - influence consumer food choices, food acceptability and diets. - Consumer behavior is clearly influenced by personal preferences, determined by a variety of interpersonal and personal factors. Besides that, is largely shaped by the existing food environment.		To achieve the expected outcomes of "end hunger, achieve food security and improved nutrition and promote sustainable agriculture", the authors highlight that an integrated approach is required, as well as an engagement of all stakeholders in active, transparent and thoughtful dialogue and attempts to seek consensus through participatory processes ensuring no one is left behind. The authors also highlight the power imbalances and conlifct of interest related to food systems, and how this shaped the way decisions are make.	
5	IPES FOOD (2015)	The different components of modern food systems have co-evolved so as to become mutually reinforcing: each component is difficult to reform alone, and collectively, these intertwined and entrenched interests represent an increasingly powerful roadblock to reform.	In the last decades, a growing emphasis were placed on working across the disciplines and with social actors to trace pathways to sustainability and resilience, instead of applying methodologies based on the assumption of fixed and predictable causal relationships and findings considered universally aplicable. Many of sustainability dimensions cannot be objectively observed. What constitutes an optimal and equitable use of resources or culturally acceptable dietary offering, requieres a normative assessment that must be subject of deliberation. The goals should not be to narrow down to a single agreed representation of reality, given the inevitable plurality of views, and the benefits of keeping the diversity of viewpoints alive.	The concept of sustainability must itself be fleshed out through collaborative efforts in order to reach a strong, collective vision of sustainable food systems to serve as the ultimate goal of reform proposal. A key part of this social deliberation may be to accommodate different versions of sustainability that prioritize different dimensions and specific qualities, in accordance with particular contexts and the priorities of different social groups (Leach et al., 2010). The goals should not be to narrow down to a single agreed representation of reality, given the inevitable plurality of views, and the benefits of keeping the diversity of viewpoints alive. The relevance and legitimacy of any assessment of food systems depend on the establishment of processes including mechanisms for self-correction. The forms of scientific rigor that should be aspired to is one that results from each perspective acknowledging its own limitations, and the need to be complemented by other perspectives in an iteratve mode of knowledge production. A food systems analysis should bring to light the diverse and differential influences of actors on decision-making. Power imbalances must be brought to light if we are to move beyond the assumptions. A challenge concerns the difficulties of engaging actors that hold dominant positions in transformative processes, in a way that do not perpetuate current power imbalances, but instead allow them to be challenged in critical and constructive ways. Food systems reform requiere advancing novel participatory assessment and research approaches that promote synergy and complementarity, rather than a fusion of perspectives.	The normative valuation of the development pathways require a grounding in ethical foundations that must be commonly reached with social actors. The setting of normative benchmarks must stem from a process that reaches out systematically beyond the scientific community to encompass various competing visions of what the problem is, as well as engaging in joint deliberation on how to rank preferences and prioritize values. Any proposal derived from food systems analysis will only be succesfully implemented if they are perceived as legimitate and feasible both by the intended beneficiaries and those to whom they are addressed.

6	IOM & NRC (2015)	Systems embedded dynamic processes by which actors can adapt their behavior. Heterogeneity in goals, constraints and information across actors and processes can shape local dynamics and lead to divergent adaptive responses to changes in the system. The decentralized behavior and interactions of the variety of autonomous actors in the food system shapes and modifies the food system; at the same time, actors respond and adapt to changes in the system around them. Consideration of adaptive responses can be important in a sufficient understanding of likely effects over time that result from any change to the food system. Ex. Agent-based modelling: Smulation approach where complex dynamics are modeled by representing individual actors in the system, each with specified initial conditions and a set of adaptive rules that govern their interaction with each other and with their environment. In that way, substantial heterogeneity can be captured, as well as spatial complexity, interactions among actors, and adaptation through time.	Stakeholders are important audiences for any assessment exercise, but they also can play an important role throughout the process by contributing to identifying, or scoping the problem or potential effects that may not have been apparent to the researchers. At the same time, stakeholder engagement requires careful attention to representation of a broad diversity of stakeholder perspectives, which implies heterogeneity in goals, constraints and information. Stakeholders inevitably have biases in their perspectives, and effective engagement processes use mechanisms to make these biases transparent.	Stakeholders are important audiences for any assessment exercise, but they also can play an important role throughout the process by contributing to, identifying, or scoping the problem or potential effects that may not have been apparent to the researchers. At the same time, stakeholder engagement requires careful attention to representation of a broad diversity of stakeholder perspectives, and scientific assessments also may require a certain distance or buffer from the influence of powerful stakeholders in order to avoid conflicts of interest and create space for objective and independent decisions—whether related to scoping, scenario development, or analysis activities. Assessing the desirability of alternative configurations of the food system depends on the goals and values of the evaluator. A useful framework provides factual and objective information that can be used by people with different judgments about the relative importance of these dimensions to develop a well-informed ranking of alternatives consistent with their own normative preferences (Nyborg, 2012).	The first step for assessment of food systems is related to identify the problem and goals, and define the scope of the problem. While scope limitation may preclude a specific study from careful consideration of all effects and drivers, it is important for any study to define boundaries and assumptions. The scoping step considers appropriate boundaries and assumptions to frame the scope of an assessment in the context of the food system as a whole. Determining the scope begins with situating the topic for the assessment in the context of the full food system, both in the food supply chain and in the biophysical, social, and institutional contexts. It entails using the framework to identify meaningful changes along the food supply chain – in various effect domains and dimensions, in the time horizon, in interacting processes, and in system feedbacks. The scope defines the elements of the food system, interactions and relationships among them to be analyzed.
7	Bortoletti, M. & Lomax, J. (2019)		The assessment of the food systems involves analyzing the actors and institutions that are linked to food systems management, by assessing the mandate and values influencing their views on sustainable food systems and their related actions, policies and regulations (Dubbeling & Zeeuw, 2007). Establishing a permanent multi-stakeholder platform will allow to understand different goals and viewpoints from a variety of actors and institutions involved in food systems. To this, it is crucial to actively involve stakeholders participating in value chain acticities, as well as those who tackle the impacts and consequences of food systems.	Multidisciplinary collaboration and enhanced dialogue are keys to building consensus for change and a joint vision towards sustainable food systems --> Establishing a permanent multi-stakeholder platform. *Creation of a multi-stakeholder group:* 1. Actively involve stakeholders. The participation of "marginalized people" is also necessary for fostering sustainable food systems (Hospes and Brons, 2016). Such people need to be empowered in order to contribute to positive transformations (UNEP, 2016). Consensus-based participatory approaches to policy development are essential. 2. Facilitate and share understanding of current and future functioning of food systems. 3. Encourage and incentive interconnected decision-making --> Opportunities for increased dialogue across stakeholders, developing better understanding of possible cause and effect across the system. 4. Utilize robust evidence to inform decision-making. 5. Prioritize action-oriented approaches. *Discuss the food system assessment:* The food system assessment should be used to guide discusssions within the stakeholders platform in a structured and constructive manner, enhance their understanding of the food systems around them and their own role in it, create a common understanding of the main issues and impacts, increase awareness of the need to promote sustainable food systems, and facilitate the developent of joint actions to support the trasition.	*Develop an action plan for sustainable food systems:* It creates a joint vision concerning the expected sustainable food systems outcomes to be achieved, with clear timeframe upon which stakeholders agree. i). Select priotity areas, trying to select triple-win areas (impacting health, environment, and profitabiity). When it is not possible, trade-offs need to be negotiated among food systems actors. ii). Define easy-to-understand objectives and targets. iii). Select policies and interventions, defining how the objectives will be met and who will be responsable of what. *For stakeholder dialogue to be effective, meaningful and fair, it should be underpinned by science-based evidence.

8	TEEB (2018)	TEEBAgriFood acknowledges that agents in eco-agri-food systems have the capacity to learn and adapt to changes, but does not delve into the self-organization capacity of the system, nor propose approaches or methods capable of capturing how agents adapt and co-evolve with the system and its context.	It also acknowledges that diversity of agents often involves a diversity of perspectives on how the situation is understood and framed, the purpose and desired change, and the pathways to achieve it, all of which must be explored and appreciated in order to have a full picture. Despite that, it does not offer guidance on how to engage stakeholder to explore their motivations, interests, concerns, and values to identify those key perspectives.	To decide how to frame and address the situation under analysis, TEEBAgriFood emphasizes and promotes creating a shared understanding among stakeholders; however, it does not pay attention to how power relations can influence the dynamics among them, even when consider address power issues crucial to promote transformations. Despite proposing Causal Loop Diagrams to create a common understanding among stakeholders and platforms that integrate less powerful voices to redirect structural power, TEEBAgriFood does not integrate these methods and approaches in the methodological framework.	TEEBAgriFood acknowledges the need to set boundaries for managing the complexity of eco-agri-food systems and does it by defining what is relevant to the assessment, taking into account the big picture. The methodology proposed begins with the creation of spaces for dialogue and exchange between stakeholders to define the perspective(s) that will be the starting point for the evaluation. Although it promotes an informed decision in that sense, it does not promote a reflection at the level of the values that underpin these perspectives, nor at the level of the consequences of these decisions and how to address them.

8	Eigenraam, M. et al. (2020)			To determine the issue of interest and clarify the purpose a key consideration is potential stakeholders. Considering who the assessment may impact or who the assessment is intended to inform will have significant impacts on how you shape your purpose and objectives. For clarifying the purpose of the assessment and the issue of interest, the authors include a step for identify stakeholders and form an advisory committe. This committe with diverse understandings of the issue, interest, expectations, and power will help to ensure that your assessment is accurate, comprehensive, and inclusive.	The process of describing is integrated with the process of scoping to ensure all connections and effects that are relevant to the assessment are identified before determining their relative importance. It is important that this process involves diverse experts and stakeholders who can accurately and comprehensively describe the relevant eco-agri-food system. Scoping helps refine or narrow the assessment based on the issue of interest determined while framing and is informed by any discoveries you made while describing the system. The rationale behind choices related to what to include/ exclude in the assessment is described through materiality assessment of the impacts identified. This assessment determine which impacts are the most important and significant in relation to the issue of interest. Using a systematic and transparent process allows you to communicate to your audiences and others about how and why you have limited the scope of your assessment by providing the rationale behind your choices. It is critical to engage your advisory committee and other relevant stakeholders while conducting your materiality assessment. As result of the materiality assessment, we will have determined which impacts are the most important to focus on in the measure and value phas of the assessment. It is important to articulate the reasons for including or excluding each of the impacts.
9	UNEP (2016)	There are numerous food system actors who undertake food system activities, and they behave, act and influence each other in a certain way to attain their objectives. They act in response to what they perceive as incentives and constraints in a particular context. These perceptions are continuously re-shaped by non-linear feedbacks that emerge from their interactions with other segments, but also from changes in the socio-economic context.	Using a "food system lens" allow to look from a range of viewpoints. There are many differences in perception in society on the critical issues and challenges, as well as on pathways forward. When it comes to sustainability along the food system, stakeholders are critical in both creating the problems and implementing the solutions. This report makes a detail description of each type of stakeholders, describing the aspects of the context in which they operate (institutional and regulatory environment; physical environment; the social, economic, and technical setting; prices and related aspects; and cultural aspects).	*A "food system lens" to look at multiple objectives:* The food system approach helps both identify and map the possible multiple goals, as well as organize and systematically structure the conversations needed to identify and work towards potential synergies between them. The coordination mechanisms in the food system are key in explaining the governance and power relations in a system as those who set the conditions for contracts and/or the standard requirements determine the playing field for the various actors in the food system. Governance in food systems have change from being related to the role of governments, to be related to downstream actors (consumers, market). Most food supply chains are dominated by a few large companies; governance mechanisms such as contracts and private standards are increasignly used, resulting in a deepening of the dependency of suppliers on their client as suppliers invest in specific assets to comply with the conditions set by their product buyer.	
10	van Berkum, S., Dengerink, J., & Ruben, R. (2018)	Interventions in the food system's context can also influence the agent response within the system by influencing their behavior through changes in the system context.			

10	Posthumus et al. (2018)	A key concept in self-organizing systems is agecy: the ability to take action and make a difference over a course of events. However, though system actors may try to purposefully influence their environment, unanticipated effects of their actions and random external events beyond the actors' control may either reinforce or counteract their actions (Klerkx et al., 2010). Soft systems thinking acknowledges that system actors are part of complex adaptive systems and have to react constantly to their changing environment, requiring adaptive innovation management. This implies that food system interventions should not try to fully plan, control and manage the food system, but to operate on the probability of events and reduce the chances of undesired results instead (Klerkx et al., 2016). System structures are rarely consciously built; often they emerge from the choices people make over time (Senge, 2014).	Joint learning and reflection among diverse actors, using participatory processes, are considered necessary to generate transformative agency of the system actors. Important features in these learning processes are visualization and communication in group-based analysis to reveal participants' assumptions and to trigger mutual understanding, and to integrate knowledge (Tröger et al. 2018). These system-learning approaches acknowledge the validity and relevance of diverse knowledge types and perspectives, encouraging local participation and capacity building (Ison et al., 1997). Mental models reflect beliefs, values and assumptions that we personally hold and feed our reasons for doint things the way we do - yet these mental models rarely come to the surface.	CLD models can be created by researchers, but they can also be developed in a multi-stakeholder process. This process of group thinking facilitates consensus building, alignments of thoughts and actions, and ownership of the model as well as future interventions (Nguyen et al., 2011). Bayesian belief networks (BNN) are used as a mechanism to facilitate the sharing and integration of the different stakeholder views. This process allows different stakeholders to externalize their knowledge within a group, combine the knowledge (co-creation) and learn from each other (internalizing joint new knowledge). Though the BNN model is not a perfect representation of the system, embedding the model in an adaptive management cycle allows its improvement through monitoring and joint learning. Developing a joint understanding of system mechanisms and structures will allow the identification of interventions points to inform the Food and Nutrition Security programming.	Although it is impossible to fully understand and measure complex systems, interventions can be designed based on bounded and temporary rationality. A "theory of limits" and strategy for managing the limits of our knowledge of the system of interest are thus needed (Richardson, 2007).
11	Allen, T. & Prosperi, P. (2016)	SESs can be defined as complex human–nature adaptive systems linked by dynamic processes and recipro- cal feedback mechanisms, with a substantial exchange of energy and materials across boundaries (Berkes et al. 2001; Folke 2006). A crucial challenge towards sustainability of food systems is the management of dynamics originating from both global and internal changes, and their different synergistic impacts on systems' outcomes. Only a better understanding of these processes will help us estimate and forecast trade-offs between human wellbeing and ecosystem services, economic performances, and environmental impacts.	Food systems outcomes are susceptible to being evaluated and ranked differently by different stakeholders, and at different levels.	Participatory processs to identify essential drivers of change and food system's outcomes, and linked them. (Vulnerability/resilience of what to what?). Outcomes are susceptible to being evaluated and ranked differently by different stakeholders, at different levels. The analysis of the connections linking global and regional drivers of change with context-specific food system outcomes could be also carried out through polycentric governance approach, where actors can use local knowledge and participate in interative and reflexive learning processes where other stakeholders are involved.	From polycentric governance it might be possible to define alternative scales of analysis and draw different artificial boundaries within the food system, in its collective units and sub-systems, and the degree of granularity of the food system's outcomes. . To carry out the analisis, the authors consider a serie of steps that involve: 1. Defining a study area and scale of analysis, drawing artificial boundaries around the system of interest. Is important to consider who are the intended users of the measurement set, and what is the degree of granularity of the outcomes to be addressed. 2. Identifying essential drivers of change, according to the scale defined. ''vulnerability/ resilience of what to what?". It also requires simultaneously identifying the main drivers of change as the food system-specific issues of concern that the drivers are likely to affect (Schröter et al. 2005). This report carries out this steps only having into account experts opinions through focus group sessions, and secondary information obtained by literature review. 3. Identifying essential food system's outcomes. Is important to formalize the hypotheses to be explored. The "what is vulnerable" is identified by the functions performed by the ecological and social service delivering entity composed of a number of actors, activities, and processes. Investigating the influence of socio-economic and environmental drivers on food and nutrition security, with regard to some essential food system characteristics, provides an approach to think the causal mechanisms that can lead to unsustainability. 4. Developing a causal model.

12	Béné, C. et al. (2019)		Food system sustainability can be understood under different narratives. These narratives reflect underlying values which shape the way communities of experts interpret the world. The authors map the current communities engaged in the food system agenda, describind their major concerns (agricutlure, nutrition, social-ecology). The three communities of experts (agriculture, nutrition, and socio ecology) define sustainability of food systems in different ways and pay attention to some dimensions while ignoring others. Agriculture is defined through its ecological dimension, but with considerations for animal welfare and ethics, as well as for nutrition (e.g. in Garnett et al., 2014). Nutrition, if considered, focuses on the environmental dimension and household capacity to sustain innovations (Combs, 2000). Socioecology focuses on ecological, social and economic dimensions, that is, a holisitic definition of sustainability.	The methodology consist in looking specifically at different expert storylines around "what the failure of food systems is about?" (the origin of the problem), "what is threatened and needs to be fixed?" (the core issue), and finally "where do the priorities for action stand?" (the way to fix the problem). Reconciliation among diverse interpretations of what is failing us from the food system are not perceived by everyone as being feasible. Yet, effects are not unidirectional and effective trade-offs, positive and negative feedback loops, and impacts at different system scales need to be contextualized. There is a wide agreement within and between the different communities that the main objective of a food system is to deliver food and nutrition security --> Reconcile productivity and quality: food security and nutrition, to also contribute to human health.	
13	Connolly-Boutin, L. & Smit, B. (2016)	In the "Climate change, food security and livelihoods framework", the vulnerability of a community is a function of the multiple and interrelated bio-physical and socioeconomic drivers that act upon the community and shape its adaptive capacity. Vulnerability is seen to have two interconnected elements: one related to external risks, shocks, drivers, and stresses to which communities are subject, and one relating to the means of coping or capacity for adapting. This framework conceptualizes adaptive capacity as the ability of a person or a community to use their assets or capitals in order to deal with or adapt to changing conditions. Adaptation strategies are the actions that people individually or collectively undertake to adjust to changing conditions, in order to mantain or improved their well-being.			

14	Ericksen, P. (2008)	Food systems outcomes and behavior are shaped both by macro-level and structural features, and by agency of individual actors and institutions – interplay between both external and internal dimensions.	The food systems approach inherently accepts that ecosystems are managed (directly and indirectly) for human benefit and that one set of services may be emphasized at the cost of another, and that these goals may be in conflict. This build upon the idea that within complex system it is possible to identify key processes and determinants that influence outcomes, although these outcomes may be contested.		Food system understood as a "problem-determined system" rather than a "system-determined problem" (Ison et al., 1997). The scale and level of observation determines which of a given range of parameters is observed to be more influential on an outcome (Wilbanks and Kates, 1999), so explanations of cause and effect will vary. The scale of observation can also limit understanding of which variables are endogenous and which exogenous. The decision of the scale to be used depend on the perspective (which links, drivers and feedbacks take into account).
15	Halbe, J. & Adamowski, J. (2019)		Multiple plausible future visions of a desirable system state often exist for a broader social-ecological issues, as the definition of the desirable end state can vary with different values or interest (e.g., Shaw et al., 2009; Iwaniec and Wiek, 2014). The first step of the Vision Design and Assessment (VDA) framework is the definition of needs, requirements, and functions. This includes the identification and analysis of relevant stakeholders and their needs with regards to a speciffic system. In the next steps, stakeholders requirements are translated into system requirements, upon which alternative designs are developed.	The first step towards defining suitable policies or strategies is the conceptualization of a desirable future system state. Thus, an explicit and collaborative discussion of shared visions is an important element of the effective management of environmental problems (e.g., Gunderson, 1999; Schultz et al., 2011). Vision modelling focuses on designing and analyzing a desired future state of a system, such as a sustainable food system. - *The Functional Organizationl Analysis (FOA)* can support the envisioning and analysis of alternative system designs because the explicit consideration of structures and processes can induce a reframing of current system designs and highlight alternatives to technical approaches (Halbe et al., 2014). - Based on FOA results, a more detailed analysis of these alternative designs ir needed to test their applicability and assess their economic, ecological and social performance. *Causal Loop Diagrams* / *Fuzzy Cognitive maps* can be built in this regard by experts and stakeholders in the scope of a participatory modelling process to draw upon available knowledge and expertise, while also considering diverse viewpoints, ideas and interests of stakeholders. These diagrams represent a high level of abstraction that provides an overview of the most important aspects of the sustainability visions. - Dynamics modeling and assessment of system designs by qualitative and quantitative models. the performance of system designs is assessed by changing the values of food systems and scenario variables, which reflect different design specifications or context conditions. It must be noted that scenario analysis is applied to analyze the performance of a sustainability vision under different conditions.	

16	Hubeau, M., et al. (2011)	A sustainable agri-food system is a complex adaptive system evolving through time i.e self organizing system that has to be analyzed as a whole and is formed by various actors (Folke et al., 2005; Klerkx et al., 2010; Liu et al., 2007). Therefore, co-creation of system, target and transformation knowledge between researchers and societal actors is indispinsable	*System knowledge* ecompasses the concepts, i.e. the indicators that allow to understand the system. *Target knowledge* represents the transformative direction for the agri-food system by combining expectations, and *transformation knowledge* describes how to transform from the current system to the targeted system by including identification of possible pathways while taking into account regulations, practices and power relations into account (Hirsch Hadorn et al., 2008; Pohl and Hirsch Hadorn, 2007; Wiek et al., 2006). Soft systems methodology: Makes use of knowledge co-cretion (Hessels and van Lente, 2008; Pohl et al., 2010) and mobilizes stakeholders who recognize that they face a joint problem and who are willing to negotiate their conflicting goals and different perspectives in order to agree collectively on action (Checkland, 1999; Reed et al., 2009; Röling and Jiggins, 1997; Uphoff, 2014).	*Soft systems methodology:* Makes use of knowledge co-cretion (Hessels and van Lente, 2008; Pohl et al., 2010) and mobilizes stakeholders who recognize that they face a joint problem and who are willing to negotiate their conflicting goals and different perspectives in order to agree collectively on action (Checkland, 1999; Reed et al., 2009; Röling and Jiggins, 1997; Uphoff, 2014). **AFSSA Implementation** - Transdisciplinary process to capture the different stakeholders' perspectives and to initiate action towards shared transition pathways. 1. Description of the current state of sustainability of the agrifood system based on indicator selection and description. The aim here is to create a common ground and language between the stakeholders through participatory methods. 2. Sustainability visioning - Creation of a shared vision on long term about sustainable agri-food system. 3. Identification of sustainability initiatives. These initiatives link the current state of the agri-food System with the long-term vision. *Focus groups to list all the possible initiatives - it highlights the divergence between stakeholders. 4. Identification of shared transformation pathways based on categorization and interative adjustment. * Method of open axial coding to make an abstraction of all data into manageable pieces of data, and further allocated into pathways. Those pathways are discussed with stakeholders, who make adjustments until a common agreement is reached. Focus on finding a shared vision among stakeholders, instead of emphasising the differences. The focus groups within a specific stakeholder group can possibly evade the implicit hierarchy of authority between stakeholders which is previously observed when applying the DPSIR framework. AFFSA is a bottom-up transdisciplinary approach - Input of stakeholders provide highly relevant information for decision options on which way to transform towards sustainability. It combines system, target and transformative knowledge, taking into account expectations, practices and power issues.	
17	Jackson, G., McNamara, K., & Witt, B. (2020)		The framework propose some participatory methods like reciprocal information exchange sessions with most members of each village. There are some limitations like power issues (who speaks for whom?). To combat this, smaller group discussions with a wide range of informats were undertaken which were constrasted with the larger community stories.	The framework propose some participatory methods like *reciprocal information exchange sessions* with most members of each village. There are some limitations like power issues (who speaks for whom?). To combat this, smaller group discussions with a wide range of informats were undertaken which were constrasted with the larger community stories. *Ethnographic methods* are participant observation methhod that allowed some verification or problematization of the collective data. Data was first primarily coded using NVivo to allow prominent themes to emerge then deductively coded onto the conceptual frameworks predefined categories (see Fereday and Cochrane, 2006).	

18	Paloviita, A. (2017)	Placing agency in context and acknowledging the interactions of a number of actors assuming various roles is a crucial step.	Food systems serve different functions for different actors, who have different perceptions on the valuable outcomes of the food system (Ericksen et al., 2010: 30).		
20	Raza, A., et al. (2020)			The framework was developed through two round of reviews by researchers with a background in agriculture, food systems, and children's and adolescent's nutrition to ensure that the conceptual framework was grounded in latest evidence. The conceptual framework also includes feedback and comments received from participants during the consultation.	

21	Vallejo-Rojas, V., Ravera, F., &; Rivera-Ferre, M. (2016)	Drivers of change in agri-food systems have a strong social and political components (Thompson and Scoones, 2009) that require specific methods and tools for analysis.	**Focus on active transformation pathways:** System no longer appears as a "given" but as something actively "constructed" by human agents (Roling and Wagemakers, 2000), which facilitate us to address the root causes of vulnerability (Feola, 2013).	To assess agri-food systems transformation, the authors combine the analysis of multidimensional agri-food systems' vulnerability with paticipatory scenario analysis. This methods allow answering of normative questions (Binder et al. 2010) by including different actor's perspectives about drivers of change as well as future impacts on prioritized goals of the agri-food system transformation. Methodology: (I) Introducing the normative question of Vulnerability of what and to what? From the actors' narratives, we select a subset of drivers of change linked to the agri- food components, which constitute the sources of exposure. (II) Different narratives of historical and current perceptions of change, exposure, and impacts of the local agri-food system are explored in order to answer normative questions: Vulnerability for whom? At which scale?. Actors identify what they meant to achieving the desired outcomes of food sovereignty – and the scale of assessment of the current sensitivity and capacity to adapt the agri-food system. (III) Actors envision future trajectories of transformation under different drivers through participatory scenario analysis and qualitatively assess how they might affect the interactions between components of the agri-food system and their final outcomes.	Agro-ecosystem boundaries set conditions for agri-food system activities. Constitute both agro-ecosystem and human constructed facilities. These boundaries set conditions for "focal action situations", when interactions occur producing certain outcomes.
22	Zurek, M., et al. (2018)	**Basic components:** The diverse sets of *actors* that are connected to the EU food system; the direct and indirect factors driving the behavior of food system actors and therefore influencing change within the food system *(drivers of change)* ; the *outcomes* that are related to the EU food system and its activities; the *goals* at the EU level that are shaping the drivers and the EU wide and national policies affecting the food system; the *interactions and feedback loops* that take place among the aforementioned food system components.	Variety of goals acknowledged in "Sustainable food and nutrition security": Several goals encompass nutritional adequacy, environmental issues as well as economic, livelihoods and equity considerations. --> Need of participation of diverse agents to propose options/ solutions to be grounded on reality.	An integrated approach can provide a framework to structure the debate of complex issues, allowing debate across food systems actors and policy makers. Without transparency on the construction of indicators, they have the potential to become a tool of control to the already powerful, rather than empower all stakeholders. The integrated approach proposed start with the creation of a participatory space, which includes building on the knowledge, experiences and values of the many actors embedded in the system. For the creation of a participatory space, the integrated approach contemplate the creation of a stakeholder core group that acted as an advisory group for the project. The use of food systems lens allows for improved collaboration between stakeholders. This contributes to a mediation of the many different, and something contesting, discourses actors hold about the trajectory of food systems. Consequently, a food systems perspective leads to more effective discussions and an ability to come to a shared understanding. The purpose of a conceptual framework aims to visualize the joint understanding of the food system to provide a common ground for the interdisciplinary work of the project team as well as for the stakeholders work. Moving through a participatory process to map food systems also increases the awareness of complexity and dynamics that are associated with the food system.	

ANNEX C

Results of assessing food systems frameworks under an STCS lens

		Exploring the big picture			Understanding the dynamics of the system			Acknowledging the role of agents in framing systems						
№	Authors (year)	1. Acknowledge multidimensionality and hierarchical structure of complex systems	2. Engage with interrelations and interdependencies	3. Address emergent properties and unpredictable behavior	4. Map the system's movements through the phase space to identify underlying patterns of change	5. Understand how a system changes between phases or states	6. Acknowledge the path dependence and context sensitivity of complex systems	7. Understand adaptive agents and the self-organization capacity that arises from the interactions among them	8. Acknowledge diverse perspectives as part of a same big reality	9. Promote dialogue and mutual appreciation among perspectives to decide how to frame the situation	10. Place boundaries to manage complexity	Exploring the big picture	Understanding the dynamics	Acknowledging the role of agents
1	Dury, S., et al. (2019)	2	1	1	0	0	1	0	0	0	0	44%	11%	0%
2	Nguyen, H. (2018)	2	2	3	0	0	0	2	1	2	0	78%	0%	42%
4	HLPE on Food Security and Nutrition (2017)	2	1	1	1	0	1	2	0	2	0	44%	22%	33%
5	IPES FOOD (2015)	1	1	1	0	0	1	0	1	2	2	33%	11%	42%
6	IOM & NRC (2015)	3	3	3	3	3	3	3	2	2	3	100%	100%	83%
7	Bortoletti, M. & Lomax, J. (2019)	2	2	1	1	1	0	0	3	3	0	56%	22%	50%
8	TEEB (2018); Eigerraam, M. et al. (2020)	3	3	3	3	3	3	2	1	3	3	100%	100%	75%
9	UNEP (2016)	2	2	2	0	0	2	2	2	2	0	67%	22%	50%
10	van Berkum, S., Dengerink, J., & Ruben, R. (2018); Wageningen University & Research and KIT Royal Tropical Institute (2018)	3	3	3	3	2	1	3	3	1	1	100%	67%	67%
11	Allen, T. & Prosperi, P. (2016)	3	3	3	3	3	3	1	1	3	3	100%	100%	67%
12	Bene, C. et al. (2019)	2	1	2	0	0	2	0	3	1	0	56%	22%	33%
13	Connolly-Boutin, L. & Smit, B. (2016)	3	2	2	2	2	0	2	0	0	0	78%	44%	17%
14	Ericksen, P. (2008)	2	1	2	0	0	2	1	1	0	2	56%	22%	33%
15	Halbe, J. & Adamowski, J. (2019)	3	3	3	3	0	0	0	3	1	0	100%	33%	33%
16	Hubeau, M., et al. (2011)	3	3	3	3	1	1	1	3	3	0	100%	56%	58%
17	Jackson, G., McNamara, K., & Witt, B. (2020)	2	1	2	1	2	0	0	1	3	0	56%	33%	33%
18	Paloviita, A. (2017)	2	0	0	1	0	0	1	1	0	0	22%	11%	17%
20	Raza, A., et al. (2020)	3	2	1	1	0	0	0	0	0	0	67%	11%	0%
21	Vallejo-Rojas, V., Ravera, F., &; Rivera-Ferre, M. (2016)	3	2	3	1	3	3	0	1	1	1	89%	78%	25%
22	Zurek, M., et al. (2018)	3	2	1	1	0	0	1	1	2	0	67%	11%	33%

	Exploring the big picture			Understanding the dynamics of the system			Acknowledging the role of agents in framing systems			
	1. Acknowledge multidimensionality and hierarchical structure of complex systems	2. Engage with interrelations and interdependencies	3. Address emergent properties and unpredictable behavior	4. Map the system's movements through the phase space to identify underlying patterns of change	5. Understand how a system changes between phases or states	6. Acknowledge the path dependence and context sensitivity of complex systems	7. Understand adaptive agents and the self-organization capacity that arises from the interactions among them	8. Acknowledge diverse perspectives as part of a same big reality	9. Promote dialogue and mutual appreciation among perspectives to decide how to frame the situation	10. Place boundaries to manage complexity
The principle is meaningfully embraced both at conceptual and methodological level	10	6	8	6	4	4	2	5	5	3
The principle is addressed in a theoretical/conceptual level	9	7	5	1	3	3	5	2	6	2
The principle is vaguely mentioned	1	6	6	7	2	5	5	9	4	2
The principle is absent	0	1	1	6	11	8	8	4	5	13
The principle is meaningfully embraced both at conceptual and methodological level	50%	30%	40%	30%	20%	20%	10%	25%	25%	15%
The principle is addressed in a theoretical/conceptual level	45%	35%	25%	5%	15%	15%	25%	10%	30%	10%
The principle is vaguely mentioned	5%	30%	30%	35%	10%	25%	25%	45%	20%	10%
The principle is absent	0%	5%	5%	30%	55%	40%	40%	20%	25%	65%
% of framework where principle is addressed at theoretical and/or methodological level	95%	65%	65%	35%	35%	35%	35%	35%	55%	25%

ANNEX D

Underlying narrative of the Causal Loop Diagram of the poultry system in Ghana – Workshop January 2022

Below is presented the underlying narrative of the poultry system causal loop diagram. Firstly, the elements that define the poultry system to be transformed are described, as well as the way they interrelate and behave as a whole. Secondly, the main feedback loops in the poultry system are outlined.

1. Causal Trees illustrating interrelations between elements of the poultry system.

   - Competitiveness of domestic poultry meat

In the market of poultry meat products, being more competitive implies complying with quality standards, diversifying the products, and lowering the costs per bird. The quality of poultry meat is affected by production, storage, and processing conditions. Production conditions that lead to greater compliance with quality standards include access to quality feed, day-old chicks, animal health services and products, and appropriate housing conditions. The product differentiation depends on the access to appropriate processing and storage facilities. Finally, reducing the cost per ready-to-sell birds means reducing poultry farming costs. In addition, this value is affected by flock size: the larger the flock size, the lower the cost per bird, due to economies of scale.

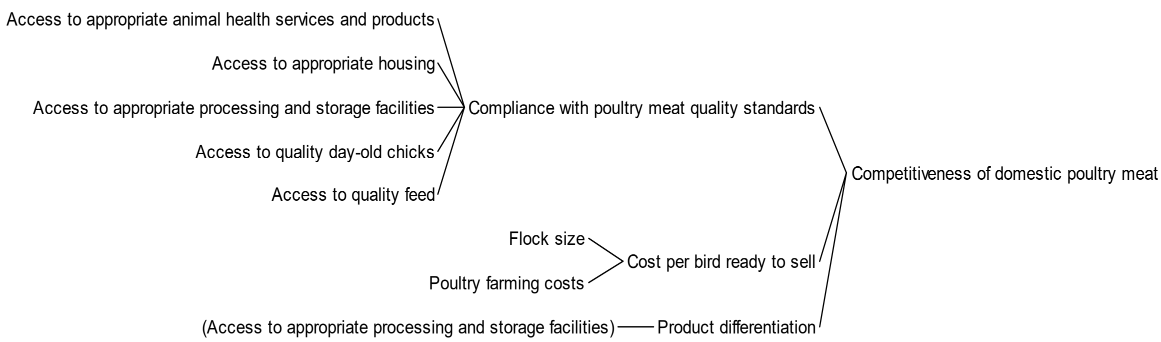


Figure D.1. Competitiveness of domestic poultry meat

- Poultry farming profitability

Making poultry farming more profitable means increasing incomes and/or reducing poultry farming costs. To increase incomes, farmers can increase flock size, obtain a better selling price for their products, or reduce the poultry mortality rates. The flock size could increase by improving poultry farmers' reinvestment capacity, assuming that a percentage will be reinvested for that purpose. The selling price is affected by poultry farmers' access to storage facilities - that allow them to wait for better prices - by their access to modern retail markets - which offer them better prices - and by the weight of broilers to sell, which is the main determinant of price when you sell live birds. The mortality rate is affected by the health issues of birds. Having more health issues in birds lead to higher mortality rates, which, in the end, will reduce the poultry farmers' incomes.

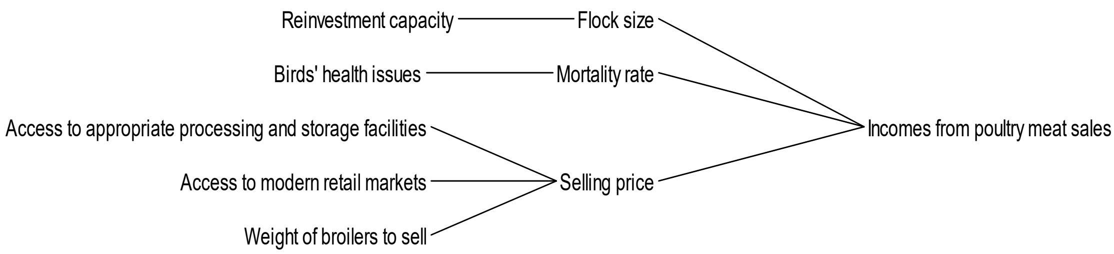


Figure D.2: Incomes from poultry meat sales

To reduce the total poultry farming costs, farmers can reduce either one of more of the following costs: poultry production variable and fixed costs, processing and storage costs, or product transportation costs. Variable costs of production, which include feed, day-old chicks, and animal health-related, are affected by the flock size and the growth rate of birds. The higher the growth rate, the lower the time of rearing poultry, leading to lower variable costs. Fixed costs of production include the cost of housing and labor. Processing and storage costs depend on the farm's closeness to markets and product differentiation. Lowering the distance farm to markets lowers the costs of poultry meat storage; on the other hand, higher product differentiation leads poultry farmers to increase processing costs. Product transportation costs also depend on farm closeness to markets.

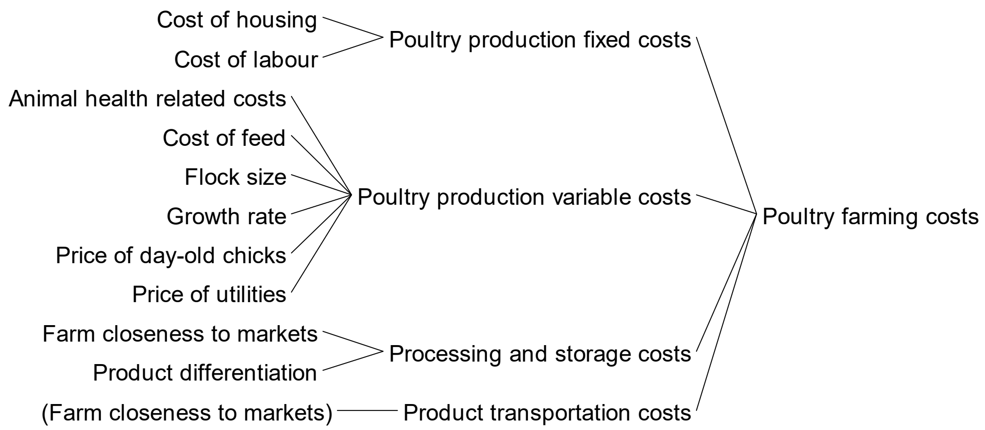


Figure D.3: Poultry farming costs

- Poultry farming productivity
  - Growth rate of birds:

The growth rate is affected positively by the access to quality feed, the access to quality day-old chicks – with better genetic conditions – and the access to appropriate housing conditions. This last one gives birds the conditions to grow appropriately, including ventilation, space, easy access to water and feed, among other sanitary and safety conditions. On the other hand, the more health issues in birds, the lower their growth rate.

  - Mortality rate of birds:

The mortality rate of birds can be reduced minimizing the birds' health issues. In turn, birds' health is affected by the quality of day-old chicks, rearing conditions – including housing and feed – and the access to veterinary services and products for animal health prevention and control. Quality day-old chicks have a genetically stronger immune system and are often vaccinated, which helps prevent animal health issues. The quality feed also strengthens the birds' immunity system, but more indirectly. On the other hand, having appropriate housing conditions helps to prevent disease outbreaks, together with other prevention measures recommended by veterinary officers.

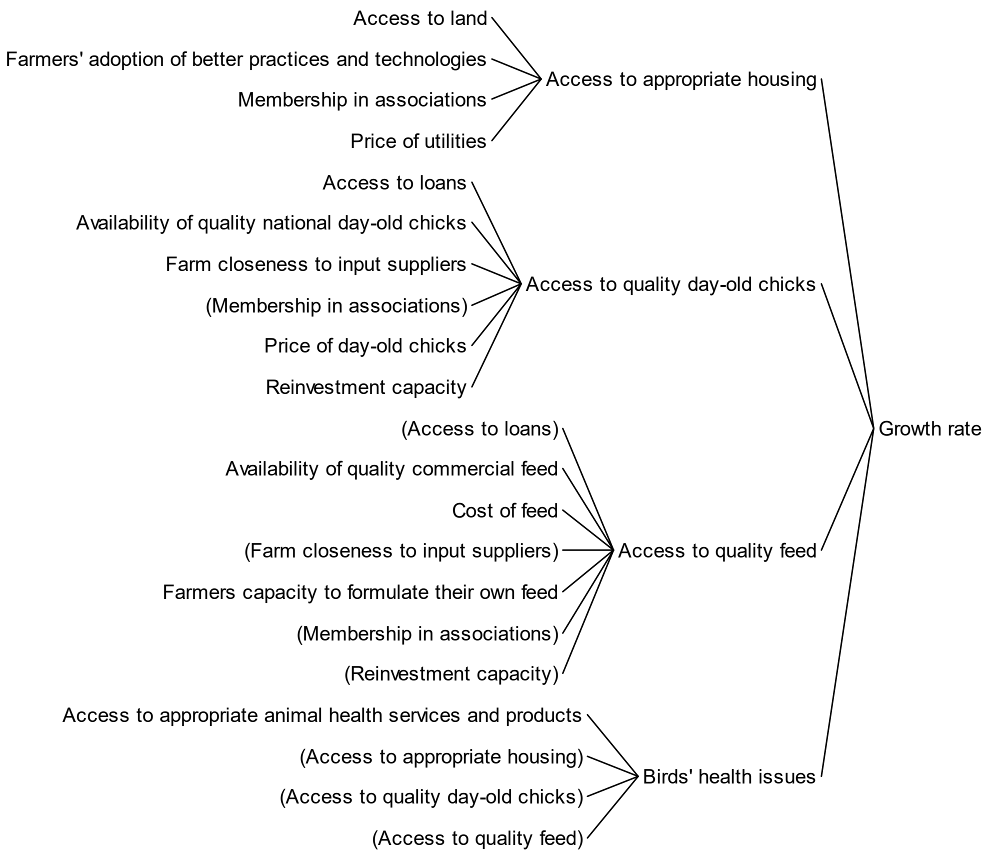


Figure D.4. Birds' growth rate

Figure D.5. Birds' mortality rate

- Access to quality inputs, services, and facilities
    - Feed

Poultry farmers can access quality feed by buying it in feed mills or formulating their own. To produce quality feed, feed mills need adequate facilities and comply with sanitary and safety standards. On the other hand, poultry farmers need to strengthen their capacities to produce and formulate quality feed, by adopting better practices and technologies.

The farm closeness to feed mills affects poultry farmers' access to them. The longer the distance, the higher the transaction costs of feed, and therefore its price; in the end, both the price and the distance between farms and feed mills affects the poultry farmers' access to feed. The price of feed could also be reduced by increasing the availability of quality commercial feed or promoting its self-formulation among poultry farmers, which generally involves lowering its costs.

To conclude, three conditions that positively affect the poultry farmers' access to all inputs, services & facilities are the access to loans, their reinvestment capacity, and their membership in associations. The first two are based on the assumption that a better financial capacity would translate into greater access to quality food, while the third assumes that by belonging to an association, producers will be able to do collective purchases having thus better access to quality inputs.

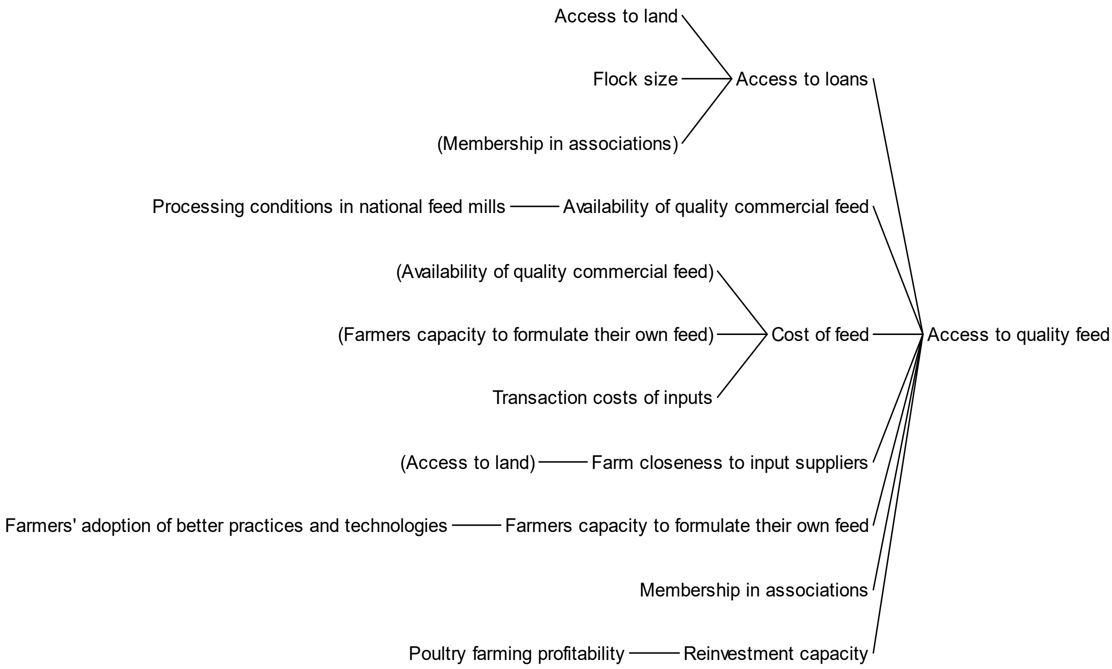


Figure D.6. Access to quality feed

- Day-old chicks

Poultry farmers can access quality day-old chicks from domestic hatcheries or through imports. For domestic hatcheries to produce quality day-old chicks, they need adequate facilities and enough production capacity, as well as compliance with sanitary and safety regulations. Bird genetics, vaccination, and disease control should be also considered.

Another aspect affecting the farmers' access to quality day-old chicks is their price. Considering that imported day-old chicks are more expensive than national, we assume that improving the breeding conditions in national hatcheries will cause a reduction in the cost of day-old chicks since farmers would pay a lower price for a product of similar quality.

As with feed, access to quality day-old chicks is also positively affected by farm closeness to input suppliers, farmers' access to loans, their reinvestment capacity, and their membership in associations.

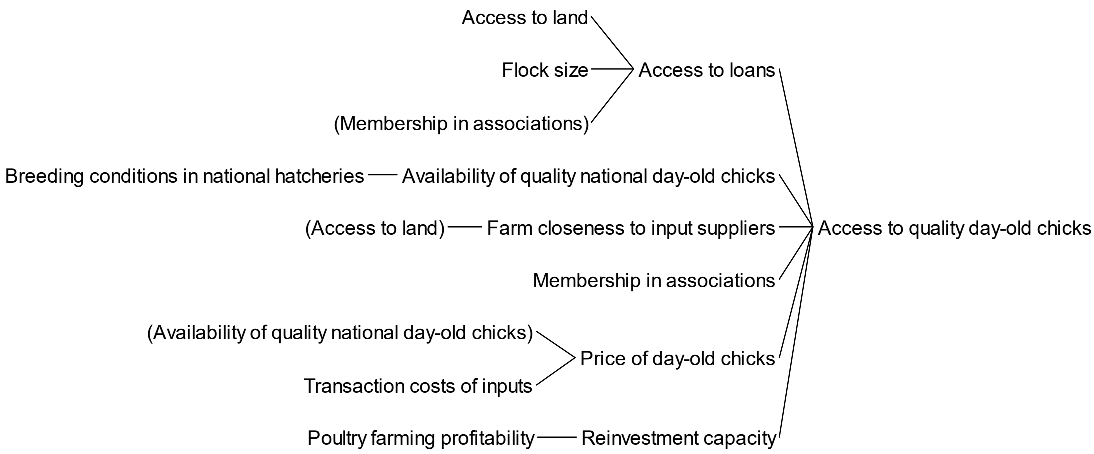


Figure D.7. Access to quality day-old chicks

- Animal health services and products

Farmers' access to quality veterinary services and products depends on the availability of vet officers, the price of animal health services and products, and how well they comply with sanitary regulations. The availability of vet officers for poultry farmers is affected by the logistic support provided to public officers since, without facilities and a budget that allows them to travel, the vet officers cannot attend to all the poultry farmers around the country. On the other hand, the price of vet services and products is affected by the availability of veterinary officers, and the transaction costs of veterinary products. Finally, the quality of vet services and products are affected by the enforcement of regulations about the use of cold chain, the minimum qualification of vet officers, the quality control of medicines, the use of antibiotics in appropriate doses to avoid drug residues in meat, the mandatory vaccinations to avoid diseases outbreaks and zoonoses, among other aspects.

As in the previous variables, the farmers' access to loans, their membership in associations, and their reinvestment capacity affect positively their access to appropriate animal health services and products.

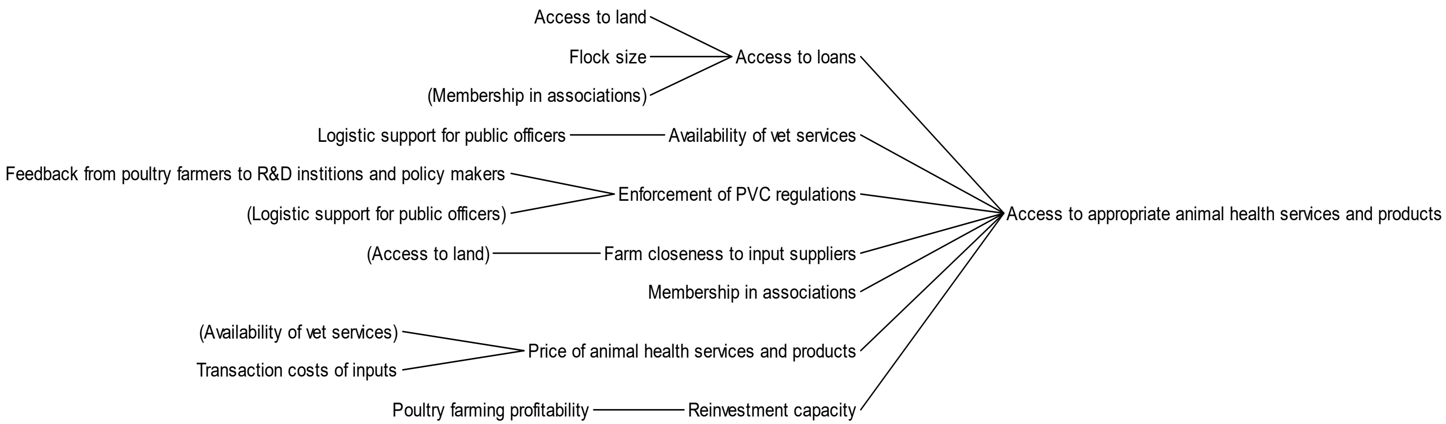


Figure D.8. Access to appropriate animal health services & products

- Housing

The access of poultry farmers to appropriate housing for poultry depends on their access to enough land, the adoption of practices and technologies to improve conditions for poultry breeding – including lighting, ventilation, access to water, adequate density, among other sanitary and safety conditions – and the price of utilities like water and electricity. Furthermore, by belonging to an association, poultry farmers could improve housing conditions through collective efforts.

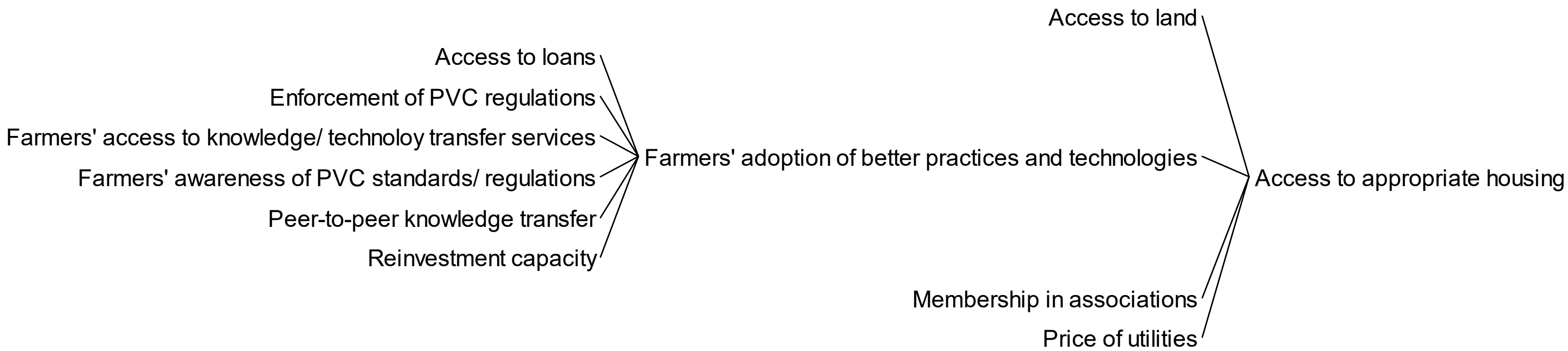


Figure D.9. Access to appropriate housing

- Processing and storage facilities

To access appropriate processing and storage facilities, those facilities must comply with sanitary, safety and quality regulations. On the other hand, poultry farmers can adopt practices and technologies that enable them to process and store their products. As in the previous variables, the poultry farmers ability to pay for those facilities is positively affected by their access to loans and their capacity to reinvest. Furthermore, belonging to association can contribute to accessing processing and storage facilities collectively.

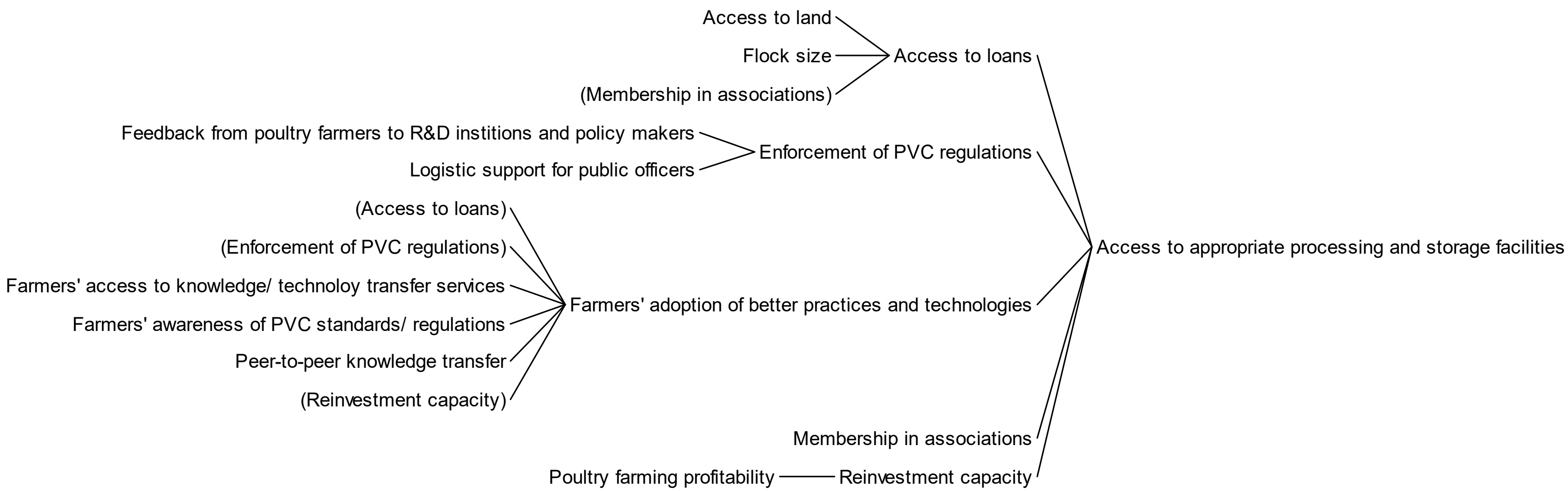


Figure D.10. Access to appropriate processing & storage facilities

- Adoption of better practices and technologies

The adoption of better practices and technologies depends on farmers having enough means and being willing to do so. Financially, access to loans and the reinvestment capacity of poultry farmers are two enabling factors to adopt better practices and technologies. Technically, accessing knowledge & technology transfer services informs poultry farmers about practices and technologies that could help them improve their activity and increases their awareness of regulations & standards related to the poultry value chain, so they can focus their efforts on improving their compliance and thus having greater access to markets. Furthermore, the enforcement of regulations acts as an incentive for farmers to adopt better practices and technologies.

Lastly, poultry farmers will be more willing to adopt new practices and technologies by hearing good experiences from their peers, who transfer evidence-based knowledge.

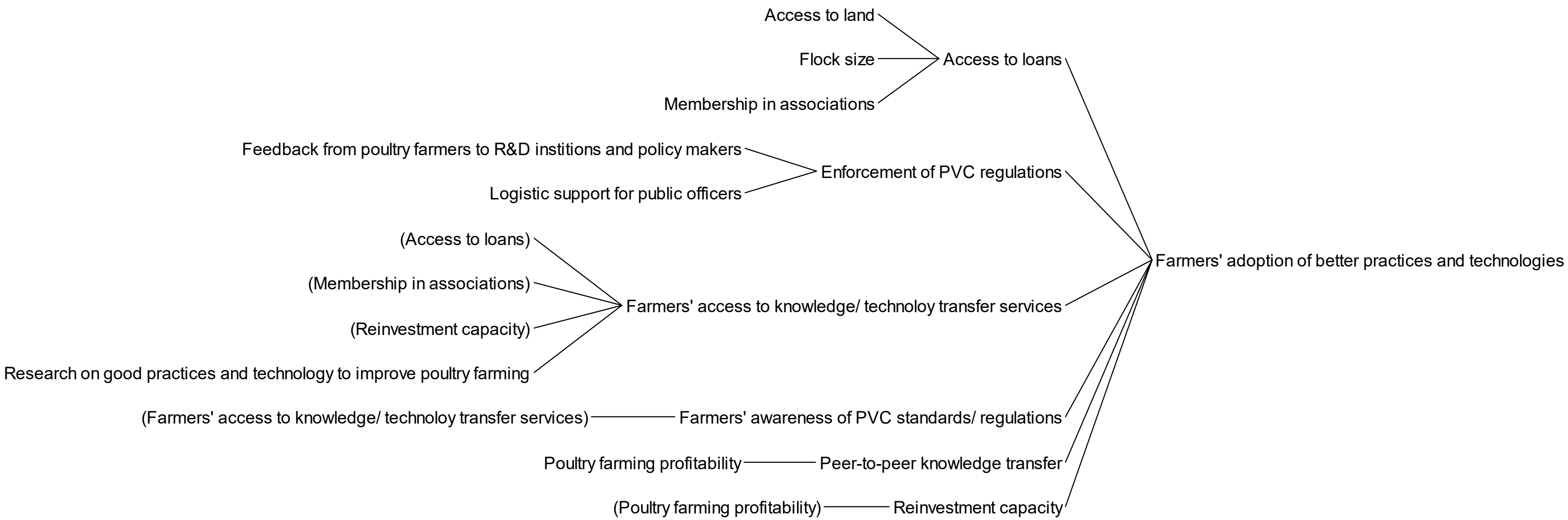


Figure D.11. Adoption of better practices & technologies

- Enforcement of poultry value chain (PVC) regulations

The enforcement of PVC regulations is affected by the logistic support given to public officers and by the feedback given from poultry farmers to policymakers, the latter assuming that the more and better the feedback, the more relevance of regulations to the strategic needs of poultry farming. To give more and better feedback to decision makers, poultry farmers need to enhance their lobby capacity and be aware of the current poultry value chain standards and regulations.

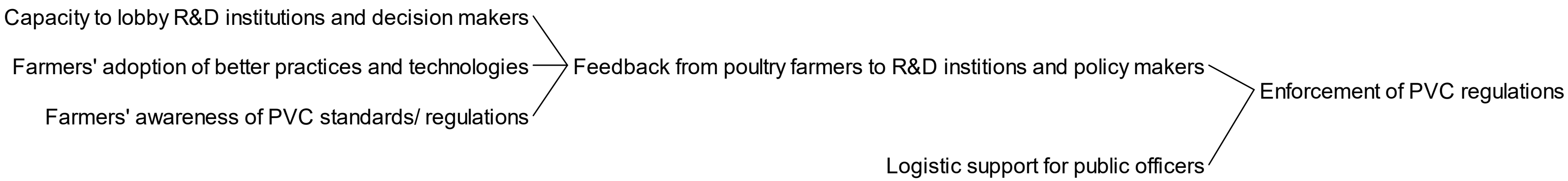


Figure D.12. Enforcement of regulations related to the poultry value chain

2. Exploring the feedback loops

- Reinvestment feedback loop

Having a greater reinvestment capacity, poultry farmers can access more training & technology transfer services and adopt more practices & technologies to improve poultry farming, among other improvements. By having more access to knowledge & technology transfer services, poultry farmers will be more aware of value chain standards and regulations, which allows them to give more feedback to R&D institutions and decision-makers. The more and better the poultry farmers' feedback to R&D institutions and decision-makers, the better the research and regulations will address the problems and needs of the poultry sector.

Promoting relevant research for poultry producers allows them to access training and technology transfer services targeted to their needs, encouraging thus a greater adoption of practices and technologies to improve poultry farming. On the other hand, improving the enforcement of regulations that address poultry key challenges, encourages the poultry farmers' adoption of better practices and technologies.

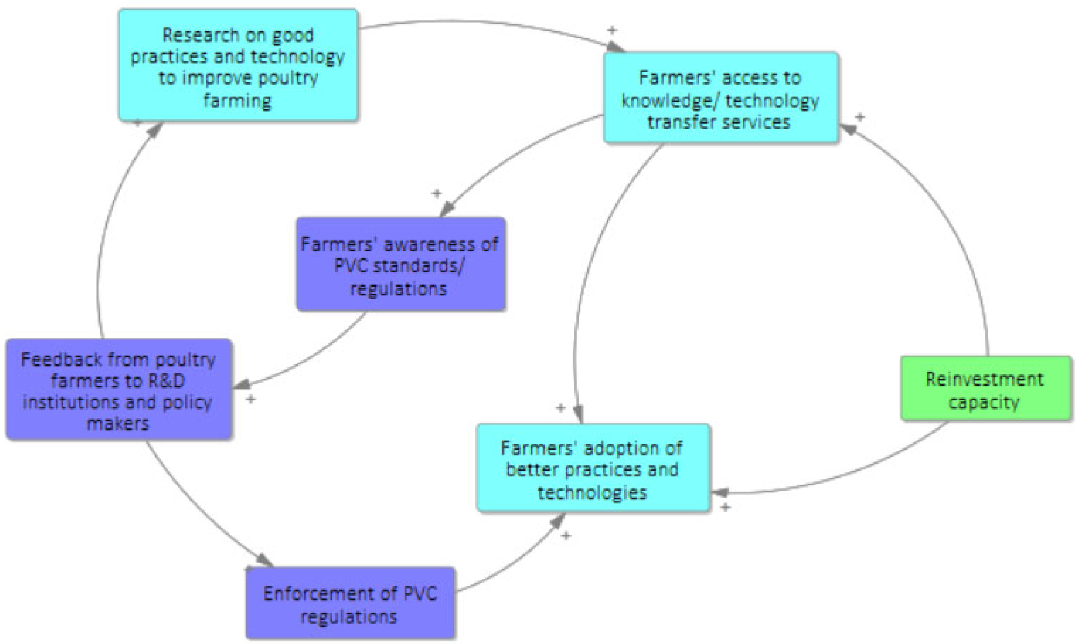


Figure D.13. Reinvestment feedback loop – Part I

Besides promoting farmers' adoption of better practices and technologies, better enforcement of regulations related to the poultry value chain leads to improvements in domestic feed mills, hatcheries, and processing & storage facilities. These improvements result in better quality products and services available domestically and at a competitive price, which improves producers' access to them. On the other hand, the adoption of better practices and technologies by poultry farmers allows them to be more integrated along the value chain and to improve their production system. Poultry farmers can integrate feed production in their activities by improving their self-formulation capabilities, or the processing and storage of their products, by improving their access to such facilities. Improvements in the production system come from the use of more appropriate and efficient practices and technologies in poultry housing, which leads to increased housing costs and decreased labor costs.

Improvements in poultry farmers' reinvestment capacity also lead directly to better access to quality inputs and services, improving their affordability.

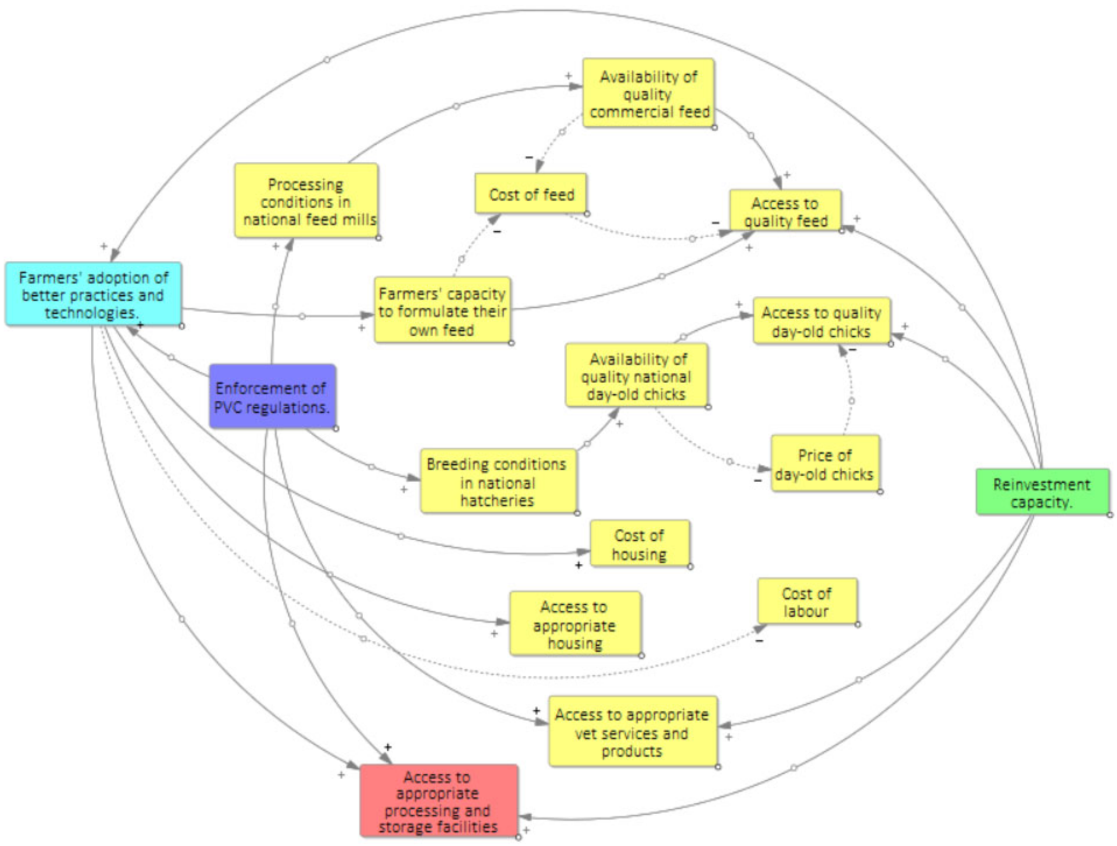


Figure D.14. Reinvestment feedback loop – Part II

By having greater access to quality services, products, and facilities, poultry farmers improve the growth rates and reduce the health issues of their birds, which at the end reduces the mortality rates. A higher growth rate of birds leads, in turn, to higher weight of broilers at sale age. Furthermore, the improvements in accessing quality inputs and services lead to better compliance of quality standards for poultry meat.

This condition, together with the product differentiation resulting from improving poultry farmers' access to appropriate processing and storage facilities, improves the competitiveness of domestic poultry meat, enabling poultry farmers to access modern retail markets. In the end, reaching higher weights per bird and accessing modern retail markets improves the selling price of poultry meat products.

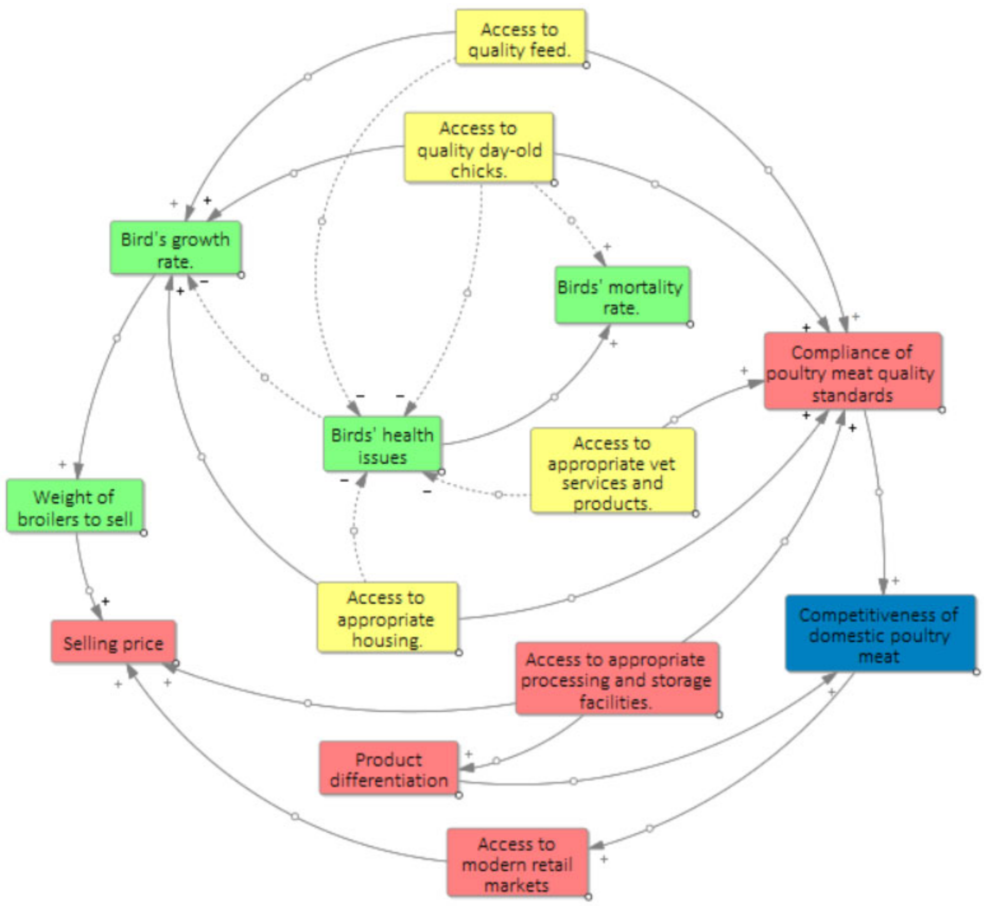


Figure D.15. Reinvestment feedback loop – Part III

Improving the growth rate of birds also reduces the birds' rearing time, which ultimately lowers the production variable costs. This group of costs includes the costs of feed, day-old chicks, and those related to bird health, which will increase if birds' health issues increase. Fixed costs, on the other hand, comprises labor and housing, which are affected by the adoption of more efficient practices and technologies.

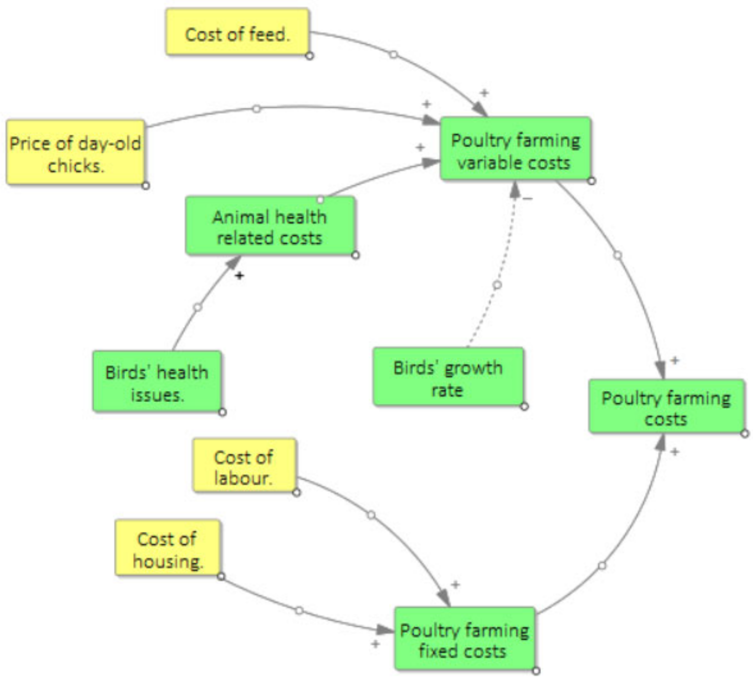


Figure D.16. Reinvestment capacity – Part IV

By accessing processing and storage facilities, poultry farmers have the option to add more value to their products. The more the product differentiation, the higher the selling price of poultry meat products and, consequently, the incomes from those sales. On the other hand, adding more value to poultry meat products brings new costs, which, together with the variable and fixed costs of production, increase the total costs of poultry farming.

Finally, the costs of poultry farming and the incomes from the sale of poultry meat products will determine the profitability of this activity, which, if increased, will lead to more improvements in poultry farming.

Figure D.17. Reinvestment feedback loop – Part V

- Competitiveness feedback loop

Improving the competitiveness of the poultry sector bring that both the government and the R&D institutions pay more attention to it. On the one hand, government logistical support to public officials (including veterinarians) increases, leading to more availability of public veterinaries, better enforcement of regulations related to the poultry value chain, and price reduction of animal health services. On the other hand, R&D institutions increase research and technological development in the sector, which improves poultry farmers' access to technology and knowledge transfer services. Improvements in both enforcement of regulations and access to knowledge and technology transfer services finally lead to increased adoption of technologies and practices by poultry producers.

By improving poultry farmers' access to knowledge and technology transfer services, their awareness of value chain standards and regulations increases, allowing them to give more feedback to R&D institutions and policymakers for regulations and research to better address poultry farming needs.

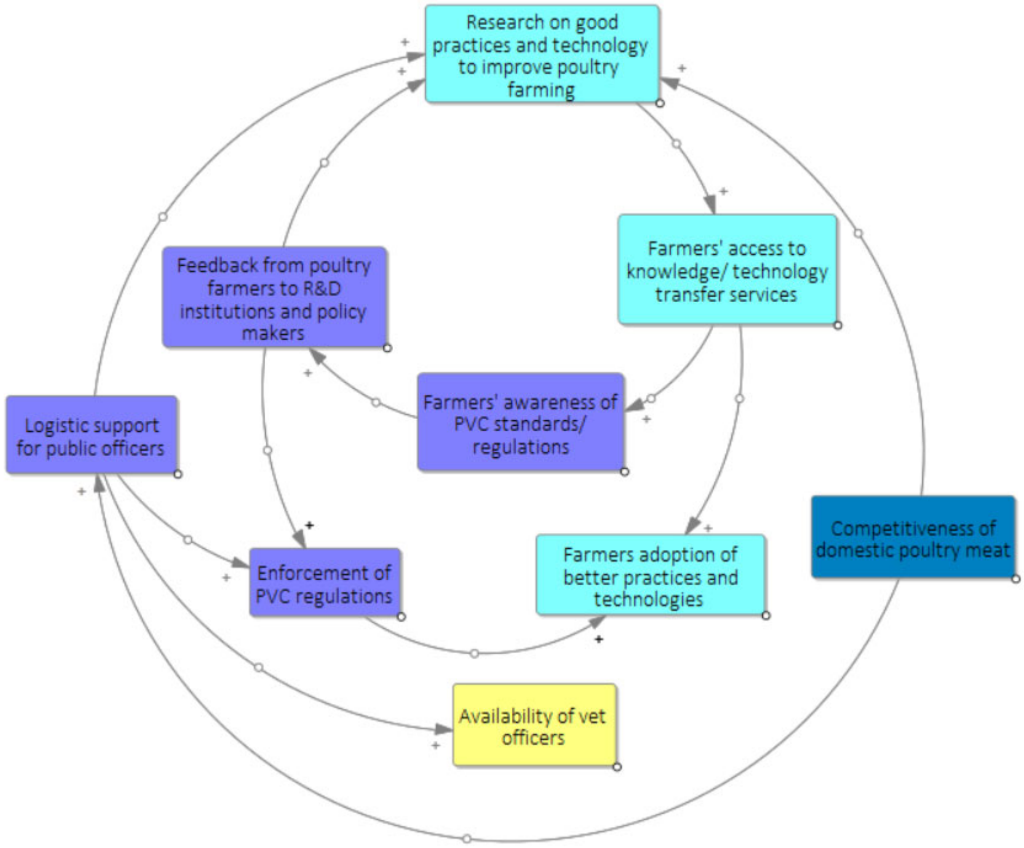


Figure D.18. Competitiveness feedback loop – Part I

Improving the enforcement of regulations related to poultry value chain improves different aspects of the production system, including access to quality inputs, services, and facilities. These improvements comes through different pathways: (a) by enhancing domestic feed mills, hatcheries, and processing & storage facilities, which result in better quality products and services available domestically and at a competitive price, improving poultry farmers' access to them; (b) by driving greater adoption of practices and technologies that lead to improvements in the production system, mainly related to housing conditions; (c) by driving greater adoption of practices and technologies that allow poultry farmers to process and store their products appropriately and enhance their ability to self-formulate the feed, allowing them a greater integration along the value chain; (d) finally, by directly acting on the access of poultry farmers to quality services & products, as in the case of veterinary services & products.

On the other hand, increasing the availability of public veterinary officers improves poultry farmers' access to public veterinary services that have lower prices than private ones.

Furthermore, the use of more efficient technologies and practices in the production system, together with the improvements in domestic feed mills and hatcheries resulting from better enforcement of regulations, lowers feed, day-old chicks, and labor costs and increases housing costs. About veterinary services and products, increasing the availability of public veterinary services will lower their price.

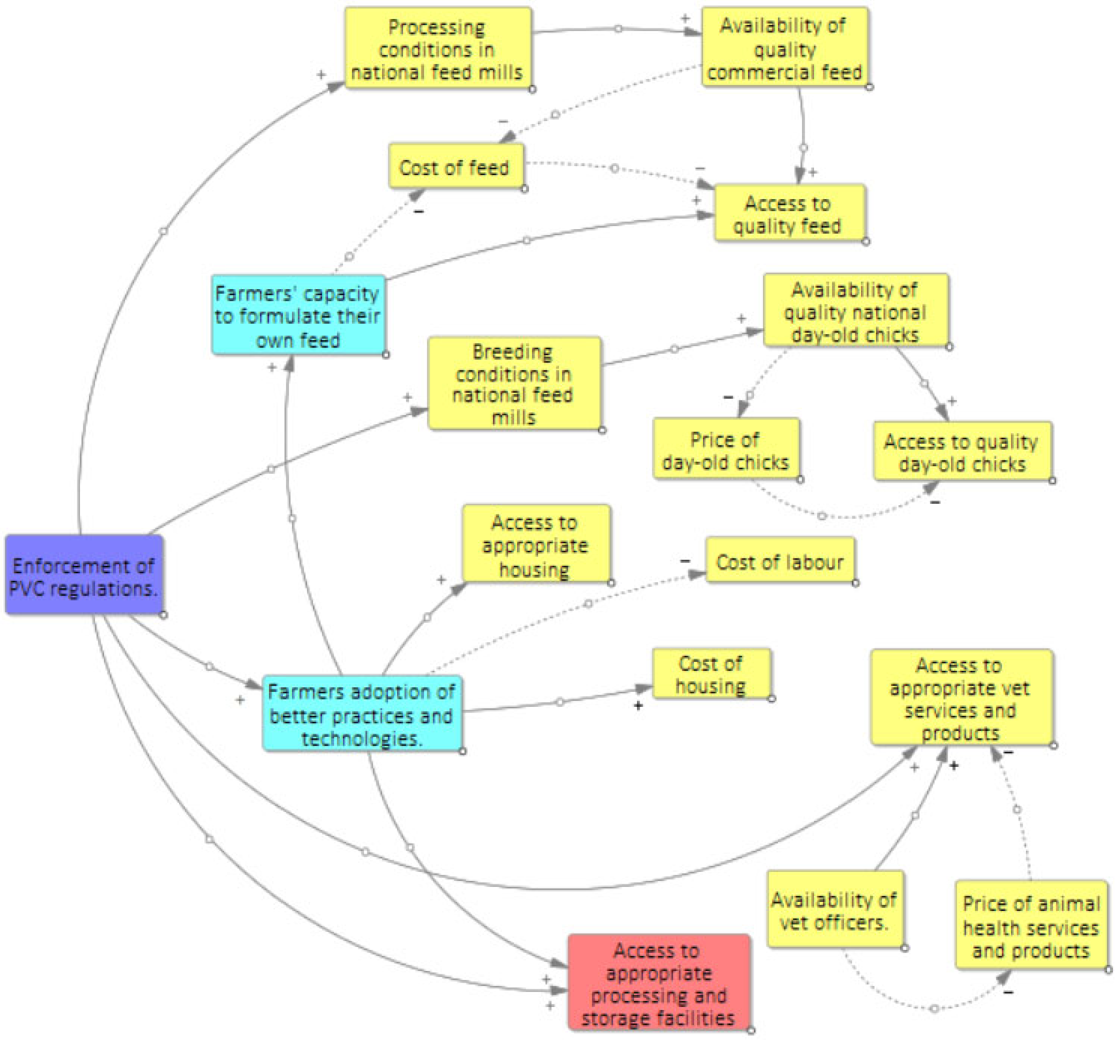


Figure D.19. Competitiveness feedback loop – Part II

Improving the access to quality inputs and facilities in the production system increase the growth rate of birds and reduce their health issues. Furthermore, all these improvements in the production system leads to better compliance with poultry meat quality standards.

A higher growth rate in poultry reduces production variable costs by reducing rearing time. Variable costs comprise the cost of feed, day-old chicks, and animal health-related ones, the last one being positively affected by birds' health issues; fixed costs, on the other hand, comprise labor and housing costs.

On the other hand, more integration of poultry farmers in the value chain implies better access to appropriate processing and storage facilities, which leads to greater product differentiation. Besides contributing to comply with poultry meat standards, access to appropriate processing and storage facilities brings new costs, which, together with poultry production variable and fixed costs, affect the total costs of poultry farming, determining the cost per bird ready to sell.

In the end, the three conditions above determine the competitiveness of domestic poultry meat, which will improve with better compliance with quality standards, more product differentiation, and lower cost per bird to be able to bargain and access more markets.

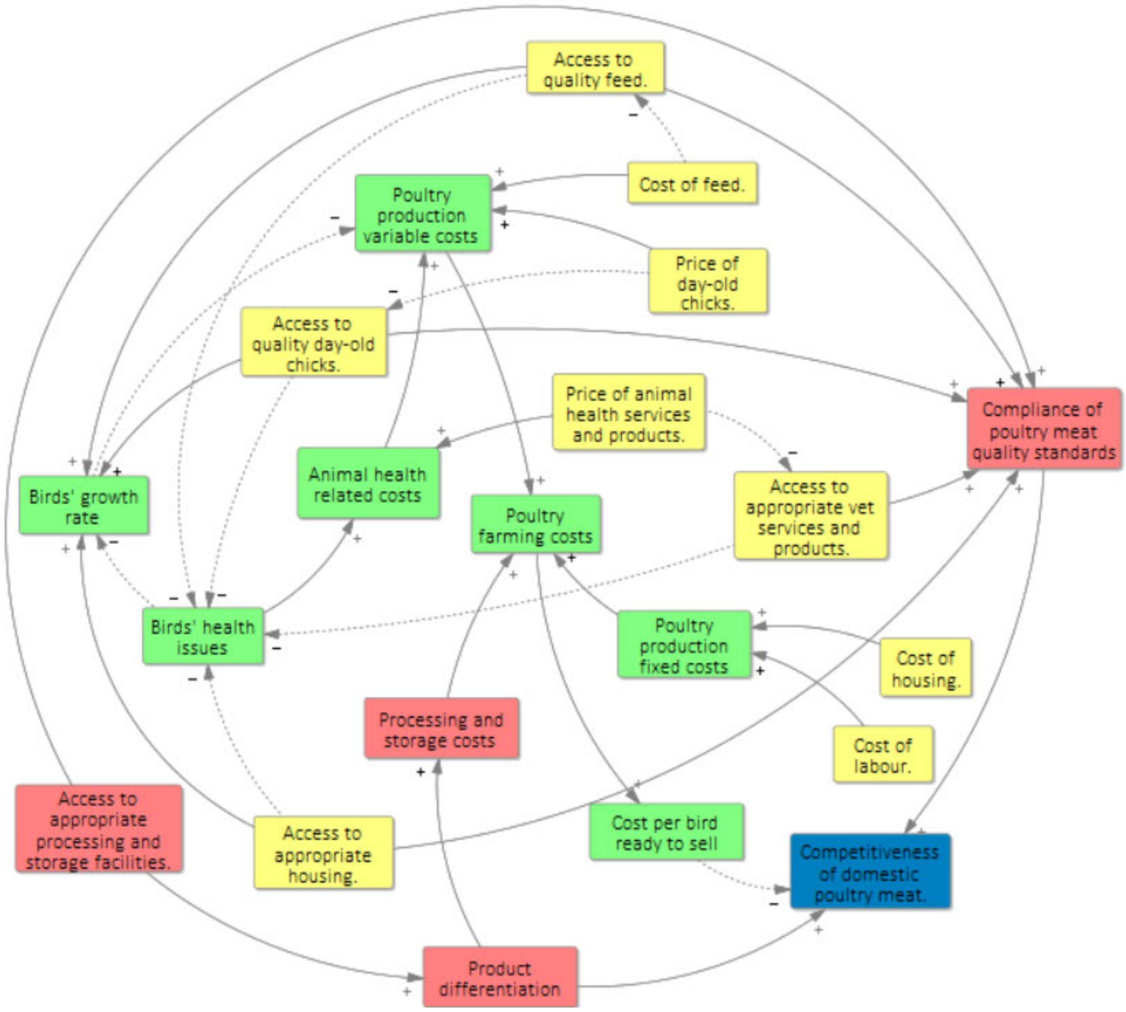


Figure D.20. Competitiveness feedback loop – Part III

- Knowledge transfer feedback loop

Poultry farmers that improve the profitability of their activity tend to share experiences with other farmers. That evidence-based knowledge transfer results in greater adoption of technologies and practices to improve poultry farming activity.

By adopting better technologies and practices, poultry farmers improve the poultry housing conditions on the farm and increase their integration in the value chain by self-formulating feed and accessing appropriate processing and storage facilities. Improving their access to quality inputs and facilities, poultry farmers better comply with poultry meat quality standards; on the other hand, by accessing appropriate processing and storage facilities, farmers can add more value to their products and wait until the best time to sell. In the end, by increasing product differentiation and improving the compliance of quality standards for poultry meat, farmers improve the competitiveness of domestic poultry meat, which allows them to access modern retail markets and increase the selling price of poultry meat products.

A better selling price translates into more incomes from poultry meat sales, which increase poultry farming profitability.

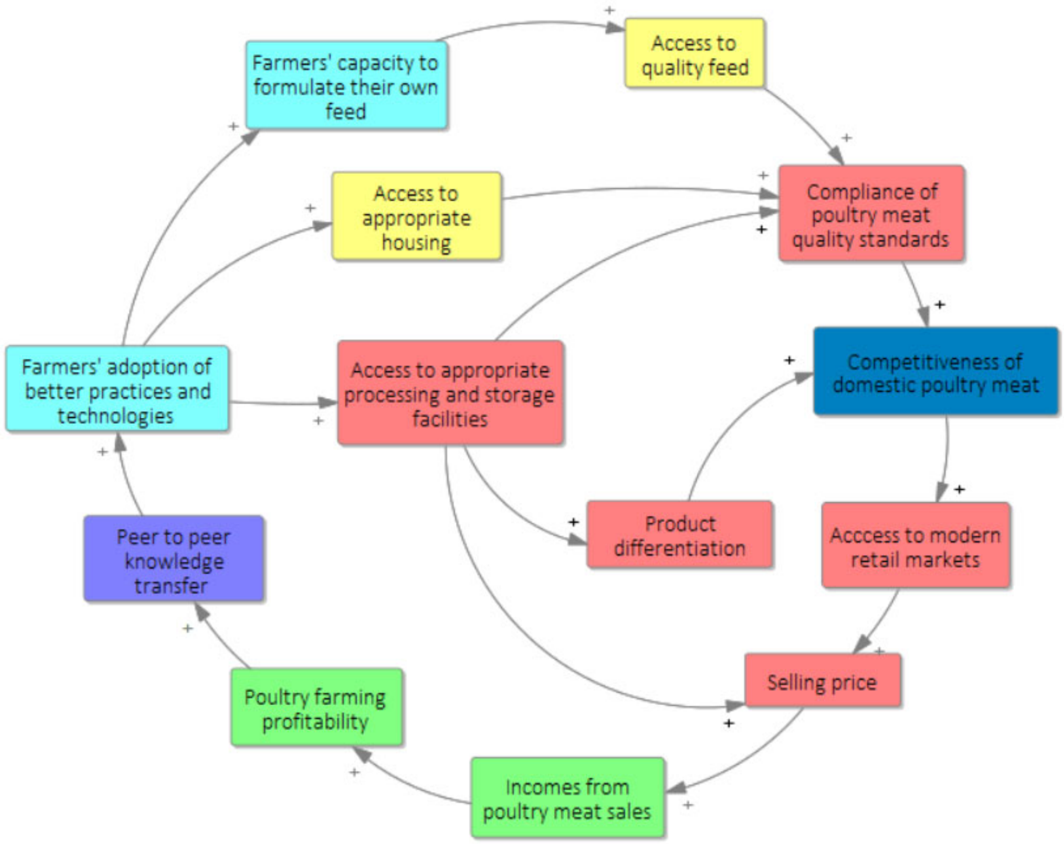


Figure D.21. Knowledge transfer feedback loop – Part I

The aforementioned improvements in the production system increase the growth rate of birds and reduce their health issues, which leads to a lower mortality rate. In turn, decreasing birds' mortality rate prevents falls in sales, while increasing their growth rate reduces the production variable costs by shortening the rearing time. Variable costs comprise the cost of feed, day-old chicks, and animal health-related ones, being the last one positively affected by birds' health issues; fixed costs, on the other hand, comprise labor and housing costs.

On the other hand, improving poultry farmers' access to appropriate processing and storage facilities brings new costs, which, together with production fixed and variable costs, comprise the total poultry farming costs. The higher the total costs, the higher will be the costs per bird ready to sell. This variable is important because it also affects the competitiveness of domestic poultry meat, i.e., if poultry farmers lower the cost per bird, they will be more competitive in the market, improving their chances to get higher prices for their products.

Finally, the costs of poultry farming and the incomes from the sale of poultry meat will determine the profitability of this activity, which, if increased, will contribute to a greater transfer of knowledge among poultry producers.

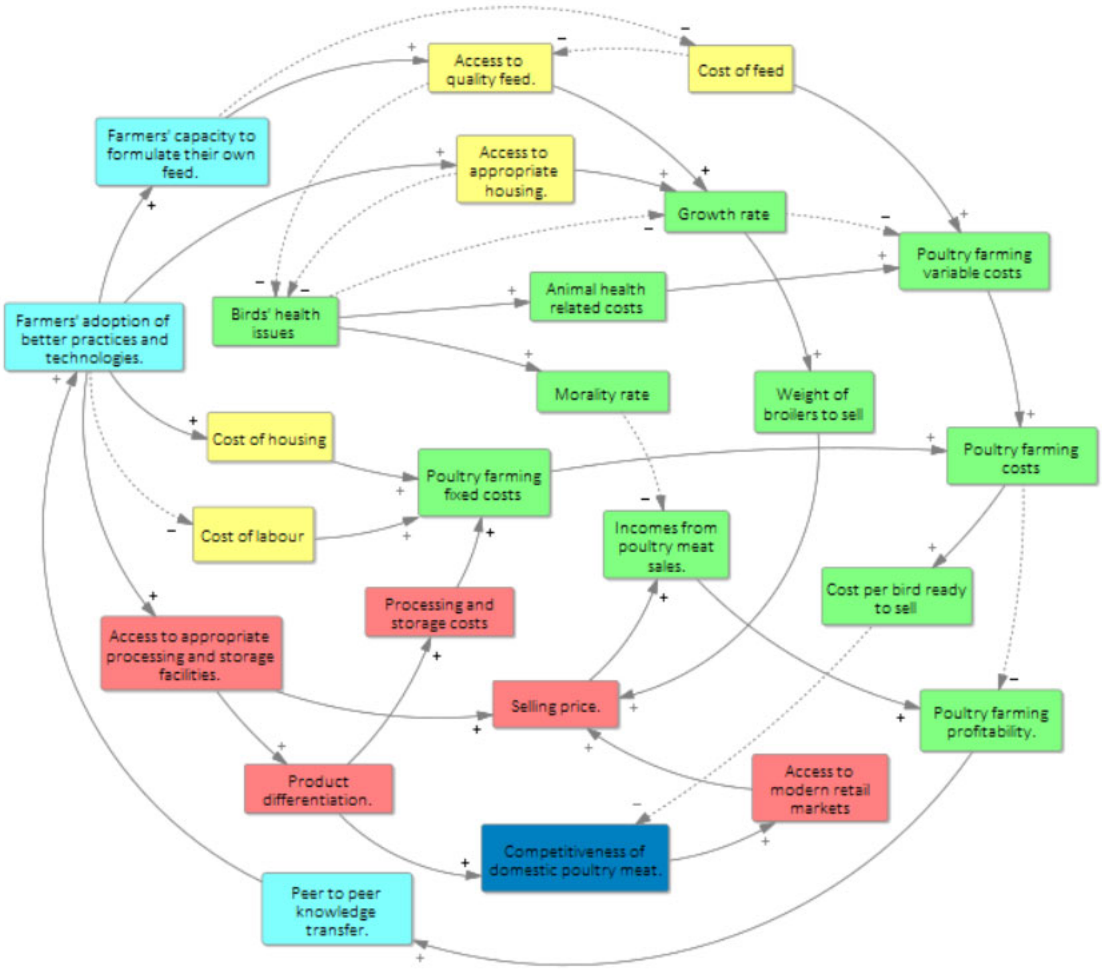


Figure D.22. Knowledge transfer feedback loop – Part II

- Flock size feedback loop

Having greater reinvestment capacity, poultry farmers tend to increase the flock size in their farms, which improves their eligibility for loans and strengthens their capacity to lobby R&D institutions and decision-makers.

By improving their access to loans, poultry farmers have more means to access training & technology transfer services and adopt practices & technologies to improve poultry farming. Furthermore, attending training sessions increases poultry farmers' awareness of poultry value chain regulations and allows them to give more feedback to R&D institutions and decision-makers. The more and better the poultry farmers' feedback to R&D institutions and decision-makers, the better the research and regulations will address the problems and needs of the poultry sector.

Promoting relevant research for poultry producers allows them to access training and technology transfer services targeted to their needs, encouraging thus a greater adoption of practices and technologies to improve poultry farming. On the other hand, improving the enforcement of regulations that address poultry key challenges, encourages the poultry farmers' adoption of better practices and technologies.

The poultry farmers' feedbacks to R&D institutions and decisions also depend on their capacity to lobby these agents; that is, the higher their capacity to lobby, the greater the feedback they give.

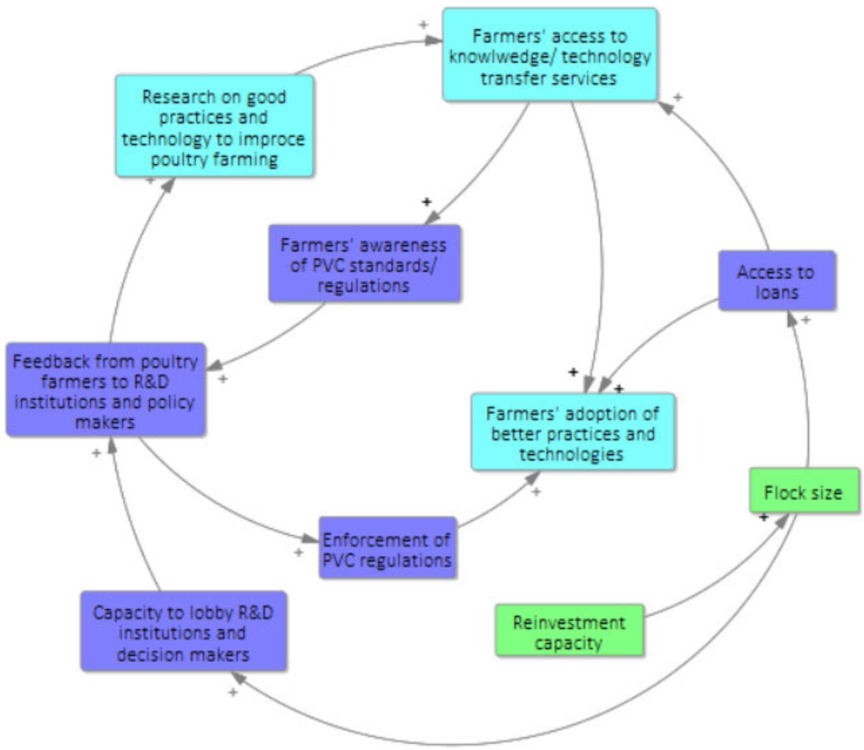


Figure D.23. Flock size feedback loop – Part I

Better enforcement of regulations related to the poultry value chain leads to improvements in domestic feed mills, hatcheries, and processing & storage facilities. In both feed mills and hatcheries, these improvements increase the availability of quality national feed and day-old chicks, lowering their price and improving the poultry farmers' access to them.

On the other hand, better enforcement of regulations drives greater adoption of practices and technologies, which allow poultry farmers to be more integrated along the value chain and improve their production system. Poultry farmers can integrate feed production in their activities by improving their self-formulation capabilities, or the processing and storage of their products, by improving their access to such facilities. Improvements in the production system come from the use of more appropriate and efficient practices and technologies in poultry housing, which leads to increased housing costs and decreased labor costs.

By having more access to loans, poultry farmers can better access quality feed, quality day-old chicks, and appropriate vet services & products. Furthermore, they will be able to adopt practices and technologies that improve the housing for poultry, increasing the housing-related costs and decreasing the labor costs.

Figure D.24. Flock size feedback loop – Part II

By accessing quality inputs, services and facilities, poultry farmers get higher growth rates and fewer health problems in poultry, which leads to lower mortality rates. Decreasing birds' mortality rate prevents falls in sales while increasing growth rate results in higher weights in broilers at sale age. In addition, greater integration of poultry farmers in the processing and storage activities results in greater differentiation of their products. Beyond the improvements in poultry productivity and product differentiation, access to quality inputs, services, and facilities contributes to poultry farmers' greater compliance with quality standards for poultry meat.

Enhancing compliance with poultry meat quality standards and offering differentiated products are two conditions that improve the competitiveness of domestic poultry meat.

Having more competitive products gives poultry farmers more access to modern retail markets, which, together with the weight of birds, positively affect the selling price of poultry meat products. Finally, the greater the selling price, the higher the incomes from poultry meat sales, which increases poultry farming profitability.

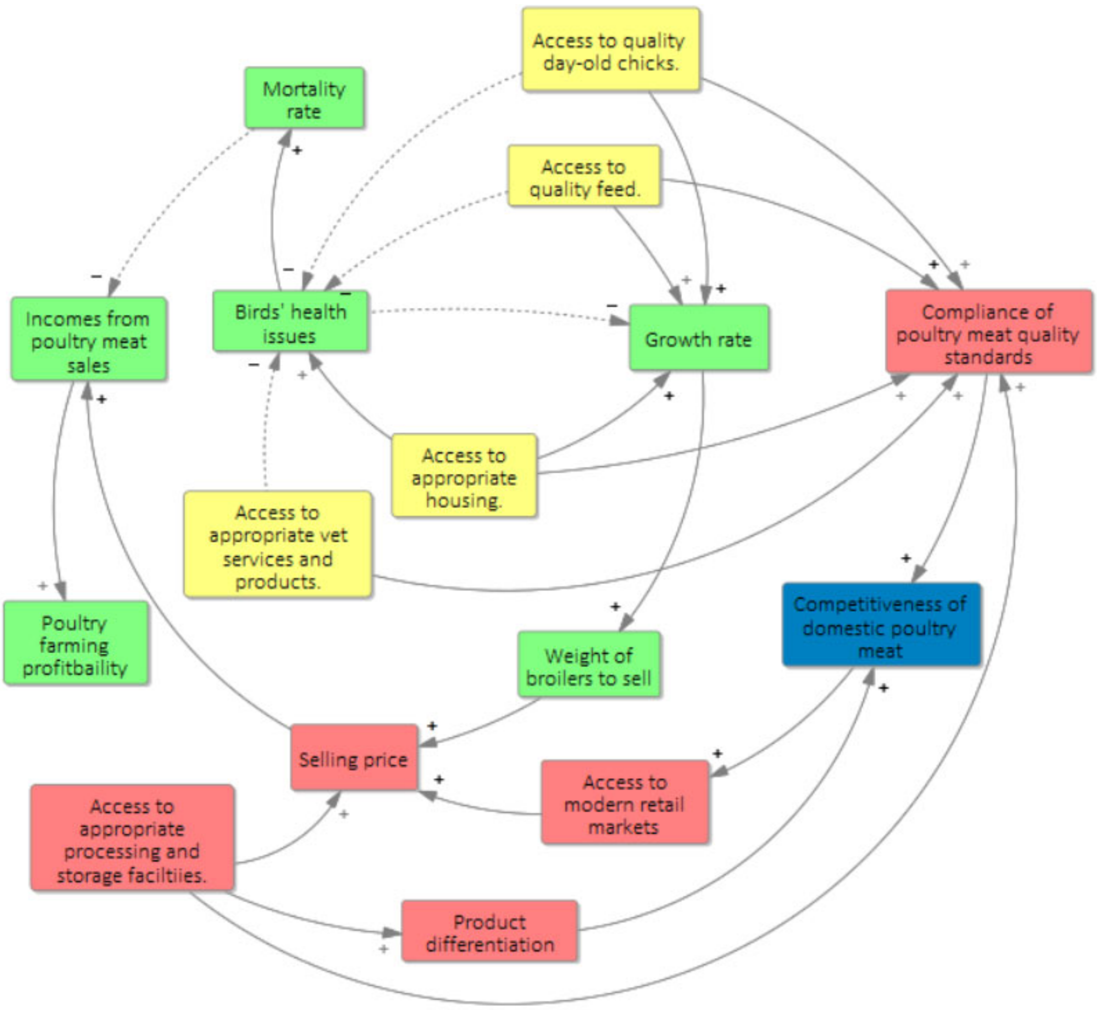


Figure D.25. Flock size feedback loop – Part III

Besides improving the birds' weight at sale age, increasing the growth rate of birds reduces the production variable costs by shortening their rearing time. Variable costs comprise the cost of feed, day-old chicks, and animal health-related ones, being the last one positively affected by birds' health issues; fixed costs, on the other hand, comprise labor and housing costs.

On the other hand, improving poultry farmers' access to appropriate processing and storage facilities brings new costs, which, together with production fixed and variable costs, comprise the total poultry farming costs. The higher the total costs, the higher will be the costs per bird ready to sell. This variable is important because it also affects the competitiveness of domestic poultry meat, i.e., if poultry farmers lower the cost per bird, they will be more competitive in the market, improving their chances to get higher prices for their products.

Finally, the costs of poultry farming and the incomes from the sale of poultry meat will determine the profitability of this activity, which, if increased, enhances poultry farmers' reinvestment capacity, and gives them the option to increase the flock size in their farms.

Figure D.26. Flock size feedback loop – Part IV

ANNEX E

Underlying narrative of the Causal Loop Diagram of the poultry system in Southern Senegal – Workshop February 2022

Below is presented the underlying narrative of the poultry system causal loop diagram. Firstly, the elements that define the poultry sector situation to be addressed are described, as well as the way they interrelate and behave as a whole. Secondly, the main feedback loops in the poultry system are outlined.

1. Causal Trees illustrating interrelations between elements of the poultry sector situation

    - Profits of poultry farming

Increasing the profits of poultry farming is achieved by reducing the total costs and/or increasing the incomes of poultry farming. To increase the incomes, farmers can increase the flock size, obtain a better selling price for their products, or/and increase the percentage of production sold after slaughter. To reduce the total costs, farmers can implement better practices or technologies, increase their capacity to pay farming costs regarding feed, day-old chicks, utilities, and land, and improve birds' productivity rates. The latter refers to reducing mortality rate and increasing birds' average final live weight, by improving animal health and welfare, therefore, decreasing disease outbreaks and incidence in animal health issues, which is affected by farmers' access to quality inputs, facilities, and services.

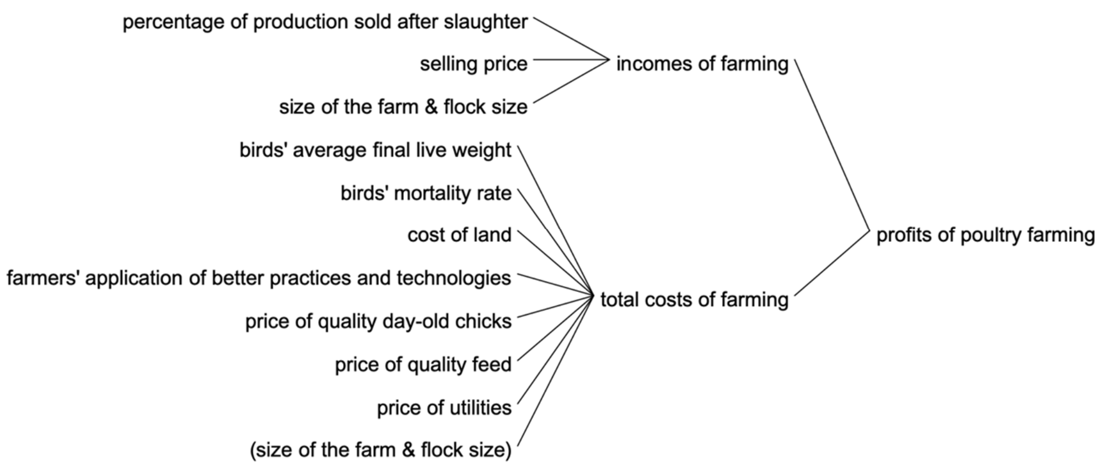


Figure E.1. Profits of poultry farming

- Total costs of farming

Total costs of poultry farming are affected essentially by the price of feed, day-old chicks, utilities, and land. Besides being affected by the price of inputs, services & facilities, poultry farming costs are affected by birds' productivity rates, flock size, and improvements in poultry farming activities, as detailed below.

- Price of quality feed:

Day-old chicks represent 25% of the total costs of farming. The price varies according to the origin of the egg, transaction costs, and the hatcheries' conditions, being better if they are official. Since few hatcheries are official and local eggs are cheaper than imported, the availability of day-old chicks from local hatching eggs and official hatcheries influences the price of quality day-old chicks.

- Price of utilities:

Particularly of basic services for poultry farming such as water and energy.

- Cost of land
- Birds' average final weight and mortality rate:

Both depend on disease outbreaks and incidence of animal health issues, but birds' average final live weight does it through birds' growth rate. Birds' mortality rate also depends on farmers' access to quality feed.

- Size of the farm/ flock size:

Depends on farmers' access to land and tenure - which is influenced by the cost of land - and on farmers' reinvestment capacity. Although enlarging the size of the farm and the flock size increases the total costs of farming, increasing the flock size also reduces the total cost per bird, because fixed costs are dissolved when the number of birds purchased at once grows.

- Farmers' application of better practices and technologies:

Initially, this will increase production costs by requiring an initial investment in equipment, technology, infrastructure, etc. But these better practices & technologies are expected to be, ultimately, more profitable.

Figure E.2. Total cost of farming

The aforementioned elements augment the total costs of farming, except a higher birds' average final live weight, and farmers' adoption of better practices and technologies, that reduce the total costs of farming.

- Performance of poultry production

Birds' growth and mortality rate are two indicators of the performance of poultry production, which is improved directly by farmers’ access to quality inputs, facilities, and services, and by the reduction of disease outbreaks and incidence of animal health issues. At the same time, farmers’ access to quality inputs, facilities, and services, contribute to the reduction of disease outbreaks and animal health issues. Birds’ growth, in turn, leads to a higher weight of birds at sale age, because having a higher growth rate, birds reach a higher weight at 35 days, therefore birds’ growth rate directly increases birds’ average final live weight.

  - Birds’ mortality rate can be directly reduced by decreasing disease outbreaks and animal health issues, and by greater farmers’ access to quality feed. At the same time, farmers’ access to appropriate housing, quality day-old chicks, and veterinary services, products, and vaccines, improve sanitary conditions and animal welfare, which translates into fewer disease outbreaks and animal health issues, reducing birds’ mortality rate.

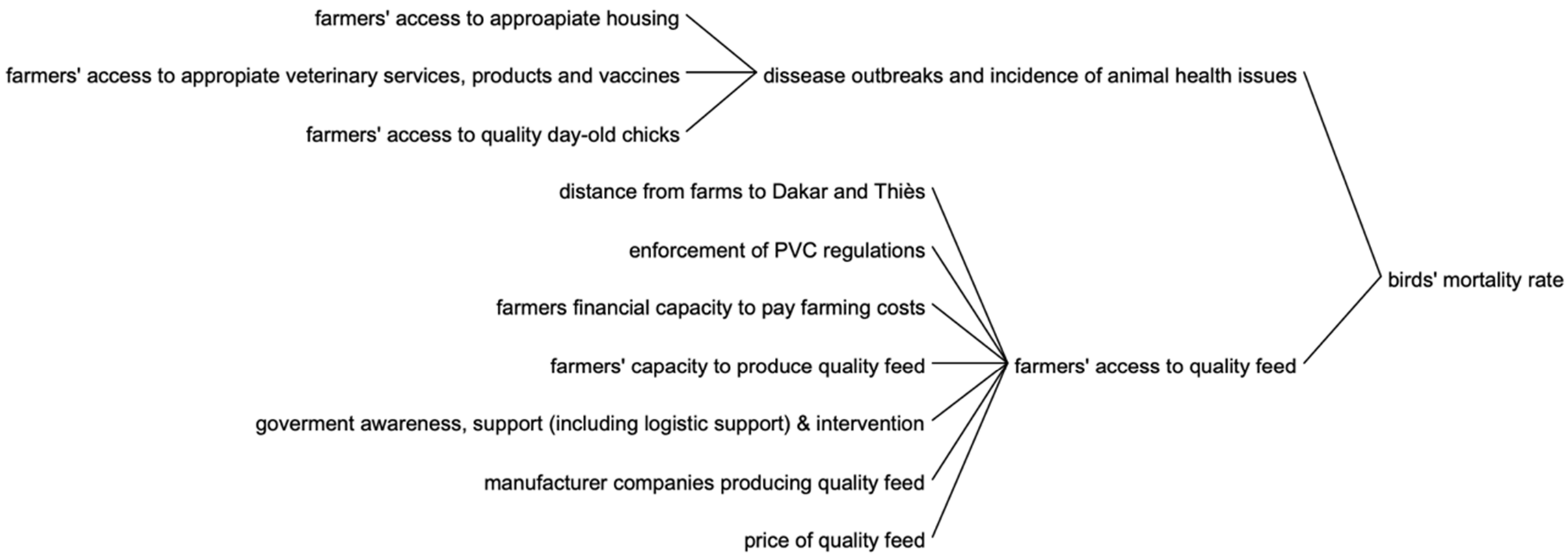


Figure E.3. Birds' mortality rate

- Birds' growth rate is improved by a decrease in disease outbreaks and animal health issues, and by greater farmers' access to quality feed, quality day-old chicks, because they are vaccinated and present a better feed conversion rate, and appropriate housing. This last one requires appropriate conditions of light, humidity, ventilation, water drainage, drinking trough, among others that affect the growth conditions of poultry.

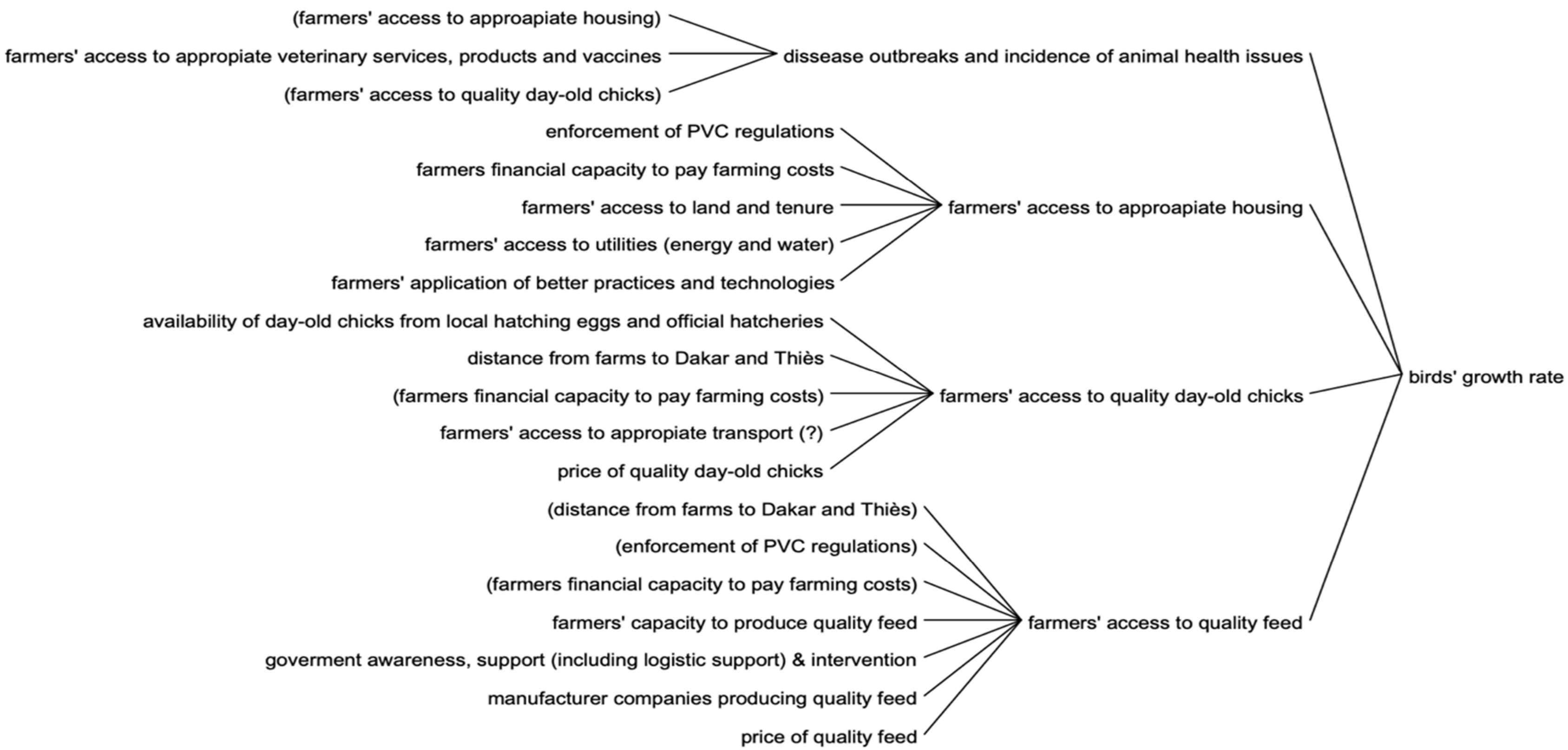


Figure E.4. Birds' growth rate

- Accessing quality inputs, facilities, and services

Farmers’ access to quality inputs, facilities, and services of poultry farming depends on their availability and on farmers’ capacity to afford them. Accessing quality feed and quality day-old chicks is essential for poultry farming, besides representing 82% of the costs of inputs. Furthermore, government awareness, support & intervention, enforcement of poultry value chain regulations, and farmers’ financial capacity to pay farming costs play an important role in enabling poultry farmers better access to quality inputs, facilities, and services.

  - Farmers’ access to quality feed:

Poultry farmers can access quality feed by buying it from resellers, or by producing quality feed themselves. The long distances between the poultry farms and Dakar or Thiès, where feed manufacturer companies are located, difficult the farmers’ access to commercial feed, making it less affordable, by increasing the price of feed due to higher transaction costs; the price of feed could be also minimized with a higher presence of resellers and feed manufacturers companies. Membership in breeders’ associations would indirectly increase government awareness, support, intervention, and enforcement of regulations, leading to greater access to quality feed.

Farmers’ affordability to pay quality feed is measured by farmers’ financial capacity to pay farming costs, which can be increased if farmers get more profits or/and access to loans.

Another way poultry farmers can access quality feed is by producing it themselves. Some conditions that improve farmers' capacity to produce quality feed are access to alternative feed inputs, access to land, access to equipment and techniques for self-formulation, and membership in associations. The latter is because being a member of an association would give farmers’ the opportunity to self-formulate feed collectively.

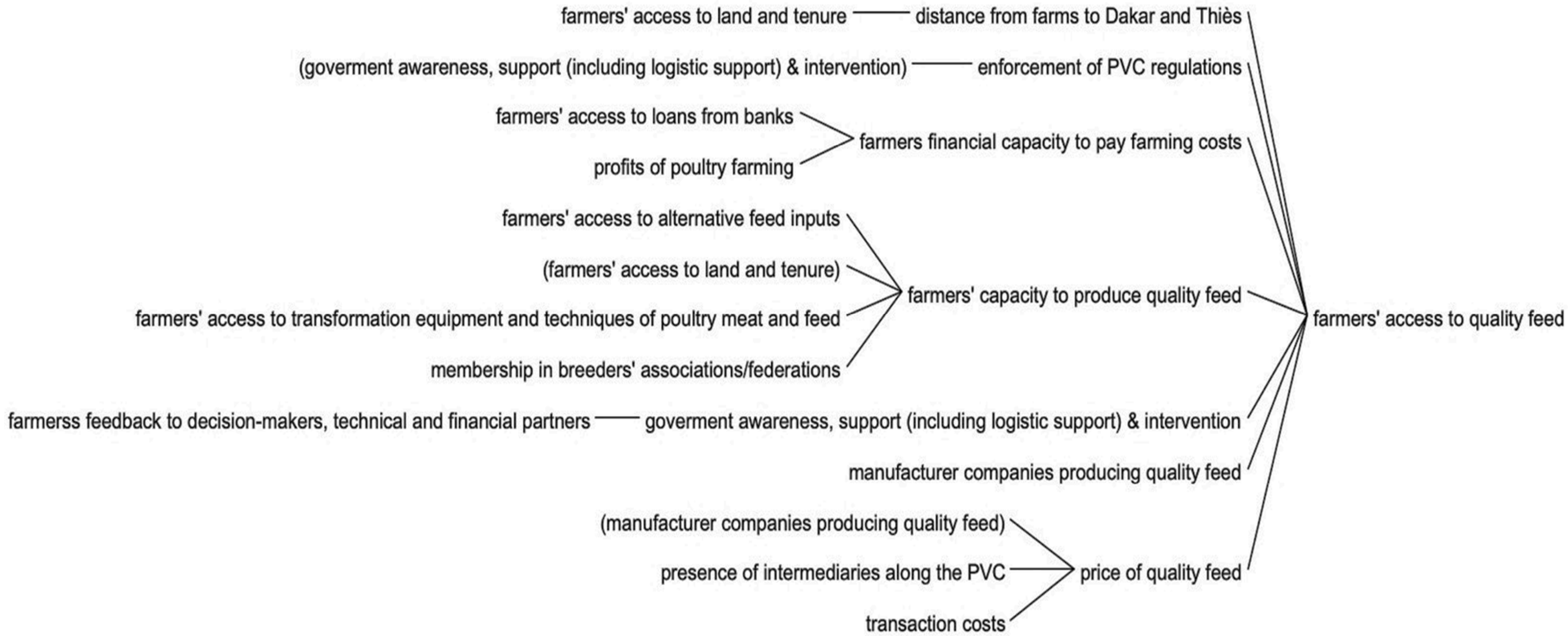


Figure E.5. Farmers' access to quality feed

- Farmers’ access to day-old chicks:

Poultry farmers can only access quality day-old chicks in national hatcheries, due to state regulations. Hatcheries can produce chicks from imported or local hatching eggs, being the cost and price of local eggs considerably cheaper than imported ones. However, chicks produced from local eggs are fewer than those produced from imported eggs, therefore less available in national hatcheries. The quality of day-old chicks is determined by the hatcheries’ compliance with quality standards, which includes vaccinations, control of diseases, origin, and hatcheries conditions. If hatcheries comply with standards means they are official, but, even if the number of hatcheries in Senegal has grown during the last years, few of them are official. For the reasons explained, the availability of day-old chicks from local hatching eggs and official hatcheries determines the farmers’ access to quality day-old chicks.

As in feed, the long distance between the farms and Dakar or Thiès, where the biggest hatcheries are located, difficult farmers’ access to day-old chicks, making it less available or less affordable, this last by increasing the price of day-old chicks due to higher transaction costs. The price of quality day-old chicks can be lower, on the other hand, enhancing the production of chicks from local eggs in official hatcheries increases.

Farmers’ affordability to pay quality day-old chicks is measured by farmers’ financial capacity to pay farming costs, which can be increased if farmers get more profits or/and access to loans.

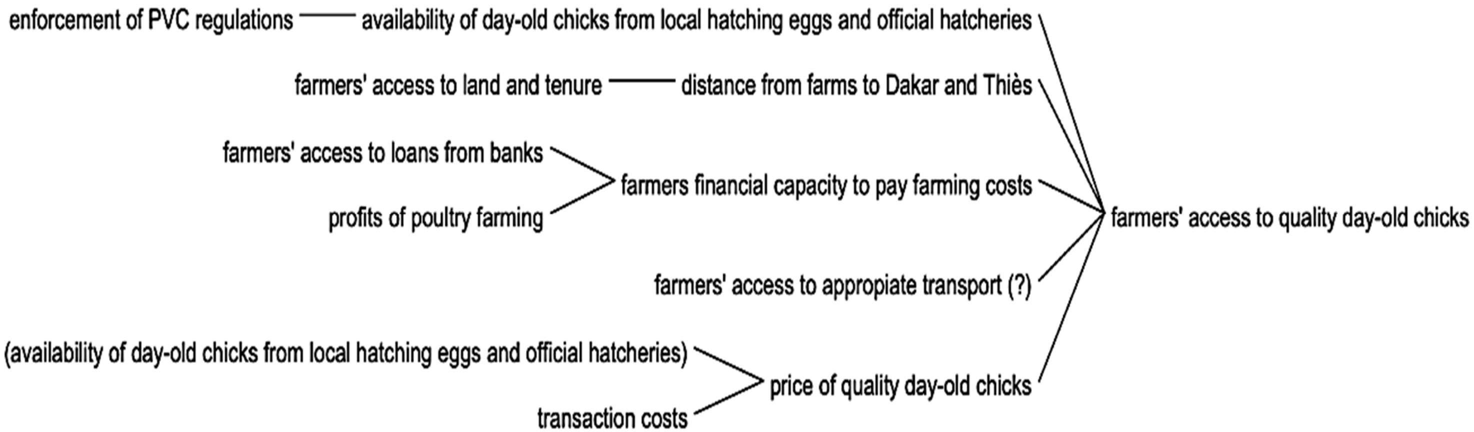


Figure E.6. Farmers' access to quality day-old chicks

- Farmers' access to appropriate veterinary services, products, and vaccines :

Farmers' access to appropriate veterinary services, products, and vaccines, as with feed and day-old chicks, depends on the distance from farms to Dakar and Thiès, and on farmers' financial capacity to pay poultry farming costs. It should be noted that, having higher distances between the poultry farms and Dakar or Thiès does not reduce farmers' access to veterinary services & products because of the lack of availability of veterinary officers, since there is at least one veterinary officer per department, but because of the lack of logistic support, including facilities. The ministry of livestock and poultry is in charge of providing logistic support for veterinary services, products, and vaccines, therefore government awareness, support, and intervention, and the enforcement of regulations can increase access to appropriate veterinary services, products, and vaccines.

The price of veterinary services, products, and vaccines is affordable for farmers and represents 2% of the total costs, therefore is not included per se, and the relationship is done through birds' productivity rates as mortality and growth, which indirectly are affected by access to veterinary services.

Finally, farmers can increase their access by getting involved in poultry national vaccination campaigns, meaning that farmers apply better practices and technologies because they get the knowledge of these campaigns from the government.

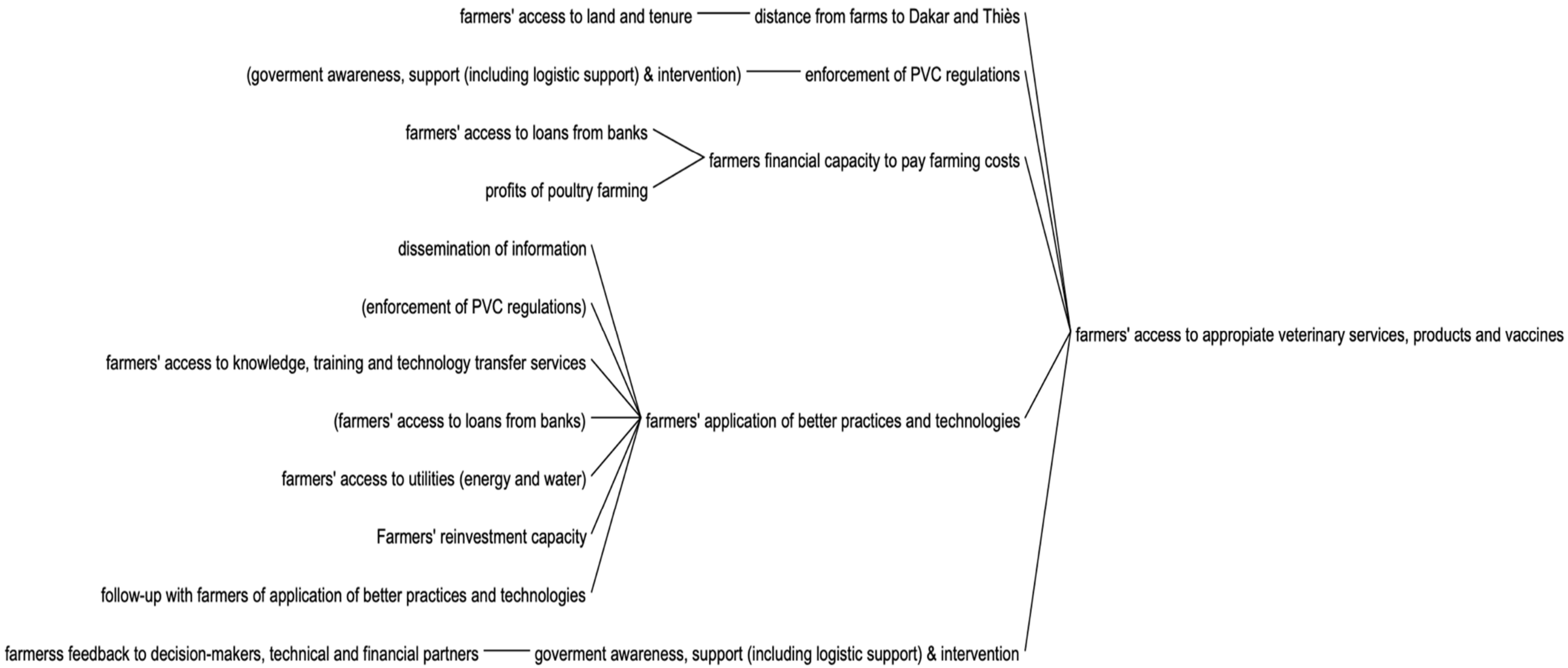


Figure E.6. Farmers' access to quality day-old chicks

- Farmers’ access to appropriate housing, utilities, land & tenure:

As in the elements mentioned above, farmers’ access to appropriate housing depends on the enforcement of poultry value chain regulations, farmers’ financial capacity to pay farming costs, and farmers’ application of better practices and technologies, the latest because, by being aware of the optimal housing conditions, farmers will apply more practices and technologies that help them to reach those conditions, and finally access to appropriate housing. And, as in veterinary services, the price of housing is affordable for farmers and represents 6% of the total costs, so the relationship is done through birds’ productivity rates as mortality and growth.

On the one hand, access to utilities (water and energy) is essential for access to appropriate housing because it is needed to accomplish quality standards, which, in turn, also affect birds’ growth and disease outbreaks. Access to energy is particularly important in the first 10 days of breeding, but there is a problem of energy availability in rural areas, and the price of water and energy makes it difficult to access utilities because farmers cannot afford it. On the other hand, farmers need to improve their access to land and formalize their tenure to improve housing conditions. Many conditions make land ownership difficult, such as the government assigning land use for other activities and projects non-related to small or medium agriculture and livestock, and the higher prices of land, which makes it not affordable for poultry farmers. Poultry farmers’ access to utilities and land & tenure can be increased by improving government awareness, support, and interventions to address poultry farming needs. Furthermore, improving poultry farmers’ membership in associations can help them access utilities.

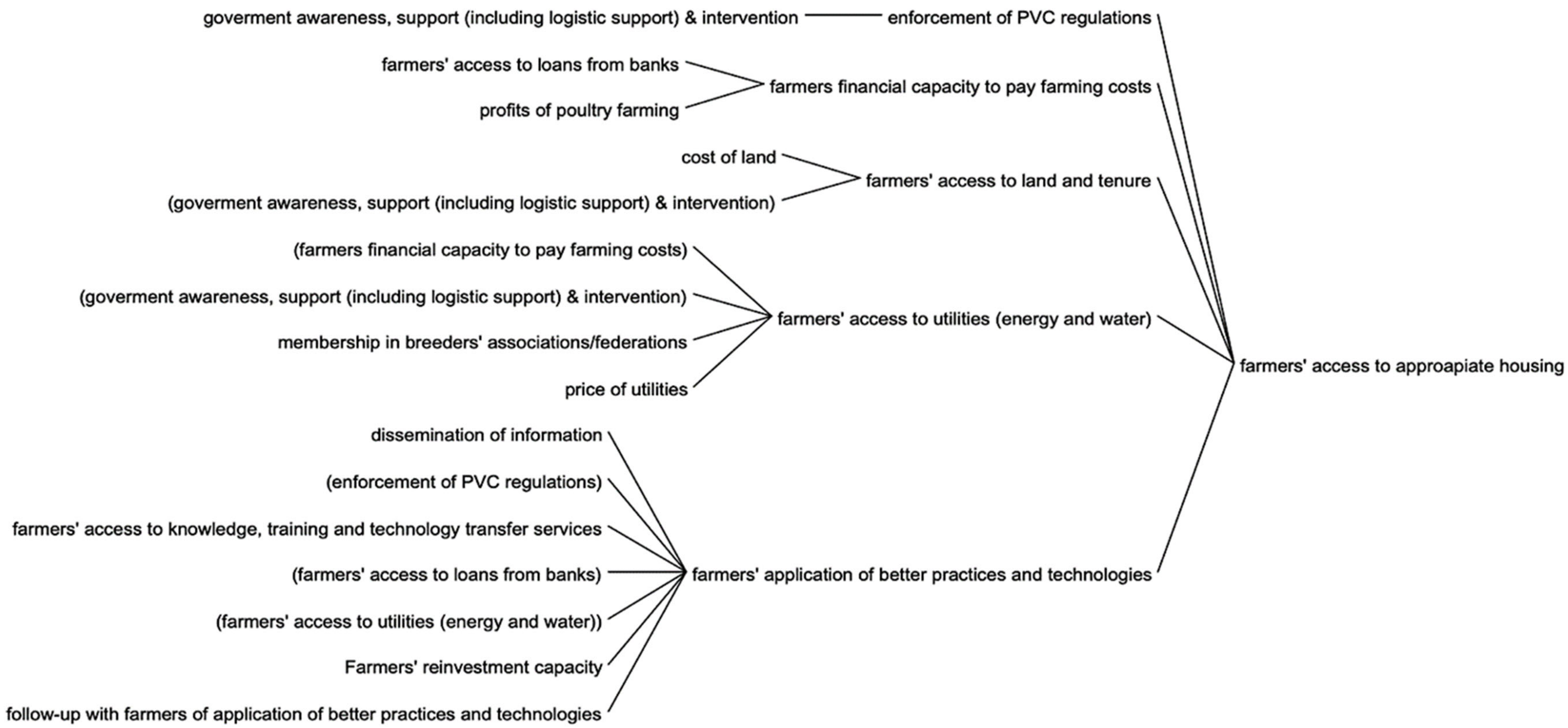


Figure E.7. Farmers' access to appropriate housing

- Farmers' access to market and selling price of live birds and poultry meat products

The selling price of live birds and poultry meat products depends on farmers' access to the market, the final live weight of the bird, the total cost per bird, and the application of better practices and technologies.

- Farmers' access to market/ dissemination of poultry meat products:

High-end markets are in Dakar and Thiès, too far from farms, so farmers don't sell poultry meat to high-end markets, such as large retail stores, but to intermediaries that facilitate and negotiate the price in the markets. Furthermore, these large retail stores require compliance with quality poultry meat standards, which are difficult to accomplish by farmers, who end up selling live birds in local markets, restaurants, and hotels in the city. Being part of a breeders' association increases poultry farmers' bargaining power, allowing them to access high-end markets and improve the selling price. It would also allow farmers to give feedback to the government and therefore raise government awareness, support, and intervention, which means that through favorable politics for farmers, farmers could have greater access to high-end markets and a better selling price.

- Birds' final live weight:

Increasing the final live weight of birds allows farmers to sell their live birds for a better price. Furthermore, it increases farmers' bargaining power, facilitating their access to high-end markets where they obtain higher selling prices.

- Farmers' adoption of better practices and technologies:

Due to difficulties accessing and affording utilities, storage facilities - which are in Dakar and Thiès - and conservation methods, poultry farmers often have to sell their birds to intermediaries, who offer them lower prices. To overcome that situation, poultry farmers can apply practices and technologies to store, transport, and transform their products under appropriate sanitary and safety conditions and at affordable costs. The access to appropriate storage, transportation, and transformation equipment and techniques increases the selling price. On one hand, the access to preservation and transportation of products during high production in rural areas, would give farmers' the opportunity to decide when to sell their products, achieving a better selling price, for example, when there is a higher demand or/and a higher market price. On the other hand, the access to transformation equipment and techniques would increase the selling price, through the diversification of poultry meat products, meaning that farmers would be able to offer different kinds of products such as smoked chicken, chicken burgers, etc., leading to a higher farmers' access to high-end market.

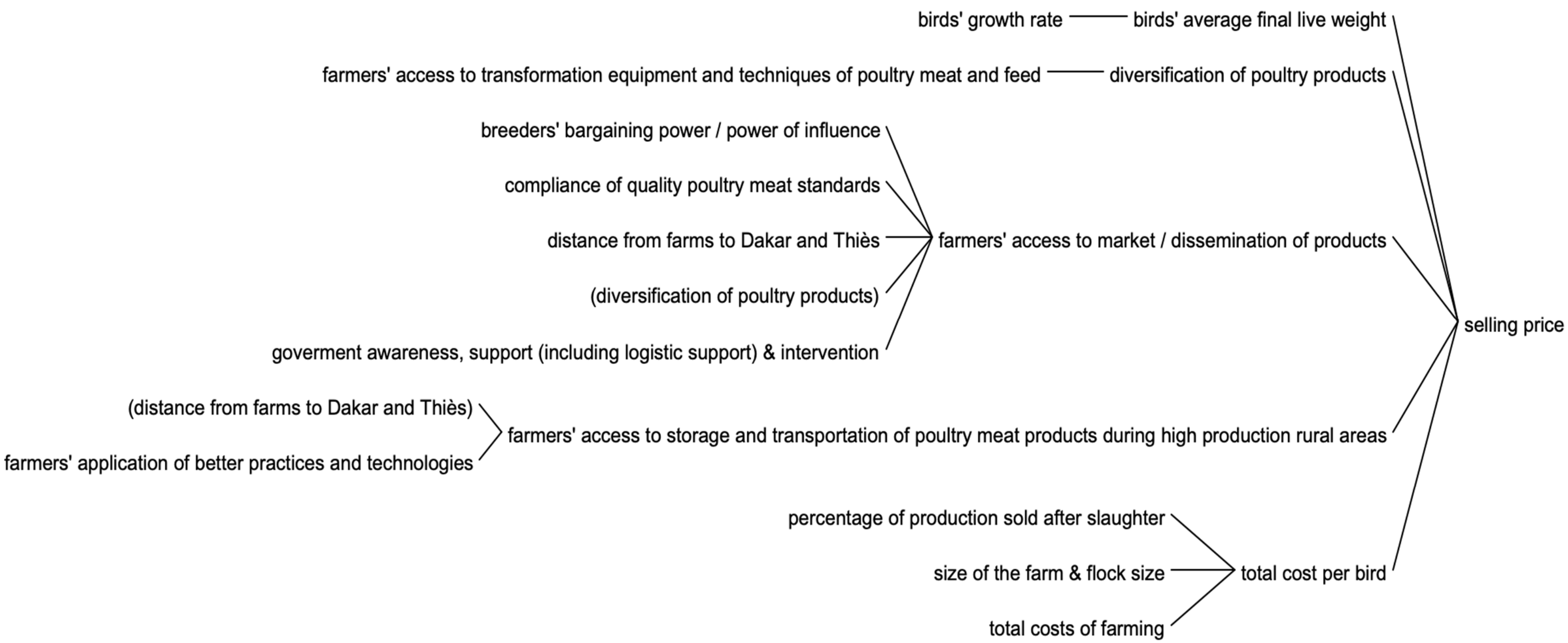


Figure E.8. Selling price

- Compliance with quality poultry meat and live birds' standards:

The compliance of quality poultry meat and live birds' standards depends on disease outbreaks and incidence of animal health issues, and on farmers' access inputs, facilities, and services, which at the same time, improve sanitary conditions and animal welfare, translating into fewer disease outbreaks and animal health issues.

Farmers' access to inputs, facilities and services that decrease disease outbreaks and incidence of animal health issues are, appropriate housing, quality day-old chicks, and veterinary services, products, and vaccines. The latter is needed during the whole production process, before starting, for advice and technical support -choice of strains, appropriate treatment, installation rules, equipment, and biosecurity-, at the beginning, for vaccinations, and permanently for the control of epidemics. For these reasons, it also directly affects the compliance of quality poultry meat & live birds standards.

Finally, farmers' access to quality feed, approved slaughterhouses, storage, transportation and transformation equipment and techniques, which directly affect the compliance of quality standards, help them to achieve the hygienic and microbiological standards controlled by the government.

Figure E.9. Compliance with quality poultry meat and live birds standards

- Farmers' educational resources and application of better practices and technologies:

Farmers' application of better practices and technologies depends, among others, on economical elements such as access to loans from banks, and reinvestment capacity, because then farmers would have more means to afford the costs of implementing improvements. Access to knowledge, training, and technology transfer services, as well as dissemination of information, are key elements raising farmers' awareness leading to the application of better practices and technologies. Farmers' access to utilities, which can be increased by government intervention, is crucial for implementing improvements and accessing information that can only be found online. The government also influences the implementation of improvements from farmers through enforcement of poultry value chain regulations, and facilitating their access to knowledge, training, and technology transfer services.

The follow-up with farmers of the application of better practices & technologies, and the development of knowledge & technology transfer services in response to poultry farmers' needs, are increased by farmers' feedback to the government and R & D institutions. Both increase the implementation of improvements, but following up does it directly, while the development of knowledge & technology transfer services does it by increasing farmers' access to those services. Finally, the access that R & D institutions have to foreign knowledge and technology influences the development of knowledge, and technology transfer services in response to poultry farmers' needs.

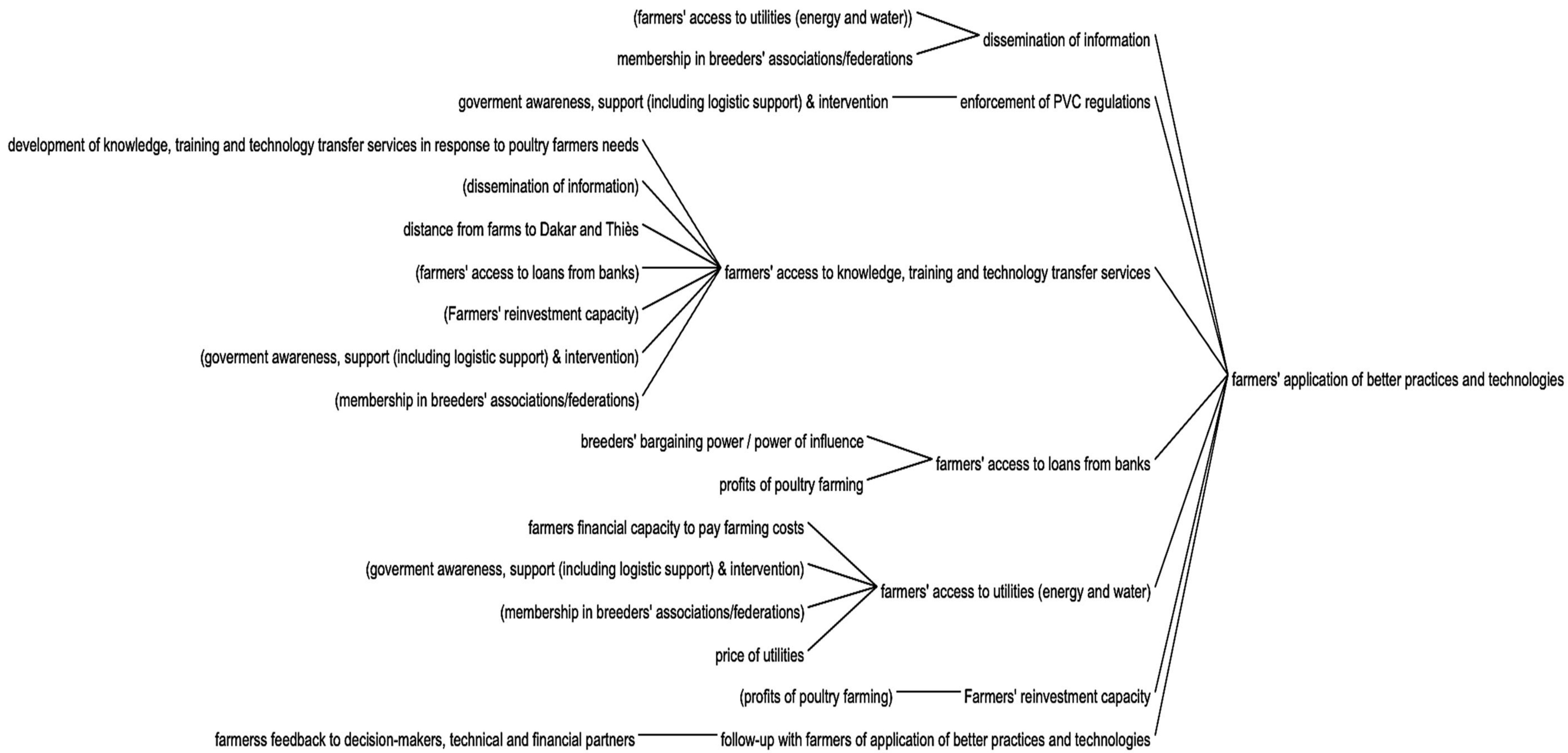


Figure E.10. Farmers’ application of better practices and technologies

2. Feedback loops in the poultry system

- Reinforcing farmers' access to inputs, facilities, and services through performance and productivity of poultry farming

Increasing **birds' growth rate**, and therefore, **birds' average final live weight**, on one hand, increases the selling price, and reduces total costs of farming, turning into higher profits of poultry farming. Total costs of farming can also be reduced by a lower birds' mortality rate. On the other side, it increases farmers' bargaining power, therefore their access to markets, being these markets large retail companies or high-end markets, which allow farmers to also increase their selling price and their percentage of production sold after slaughter, therefore increasing their incomes and profits of poultry farming. These are two ways of increasing profits of poultry farming, therefore farmers' financial capacity to pay farming costs, by achieving the performance of birds' productivity indicators.

Another way of farmers to increase their financial capacity to pay farming costs is by increasing their access to loans from banks, being this more difficult for farmers, because of high guarantees, high loan rates, repayment requirements with very short deadlines, etc.

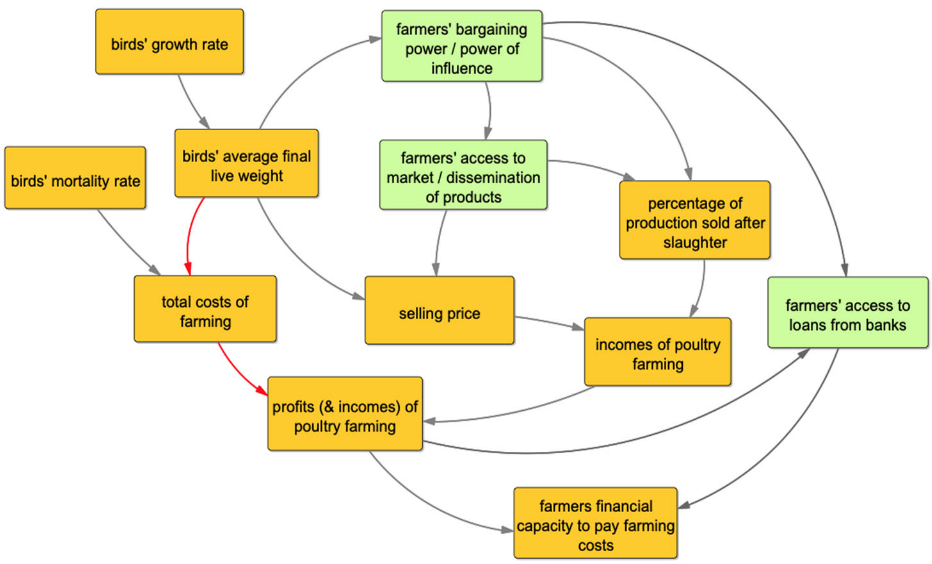


Figure E.11. Access to inputs, facilities, and services feedback loop – Part I

Increasing **farmers' capacity to pay farming costs**, allows farmers' access to multiple inputs, facilities and services, such as utilities, housing, health, day-old chicks, and feed. All of it increases the compliance of quality poultry meat and live birds' standards, directly, or by a decrease in disease outbreaks and incidence of animal health issues. Access to appropriate housing and day-old chicks directly increase birds' growth rate. The compliance of quality poultry meat and live birds' standards increases farmers' bargaining power and farmers' access to market, reinforcing farmers' capacity to pay farming costs. Birds' growth rate also reinforces farmers' capacity to pay farming costs, by the two ways explained above.

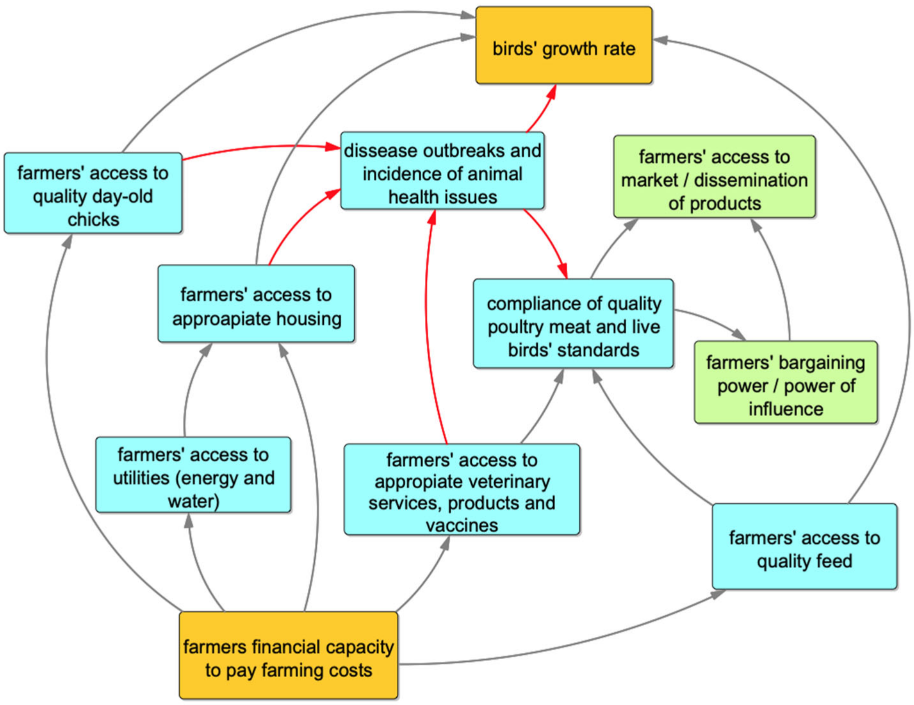


Figure E.11. Access to inputs, facilities, and services feedback loop – Part II

- Reinforcing farmers' integration along the poultry value chain through reinvestment capacity and application of better practices and technologies

Increasing profits of poultry farming, therefore **reinvestment capacity**, increases on one hand, farmers' affordability to access new knowledge, training and technology transfer services, which results in farmers' awareness. And, on the other hand, farmers' application of better practices and technologies, because they would be able to afford the costs of it. Both access to knowledge and the application of improvements can also be increased by dissemination of information in associations, and by farmers' access to loans from banks.

Other factors as, the development of knowledge according to poultry farmers' needs, and government awareness, technical and financial support, increase farmers' access to knowledge, training and technology transfer services, but the distance from farms to Dakar and Thiès, difficulties the access, because farmers don't have the resources to travel that far. If farmers' access to knowledge, training and technology transfer services increases, then farmers' raise awareness which encourages their implementation of improvements. But there are also other factors that influence the implementation of improvements by farmers, such as access to utilities which are essential to have water and energy, and the monitoring or follow-up with farmers of the activities and improvements they applied.

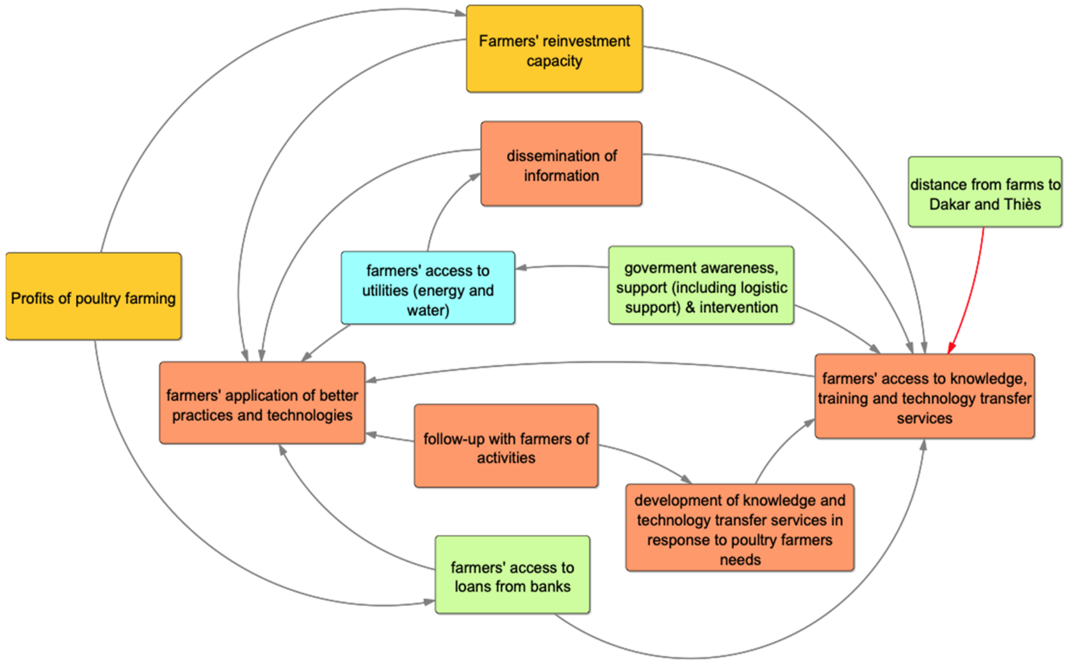


Figure E.12. Integration along the value chain feedback loop – Part I

Farmers' application of better practices and technologies can have an impact on farmers' access to inputs, facilities and services of poultry farming as housing, health -veterinary services, products and vaccines-. And, on farmers' access to new inputs, facilities and services, such as storage, transportation, transformation equipment and techniques, and alternative inputs for self-production of feed. Access to health services and products, storage, transportation, and transformation equipment and techniques directly increase the compliance of quality poultry meat and live birds' standards, while access to housing, and to alternative feed inputs, do it indirectly. The first one, does it through a decrease in disease outbreaks and incidence of animal health issues, and the second one does it through increasing farmers' capacity to self-formulate feed, therefore, increasing their access to quality feed.

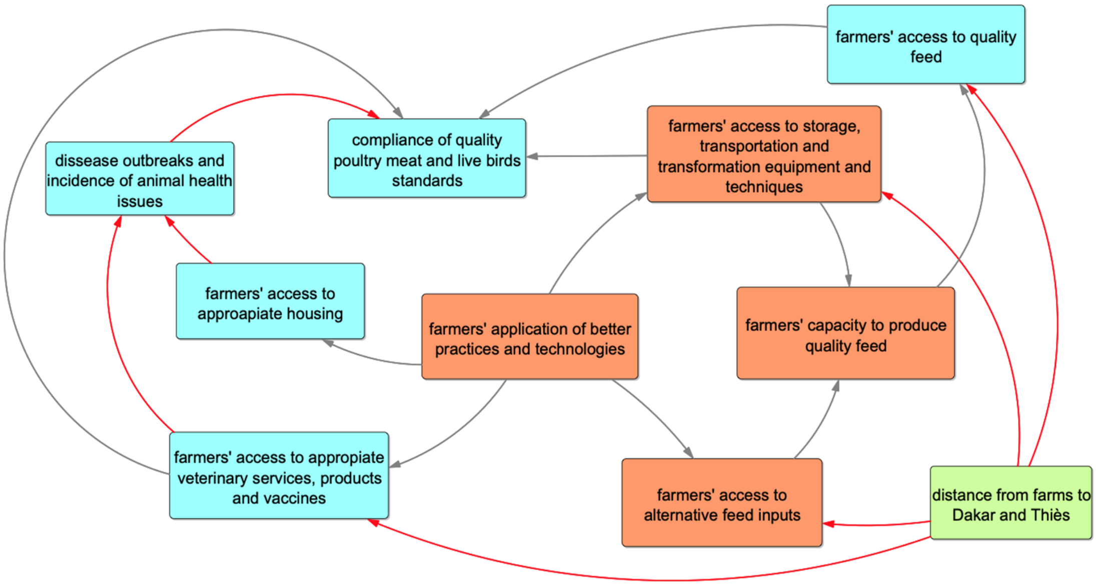


Figure E.13. Integration along the value chain feedback loop – Part II

Increasing the **compliance of quality poultry meat and live birds' standards** can be developed in two ways. The first one, increasing farmers' bargaining power, and therefore farmers' feedback to R&D institutions and the government because they can share their interests and concerns, leading to a higher follow-up with them of the activities, or/ and increasing access to loans from banks because they can negotiate better conditions. Both, access to loans from banks and follow-up with farmers of the activities, reinforce farmers' application of better practices and technologies. The second one, increasing farmers' access to markets, allowing farmers to increase their selling price and their percentage of production sold after slaughter, since they can sell their products in more places or in bigger quantities. The diversification of poultry products allows farmers to access new markets, and it also directly increases the selling price, since the product has an added value when it is processed. The selling price can also be increased by access to storage because then farmers' can decide when to sell them without losing its quality. Increasing the selling price and the percentage of production sold after slaughter increase incomes and profits of poultry farming, and therefore reinforcing reinvestment capacity and farmers' application of better practices and technologies.

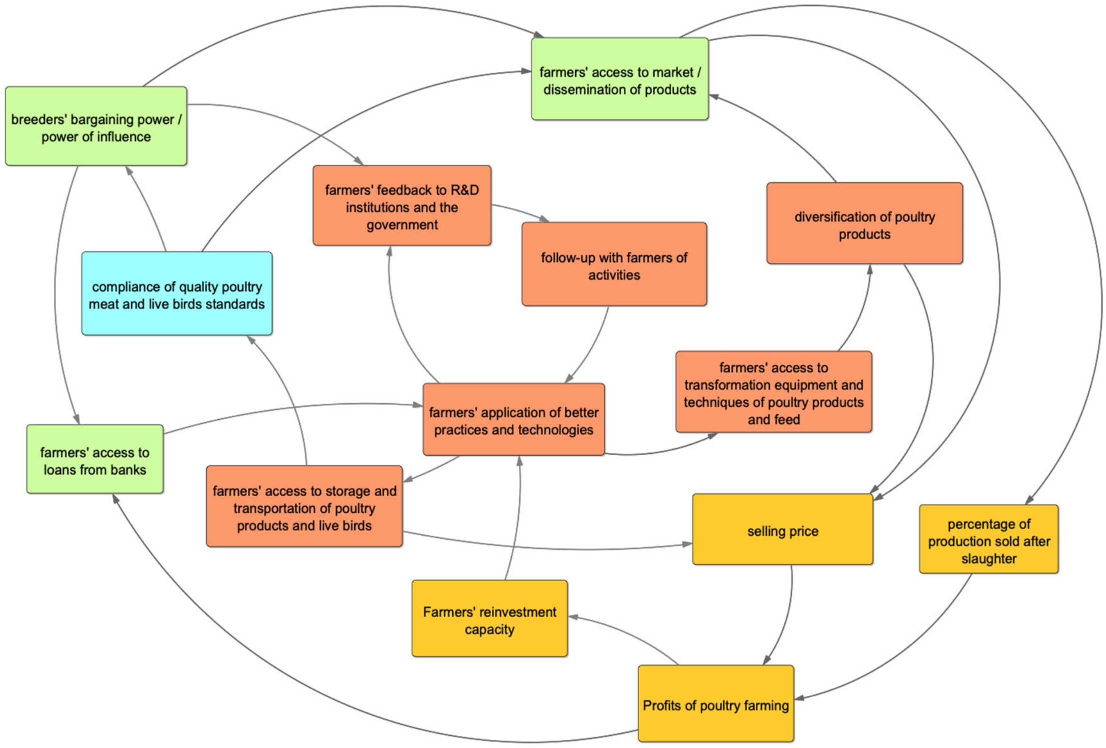


Figure E.14. Integration along the value chain feedback loop – Part III

The reinforcing feedback mentioned above facilitates farmers' integration in the poultry value chain, as well as it also improves their knowledge and awareness so they can apply improvements along the poultry value chain.

- Reinforcing animal welfare and health through political and economic conditions

Farmers' access to knowledge, application of better practices and technologies and bargaining power, allow farmers to give feedback and share their concerns and interest, increasing **government awareness, support, and intervention**.

Government awareness, support and interventions can facilitate, on one hand, **farmers' access to land and tenure**, improving access to appropriate housing and decreasing the distance from farms to Dakar and Thiès.

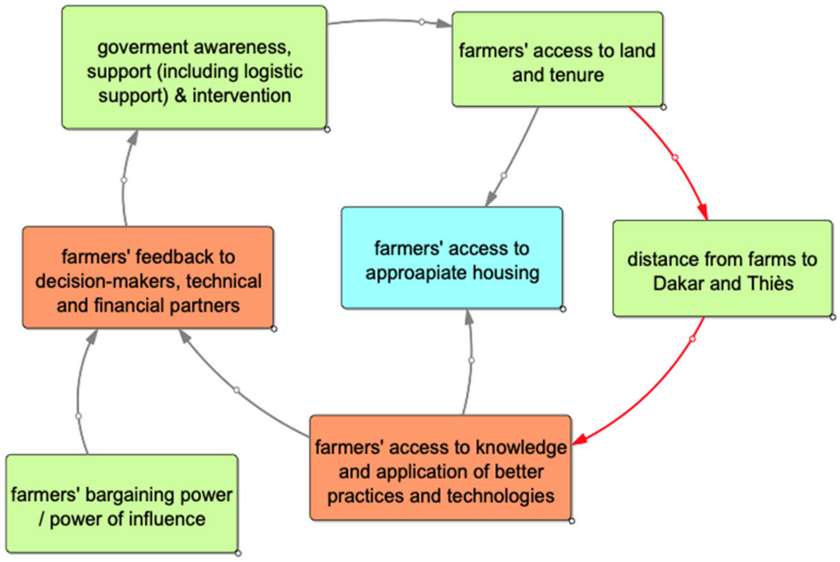


Figure E.15. Governance awareness and support feedback loop – Part I

On the other hand, it can improve farmers' access to inputs, facilities, and services directly, such as access to veterinary services, products and vaccines, and to utilities, or indirectly **enforcing the regulations in the poultry value chain**. This enforcement increases farmers' access to other inputs, facilities, and services, such as access to approved slaughterhouses, feed, housing, and day-old chicks, this last one through increasing availability of day-old chicks from local eggs and official hatcheries. The distance from farms to Dakar and Thiès decreases farmers' access to those inputs, facilities, and services. All of them increase birds' productivity indicators, and/or the compliance of quality poultry meat and live birds' standards, leading to a higher bargaining power, therefore, farmers' feedback, reinforcing government awareness, support, and intervention. The enforcement of regulations can also directly increase farmers' application of better practices and technologies, reinforcing government awareness, support, and intervention, or by reducing the distance from farms to Dakar and Thiès, and/or by improving farmers' access to utilities, as is explained in the other feedbacks.

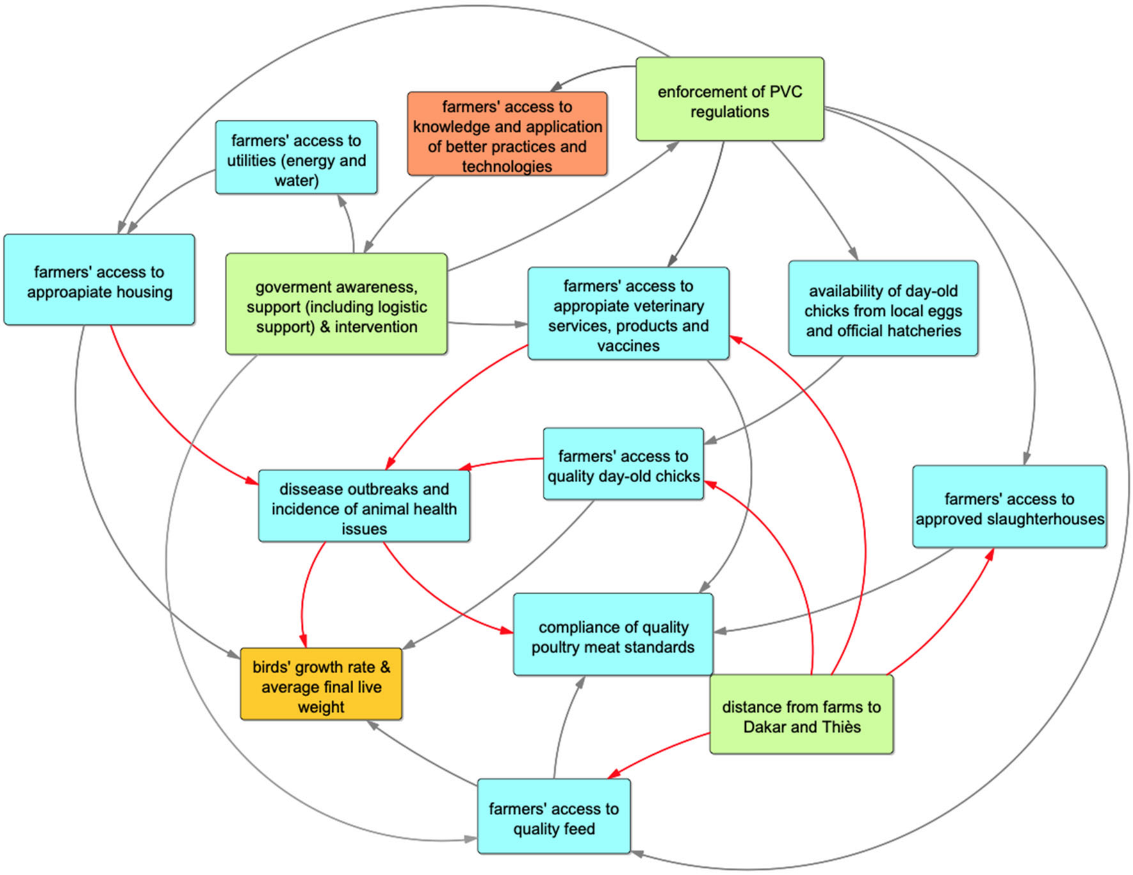


Figure E.16. Governance awareness and support feedback loop – Part II

Finally, farmers' access to quality feed and day-old chicks can also be improved directly, by decreasing the distance from farms to Dakar and Thiès regions, or indirectly, increasing transaction costs, therefore the price of those inputs. But, the latter, can decrease with a greater presence of intermediaries and a higher number of manufacturer companies producing quality feed.

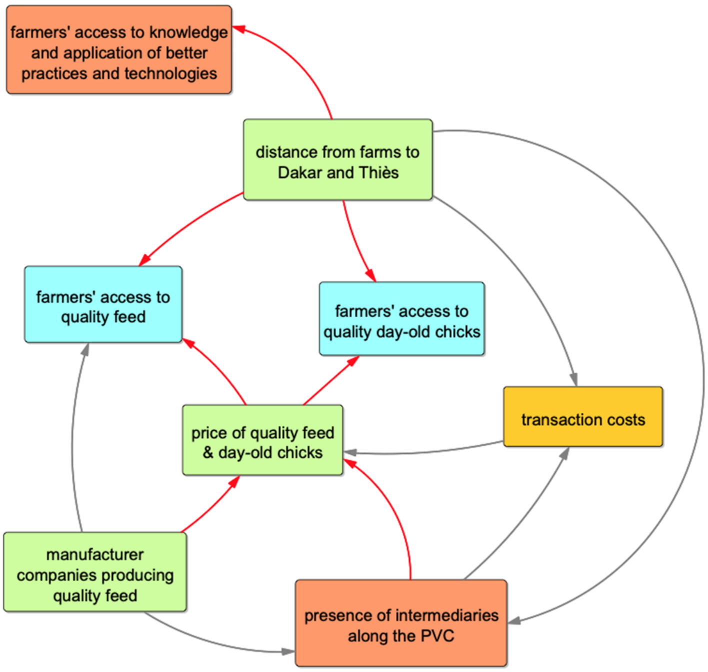
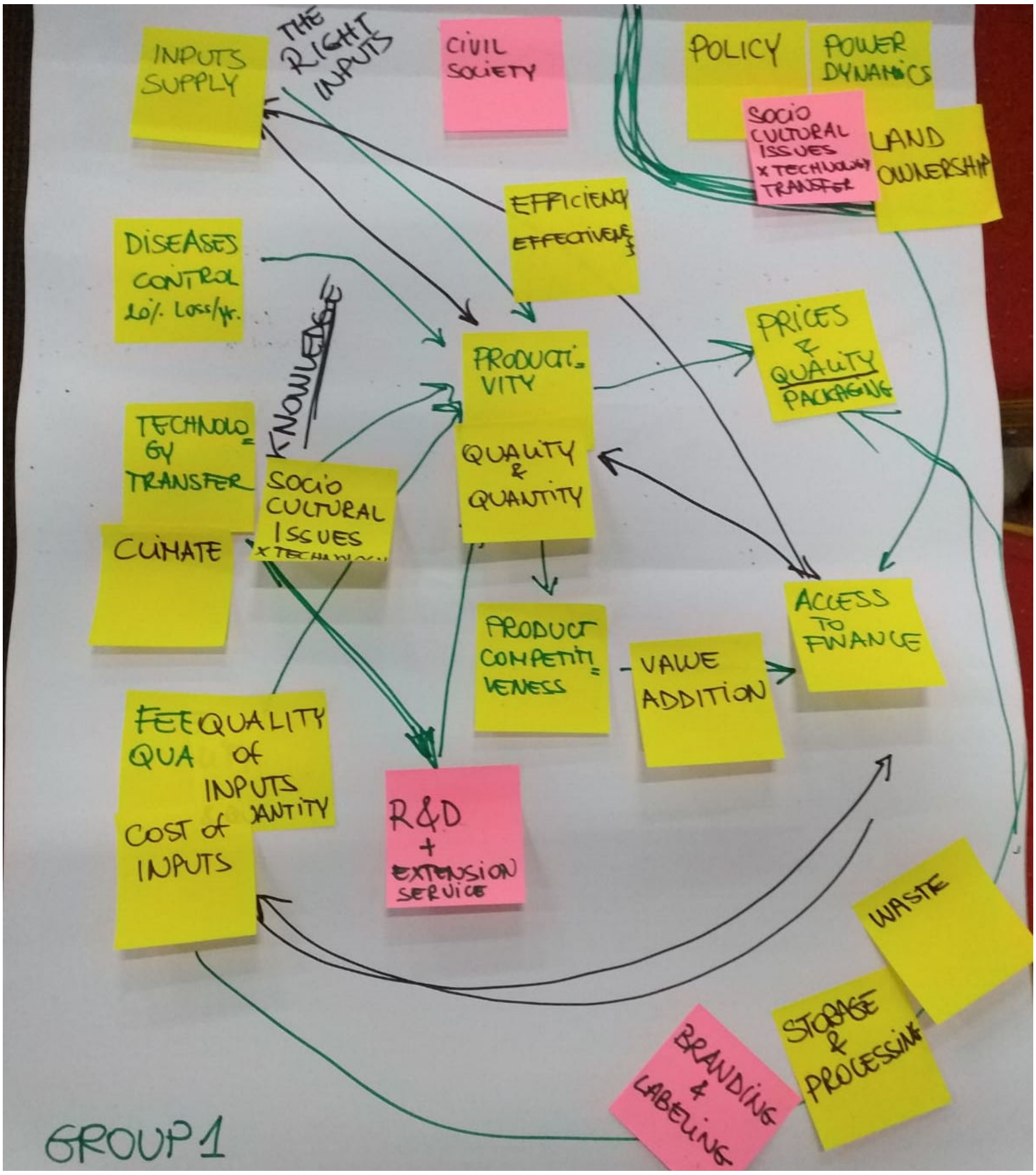


Figure E.17. Governance awareness and support feedback loop – Part II

ANNEX F

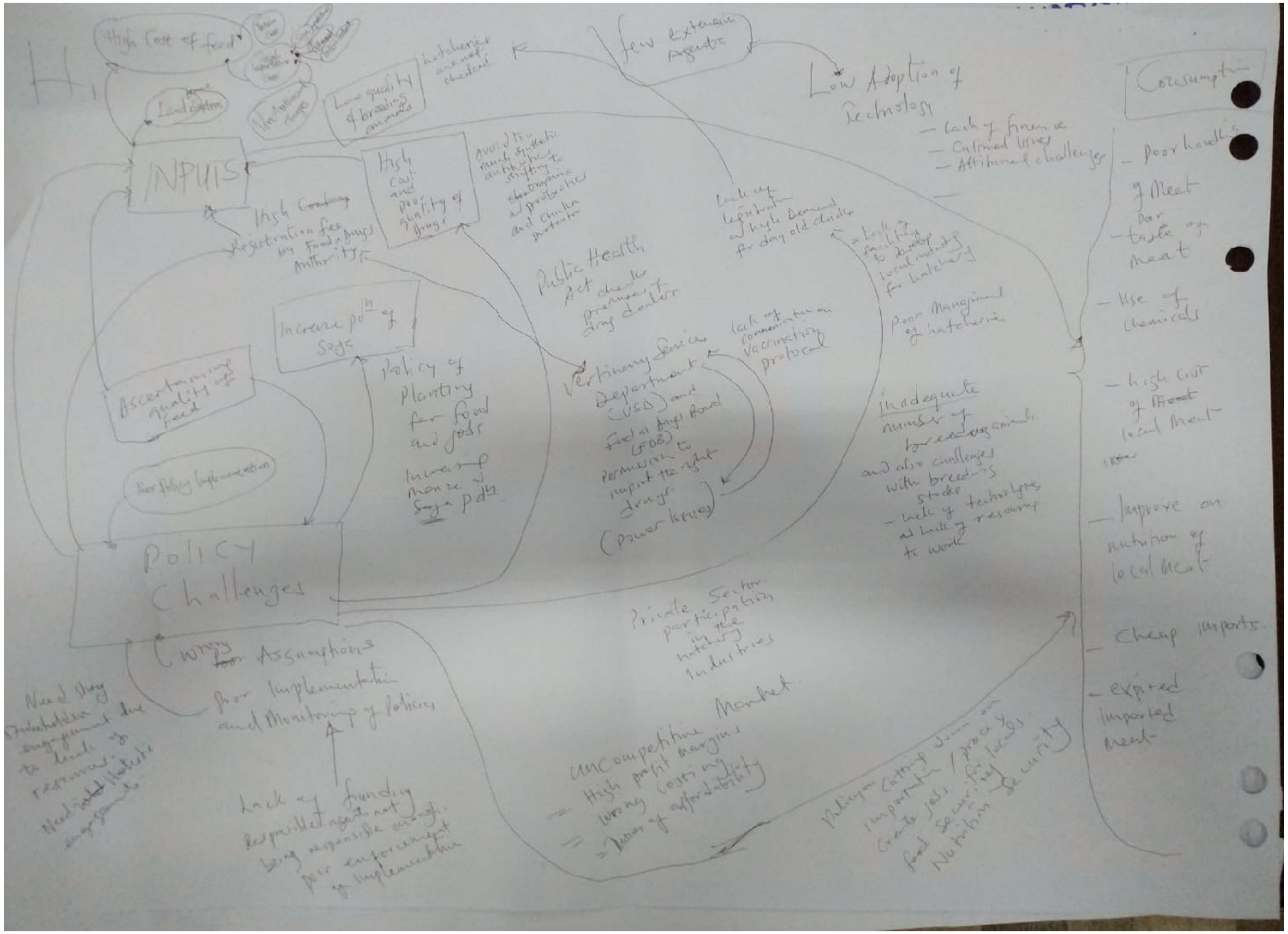
Diagrams that illustrate the poultry sector situation in Ghana

- Poultry sector situation – Group 1. Participatory Workshop Accra, September 2019.



- Poultry sector situation – Group 2. Participatory Workshop Accra, September 2019.

- Poultry sector situation – Group 3. Participatory Workshop Accra, September 2019.



ANNEX G

Results of the consultation process with key stakeholders of the poultry system in Ghana

INTERVIEWEE PROFILE: POULTRY FARMERS

QUESTIONS	RESPONSES
1. Can you give us an estimate of your annual production of broilers? (heads)	2,000-3,000 broilers
2. Approximately, how much is the cost of production? Can you give us an estimate of the distribution of those costs? (ex. 70% for feed, 5% for day-old chicks, 20% for vets' supplies and services, 5% for infrastructure	- Feed = 90% - Day-old chicks = 3% - Labour = 2% - Vet supplies = 2% - Infrastructure and utility = 3%
3. Key indicators in poultry production • Time to reach the weight of the bird to sell, in weeks. • Mortality rate? • Overhead cost per bird? • Selling price? Is it adequate to cover costs? Any other?	- Time to reach the weight: 8 weeks. - Mortality rate: 5%-10% - Cost per bird: GHc30-60 The selling price is not adequate to cover the cost
4. Availability and access to feed:	
Do you have any difficulties accessing or affording the feed?	Yes - Limited availability - High cost of feed - High cost of transportation
Where does the feed come from (national, local, or importation)?	Compound feed is nationally/ locally produced, but some feed inputs are imported.

	Small and medium-scale farmers buy commercial feed, while large-scale farmers prepare their own feed (feed mills integrated into their productive activities).
What shapes your decision about the type of feed to be used? (e.g., national/local vs. imported, or maize vs. different compositions of compound feed).	The decision is based on cost and availability.

Can you give us some numbers to illustrate the quality/cost relation of the different types of feed?	Poultry Farmers use local feed. There are different brands with different formulas.
	
	Average Price for starter feed
	- Broiler starter-Ghc 170/50kg
	- Broiler finisher – Ghc
	- Layer starter feed- Ghc 151/50kg
	Protein level, Fibre Level & Calcium level*
	    - Pre-layer mash – Ghc 138/50kg
	    - Layer 1 mash - Ghc 138/50 kg
	    - Layer 2 mash – Ghc 135/50 kg
	*The fiber level and calcium level increase as birds grow, to strengthen them and reduce the accumulation of fat.
	The consumption of broiler feed per bird is 5kg for 6 weeks. Layer is 8kg for 18 weeks

Do you use mainly maize or compound feed? If you use compound feed, can you describe the composition?	- Compound feed is used. <u>Composition</u> - Maize, soybeans, wheat bran, oyster shells, palm kernel cake, salt, lysine, methionine

Please describe the right mix of quality and quantity of feed that can improve poultry production.	- The compositions of the feed are the same but vary in quantity. - maize/wheat bran/soybeans/shells/amino acids (methionine & Lysine)/ premix. - For chick starter feed, for instance, the maize will be about 10 bags (50 kg each) soybeans will be about 4 bags, and shells about 10 kg. - When it comes to the grower feed, the maize will be 10 bags, soybeans around 3.5 bags, and wheat bran will increase a bit as well as shells because of building their calcium reserves as they grow.
5. Availability and quality of day-old chicks:	
Do you have any difficulties accessing or affording day-old chicks?	- Yes, due to high cost. Most of the day-old chicks are imported hence the high cost, reflecting the dollar rate.
Do you prefer national/local or imported day-old chicks? Why?	- Prefer imported day-old chicks - Because of quality, faster growth rate, and low mortality. - There is also a production guide and manual that come with the supply of imported day-old chicks (unlike domestic day-old chicks).
Are there enough hatcheries to cover poultry farmers' demand for day-old chicks? If there is a gap, is it a matter of quantity or quality?	- There are local hatcheries here in Ghana. However, several poultry farmers do import day-old chicks because they perceive the imported ones are better compared to the local ones. Also, they

	perceived imported ones to have better immunity than the local day-old chicks. - Poultry farmers also prefer the imported ones because they come with management guides.
What conditions determine the quality of day-old chicks? (e.g., infrastructure and sanitary conditions of hatcheries, poultry breeds, etc.).	Factors that determine the quality of day-old chicks: - Type of breed (sometimes when old parent stock is used, the birds have low immunity). So a good quality day-old chick must have some immunity against major poultry diseases - Mortality and growth rates - Moisture level - Lighting system
6. Infrastructure and equipment required for poultry farming:	
What kind of infrastructure and equipment do you have for poultry farming? Please refer also to the state of this infrastructure and equipment. Is this enough? If not, what else is needed?	- Deep litter system with manual feeding and water administration
What prevents you from having an adequate infrastructure? E.g., Funding issues, lack of information and advice, difficulties to find/transport materials, access to water, etc.	- Access to finance/funding - Access to land and cost of land
What are the main problems derived from inadequate infrastructure? E.g., Productivity	- Low productivity (low growth rate and increased mortality rate) - Poor biosecurity implementation

levels, link with sanitary and hygienic conditions, etc.	- Feed wastage that leads to low profit - Disease outbreak
7. Animal health services:	
When and how often do you need veterinary services?	- Monthly. Throughout the breeding process
Do you have any problems accessing veterinary services, medicines, and vaccines? (It could be related to the availability of vets, medicines, or vaccines; related to the capacity to afford these services and products, among others.)	- Limited availability of vets - High cost of medicines and vaccines - We travel a very long distance from where we are to access the service. When you call the vet officers, they give excuses that they are not available. We always end up falling on the private vets who travel all the way from long distances.
Are there enough farm vets available to meet poultry farmers' demands?	- There are not enough veterinarians available. - When government extension officers are unavailable, farmers fall on the private vets who also travel long distances to render services to farmers.
Who provides vet services and products—public or private?	Both public and private. Public services are not always accessible, while private ones are more expensive.
Do you access these services independently or as part of a financed program?	- Independently - There is a need to strengthen our farmer organizations, so we can assess these extension services in an organized way.
What are the consequences of a lack of access to vet services and	

products in poultry production? E.g., animal losses, costs of production, quality and quantity of meat, etc.	
8. Extension, training, and technology transfer services:	
Do you know how to access these services?	Yes
What do you know about public or private programs and institutions that provide extension, training, and technology transfer services?	- Women in the Poultry Value Chain Association provide training on biosecurity and poultry husbandry. - GPP (Ghana Poultry Project) is a USDA-sponsored project. They do capacity building and training for poultry farmers.
Do you think these services are available to poultry farmers as and when needed? Is the technical staff enough to meet the needs of all farmers, including smallholders (coverage, periodicity)?	At times some of these trainings are organized but farmers who are direct beneficiaries of these trainings may not have any information on them so only a few farmers end up attending.
Have you ever participated in extension or training programs, or received technical advice? o If you do, can you give us some examples and share your impressions?	Yes, - Training conducted by Ghana Poultry Project and Women in Poultry Value Chain on biosecurity - Training on administration of fowl pox - Training on debeaking - The topics address partially the concerns of farmers.

○ Do the topics addressed in the training programs and extension services address the main concerns and interests of poultry farmers?		
What does the adoption of new technologies (e.g., improved feed) for poultry production depend on?		
Do you think poultry farmers receive enough information, training, and financial assistance to adopt new technologies? *It will be interesting to explore if farmers' willingness is also a challenge in this regard.*		
9. Do you have access to financial services to invest in improving the production conditions and/or to cover costs? What are the conditions?	-	No. Most financial institutions are not willing to advance credit to the poultry sector because they consider the sector as high risk.
10. Associations in the poultry sector:		
Do you belong to any poultry farmers association/cooperative/	-	Yes, Greater Accra Poultry Farmers' Association

council? Which one do you belong to?	
What do you need to be part of an association?	- You need to have a business in the poultry value chain. - You need to register
Do most poultry farmers belong to these associations?	- There are several poultry farmer's platforms but most of them are not functional.
What role do these associations play? How do their members benefit? (e.g., input purchase, negotiation, access to markets, financial assistance, participation in training programs, etc.)	The roles of the associations are as follows: ○ Training ○ Advocacy ○ ESLG (Entrepreneurship Savings and Loans Group) – Available for the members of the "Women in Poultry Value Chain" association.
11. Channels of sale for poultry farmers:	
Where and how do you sell your products?	- Live bird market - Dressed birds are sold to homes/offices through delivery services
Are you also a processor or do you sell the live birds?	- Mostly sell live birds but also process for customers on a demand basis
Do you sell the birds in local markets, to processors (butchers), or integrate the processing and sell the final product to distributors or retailers?	
What determines the final price of sale?	- Cost of inputs (i.e., day-old chicks, feed)

Do you have any market information to negotiate the sale price?	- The form in which it is presented – Value added. However, in the end, the market determines the final price. Yes. Information on prevailing market price levels is obtained from colleague farmers, media (radio, TV), and personal observations on the market.
What is the average carcass weight of poultry (gr/animal) sold?	
Is there a minimum weight for selling in certain markets? o How does the price change in relation to the weight?	
Do you find any problem in selling and distributing your products? e.g., cold storage or transportation, state of roads to the market centers, etc. What difficulties do you face in meeting market demands?	- Yes. These include a lack of cold storage, and transportation challenges (poor road networks, high transport costs, lack of appropriate or well-designed transport to convey live birds or frozen meat to the market). - Capital is needed to expand the farm. - Competition from imported poultry products (lower price compared to domestic products)
What qualities do the markets demand (street markets, fairs,	- White meat - Low fat

local markets, supermarkets, retailers, etc.)? How much do the selling prices differ in different markets?	- Packaging - Cut parts - Semi-processed (Dressed) - Weight
Do you know if there is a minimum quality standard to sell poultry meat products in Ghana? If yes, explain	- There is a quality standard outlined by the Ghana Standard Authority (GSA).
As producers, how do these standards affect you when selling your products? What are the main challenges in this regard?	
12. Poultry farming as a livelihood:	
What percentage of your average annual income is from the poultry business only?	- 10%-20% for small and medium-scale commercial poultry farmers
Do you think the price you get for your products (live birds, or poultry meat) is fair? If not, how much do you think would be enough to make for a decent living?	- No, because we are not even able to break even.
What percentage of the family income is from poultry production and what percentage from other jobs?	- 20% poultry - 80% other jobs
13. Final reflection	
What do you think are the main challenges in poultry farming?	- Feed - Funding - Land Tenure - Poultry Insurance

- Technical Capacity
- Veterinary services
- Capacity Building
- Record keeping
- Availability of Data on actors in the poultry value chain

INTERVIEWEE PROFILE: POLITICIANS, PUBLIC OFFICERS, RESEARCHERS, AND TECHNICAL EXPERTS

QUESTIONS	RESPONSES
1. Is there any characterization or stratification of poultry farmers in terms of flock size, modernization level, or any other feature?	Poultry farmers are characterized as large-scale, medium-scale, and small-scale.
2. Production and efficiency levels	
Annual production (heads)	
Time to reach the weight of the bird to sell, in weeks.	- Broilers are sold when they are 6 to 7 weeks old, at a weight of 1.5kg to 2kg. - Broilers are 2.5kg to 3kg in weight when they are 8 to 10 weeks old. - Others also raise their broilers and wait to sell at week 10, 12, or 14 to reach better prices.
Mortality rate	- Generally, the mortality rate of broiler day-old chicks ranges from 5 – 10% and 6% on average. Formerly, the poultry farms were far apart so the mortality rate was higher (about 25%) but the farms are closer now, enhancing more security measures to control disease outbreaks. - Normally, the mortality rate at the small-scale level is 7% while that of the commercial scale level is about 3%. This is because commercial-scale farms have a better system of brooding and

	institute more bio-security measures to curtail more deaths. - On the other hand, small-scale farmers may have alternative sources of income, so they do not normally pay much attention to the chicks, which results in a higher mortality rate. - It is difficult to get the total number of poultry farmers in Ghana. This is because while some are folding up, others are entering the business. However, the Poultry Farmers' Association has figures on the number of farmers. For instance, the greater Accra Poultry Farmers Association has 1,810 registered poultry members. - The poultry zone in Ghana is Dormaa in the Brong Ahafo Region.
Cost's structure	- The cost structure of poultry farming includes the following: o Feed = Between 70% o Day-old chicks = 2 - 5% o Utility and water = 5% o Drugs and Vaccine = 3 - 5% o Labour = 3 – 5% o Equipment = 5% o Others = 5% - In terms of feed, 100 broiler day-old chicks consume 11 – 13 number of the 45kg bags for 8 weeks until they are

		sold. 100 layers take about 177 number of the 45kg bags of feed for 20 weeks.
Overhead cost per bird	-	Layers take about 150 grams of feed per bird per day.
	-	The total cost to raise a broiler from a day-old chick to week 8 is about 30 to 33 cedis per bird.
Kg feed/ Kg poultry meat.	-	Broilers require 5 kg of feed for 6 weeks, and in that time the weight ranges from 1,5 to 2kg.
	-	Feeding takes about 70% of the total cost of poultry keeping.
	-	It must be noted that the cost of poultry farming is cheaper when you produce your own feed. The feed processing industries put about a 10% profit margin on the feeds produced.
3. Modernization (infrastructure of housing and equipment).	-	The equipment takes about 5% of the total cost of producing broilers.
Access to services:		
• Veterinary services	-	Access to veterinary services is poor for all levels of poultry farming. However, it is relatively better in commercial poultry farming than in small-scale and medium-scale farms. This is because small-scale farmers do not have money to pay for veterinary services.

• Extension and training	- Training program for poultry farmers is very high for all levels of poultry farming in Ghana; NGOs, Government institutions, Universities, and Research institutions offer training services to farmers such that the system is saturated with training. - The Departments and District offices are there to offer advice to farmers who want to set up poultry farms. The problem is that; many farmers just venture into poultry farming without training assistance. Therefore, these farmers start on a bad note. - To access training, farmers must position themselves in better ways – only 50% of small-scale farmers have access to extension and training services. In comparison, scale farms have much more networks and resources to tap into such services (approx. 80% access it).
• Information	- The availability and accessibility of information are high for all levels of farmers.
• Financial services	- Financial service is a challenge for both small-scale and commercial farmers due to the high risk in the poultry industry.

Access to inputs in the right quality and quantity:	
• Feed	- Feed is generally expensive or not available.
• Day-old chicks	- Day-old chicks are readily available, but most are imports.
• Drugs and vaccines	- Readily available but normally imported.
Negotiation power and trade margins	- The prices of poultry products are regulated by the market forces of demand and supply, so farmers do not normally have negotiation power. It is only during Christmas when farmers are able to control prices because the demand for poultry products is high. - The National Poultry Farmers Association is unable to step into control prices due to personal interest and lack of finance to run the association.
Level of integration along the value chain: Relationships with agents involved in the poultry value chain:	
• Day-old chicks' suppliers (Hatcheries)	- There is a good relationship between farmers and suppliers or hatcheries of day-old chicks. Most day-old chicks are

	imported but some farmers or association members even go for fun trips abroad where the chicks are imported from.
• Feed mills	- There is a feed millers' association in Ghana that produces feed. However, some of the feed concentrates are imported. APD has a tripeptide relationship with CSIR-ARI and FDA. - FDA has standards and regulates feed processing. Some of the veterinary services and GSA also test for the aflatoxin content of the feeds produced. Normally, the APD collects the samples and sends them to the University of Ghana or the CSIR-ARI for analysis. Those who do not meet the standards are engaged to do the right thing.
• Processors	The processors have an association, but the farmers also process poultry for sale. - There are no companies in Ghana that purchase broilers, process them, and sell them. Facilities for slaughtering and processing poultry in Ghana are limited. Much of the slaughtering of live birds takes place at the household level or in live bird markets. Some of the large commercial farmers process

		their own poultry (they integrate the processing into their business). Generally, there are about two certified poultry processing facilities in Ghana.
• Retailers	-	There are live bird sellers associations and egg sellers associations. The association has high power to determine prices.
• Distributors	-	The egg seller's association is powerful in determining the prices of eggs, and they act as distributors who buy eggs from the producers to other centers.
• Final consumers	-	The final consumers are the households, caterers, and restaurants. The consumers normally buy from the distributors (live birds' sellers and egg sellers). So, the consumers do not have the power to determine prices as compared to the distributors.
4. Availability and access to feed:		
Are there problems with the national supply of poultry feed? If there yes, is it a matter of quantity or quality?	-	There is nothing like the national supply of poultry feed.
What determines the quality of poultry feed? (Protein content, etc.)	-	The quality of poultry feed is determined by the following factors:

<table>
<tr><td></td><td>

- quality of the ingredients used to formulate the feed,
- How the feed is stored
- Handling and transportation of the feed

</td></tr>
<tr><td>What are the characteristics of feed mills in the country (Capacity, sanitary conditions, etc.)</td><td>Check this document for more details https://www.rvo.nl/sites/default/files/2019/12/Update-poultry-report-ghana-2019.pdf</td></tr>
<tr><td>What is the composition of compound feed?</td><td>

- The proportion of nutrients in poultry feed formulation depends on the stage of growth of the bird. There are starter mash, grower mash, and finisher mash. In layers, there is a pre-layer mash before a layer mash.
- The various nutrients that come together to make a complete quality feed are Carbohydrates (About 65% Maize), Protein (18 – 22%), Vitamins, Calcium (2%), and Phosphorus. Protein is the key nutrient in the formulation of a broiler feed to enable it to grow fast for sale.

<table>
<tr><th></th><th>Starter</th><th>Grower</th><th>Finisher</th></tr>
<tr><td>Age (days)</td><td>0-21</td><td>22-35</td><td>36+</td></tr>
<tr><td>ME(MJ/Kg)</td><td>12</td><td>12.5</td><td>13</td></tr>
<tr><td>Crude Protein (%)</td><td>23</td><td>21</td><td>19</td></tr>
<tr><td>Crude fat (%)</td><td>3.6</td><td>3.3</td><td>3.1</td></tr>
</table>

</td></tr>
</table>

Fibre (%)	2.4	2.6	2.7
Lysine (%)	1.25	1.10	1.14
Methionine (%)	0.51	0.51	0.51
Calcium	1.0	1.0	0.95
Phosphorus	0.44	0.44	0.42
Sodium	0.17	0.17	0.17

Is there a significant difference between national and imported feed? If yes, what are the differences?	- Ghana may import a concentrate but not the entire poultry feed. The complete feed is locally made.
Please describe the right mix of feed (in terms of quality and quantity) that can improve poultry production, and how (e.g., Improvements in productivity, time to reach the weight of the bird to sell, kg feed/ kg poultry meat, etc.). *It would be interesting to understand the relation between protein content or other quality variables – especially in the feed available for the first month of life - with improvements during poultry production.*	- Comparing self-formulated feed to commercially formulated feed, the self-formulated feed is the best because the farmer knows the ingredients, so the feed is customized to the needs of the birds at any particular stage in time. - Again, farmers buy quality maize and other ingredients when formulating their own feeds. - However, the farmers who formulate their own feeds and have no milling machines find it difficult to mix the ingredients thoroughly, especially when it comes to micro-ingredients. That affects the quality of the feed. Again, the commercial feed processing units are able to do postproduction

		analysis of the feed to ensure that the nutrients are in their right proportions but the farmers who do self-formulated feeds may find it difficult to practice postproduction analysis. These are some of the reasons why most small-scale farmers go for commercially formulated feeds rather than self-formulated feeds.
Are there any key initiatives (governmental or from other institutions) to improve the availability and accessibility of quality feed? Please mention and describe if any.	-	The availability of feed is a problem now because there are no raw materials (maize). The problem is that people smuggle the maize to sell to the neighboring countries. So, there is a policy in place to control the exportation of maize.
	-	Again, there is a re-activation of the Association of Feed Millers of Ghana (AFMoG). There is also the development of a poultry master plan which involves the formation of a Poultry Council to control the exportation of maize.
5. Availability and quality of day-old chicks:		
Are there problems with the supply of day-old chicks? Is it a matter of quantity or quality?	-	There are no problems with the supply of day-old chicks in Ghana. The local chicks are cheaper (6 cedis) compared to the imported chicks (8 cedis). However, the local hatcheries do not

		have high-quality day-old chicks. Thus, the mortality rate for the local chicks is higher than the imported ones.
What conditions determine the quality of day-old chicks? (e.g., infrastructure and sanitary conditions of hatcheries, poultry breeds, mortality, etc.)	-	The vaccination regime determines the quality of the day-old chicks, in terms of building the immune system of the chicks (antibodies from the parent stock) to reduce mortality rate. Some of the local hatcheries claim the vaccination is expensive so they immunize the chicks.
	-	Additional determinants of quality day-old chicks are; Biosecurity measures, type of breeds, managerial skills of the hatcheries, and so forth.
	-	The biosecurity is an issue for the local hatcheries.
	-	Some of the local hatcheries in Ghana are; Topman, Asamoah and Yamoah, CSIR-ARI, Darko farms, Mfum farms, and Parkagrotech.
Is there any significant difference between national and imported day-old chicks? If yes, how different?	-	The main differences between the local and the imported day-old chicks are that the imported ones have; o Less mortality rate o Higher percentage rate of laying for layers, o Higher growth rate for broilers o and a vaccination regime that improves the anti-bodies levels

Characteristics of hatcheries in the country (Total number, capacity, sanitary conditions, etc.).	- There are about ten local hatcheries in Ghana but all are operating below capacity due to the high importation and low demand for locally produced chicks. - With an enabling environment and appropriate policy in place, Ghana can supply all the chicks needed. For – instance the CSIR – ARI alone can produce 10,000 chicks weekly. - The current sanitary condition of the local hatcheries is not good enough. The sanitary condition is rated between 4 and 6 on average, on a scale of 1 to 10.
Are you aware of any initiatives (governmental or from other institutions) to improve the availability and access to national day-old chicks? Please mention and describe	- The Ghana Standards Authority (GSA) and the Food and Drugs Authority (FDA) are coming out with the standards training for the hatcheries. Monitoring of hatcheries will also be in place to ensure compliance.
6. Infrastructure and equipment required for poultry farming:	
What infrastructure and equipment are essential for poultry farming? Do the poultry farmers have difficulties accessing those essential conditions? What prevents them? (Financial facilities, lack of information and training,	- The infrastructure requirements of poultry farming are land, housing or coup, feeders, drinkers, and so forth. - Except for land, it is not difficult to access these facilities. It must be noted that the breeder farms should have feeders and drinkers different from the

access to water and/or electricity, etc.).	types used by ordinary farms, and for that, they need to access funds.
How does an adequate infrastructure and equipment, or the lack of them, influence productivity levels, product quality, etc.?	- The housing used by the local poultry farms is normally not standard. Farmers have more birds but poor housing. - The use of cages has been banned in Europe due to animal welfare issues where the birds are limited in movement and the birds have arthritis. However, the cages are still used in Ghana. - The deep litter system is the ideal management system used nowadays, and the most commonly used in Ghana.
Are you aware of any key initiatives (governmental or from other institutions) to improve the availability and access to essential infrastructure and equipment for poultry farming? "*In 2009, the Animal Research Institute (ARI) of the Council for Scientific and Industrial Research (CSIR) introduced a broiler breed, Aribobroilers, to produce day-old chicks for broilers in the country.*" Can you tell us about this experience?	- Some institutions bring the housing equipment (the battery cages) to Ghana. Some other local companies and welders also fabricate metallic or wooden battery cages. Others also import accessories of battery cages and assemble them in Ghana. - Housing manuals are in place to guide farmers and fabricators through the standardization policy by the GSA. - Aribo broiler breed is doing well. However, the ARI did not advertise because the parent stock of Aribo was few so the management thought we

	could not meet the demand if we advertised. The good news is that the stock has increased now so an arrangement is in place to commence advertisement. - In terms of quality, the Aribo matches the imported chicks. There has been a survey where farmers were asked how a particular breed of broiler (Aribo) was doing without mentioning the name of the breed. It was found that the Aribo was doing well.
7. Animal health services:	
Who provides vet services and products—public or private to poultry farmers?	There are two main providers of Vet services in Ghana. They include: 1. Public --Provided by staff of the Ministry of Food and Agriculture (MOFA)- They include, veterinary surgeons, technicians, animal health officers, nurses (18 nurses in total) 2. Private – they employ mostly retired animal health officers. Some of these experts may also be working with the private people. NB: Other private people provide veterinary services, but their activities are illegal. They are not well trained and present themselves as experts (quark doctors).

Are there enough personnel and vet products to meet the demands of poultry farmers countrywide?	- Regarding personnel providing vet services, they are woefully inadequate. So, there is limited human resource capacity to cater for the needs of the poultry farmers. - There is demand for these services from the farmers. However, the activities of the vet services are not available in the various districts of the country.
What are the challenges in meeting the demands for vet services and products in the country?	- There is no monitoring mechanism or regulation of shops selling veterinary products. - Access to the services of veterinary officers is very difficult. - Farmers have lost confidence in the veterinary officers. - Products are available but the service charge/cost by vets is very high (e.g., GHS0.5-1/bird) - Implementation/enforcement of existing policies on the poultry industry is weak. - Farmers sometimes do not want to go for the services of experienced vets because of the travel distances and the prices.

- Some of the vet staff/officers do not go when they are called but now there are systems to check the staff.
- Inadequate/limited logistical support for Vets to carry out services.
- There is a system failure – the whole industry is not properly regulated. For example, in terms of deciding on how much to charge for veterinary services, there is no consultation with farmers, and this sometimes leads to resistance from farmers. Policymakers usually send the bill to parliament for prices to be set without the input of farmers.
- Weak compliance with existing laws governing the provision of vet services.
- The product range (type) is inadequate. Lack of knowledge of certain products leads to low demand from farmers. Sellers stop selling such products and when needed, they are not in stock.
- The need to check and regulate what is imported (quantity, expiry date, composition, etc.)
- There is a lack of knowledge of available products.
- There are fake products in the system. These products normally come into the country without the approval of the Ghana Standards Authority and Food

	and Drugs Authority. Sometimes the dosage is not even known. - Most drugs are also not labeled in English as required, especially in remote areas. - Most of the poultry farmers do their own hatcheries without anybody regulating them. Others sell day-old chicks from China, which usually do not comply with regulations.
How does the lack of access to these services and products affect national poultry production and competitiveness? E.g., animal losses, costs of production, quality and quantity of meat, etc.	- Farmers waste money to buy fake drugs that increase the mortality of their birds. These decisions are usually made in response to inadequate diagnosis and prescriptions of fake drugs made by quark doctors. - Farmers also usually put pressure on the few veterinary doctors to give them immediate diagnoses. In the process, mistakes are being made. Sometimes, only one diagnosis is used to prescribe drugs.
Are you aware of any key initiatives (governmental or from other institutions) to improve the access to animal health services and products of poultry farmers? Please mention and describe.	- Rearing for Food and Jobs (RFJ) has been implemented for the benefit of the small-scale farmers in selected districts. This program has been positive in giving at least ten (10) imported cockerels (birds) to farmers to start, in response to the need for

	genetic improvement. However, the Ghana National Association of Poultry Farmers claims they were not consulted in the implementation of the RFJ. - Savanna Investment Program (SIP) at the Northern Region and parts of Bono and Oti regions. This program provides livestock to selected farmers and investigates whether they have the capacity to manage the livestock. When the animals give birth, the progeny is picked for other farmers. Farmers are required to pay within two years. Veterinary services are provided to assist these farmers. - There is also the Savanna Zone Agricultural Productivity Improvement Program.
8. Extension, training, and technology transfer services:	
What are the public or private programs, and institutions that provide extension, training, and technology transfer services to poultry farmers?	- MOFA has been doing well to take farmers through training (e.g., training on biosecurity) and capacity building. - FAO also supports MOFA to provide extension services to poultry farmers. - The Ghana Poultry Project (GPP) of USDA also works with MOFA to provide training to farmers.

	- Ghana Poultry Farmers is an NGO that works through the FDA - Ghana Standards Authority provides training on standards by linking up with the associations.
How is the content or purpose of these services decided? (e.g., consultation processes, user demand & feedback, priorities set by national or institutional plans, etc.).	- It comes through Research Extension Linkage Committees which are cantered at the CSIR. There is user demand for these services. - Sometimes the capacity to implement decisions after certain diseases are diagnosed is a problem.
Who can access these services? What are the requirements and costs, if any??	- Government extension and training programs are provided free of charge to farmers. The associations also attract funds to build the capacity of farmers through partnerships with MOFA and other government agencies.
At the country level, are there difficulties in meeting poultry farmers’ demand for these services? Is it a matter of availability of services, accessibility, or where the focus is (aligned with poultry farmers' interests and concerns)?	- Yes, accessibility and affordability are a major problem. This is because the providers of these services, for example, the Extension and Vet Services directorate of MOFA lack the logistics and resources to visit farmers when needed or provide services at various communities/locations within the country.

	- Also, the poultry industry is not formalized/organized to take advantage of available training programs, i.e., there is no well-established auditing system or database of farmers (e.g., data on farmers, their farm sizes, etc.). - There is no or poor record keeping (budget, cost of operations, number of birds) which makes it difficult to administer these services or training programs. - MOFA is advocating for insurance policies for commercial large-scale farmers. Some of the farmers are not willing to pay and the insurance companies are also afraid to support the poultry industry due to the high risk involved. There is a need for the government to support in this regard.
Can you share your impressions about poultry farmers' willingness to adopt new technologies or practices? (aligned with poultry farmers' interests and concerns)?	- Farmers are willing to adopt new technologies, especially when they face a high cost of production. - In the Aribo broiler project (by CSIR-Animal Research Institute) the adoption was low or not as expected because the meat industry is not well developed, and thus many farmers prefer to go into layer production. Also,

	some farmers do not like the local breeds and that may have led to low adoption. - There is a need to engage the Ministry of Food and Agriculture to select farmers for the demonstration program when a new technology is developed by a research institute.
Do you know of any financial services and products to help farmers invest in better production infrastructure, equipment, and/or practices? Or to cover production costs?	- Mostly access to financial services is very difficult. Those financial institutions that are willing to provide credit/loans to poultry farmers also have high-interest rates - However, the Agricultural Development Bank (ADB), which is a public bank, offers loans/credit to farmers at an interest rate that is lower than other banks or financial institutions (about 24% interest rate). - Mostly small-scale farmers are not able to access the loans due to poor record keeping. They are not able to satisfy the conditions of the financial institutions. - The reality is that most of the farmers do not make 25% profit and most banks offer loans at a rate that is far higher than 25%. So, farmers prefer not to go to banks but rather rely on other forms of financial assistance. These

		include merchant credit--- this is whereby input providers give in-kind credit (e.g., maize, vet drugs, day-old chicks, etc.) to farmers.
9. Associations in the poultry sector:		
Do you know how many associations/ cooperatives are in the country?	-	There is no idea as to how many poultry farmers associations are in the country.
	-	But there is a national association, called the Ghana National Association of Poultry Farmers. This association comprises 16 regional associations in the country.
	-	Also, there is another association called Women in Poultry Value Chain.
Do most poultry farmers belong to these associations?	-	Most of the farmers do not belong to poultry associations. A lot of them are operating on their own and this makes it difficult to have a uniform voice.
	-	It is very necessary to have a body that brings all the farmers together. This will aid in accessing vital services from the public as well as private sectors. There is therefore the need to have a well-regulated system.
What are the requirements to be part of an association? What role	-	The poultry associations are responsible for articulating the needs

do they play? How do the members benefit?

and concerns of the industry for redress.

Conditions to be part of an association:

- Anyone who wants to be part of a poultry association must be a poultry farmer.
- The person must have at least 200 birds onwards

The role that the associations play

- Capacity building to impart knowledge
- Collaborate with the government for the provision of inputs and services. Currently, the National Poultry Farmers Association is working with the government to provide maize for feed as there is a national shortage.
- Advocacy to inform decisions.

Benefit

In terms of benefits, it is a yes and no. In terms of knowledge, it can be enhanced through association, however, some farmers have the perception that they know it all. The general mindset is focused on how to get money so if they don't get it, they leave the group and turn.

The associations can mobilize funds themselves to support their members.

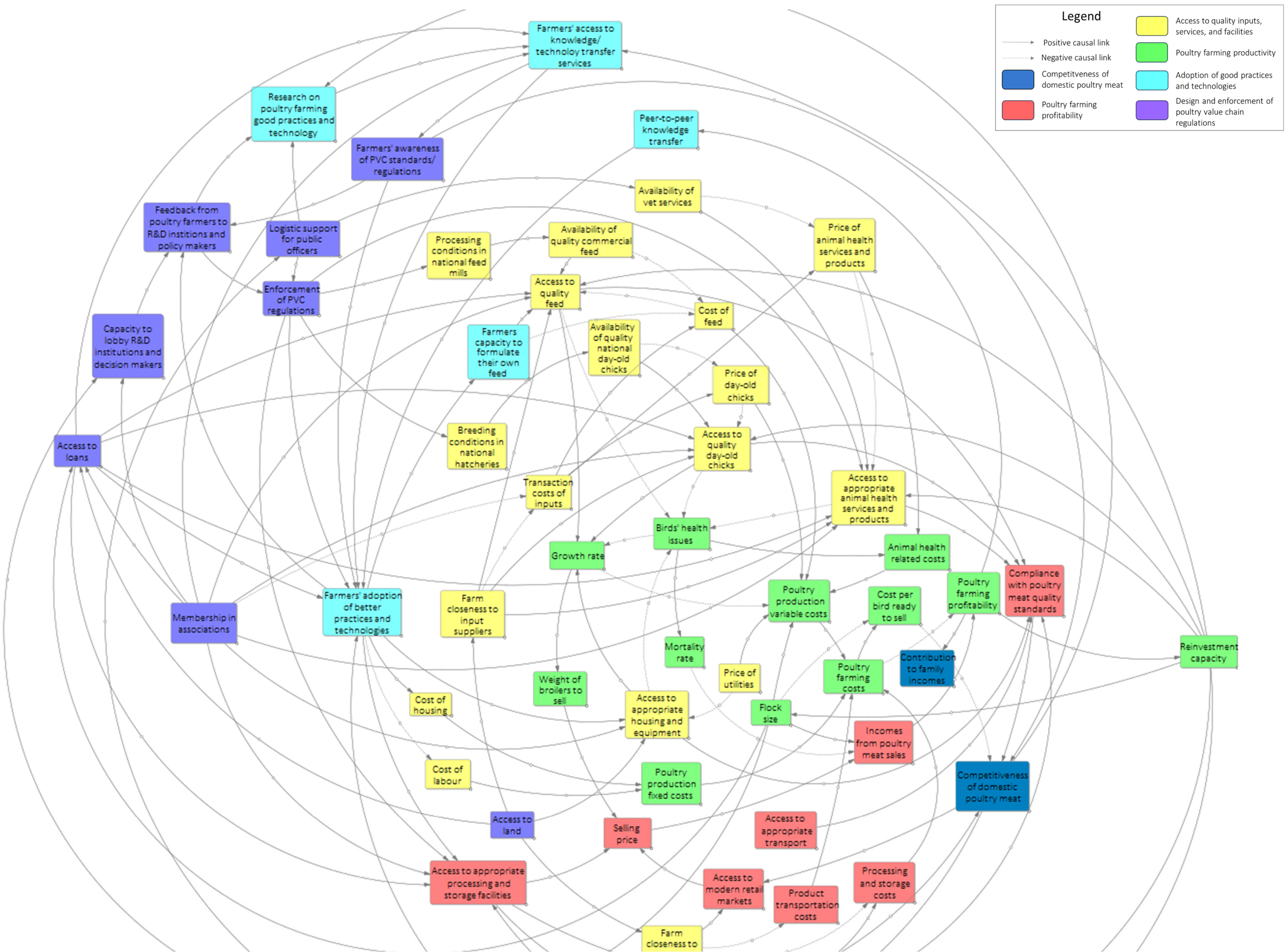
	***There is a need to strengthen the associations.
10. Channels of sale for poultry farmers:	
What are the main sales channels for poultry farmers?	- Street vendors or live bird market (they dictate the price but have ready cash) - Restaurants (payment sometimes delayed) - Supermarket (involves middlemen) - Export (Côte d'Ivoire)—broilers/spent layers (difficult to dispose) - Consumers/individuals
In what form do poultry farmers sell their products (live birds or dressed/processed)? ○ Small-scale ○ Medium scale ○ Large scale	The forms that farmers sell their products include: • Live birds • Dressed • Proceed Mostly small farmers sell their products as live. Some of the medium- and large-scale scale farmers are able to process or provide dressed chicken for sale.
What determines the final price of sale?	The final price of sale mostly depends on: • Negotiation power • Operational cost

What is the average carcass weight of poultry (gr/animal) sold?	The average carcass weight of poultry sold ranges between 1.5kg – 1.9kg.
Does the weight differ by the scale of production? If yes give details.	The weight of the birds does is not different or does not differ by type of farm or scale of production.
Is there a minimum weight for selling in certain markets? ○ How does the price change in relation to the weight?	There is no minimum weight for selling poultry in markets. But prices in the market depend on the weight of the bird.
Are there quality standards at the country level for poultry meat production? Please, give details.	Are there standards for the poultry industry on the following products: • Frozen and dressed chicken. • Feed • Edible eggs • Poultry hatchery • Vet medicines
What is the level of compliance with these standards? Please rate the level of compliance with these standards. (1=very low to 5=very high)	The FDA regulates the industry. However, most actors in the poultry value chain are not even aware that there are standards. This is because the awareness and promotion of these standards have been low. Compliance with these standards is average (rank of 3) as most actors are not even aware of such standards.

What are the main challenges that poultry farmers face in marketing their products? o Logistics issues (transportation, cold storage, etc) o Market access o Quality issues (size, meeting quality standards, etc) o Negotiation power o Etc.	The main challenges include: • Negotiation power • Difficult access to markets/absence of ready market

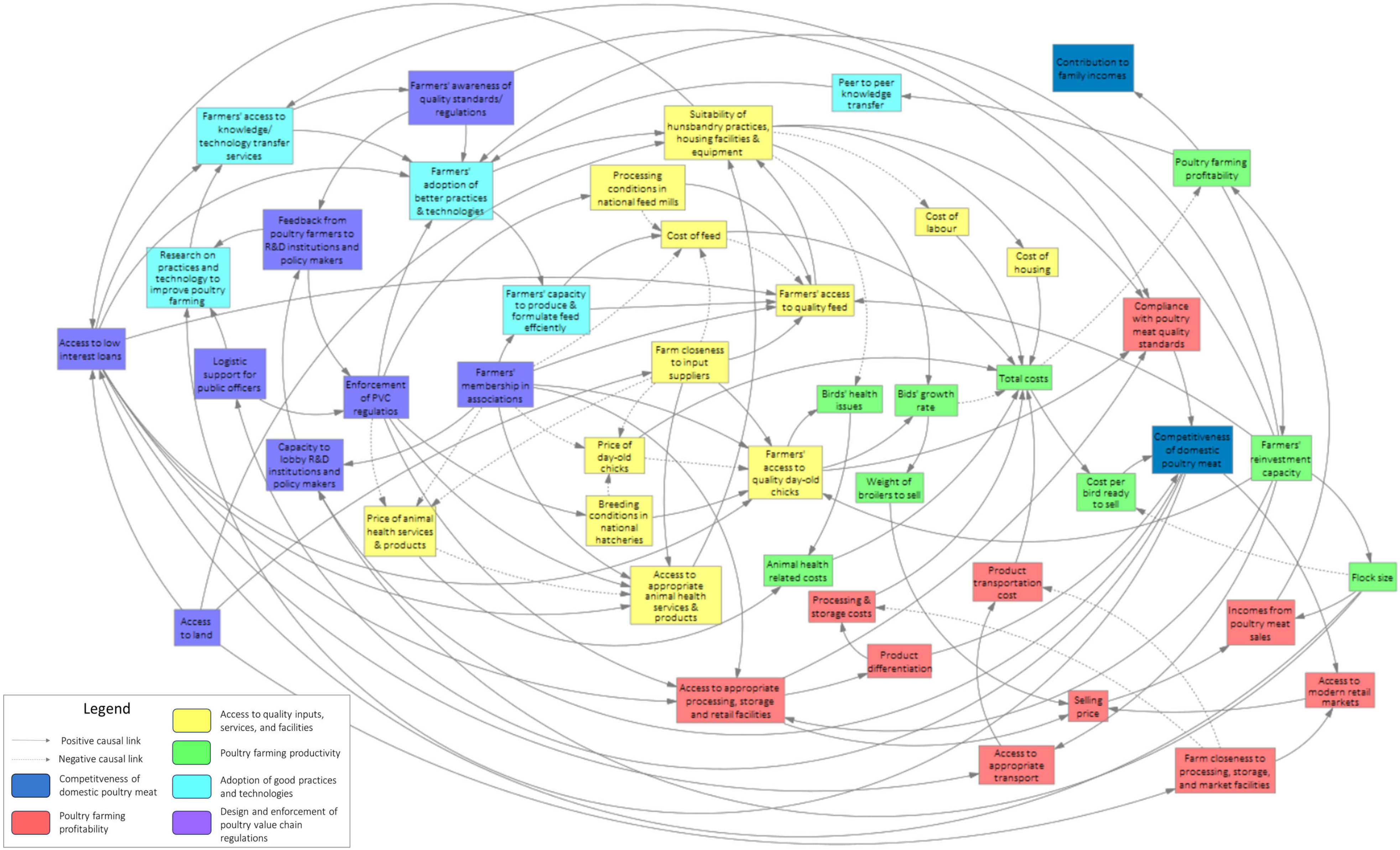
ANNEX H

Preliminary Causal Loop Diagram of the poultry system conceptual model in Ghana case study


Legend
Positive causal link
Negative causal link
Competitiveness of domestic poultry meat
Poultry farming profitability
Access to quality inputs, services, and facilities
Poultry farming productivity
Adoption of good practices and technologies
Design and enforcement of poultry value chain regulations
Farmers' access to knowledge/ technoloy transfer services
Research on poultry farming good practices and technology
Farmers' awareness of PVC standards/ regulations
Peer-to-peer knowledge transfer
Availability of vet services
Price of animal health services and products
Feedback from poultry farmers to R&D institions and policy makers
Logistic support for public officers
Processing conditions in national feed mills
Availability of quality commercial feed
Access to quality feed
Cost of feed
Enforcement of PVC regulations
Capacity to lobby R&D institutions and decision makers
Farmers capacity to formulate their own feed
Availability of quality national day-old chicks
Price of day-old chicks
Breeding conditions in national hatcheries
Access to quality day-old chicks
Access to loans
Transaction costs of inputs
Access to appropriate animal health services and products
Birds' health issues
Growth rate
Animal health related costs
Membership in associations
Farmers' adoption of better practices and technologies
Farm closeness to input suppliers
Poultry production variable costs
Cost per bird ready to sell
Poultry farming profitability
Compliance with poultry meat quality standards
Reinvestment capacity
Mortality rate
Weight of broilers to sell
Price of utilities
Poultry farming costs
Contribution to family incomes
Cost of housing
Access to appropriate housing and equipment
Flock size
Incomes from poultry meat sales
Cost of labour
Poultry production fixed costs
Competitiveness of domestic poultry meat
Access to land
Selling price
Access to appropriate transport
Access to appropriate processing and storage facilities
Access to modern retail markets
Product transportation costs
Processing and storage costs
Farm closeness to

ANNEX I

Causal Loop Diagram of the poultry system in Ghana incorporating the feedback of stakeholders (provided in January 2022)


Contribution to family incomes
Peer to peer knowledge transfer
Farmers' awareness of quality standards/ regulations
Farmers' access to knowledge/ technology transfer services
Suitability of hunsbandry practices, housing facilities & equipment
Poultry farming profitability
Farmers' adoption of better practices & technologies
Processing conditions in national feed mills
Cost of labour
Feedback from poultry farmers to R&D institutions and policy makers
Cost of feed
Cost of housing
Research on practices and technology to improve poultry farming
Farmers' capacity to produce & formulate feed effciently
Farmers' access to quality feed
Compliance with poultry meat quality standards
Access to low interest loans
Logistic support for public officers
Enforcement of PVC regulatios
Farmers' membership in associations
Farm closeness to input suppliers
Total costs
Birds' health issues
Bids' growth rate
Competitiveness of domestic poultry meat
Farmers' reinvestment capacity
Capacity to lobby R&D institutions and policy makers
Price of day-old chicks
Farmers' access to quality day-old chicks
Weight of broilers to sell
Cost per bird ready to sell
Price of animal health services & products
Breeding conditions in national hatcheries
Animal health related costs
Product transportation cost
Flock size
Access to appropriate animal health services & products
Processing & storage costs
Incomes from poultry meat sales
Access to land
Product differentiation
Access to appropriate processing, storage and retail facilities
Selling price
Access to modern retail markets
Access to appropriate transport
Farm closeness to processing, storage, and market facilities
Legend
Positive causal link
Negative causal link
Competitveness of domestic poultry meat
Poultry farming profitability
Access to quality inputs, services, and facilities
Poultry farming productivity
Adoption of good practices and technologies
Design and enforcement of poultry value chain regulations

	Access to appropriate transport	Birds' health issues	Growth rate	Weight of broilers to sell	Poultry farming costs	Cost per bird ready to sell	Poultry farming profitability	Reinvestment capacity	Flock size	Processing conditions in national feed mills	Farmers capacity to produce & formulate feed efficiently	Cost of feed	Farmers' access to quality feed	Breeding conditions in national hatcheries	Farmers' access to quality day-old chicks	Price of day-old chicks	Price of animal health services & products	Animal health related costs
Access to appropriate transport	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Birds' health issues	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00
Growth rate	0,00	0,00	0,00	1,00	-1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Weight of broilers to sell	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Poultry farming costs	0,00	0,00	0,00	0,00	0,00	1,00	-0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost per bird ready to sell	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Poultry farming profitability	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Reinvestment capacity	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,75	0,00	0,75	0,00	0,00	0,00
Flock size	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Processing conditions in national feed mills	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,50	0,75	0,00	0,00	0,00	0,00	0,00
Farmers capacity to produce & formulate feed efficiently	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,50	0,50	0,00	0,00	0,00	0,00	0,00
Cost of feed	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,50	0,00	0,00	0,00	0,00	0,00
Farmers' access to quality feed	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Breeding conditions in national hatcheries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	-0,50	0,00	0,00
Farmers' access to quality day-old chicks	0,00	-0,75	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Price of day-old chicks	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,50	0,00	0,00	0,00
Price of animal health services & products	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00
Animal health related costs	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to appropriate animal health services & products	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost of labour	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Suitability of husbandry practices, housing facilities & equipment	0,00	-0,75	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost of housing	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to knowledge/ technology transfer services	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' adoption of better practices & technologies	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Peer to peer knowledge transfer	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' membership in associations	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	-0,25	0,50	0,00	0,25	-0,25	-0,25	0,00
Farmers' capacity to lobby R&D institutions and decision-makers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' awareness of quality standards/ regulations	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Design and enforcement of regulations to support PVC	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	1,00	0,00	0,00	-0,75	0,00
Feedback from poultry farmers to R&D institutions and policy-makers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Logistic support for public officers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Compliance with poultry meat quality standards	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to low interest loans	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,75	0,00	0,00	0,00
Access to land	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farm closeness to input suppliers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,25	0,50	0,00	0,50	-0,25	-0,25	0,00
Farm closeness to processing, storage, and market facilities	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to appropriate processing, storage, and market facilities	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Product differentiation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Processing and storage costs	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to modern retail markets	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Selling price	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Incomes from poultry meat sales	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Competitiveness of domestic poultry meat	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Research on practices and technologies to improve poultry farming	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Product transportation cost	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

	Access to appropriate animal health services & products	Cost of labour	Suitability of husbandry practices, housing facilities & equipment	Cost of housing	Farmers' access to knowledge/ technology transfer services	Farmers' adoption of better practices & technologies	Peer to peer knowledge transfer	Farmers' membership in associations	Farmers' capacity to lobby R&D institutions and decision-makers	Farmers' awareness of quality standards/ regulations	Design and enforcement of regulations to support PVC	Feedback from poultry farmers to R&D institutions and policy-makers	Logistic support for public officers	Compliance with poultry meat quality standards	Access to low interest loans	Access to land
Access to appropriate transport	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00
Birds' health issues	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Growth rate	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Weight of broilers to sell	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Poultry farming costs	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost per bird ready to sell	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Poultry farming profitability	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Reinvestment capacity	0,75	0,00	0,00	0,00	0,50	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Flock size	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,75	0,00
Processing conditions in national feed mills	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers capacity to produce & formulate feed efficiently	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost of feed	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to quality feed	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Breeding conditions in national hatcheries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to quality day-old chicks	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00
Price of day-old chicks	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Price of animal health services & products	-0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Animal health related costs	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to appropriate animal health services & products	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost of labour	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Suitability of husbandry practices, housing facilities & equipment	0,00	-0,50	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,25	0,00
Cost of housing	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to knowledge/ technology transfer services	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' adoption of better practices & technologies	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00
Peer to peer knowledge transfer	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' membership in associations	0,50	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,50	0,00
Farmers' capacity to lobby R&D institutions and decision-makers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00
Farmers' awareness of quality standards/ regulations	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,25	0,00	0,00
Design and enforcement of regulations to support PVC	0,75	0,00	0,00	0,00	0,00	0,50	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Feedback from poultry farmers to R&D institutions and policy-makers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00
Logistic support for public officers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00
Compliance with poultry meat quality standards	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to low interest loans	0,75	0,00	0,00	0,00	0,25	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to land	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00
Farm closeness to input suppliers	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farm closeness to processing, storage, and market facilities	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to appropriate processing, storage, and market facilities	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00
Product differentiation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Processing and storage costs	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to modern retail markets	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Selling price	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Incomes from poultry meat sales	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Competitiveness of domestic poultry meat	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,50	0,00	0,00	0,00
Research on practices and technologies to improve poultry farming	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Product transportation cost	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

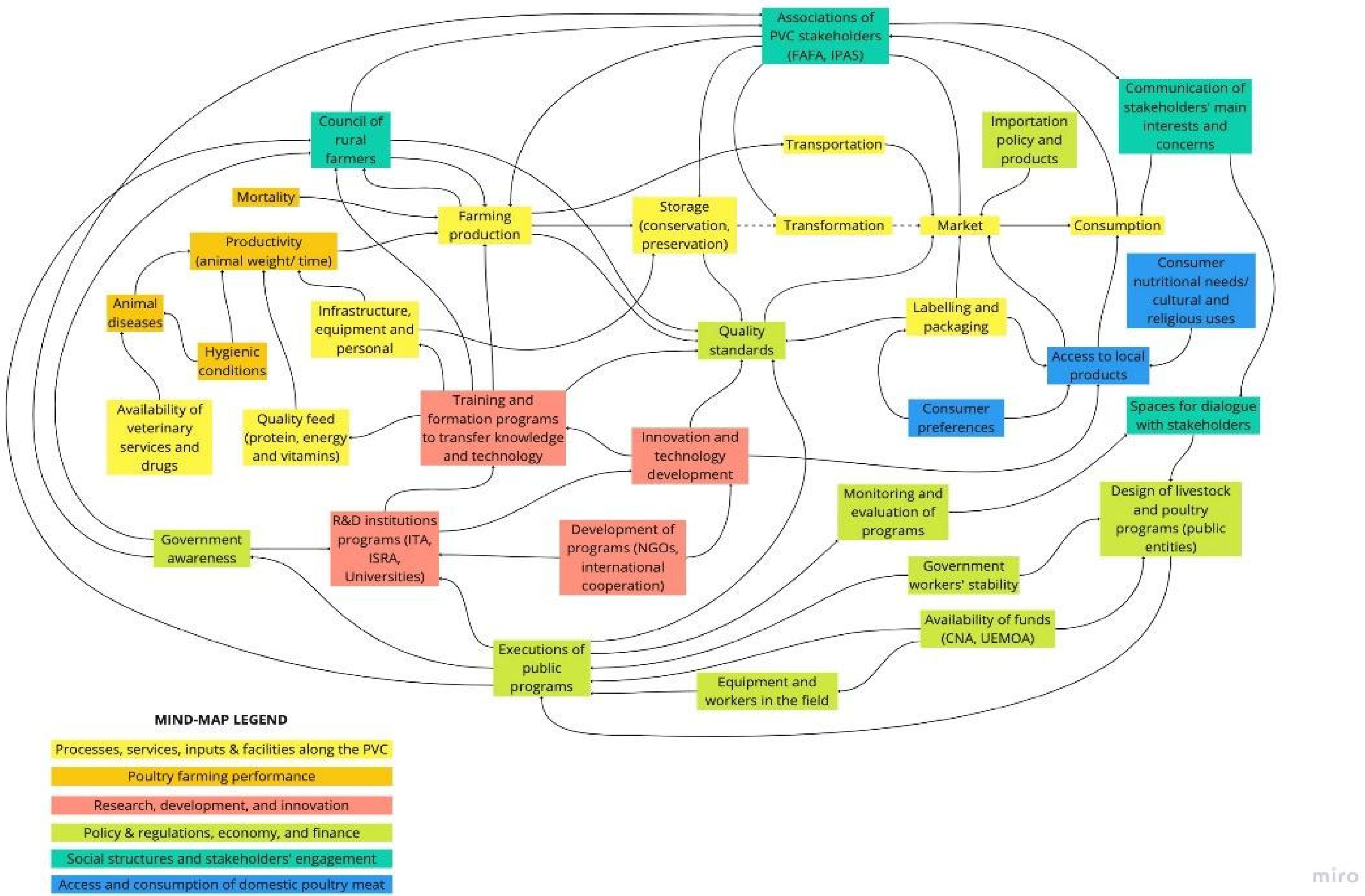
	Farm closeness to input suppliers	Farm closeness to processing, storage, and market facilities	Farmers' access to appropriate processing, storage, and market facilities	Product differentiation	Processing and storage costs	Access to modern retail markets	Selling price	Incomes from poultry meat sales	Competitiveness of domestic poultry meat	Research on practices and technologies to improve poultry farming	Product transportation cost
Access to appropriate transport	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Birds' health issues	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00	0,00
Growth rate	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Weight of broilers to sell	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00
Poultry farming costs	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost per bird ready to sell	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,00	0,00	0,00
Poultry farming profitability	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Reinvestment capacity	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Flock size	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
Processing conditions in national feed mills	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers capacity to produce & formulate feed efficiently	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost of feed	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to quality feed	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Breeding conditions in national hatcheries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to quality day-old chicks	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Price of day-old chicks	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Price of animal health services & products	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Animal health related costs	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to appropriate animal health services & products	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost of labour	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Suitability of husbandry practices, housing facilities & equipment	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cost of housing	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' access to knowledge/ technology transfer services	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' adoption of better practices & technologies	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Peer to peer knowledge transfer	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' membership in associations	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' capacity to lobby R&D institutions and decision-makers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farmers' awareness of quality standards/ regulations	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Design and enforcement of regulations to support PVC	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Feedback from poultry farmers to R&D institutions and policy-makers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00
Logistic support for public officers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00
Compliance with poultry meat quality standards	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00
Access to low interest loans	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to land	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farm closeness to input suppliers	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Farm closeness to processing, storage, and market facilities	0,00	0,00	0,00	0,00	-0,25	0,75	0,00	0,00	0,00	0,00	-1,00
Farmers' access to appropriate processing, storage, and market facilities	0,00	0,00	0,00	0,50	0,00	0,00	0,50	0,00	0,00	0,00	0,00
Product differentiation	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,75	0,00	0,00
Processing and storage costs	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Access to modern retail markets	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00
Selling price	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
Incomes from poultry meat sales	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Competitiveness of domestic poultry meat	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,50	0,00
Research on practices and technologies to improve poultry farming	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Product transportation cost	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

ANNEX J

Coding matrix of the interrelations between the variables elements of the Ghana poultry system conceptual model

ANNEX K

Non-structured mind map of the poultry sector situation in Southern Senegal case study



Associations of PVC stakeholders (FAFA, IPAS)
Communication of stakeholders' main interests and concerns
Council of rural farmers
Importation policy and products
Transportation
Mortality
Farming production
Storage (conservation, preservation)
Transformation
Market
Consumption
Productivity (animal weight/ time)
Consumer nutritional needs/ cultural and religious uses
Animal diseases
Infrastructure, equipment and personal
Quality standards
Labelling and packaging
Hygienic conditions
Access to local products
Availability of veterinary services and drugs
Quality feed (protein, energy and vitamins)
Training and formation programs to transfer knowledge and technology
Innovation and technology development
Consumer preferences
Spaces for dialogue with stakeholders
Monitoring and evaluation of programs
Design of livestock and poultry programs (public entities)
Government awareness
R&D institutions programs (ITA, ISRA, Universities)
Development of programs (NGOs, international cooperation)
Government workers' stability
Availability of funds (CNA, UEMOA)
Executions of public programs
Equipment and workers in the field
MIND-MAP LEGEND
Processes, services, inputs & facilities along the PVC
Poultry farming performance
Research, development, and innovation
Policy & regulations, economy, and finance
Social structures and stakeholders' engagement
Access and consumption of domestic poultry meat
miro

ANNEX L

Results from interviews to key stakeholders in the poultry systems of Kolda and Ziguinchor

INTERVIEWEE PROFILE: POULTRY FARMERS

1. **Main difficulties faced by smallholders:**

- *Transport of the chicks:*
  - The conditions for transporting the chicks are not appropriate. Ziguinchor and Kolda are far from Dakar (where the Kolda day-old chicks come from): transport is done in buses with luggage and men at the same time. A car adapted for the transport of poultry doesn't exist.
  - Poor supply of chicks.

- *Animal health:*
  - Non-compliance with biosecurity rules at the level of hatcheries: On the arrival of the chicks, the receiving habitat is not cleaned or disinfected, hence cross-contamination happens before delivering to customers.

- *Feed price:*
  - The prices of the feed for poultry are expensive: the manufacturing plants are all located in Dakar (SEDIMA and AVISEN).
  - Not all of them have representatives, so wholesalers increase the price of feed by adding the cost of transport, and small producers end up buying more expensive from resellers.

- *Financing:*
  - Access to financing is difficult for small farmers who want to increase their flock size or modernize their farms: loans are binding from banks (high guarantees, high loan rates, repayment requirements with very short deadlines);
  - Project or government funding is captured by politicians.

- *Concurrence:*
  - Presence of large producers throughout the value chain (production of chicks and feed, processing with butchering, distribution of broilers, weighing machines, and poultry feed) with high production capacities including GMD, SEDIMA, and AVISEN.
  - Installation of new foreign producers with enormous capacities and loans from the Senegalese capital (Jai Lami, etc.)

- *Breeders organizations:*
  - Poor structuring of the instances of the breeders' organization,
  - The information does not reach small producers,
  - Most of the sector's promotion activities are carried out in Dakar.

- *Formation and reinforcement of capacities:*
  - Weak training in good agricultural practices, production, biosecurity, and animal health.
  - Lack of training in processing and financial management of farms
  - Lack of monitoring of training activities: Most of the training programs for producers are not monitored or evaluated.
  - Lack of evaluation of the profitability of farms.

2. <u>What are the factors that affect the productivity of livestock and poultry?</u>

Productivity is improved by:

- Professional experience: Smallholders who have received training in animal husbandry, animal health, and good hygiene practices have better performance.
- The use of quality feed for chicks.
- Compliance with biosecurity rules.

- *Veterinary services:*
  - There is a veterinary practice in the department of Ziguinchor, however, prices are expensive, in particular those related to transportation and medicines. The high cost of veterinary services leads to self-medication.
  - Veterinarians are not available enough. Care is provided by technical agents or attendants who are inexperienced or not competent.

- *Feed quality :*
  - The qualities of industrial feed do not influence the purchase: Small farmers buy according to price (food items: GMD 14,700 / 50 kg bag; Sédima 15,500 / 50kg bag, NMA Sanders: 15,500FCFA / 50kg bag)
  - Some breeders produce their own feed, but the quantities are low, and the quality is not controlled.
  - Corn is the main component of the feed (imported, due to insufficient production in Senegal), as well as wheat (imported) which is often replaced in artisanal productions with rice bran. Other components are peanut meal, vitamins, calcium, and often a remix for food stability.

- *Infrastructures and equipment:*
  - The henhouses are built with the available resources (wood, wire, canvas, etc.)
  - Most of the time, farmers respect the orientation of conventional henhouses, especially for wind and sun.
  - Certain standards are not respected in most henhouses (unsuitable breeding environment, high-rise housing in houses, cohabitation with family, non-compliance with biosecurity rules).

- *Technology transfer:*
  - For production, ISRA (Senegalese Institute for Agricultural Research) develops and transfers research results and technologies through training and technical supervision in the establishment of henhouses, in vaccination,

and in monitoring the performance of poultry (feed, animal health, biosecurity).

- ISRA has a vaccine production center. The production is donated to the Ministry of Livestock and Animal Production, which is responsible for distribution to the actors.
- Regarding ITA's work, the stakeholders know the results of their research but do not apply them for various reasons (price of training, high acquisition of equipment, concentration of investments on the breeding and marketing of chickens, and absence of supervision of projects and programs by employees and the government.

- *Land issues:*
  - There is a reduction in agricultural and livestock spaces because the land is being used by local communities for youth spaces, and real estate projects. In poultry farming, this is evidenced by the decrease in henhouse spaces.

- *Energy :*
  - Access to chicks' water and feed overnight for the first few days increases the weight at maturity that is at 45 days).
  - lack of freezing and refrigeration due to lack of electricity.
  - delivery just at slaughter which lowers selling prices.

3. Poultry feed

3.1. How is the access to poultry feed?

The poultry feed manufacturing companies are mainly located in Dakar (450 km from Ziguinchor and Kolda). Transportation makes food prices expensive for producers. The low number of wholesalers and resellers in these two regions often leads to disruptions.

3.2. Is there any problem with the availability and access to quality feed?

The price of food that has increased because of the Covid leads to production cuts.

3.3. What determines the quality of feed?

The inputs of poultry feed manufacturing, especially the corn and animal proteins.

3.4. How does feed quality influence the productivity of animal farming?

- The weight of the chicken is determined by the quality of the feed. At 35 days, with a good diet, the chicken reaches 2Kg and commercialization can be done. Beyond the rearing period (45 days), feed is considered a waste. Hence, the importance of choosing a quality diet.
- Adaptation to the age of the chicks: starter foods that go from day 1 to day 14 (are high in energy, protein, calcium, fat, and minerals), growth from the 3rd week (21st day), and the finish after.
- The initial amount of food and water consumption is key, hence the importance of having light at night. Housing conditions also influence consumption (ventilation, space between chicks, density of chicks, rearing period).

3.5. Where does the feed come from (national, local, or importation)?

Poultry feed is produced in Senegal, mainly in the regions of Dakar and Thiès (SEDIMA, AVISEN, GMD, and NMA Sanders).

4. Infrastructure and Equipment

4.1. What infrastructure and equipment are required for animal farming?

- Suitable room: rearing houses, hen house, ventilation, water drainage, electricity accessibility, construction material, etc.

- Drinking trough, gas
- Incubators.

4.2. What prevents some smallholders from having an adequate infrastructure? What are the main problems derived from inadequate infrastructure?

- The initial amount of food and water consumption is key, hence the importance of having light at night. Housing conditions also influence consumption (ventilation, space between chicks, density of chicks, rearing period).

5. Veterinary services

5.1. When and how often do you need veterinary services?

- Before starting production: Advice and technical support (choice of strains, appropriate treatment, installation rules, equipment, and biosecurity).
- At the beginning of the production stage, essentially for vaccinations against Gumboro – infectious bursal disease – and for anti-stress management of chicks.
- For vaccinations in case of an epidemy and during the epidemy, during sudden mortalities, etc.

5.2. Do you have any problem accessing veterinary services and medicines when needed?

- As the number of veterinarians is low, the practices are managed by technical agents or auxiliaries whose skills and availability are reduced.
- High prices of veterinary services.

5.3. Is there a strong local knowledge about traditional cures or medicines?

Traditional medicine is not common for the breeding of broilers.

5.4. Does the lack of access to veterinary services and medicines prevent you from treating some diseases?

During epidemics and for vaccination of certain diseases not considered by the government.

5.5. How does it translate the lack of veterinary services and medicines into animal losses, costs of production, quality, and quantity of meat, etc.?

- High mortality of chicks (more than 5% according to standards)
- Growth retardation (the weight of the chicks is too low after 35 days (less than 2 kg)
- High production cost
- Ease of transmission of zoonoses.

6. Training programs and extension services by research institutions, government programs, NGOs, and international cooperation for farmers.

6.1. What do you know about those programs?

- Some actors do not know about innovative research technologies, and those who know haven't received training on how to use those technologies.
- The research programs and projects are known by most of the managers of associations or organizations of breeders, who assist in the development and/or validation. Direct beneficiaries only see a part of it (smoked chickens, canned poultry, for example) or do not know them.

6.2. Can you share some impressions?

- The format of the seminars of research programs isn't adapted, mainly due to the language and the organization.
- Technology transfers are more suited to industry, to SMEs / SMIs.
- Weaknesses in the communication for its popularization
- Weak accessibility of the program results for farmers.

7. Participation in programs of training/ technical advice

7.1. Have you ever participated in those programs or received technical advice?

- Among those surveyed, 40% received technical advice and training from ISRA, ITA, or partners who were trained by these two research institutes.

7.2. What does access to these services depend on?

- Financial means
- Location
- Technical and financial partners
- Government priorities.

7.3. Are these services available for all smallholders?

All smallholders can benefit from these services.

7.4. Is the technical staff enough to meet the needs of smallholders (coverage, periodicity)?

The technical staff is not sufficient and the logistics for the realization are also weak. The delay in the realization of the training/ extension service is due to these technical and human resource constraints.

7.5. Can you give us some examples of innovations, technologies, and extension services given to smallholders?

- Vaccine production.
- Methods of preserving and storing chickens (refrigeration, freezing).
- Processing techniques for animal products (drying, smoking, appertisation, cooking, etc.);
- Training and awareness-raising on good hygienic and manufacturing practices, the installation standards of henhouses, the choice of equipment, the country's laws and regulations, etc.
- Monitoring of facilities, production, and management of animal husbandry for animal health.

7.6. Do the topics addressed in the training programs and extension services answer the main concerns and interests of smallholders?

- Yes for 60% of respondents.
- No for 15% of respondents.
- The rest (25%) consider that the actors’ expectations must be asked, before the realization of technologies, and respect the breeders’ priorities instead of research or the advancement of researchers.

8. Storage needs and importance:

8.1. What are the storage needs of smallholders?

Preservation methods that smallholders need: refrigeration, freeze, drying stabilization, or smoke.

8.2. What these storage facilities could prevent or facilitate?

- These methods allow products to be preserved during periods of high production.
- Avoid damaging the chickens after slaughter in the event of a lack of customers or a too-low market price.

- To facilitate the diversification of products on the market.

9. Difficulties in storage:

9.1. What are the main reasons for not having storage facilities in rural areas?

- Lack of electrical energy.
- Weaknesses in training on storage techniques.
- Weak income for the purchase of conservation equipment.

9.2. Can you give us more detail about the difficulties you face without storage facilities?

- Loss of production after slaughter and absence of a buyer (After 45 days the breeders are obliged to slaughter the chickens to reduce expenses, especially of feed)
- Problems of access to markets outside production areas (City of Kolda, Ziguinchor, Vélingara, Bignona, Kaolack).
- Weakness of the products offered, in terms of biosecurity.

10. Do the storage facilities determine production? For example, in terms of quantity, and capability of growth, among others.

- In Ziguinchor and Kolda areas, the quantities produced by small farmers range from 200 to 500 chickens per flock.
- There are a few operators that go up to 1000 chicks per flock.
- The chickens sold weigh between 1.7 kg and 3 kg.
- The production and quantities of chicken slaughtered depend on the storage equipment available.

11. Can you mention some of the key actors involved in providing or enabling storage facilities?

- Transformers in urban areas thanks to the support of projects, research, and the private sector
- Feeders, sellers of conservation equipment.

What role do they play?

Training, awareness, and networking with technical and financial partners.

12. Ways to overcome barriers related to storage.

12.1. Are there ways to overcome the barriers that prevent smallholders from storing their products appropriately?

- Training on innovative techniques for preserving products,
- Acquisition of suitable materials and infrastructure,
- Search for technical and financial partners in support of training, financing, and the acquisition of equipment.

12.2. Do you know any method or technology that could help in that regard and that is feasible for smallholders to adopt?

- The techniques proposed by research institutions, particularly ITA and ISRA (drying, refrigeration, freezing, and appertization).
- Foreign technology transfers to see the adaptation to our practices.

INTERVIEWEE PROFILE: INTERMEDIARIES

13. **After the smallholder sells his product, processed or not, what happens? Who is involved until the product arrives on the market?**

- The main intermediary of the breeders is the tefanké or reseller. “The Tefanké” sells live cattle to wholesale butchers (or “chevillard”), and to consumers directly for major ceremonies (weddings, baptisms, pilgrimage, deaths, etc.) in cattle markets or on farms.
- The “chevillards” located at the slaughterhouse level provide retail butchers with meat.
- Retail butchers sell the meat in the city's markets or butcher shops and provide it to restaurants and consumers.

14. **Do you consider that there are enough slaughterhouses in the country? Where are they located? Is it easy for breeders to access it, or do they usually have to travel long distances?**

- In Senegal, we have 18 functional slaughterhouses, with the absence of hygienic conditions and standards in most of these slaughtering and meat market facilities. Slaughterhouses are public-private structures: with state participation in administrative and health control and private participation in technical and financial management.
- The slaughterhouses are located in the capitals of departments or regions.
- Most of them are outside built-up areas but accessible to breeders. However, with the demographic progression, homes are getting closer and closer.

15. **Who is usually involved in the slaughter and the first processing of meat? How does the product get to market? Are the "intermediaries" who contact smallholders on their farms? Or is it the other way around? Or both?**

- Slaughtering must be carried out by slaughterhouse butchers with verification by the public veterinarian (depending on the Ministry of Livestock and Animal Production) before selling.
- The slaughterhouse sells the carcass; the cutting is done outside the slaughterhouses in the markets or the butchers of the cities.
- Transport is done with rarely refrigerated cars, passenger cars, motorcycles, motorcycles, etc.
- The main intermediary that regulates the market is the "Tefanké" (cattle wholesaler): they buy from breeders on farms and livestock markets to sell to slaughterhouses or retailers.
- The contact takes place at the level of livestock markets, on farms, among breeders, and at slaughterhouses.

16. **Where is poultry/ cattle smallholder meat ultimately sold? What path do these products take to reach the final consumer? Which agents are involved? (Wholesalers, retailers, supermarkets, catering sectors, etc.)**

Meat path:
Breeders - Tefanké (Cattle wholesaler) - Slaughterhouses - Wholesale butchers (Chevillards) - butcher retailers - supermarkets or markets or butchers - restaurants or consumers.

17. **What are the factors that determine the product's access to the market, in addition to purchase price decisions?**

- Feed and the number of cattle: In unfavorable periods in agriculture (corn, peanuts, or millet), breeders sell animals to buy animal feed and for family management (children's supplies, food purchases, ceremonies, etc.); they also sell while the herd grows.

- Infrastructure: Slaughterhouses in large cities allow breeders to increase their incomes. To access large livestock markets, which are located in Dakar, roads are essential.
- Animal health: The monitoring of pathologies and a good diet make it possible to have quality animal production and a good sale.

18. <u>How is the selling price set? How does the place of sale influence the price? Between what values has the price fluctuated over the past year?</u>

- The price of cattle depends on the resellers or "tefanké", time of year, availability of feed, and the purchasing area.
- Meat has a relatively constant price at the slaughterhouse level and at the retail level.
- For the consumer, the price varies between 3000 FCFA and 3500 FCFA (cattle and sheep).

INTERVIEWEE PROFILE: AGENTS INVOLVED IN POLICIES AND REGULATIONS:

19. Some national standards and regulations establish quality standards for the commercialization and consumption of agri-food products. **What do these regulations cover? How do these regulations shape the commercialization of animal meat, and what impact do they have on the participation of smallholders in the market?**

National and international regulations: Laws (LOASP), regulations (national and international), orders applied by the departments of the ministries of livestock, health, and trade, ASN, Codex, HACCP, and ISO standards. They relate to:

- Hygiene rules for premises, staff, processing equipment, etc.
- Acceptability or non-microbiological (presence or absence of salmonella, staphylococci, FMAT, listeria, etc.).
- Consumer protection (information on labels, presence of additives, non-halal products, etc.)
- Protection against illegal slaughter, poor quality meat from sick animals, or the use of drugs, etc.

20. Can you briefly describe what these regulations address? (Sanitary and hygienic conditions throughout the stages of the value chain, traceability, and quality of the final product, among others).

- Good hygiene practices in places where animal products are sold.
- Slaughterhouse biosecurity
- Monitoring and vaccination against animal pathologies.
- control of diseases transmissible from animals to humans, respect for processing and marketing facilities, traceability, and hygiene of products of animal origin.

21. How does the livestock sector meet these requirements? Are they feasible for industrial production as well as for family or small-scale production?

- Presence of a Ministry in charge of livestock and animal production with central departments (livestock department, veterinary services department, animal industry departments), regional and departmental inspections, field verification officers, and veterinary officers.
- All productions (cattle, sheep, pigs, goats, poultry, etc.) as well as artisanal and industrial processing are represented in a national network.
- Livestock Development programs and projects are designed to ensure the professionalization of stakeholders and meet the expectations of consumers.

22. <u>How do these regulations influence market access for cattle meat from smallholders?</u>

- Improvement of the sanitary and nutritional quality of meat on the market.
- Protection of consumers from toxic and damaged products from pathologies transmissible to humans.

23. <u>What are the main difficulties encountered by smallholders in getting their products to meet these standards?</u>

- Weaknesses in training and awareness of standards.
- Processing and commercialization facilities and equipment are not up to standards.

24. <u>For products that do not meet national regulations, are there alternative sales channels? Are there any markets which are not subject to strict control in this sense?</u>

Illegal markets. All markets are monitored, however, there are clandestine markets for meat selling.

25. **<u>What are the advantages and disadvantages of participating in these markets, both for the producer/ seller and for the consumer?</u>**

- Advantages: health and safety; traceability, ease of control by the authorities, better meat quality, good selling price.
- Disadvantages: constraints to selling due to non-compliance with standards, fines, and business closures.

26. **<u>Interventions that help to overcome the barriers smallholders face in meeting quality standards and accessing the national market.</u>**

- Training on hygiene standards, and national and international regulations.
- Establishment of quality infrastructure, slaughterhouses, refrigerated trucks, cattle market, presence of veterinary agents, etc.
- Availability or easiness to obtain authorizations and approvals for transformation and commercialization.
- Information and updating of regulations.

27. **<u>Are government programs, research & technological development institutions, universities, and other civil society organizations helping to overcome the difficulties smallholders face in meeting quality standards? How? To what extent?</u>**

- Research projects aimed to improve smallholders' awareness of regulations and standards.
- Organization of training and informative workshops.
- Proposals for standards on meat and meat products (Association Sénégalaise de Normalisation)
- Analysis of products to obtain the manufacturing and marketing authorization (Aut FRA).

28. **<u>How is the communication going between these institutions and the smallholders? Does it involve participatory processes to design interventions that address their concerns? Can smallholders provide feedback during the implementation of these interventions?</u>**

- Workshops and seminars for sharing regulatory texts, good practice guides, and raising awareness of standards.
- Implications of smallholders in livestock projects and programs to upgrade breeders, livestock markets, vaccination, processing, etc. (PRAPS, PRADELAIT, PROGRES-LAIT, etc.).
- Participation in the establishment and validation of strategic plans for universities and research institutes.

TO ORGANIZATIONS THAT PLAY A ROLE IN INNOVATION AND RESEARCH:

29. **Can you tell us more about the role that research institutions, universities, government programs, international cooperation, and other civil society organizations play in the production and transfer of new knowledge and technologies to respond to the needs of the livestock and poultry sector?**

i. ITA (Food Technology Institute): under the technical supervision of the Ministry of Industrial Development and Small and Medium Industries.

- Contribution to improving the performance of the livestock sector by intervening in the entire process of transformation and conservation of food products, through research and development.
- Provide to local promoters (transformers?) and industries, a team of researchers and technicians specialized in meat transformation processes and methods.
- Provision of specialized equipment (laboratories and pilot plants) allowing the experimental validation of the processes and methods developed.

ii. ISRA (Senegalese Agricultural Research Institute): under the technical supervision of the Ministry of Agriculture and Rural Equipment.

- Participation in their areas of expertise in the establishment of the national livestock development policy (LNERV, CRZ).
- Promotion of research results, both at the level of the scientific community and of all sectors of the economic and social life.
- Transfer of scientific and technological knowledge.
- Research training.

iii. Universities, training schools, and research centers: Academic and certification training (University of Dakar, EISMV, UGB, USSEIN, ISFAR): Continuous and initial academic training.

iv. Government programs and international cooperation: training, supervision, and funding of small livestock farmers.

30. <u>What communication channels exist between the different institutions and agents that develop and transfer new knowledge and technologies to the livestock and poultry sector? Do they coordinate to improve the problematic situations of livestock and poultry? How?</u>

- Projects and programs: PSE; Agro-poles south, north, and center.
- SNRAAS: which brings together universities, and agricultural & agro-food research centers.
- Board of directors and scientific advice, with representation from the public and private sector.

31. **Are the innovations developed by research institutions validated and shared with smallholders? How are knowledge and technologies transferred to them?**

- Training
- Incubations and technical support.
- Popularization through articles, national or regional fairs, and open days.

32. **Can you tell us more about your work in developing and transferring new knowledge and technologies? What are the innovations and research developed by your organization focused on? What problems or bottlenecks are you trying to solve?**

i. ITA:

- Guide and coordinate research on the treatment, transformation, packaging, and preservation of local food products, mainly to promote the establishment of corresponding industries.
- Develop new food resources derived from productions that have a good nutritional value and that are adapted to the taste and purchasing power of consumers.
- Assist in the quality control of food products at the production, marketing, and export stages.
- Participate in the training of food trades.
- Promote the installation of industrial or artisanal food processing units.

ii. ISRA:

- Enhancing productivity to improve food and nutritional security: basic research on variety selection and biotechnology; applied research and research development on soil fertility management, improved animal health and production.

- Climate change and mitigation measures for its impacts: Climate variability compromises our production systems and harms the competitiveness of our agriculture.
- Professionalization of sectors: In the context of the socioeconomic worldwide challenges and the globalization of trade, agricultural sectors are called upon to adapt to the requirements of national and international markets. The research to be included in this strategic plan will aim at a better professionalization of the sectors by improving the processing, distribution, and marketing circuits, but also by choosing agricultural policies sensitive to the competitiveness of sectors.

TO RETAILERS, SUPERMARKETS, OR OTHER AGENTS WHO SELL THE PRODUCTS TO END CONSUMERS:

33. Which animal meat products are more in demand? Locally produced or imported? Poultry, pork, sheep, beef, goat meat? What presentations (animal pieces)?

Listed from more to less demanded.

- Local meat: Beef, poultry, sheep, pigs
- Presentation: whole or cut into pieces (shoulders, fillets, chops, thighs, etc.), chopped, local cold cuts (sausages, dry sausages, ham).
- Imported deli meats: mainly in the town of Ziguinchor (town center)

34. How does demand fluctuate throughout the year? Why?

- Depending on the time of the year. Ramadan, religious festivals (Tabaski, Korité, Christmas, and Easter), and weddings are periods of high consumption.

35. <u>Do you have supply problems? With which products? Why? What are you doing to resolve them?</u>

- Holiday season: meat in pieces, whole chickens (Christmas, Easter and Ramadan)
- Imported and local cold cuts (sourcing outside the Kolda and Ziguinchor regions)
- Supply very early, preservation by freezing to increase the shelf life.

36. <u>What requirements must products meet to be sold in your establishment? How does this affect the type of products you offer to the consumer? (Imported or locally produced products, products of smallholders or industrial producers, etc.)</u>

- FRA authorization, labeling, health and safety quality, and good presentation.
- Compliance with regulations.
- Demand increases and consumers are more and more demanding quality.
- All products are affected.

37. <u>What does the final price of meat products depend on? (Type of product, degree of processing, origin, type of production - artisanal or industrial, quality, etc.) Between which values has the price of meat products fluctuated during the last year?</u>

- Type of products (bovine, poultry, or pork meat)
- Sanitary and hygienic quality
- Degree of transformation; industrial or artisanal
- Local or imported production.

TO CONSUMERS:

38. <u>Consumer preferences: What kind of meat do you prefer?</u>

- Sheep, bovine, goat, chicken, pig meat.
- Local cold cuts: minced beef, sausages, and dry sausages made from beef, pork or chicken, Merguez, smoked chickens).
- Imported cold cuts: sausages, dry sausages, salamis, etc.

39. <u>Can you tell us what you take into consideration when choosing which meat to buy, in addition to the price?</u>

- animal origin (Halal or not)
- colors and composition (proteins, fats, presence or absence of additives)
- native country

<u>Why?</u>

- religion
- health
- confidence in producers
- sanitary conditions
- compliance with regulations
- toxicity.

40. <u>Do you prefer local or imported products?</u>

- Local products (80% of respondents): composition, reduces the risk of consuming additives, mixing with prohibited meat (especially pork or pork components).
- Imported products (20% of respondents): good presentation and tastier.

41. Does presentation play a role in your decision? (Packaging and labeling, animal parts).

- Yes: information on the composition, compliance with regulations, visual appreciation, ease of use, etc.

42. Do you prefer products with a certain type of certification? (Sanitary of another type).

- Yes: 90% of those questioned, particularly on the origin and health certification of the competent authorities.
- No: 10% do not know the certification so they rely on the intermediary or points of sale (restaurants, supermarkets, butchers).

43. Consumer Nutritional Needs: Do you find that you and your family are meeting your nutritional needs with the products you buy and consume?

- Not sure. Doubts about the composition of meat and meat products (presence of fats, additives, colorings, etc.)
- Red meat is a potential source of cholesterol and hypertension.

44. What role do you think meat products play in meeting your family's nutritional needs?

- Intake of proteins, carbohydrates, and minerals.
- Diversification of consumption.
- Ease to prepare/ consume.

45. Are your preferred meat products available in nearby markets?

- Meat and cuts of 1st processing are much available across the regions.
- Cold cuts and other processed products are available in towns.

46. **<u>What does the availability of poultry meat depend on?</u>**

Presence of distributors and transformation companies (for processing products).

47. **<u>What type of meat is most available to consumers at the country level?</u>**

Bovine, ovine, caprine, chicken and pork.

48. **<u>Are there significant differences between urban and rural markets?</u>**

Absence of meat products, especially cold meat, in rural areas.

49. **<u>How do cultural or religious celebrations influence the supply, demand, and consumption of animal meat during the year?</u>**

Consumption is strongly influenced by religious festivals.
During Tabaski, sheep demand and consumption usually grow exponentially. During Christmas and Easter festivals, the demand and consumption of pork and chicken increase. For marriage celebrations and Muslim religious ceremonies or burials, the demand and consumption of oxen increase. Finally, during the feast of Korité or at the end of Ramadan, the demand and consumption of goats and chickens increase.

50. **<u>Do you have access to the meat products of your choice?</u>**

Depends on the location and the price.

<u>If not, why (affordable price)?</u>

- High prices
- Lack of meat processing facilities outside Dakar or other main cities, which limits the availability of processed products
- Difficulties in accessing processing products (from Dakar or imported ones).

51. **<u>Are you replacing the meat product of your preference with other meat or non-meat products?</u>**

Yes, by consuming meat in pieces with meals and legumes (cowpeas, peas, etc.) and dairy products.

TO ASSOCIATED FARMERS OR OTHER STAKEHOLDERS INVOLVED IN LIVESTOCK ASSOCIATIONS:

52. **<u>How are stakeholders organized in the livestock sector and along value chains? Are they organized in associations or cooperatives? Can you name a few in the poultry, cattle, goat, sheep, and pig industries?</u>**

    Most breeders are organized in regional associations, some in federations or inter-profession.

    Example:

    - Professional livestock organizations: Maison des Breeders (MDE), National Association of Meat and Cattle Producers of Senegal (ANPROVBS)
    - Association of milk producers in the Linguère milk sector (APAFILS)
    - Federation of Poultry Farmers of Senegal (FAFA)
    - Association of actors in the pig industry.
    - Regional Association of Actors in the Goat Industry in Fatick (ARECAF).

53. **<u>How are these associations formed? What is its purpose?</u>**

    - Defense of the moral and financial interests of the members of the association.
    - Representation to local or central authorities
    - Search for technical and financial support
    - Create opportunities for farmers to leverage economies of scale in production, transformation, and commercialization activities.
    - Increase awareness of members of the association on vaccinations, good practices, financial and technical management of the operation, etc.

54. <u>How does the organization work internally (roles, responsibilities ...)?</u>

Constitution: Election of the management board at the level of each department and region (President, secretary general, treasurer, organization commission, external relations commission, etc.). Each region sends its representative for the election of the national association.

55. <u>Who constitutes/creates these associations?</u>

Stakeholders in the value chain (producers or breeders, transformers, distributors, consumers).

56. <u>How does representation work regarding communication with other agents (decision-makers, research institutions, technicians, etc.)?</u>

National or regional presidents and secretary general ensure communication with decision-makers and technical and financial partners.

57. <u>Are the associations stable over time?</u>

- The associations are stable. However, this « stability » sometimes is counterproductive, with presidents who have done more than twenty years (20 years) without renewing institutions.
- The number of active members is low due to the absence of democracy in decision-making bodies, lack of confidence in leaders, non-transparency in technical and financial support, poor financial management, etc.

58. <u>What does this stability depend on?</u>

Application of the statutes of Associations, the State's perspective in the operation and governance of associations, motivation of members, awareness of members on the importance of the associations, and transparency in internal management.

59. <u>How do stakeholders benefit from their membership in associations or cooperatives?</u>

- Participation in regional or national fairs
- Access to training programs,
- Transfer of knowledge and technology
- Access to financing, technical and material support from public and private partners, etc.

60. <u>Benefits of associations and cooperatives as communication platforms with policymakers and decision-makers.</u>

- Facilitates communication within the value chain
- Have a supporting role in designing policies.
- Strengthens the role of farmers and other stakeholders in governance structures.

ANNEX M

List of publications

Type of contribution	Title	Source	Authors	Status
Scientific paper	Systems thinking and complexity science-informed evaluation frameworks: Assessment of The Economics of Ecosystems and Biodiversity for Agriculture and Food https://doi.org/10.1002/ev.20455	New Directions for Evaluation SJR Q2 (2021)	María Bustamante, Pablo Vidueira, and Lauren Baker	Published (2021)
Conference presentation	Developing and applying ten Systems Thinking and Complexity Science principles to an agricultural meta-evaluation	American Evaluation Association	María Bustamante	Presented (2021)
Scientific paper	Navigating food systems transformation: The contributions of Systems Thinking and Complexity Science	Global Food Security JCR Q1 (2022)	María Bustamante, Pablo Vidueira, and Lauren Baker	Sent
Scientific paper	Identification of food systems transformation pathways through Participatory Food Systems Modeling. Application in poultry systems in Kolda and Ziguinchor regions, Senegal.	Agricultural Systems JCR Q1 (2022)	María Bustamante, Carlota Rillo, Ibrahima Niang, Pablo Vidueira, Lauren Baker	In review