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Harvesting insights for transformation: Developing and testing a participatory food systems modeling framework in Southern Senegal's poultry system

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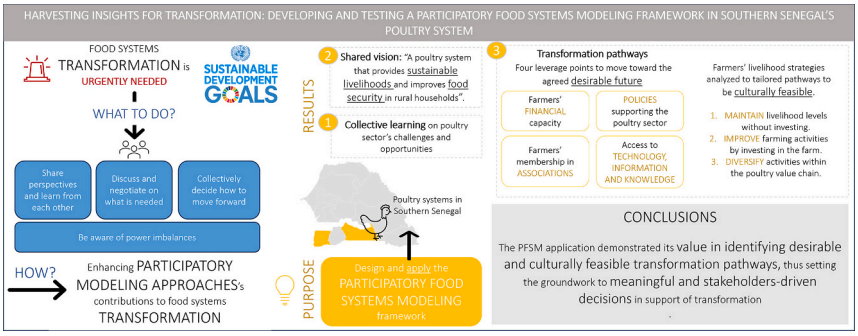
HIGHLIGHTS

- Transforming food systems involves challenging the status quo by engaging diverse stakeholders and perspectives.
- We propose and apply a Participatory Food Systems Modeling framework to identify suitable transformation pathways.
- The framework fosters stakeholders' exchanges and cross-learning, providing valuable insights for transformation.
- The case study reveals transformation pathways for poultry systems in Senegal adapted to farmers' livelihood strategies.
- The framework proved significant for stakeholders to inform and support the transformation of food systems.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Food systems urgently need transformations to meaningfully reduce food insecurity and hunger without compromising sustainability. These structural changes involve challenging the status quo by engaging diverse stakeholders and perspectives.
PURPOSE: This research aims to enhance the contributions of participatory modeling approaches in supporting the transformation of food systems. Thereby, it proposes and applies a Participatory Food Systems Modeling (PFSM) framework to identify desirable and culturally feasible transformation pathways in food systems.
METHODS: Aligned with Participatory Modeling and Soft Systems Methodology principles, the PFSM framework proposes three phases for stakeholders with diverse perspectives to collectively make sense and learn about food systems complexity, negotiate and agree on a desired future, and explore desirable and culturally feasible

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pathways that move forward. To test its value to support transformations, the PFSM is applied in poultry systems in Southern Senegal, where traditional poultry farming prevails.

RESULTS AND CONCLUSIONS: The PFSM application in the case study demonstrated its value in identifying desirable and culturally feasible pathways, thus setting the groundwork for informing meaningful, realistic, and stakeholders-driven decisions in support of the needed transformation. Linking the PFSM to real-world situations offered valuable insights into how participatory modeling approaches can contribute to addressing barriers to food systems transformations, such as power imbalances and conflicts and undesirable trade-offs arising from divergent perspectives.

In Southern Senegal's poultry system, the PFSM framework informed the identification of four transformation pathways focused on (i) enhancing farmers' financial capacity, (ii) reinforcing policies supporting the poultry sector, (iii) improving farmers' membership in associations, and (iv) enhancing farmers' access to technologies, information, and knowledge. Tailored to poultry farmers adopting different livelihood strategies, these pathways aim to provide sustainable livelihoods and improved food security in rural households.

SIGNIFICANCE: The significance of the PFSM framework extends to political, scientific, and practical reams. Politically, it informs the debates and decisions on the future of food systems based on stakeholders' interests, concerns, and aspirations, thereby improving the significance and meaningfulness of decisions. Scientifically, it elevates the contributions of participatory modeling contributions to transformative processes. Practically, it supports addressing real-world challenges through transformations.

1. Introduction

Food insecurity and hunger are central challenges on sustainable development agendas worldwide that demand thinking systemically to develop comprehensive solutions that recognize their complex and intricate nature (Meadows, 2008; Plate, 2010; Reynolds et al., 2016; Reynolds and Holwell, 2010; Williams and Hummelbrunner, 2009). This shift toward systemic approaches has gained traction in the scientific and socio-political spheres that work for sustainable food systems (e.g., Allen and Prosperi, 2016; Calicioglu et al., 2019; Dury et al., 2019; Ericksen, 2008; FAO et al., 2021b; Halbe and Adamowski, 2019; HLPE, 2020; Hubeau et al., 2017; Ingram, 2011; Kopainsky et al., 2018; TEEB, 2018; van Berkum et al., 2018; Waterlander et al., 2018).

Despite the undeniable progress made in understanding food systems challenges, global trends reveal significant deviations from fulfilling the Zero Hunger goal (FAO et al., 2021b; Kakar et al., 2021; United Nations Economic and Social Council, 2021; Sachs et al., 2023; WHO, 2020), especially in countries with conflicts or political instability (Food Security Information Network and Global Network Against Food Crises, 2023).

The growing understanding of food systems, coupled with the discouraging trends in addressing their challenges, has led to a global demand for transformations to meaningfully reduce food insecurity and hunger without compromising other sustainability outcomes (Béné et al., 2019; Calicioglu et al., 2019; Dury et al., 2019; El Bilali et al., 2019; Ericksen, 2008; Fanzo et al., 2020; FAO, 2017; FAO et al., 2021; Garnett, 2014; Global Panel on Agriculture and Food Systems for Nutrition, 2020; HLPE, 2020; Kopainsky et al., 2018). Béné (2022) asserts that these transformations require structural adjustments that challenge the status quo, where the aim is a more sustainable food system with positive outcomes for both people and the environment.

Making structural changes that modify systems' behavior and trends requires engaging with diverse agents and perspectives (Midgley, 2006; Reynolds and Holwell, 2010). In this context, scholars emphasize the pivotal role of participatory processes in fostering collective learning about the situation to be addressed to inform the design of practical interventions that resonate with diverse perspectives (Blesh et al., 2019; Checkland, 2000; Checkland and Poulter, 2010; Eppel et al., 2011; Foster-Fishman et al., 2007; Kania et al., 2012; Midgley, 2006; Vincent, 2012; Williams and Hummelbrunner, 2009). Along the same line, Schot and Steinmueller (2018) advocate for participatory approaches to: assess what is failing in the current situation; accommodate diverse viewpoints in making decisions about what the desired future should be and how to achieve it; and be aware of the governance and power structures that influence the decisions needed for the required shifts to contribute to transformative changes.

In the food systems field, various authors highlight tensions, conflicts, and undesirable trade-offs resulting from the lack of acknowledgement and engagement with diverse perspectives, hindering the necessary transformations (Béné, 2022; Caron et al., 2018; Hubeau et al., 2019; van Bers et al., 2019). A significant emphasis lies on how governance structures limit the agency of certain groups while favoring the interests of those benefiting from the current status quo. These imbalances further strengthen the resistance to transitioning to more sustainable systems (Blesh et al., 2019; Brouwer et al., 2020; FOLU, 2019; Garcia-Gonzalez and Eakin, 2019; Leeuwis et al., 2021; van Bers et al., 2019). Authors addressing these transformation barriers advocate for engaging and empowering stakeholders with diverse perspectives to participate on equal footings in dialogs on food systems challenges to, thus, inform actions based on realistic assumptions with collective support (Béné, 2022; Boogaard et al., 2011; Brouwer et al., 2020; Caron et al., 2018; HLPE, 2020; Leeuwis et al., 2021; Ruben et al., 2021).

In response to this call, a substantial body of work aims to design practical stakeholders-driven strategies through Participatory Modeling approaches in food systems. Group Model Building (GMB) stands out as a participatory modeling approach that fosters stakeholders' collaboration and engagement by building a shared understanding of complex issues and proposing bottom-up solutions that are acceptable and, thus, owned by the involved community (Andersen et al., 2007; Gerritsen et al., 2019; Hovmand, 2014; Vennix et al., 1996). In agricultural and food systems, GMB has been applied in developing systems dynamics models (e.g., Gerritsen et al., 2019; Jagustovic et al., 2019; Jagustovic et al., 2021; Lie et al., 2018), Spatial GMB (Rich et al., 2018; Rich et al., 2022) and Agent-Based Modeling (Koh et al., 2018).

Lessons from Kotir et al. (2024) on GMB stress the importance of creating spaces for stakeholders with diverse viewpoints to freely express their interests and concerns to foster shared learning and respect when exploring a situation and discussing strategies to address it. They recommend designing strategies that recognize and address the impact of the governance structures and power imbalances in stakeholders' participation to, thus, prevent certain groups from dominating discussions.

Although the contribution of Participatory Modeling approaches in fostering learning and facilitating joint decisions among stakeholders with different perspectives is tangible, we consider there is a substantial opportunity to elevate and make explicit their potential to inform and support transformative processes.

We take as a departure point and source of inspiration for this research the Agri-Food Systems Sustainability Approach (AFFSA) framework proposed by Hubeau et al. (2017) which, based on Soft Systems Methodology (SSM), mobilizes stakeholders that face a common issue to share their goals, interests and expectations, by fostering

mutual learning and knowledge co-creation to collectively identify the pathways for transformation.

Building on Schot and Steinmueller (2018) recommendations for participatory approaches to inform transformative processes – described above – and drawing on key previous work, this research proposes and applies the Participatory Food Systems Modeling (PFSM) framework to identify desirable and culturally feasible transformation pathways in food systems. The PFSM framework, aligned with Participatory Modeling (Duboz et al., 2018; Voinov and Bousquet, 2010; Voinov et al., 2016) and Soft Systems Methodology (Checkland, 2000; Checkland and Poulter, 2010) principles, mobilizes diverse stakeholders and perspectives to collectively make sense of food systems challenges, negotiate and agree about a desired future, and explore desirable and culturally feasible pathways that move forward. By enhancing stakeholders' awareness and respect for diverse perspectives, the PFSM framework aims to foster collective learning and strengthen commitment to the decisions that support transformations (Béné, 2022; Blesh et al., 2019).

Section 2 presents the PFSM framework by briefly describing its theoretical foundations and application in poultry systems in the Kolda and Ziguinchor regions in southern Senegal. Section 3 discusses the results of implementing PFSM in the case study areas and reflects on the learned lessons. Finally, Section 4 concludes with the value of the PFSM framework for supporting the identification of desirable and culturally feasible pathways to transform food systems by considering the insights gained and lessons learned from its application.

2. Methodology

2.1. Research background

Both the design of the Participatory Food Systems Modeling framework and its application were framed within a research project entitled "Empowering small-scale farmers (SPEAR): Towards the SDGs through participatory, innovative, and sustainable livestock and poultry value chain".

The SPEAR project was funded by the 2017 LEAP-Agri Call (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 Programme for Research and Innovation – Horizon 2020.

The main purpose of the SPEAR project was to improve productivity and quality in local livestock and poultry value chains in Africa to, thus, strengthen the competitiveness of local production, mainly small-scale farmers, on domestic markets. By contributing to this ultimate goal, SPEAR aimed to develop and test a Participatory Modeling approach to collectively identify evidence-based challenges and opportunities to improve the poultry system, especially for small-scale farmers and their families.

Collaborating in this paper are two of the project's five partners: the Senegalese Institute of Food Technology (ITA) and the Technical University of Madrid (UPM). The ITA, which specializes in food technology and research, provides deep insights into the challenges and opportunities in the local and regional poultry sector. The UPM, with a specialized focus on food systems, employs modeling techniques to enhance participatory processes and collective decision making in research.

2.2. Case study context

The food crisis in Senegal, like most countries in the West African region, has been exacerbated by insecurity and armed conflicts, climate change, and market disruptions, of which the last two have led to prices inflation that have the most significant impact on food insecurity in that country (Global Network Against Food Crises and Food Security Information Network, 2022).

As of March 2022, 5% of the Senegalese population faced acute food insecurity and require immediate assistance (Cadre Harmonizé, 2022). Moreover, 22% have adopted stress-coping strategies to address their nutritional needs, mainly in response to inflation (Baoua et al., 2022; Cadre Harmonizé, 2022).

Enduring external shocks like the COVID-19 pandemic and the Ukraine war have decelerated economic growth in Senegal from 6.1% in 2021 to 4.2% in 2022 (World Bank, 2023). This has disrupted income-generating activities, impacting the market and prices of agricultural products, oil products, and food (Onyeaka et al., 2022). As a result, household purchasing power, particularly among vulnerable groups like the rural poor, been constrained (FAO-GIEWS, 2021).

The agriculture sector, which employs the majority of people living below the poverty line, only grew economically by 4.6% in 2021 after increasing 23.4% in 2020 (International Trade Administration, 2023). Agriculture plays a key role in the Senegalese economy by accounting for 15.3% of the national GDP in 2021 (World Bank, 2023b) and 29.4% of total employment in 2020 (World Bank, 2023c).

In Senegal, much like in other West African nations, most of the food production occurs on smallholder farms with low yields. These farmers, who live below the official poverty line (Gassner et al., 2019) and struggle to achieve food self-sufficiency (Giller, 2020), find themselves in vulnerable positions. When talking about smallholder farmers, it is also essential to acknowledge their heterogeneity in capabilities, resources, potential, interests, and expectations (Gassner et al., 2019). The vulnerability, diversity, and relevance of this group underscore the importance of implementing tailored interventions in agriculture as a powerful lever for reducing poverty and inequality (Maisonnave and Mamboundou, 2022).

In the agriculture sector, poultry is an important source of employment in Senegal, with over 500,000 people directly and indirectly employed (RVO Netherlands Enterprise Agency, 2021), and contributes to family incomes and rural development (Ly, 2020). Poultry farming also plays a crucial role in ensuring food security in Senegalese households by providing animal-source food with potential to enhance the "nutritional adequacy of poor and vulnerable populations … with limited food intake capacity" (FAO et al., 2021, p.69). According to the RVO Netherlands Enterprise Agency, "both chicken meat and eggs are gram for gram the second most affordable animal protein after sardines (2021, p.3).

Poultry production in Senegal has exponentially increased since the importation ban of poultry products in 2005, with 51.4 million broiler chicks in 2019 (Ba et al., 2022). Poultry sector growth is attributed to not only socio-economic trends and import control, but also to the modernization of poultry farming in Senegal (Ly, 2020). Although modernizing poultry farming has been critical for this sector's growth, it is worth noting that traditional poultry farming accounts for 40% of national consumption and generates about 30% of modern poultry farming's revenue, according to Ly (2020). In rural areas, the traditional type of poultry farming plays a significant role in households by covering food needs and generating incomes that may be used to pay for school feeds, medical expenses, among other social requirements, with relatively low investments (Birhanu et al., 2021; Faye, 2022).

The poultry value chain concentrates in three geographic areas: the western peri-urban zone, the north-central, and the central south-southeast. The western peri-urban zone concentrates 80% of poultry activity and is the basis for industrial and semi-intensive farms; the central south-southeast area shows a high potential for such activity, but is limited by accessibility and connectivity (Ly, 2020).

The location of our case study is in Kolda and Ziguinchor, in the Casamance region of southern Senegal. Traditional poultry farming predominates in both regions (Diédhiou et al., 2022; Faye, 2022), and supply and marketing circuits very much depend on Dakar.

Fig. 1 outlines the structure of the poultry value chain in Senegal. As depicted, backyard producers and small-scale commercial farmers work involves traditional poultry farming, and supply and marking circuits very much depend on Dakar. This type of poultry farming faces genetic,

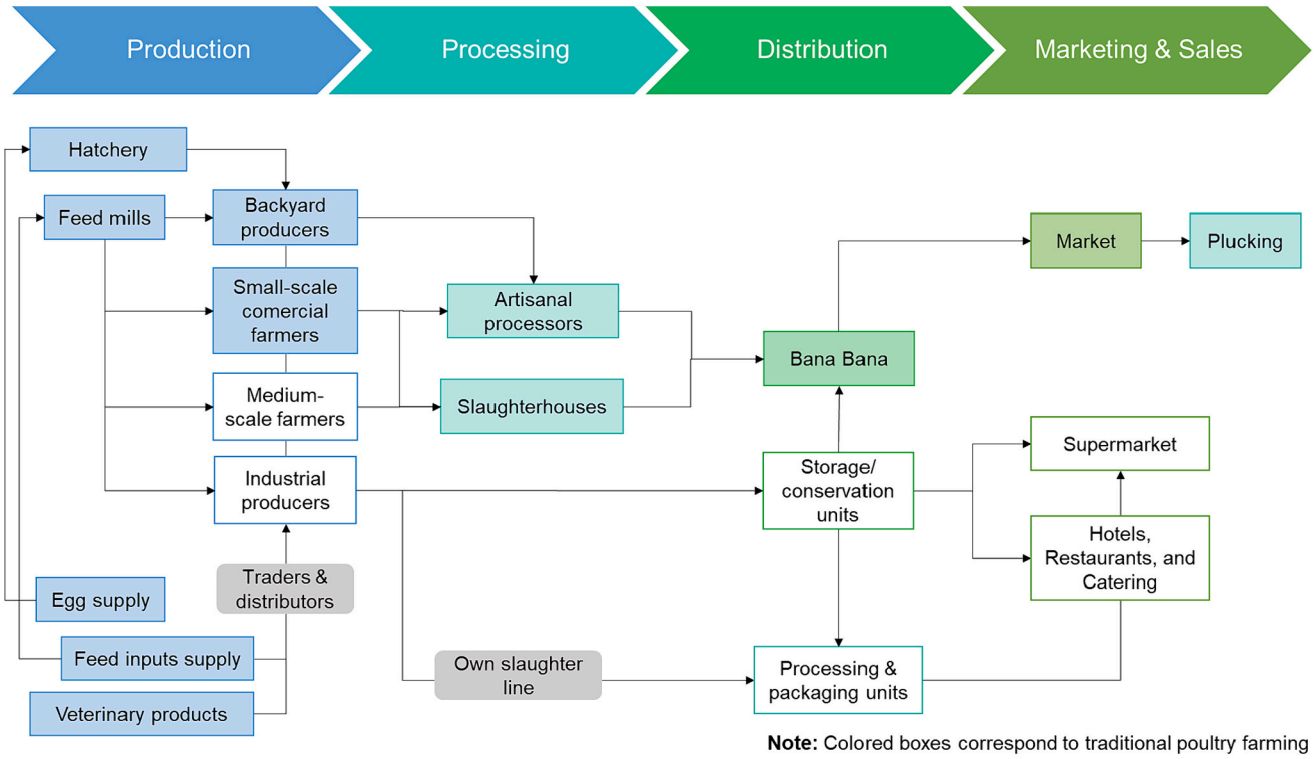

Fig. 1. Poultry value chain in Senegal.

sanitary, technological and organizational challenges that hinder its full potential, as noted by Ly (2020).

On processing and distribution, the RVO Netherlands Enterprise Agency (2021) highlights the essential role that the slaughtering, storing and processing facilities could play to help farmers to control their production cycles, optimize productivity, and manage both surplus and demand peaks. As these alternatives are emergent at best in the Senegalese poultry value chain, and as availability is only accessible for industrial farming, the competition for selling birds on fresh markets tends to intensify and has the most substantial impact on small-scale and backyard producers who sell their complete production on local markets (RVO Netherlands Enterprise Agency, 2021).

Although Fig. 1 shows that all types of poultry farmers work with intermediaries (or "bana banas"), Ly (2020) highlights the relation between industrial farmers and these intermediaries, who sell their live birds almost exclusively on markets around the country, especially in Dakar. In contrast, traditional poultry farmers are constrained to rural weekly markets and direct sales to consumers in villages and small towns, which leaves regular market gaps that force them to extend their production cycles and reduce their productivity levels.

In addition to the overview of the poultry sector in Senegal and the structure of its value chain, below we outline some characteristics of the poultry system in the regions where the case study took place.

In Ziguinchor, on the one hand, poultry farming forms part of the informal economy for diversification and income generation to face unemployment. As such, it is precarious and unsafe (Diédhiou et al., 2022). On the other hand, poultry farming in Kolda shows improvements in husbandry practices that derive from project interventions, which are limited by their high implementation costs (Faye, 2022). Dependence on Dakar, and its impact on production and marketing costs, and the informality and lack of modernization inherent to traditional poultry farming lower the competitiveness of the poultry products from Kolda and Ziguinchor.

2.3. *The Participatory Food Systems Modeling (PFSM) framework*

This section introduces the PFSM framework proposed in this research paper. First, the theoretical foundations on which the PFSM framework is grounded are introduced. Next the phases, activities, methods and tools proposed by the PFSM framework to identify desirable and culturally feasible transformation pathways are described.

2.3.1. *Theoretical foundations of the PFSM framework*

The PFSM framework is grounded on three foundational elements: the Participatory Modeling (PM) approach, the SSM and the TEEBAgriFood framework.

The PM approach is adopted as the heuristic of this research because it leverages systems modeling techniques in participatory exploration processes to foster individual and collective learning about complex issues (Duboz et al., 2018; Hedelin et al., 2017; Jones et al., 2009). This approach uses models not as solution generators, but as devices to leverage the knowledge of people with different viewpoints through the collective exploration of trends, processes, and dynamics in a situation of interest (Stirling, 2010). The exchange of ideas and negotiations among stakeholders with different perspectives ultimately facilitates joint decision making to support transformational processes (Daniell et al., 2006; Duboz et al., 2018; Voinov and Bousquet, 2010).

The SSM forms part of the soft systems tradition, which considers systems to be social constructs influenced by individual knowledge, social values and structures (Scotland, 2012). As the PFSM framework aligns with these assumptions, it draws upon the SSM to define the phases and activities that guide the exploration and conceptualization of the problematic situation in food systems to identify desirable and culturally feasible transformation pathways.

The SSM provides detailed steps to guide practitioners through a learning process that brings together different perspectives to comprehensively explore problematic situations and to identify pathways for transformation that are desirable and culturally feasible for the involved agents (Checkland and Poulter, 2010; Williams and Hummelbrunner, 2009). The SSM delves into the different ways of understanding a

problematic situation by illustrating them in conceptual models to be used as inquiry devices. By employing the conceptual models of each perspective, stakeholders dialog and negotiate until they agree on the system to be transformed and its desired transformation (Checkland, 2000; Checkland and Poulter, 2010). It is worth noting that Checkland (2000) speaks about "accommodations" rather than agreements by arguing that stakeholders would reach a middle ground, which would reflect a future that they would all support and work for, even if it is not their ultimate desire.

Finally, the TEEBAgriFood framework (TEEB, 2018) is a food systems framework that stands out as a systemic evaluation model that brings substantively systems thinking into practice (Patton, 2019). This framework, as several others developed in the last two decades, aims to contribute to more effectively understand and address the complex challenges related to food and agriculture (TEEB, 2018).

The TEEBAgriFood framework comprehensively describes the human, social, economic and natural elements that shape food systems' behavior, outcomes and trends and, thus, sheds light on what is failing in food systems, why, and the potential pathways to transform them. Describing food systems in terms of the four capitals makes TEEBAgriFood a flexible and adaptable framework that allows exploring food systems in different contexts and for diverse purposes. Finally, TEEBAgriFood acknowledges the diversity of the perspectives involved in food systems while encouraging the exploration and engagement with them to gain a closer-to-reality view of the situation and to, thus, make informed decisions about the scope of the analysis (TEEB, 2018; Bustamante et al., 2021).

Besides the comprehensive and systemic conceptual framework, TEEBAgriFood provides four-phase implementation guidance to make a systemic assessment of food systems (Eigenraam et al., 2020), which inspired the phases and activities proposed in the PFSM framework. Eigenraam et al. (2020) guide practitioners to: frame the issue of interest by engaging with relevant stakeholders (Phase 1); scope the assessment by describing the relevant elements and connections that constitute the system of interest (Phase 2); take the measurement and perform the valuation deemed necessary to the purpose of the assessment (Phase 3); apply the results of the evaluation by informing practice and policy (Phase 4).

2.3.2. PFSM framework implementation

The PFSM framework proposes three implementation phases to collectively make sense of problematic situations and to gain insights to inform the identification of potentially desirable and culturally feasible pathways for transformation. The purpose of each phase and the expected results are outlined in Fig. 2.

COVID-19 restrictions prevented the methodology from being implemented as planned, affecting mainly the in-person participatory activities whose aim was engaging with stakeholders in Kolda and Ziguinchor during the participatory modeling process. 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 research team from the ITA in Senegal, and the research team from the UPM in charge of the participatory modeling process, based in Spain.

Fig. 3 illustrates the flow of activities carried out in each PFSM phase in the case study over time and indicates the results deriving from each activity. The methodology was nuanced to the contextual conditions, information availability, timing and stakeholders' engagement in the case study.

It is noteworthy that the scope of the exploration of the poultry sector situation in Kolda and Ziguinchor was limited to traditional poultry farming, i.e., backyard producers and small-scale commercial farming. Accordingly, stakeholders' engagement was limited to those agents who participate in the traditional poultry system, who affected or were affected by it.

Stakeholders' engagement in participatory modeling was affected by several factors, including COVID-19 restrictions, mobility limitations, travel distances and time availability. As shown in Table 1, by means of interviews conducted in the study area to make sense of the poultry sector situation from different viewpoints, it was possible to engage a significant number and diversity of stakeholders. However, in the

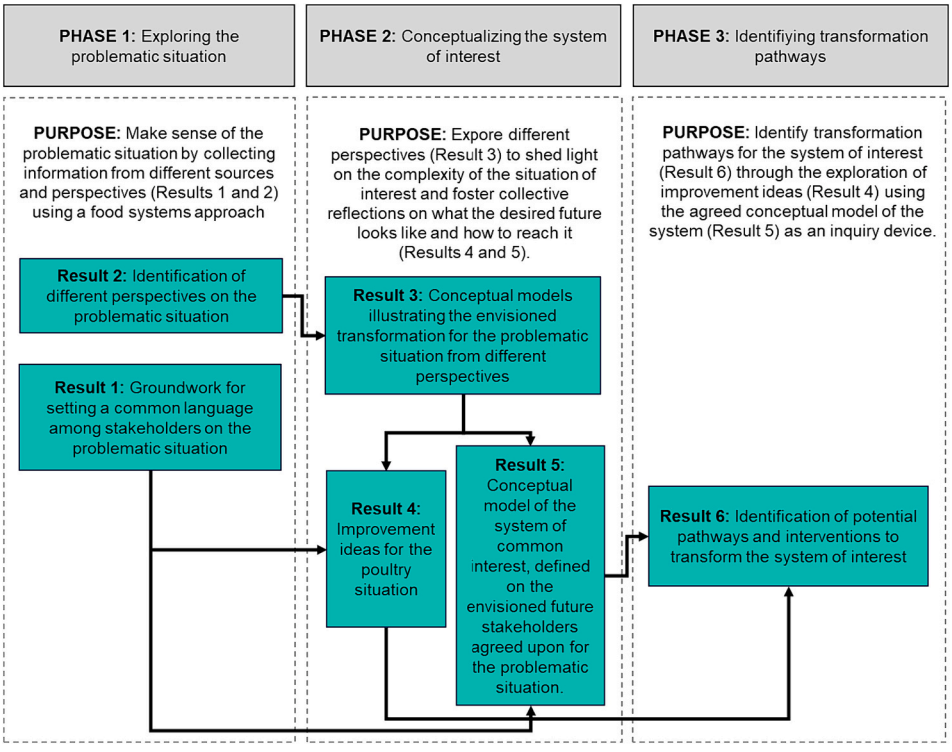

Fig. 2. Overview of the Participatory Food Systems Modeling framework.

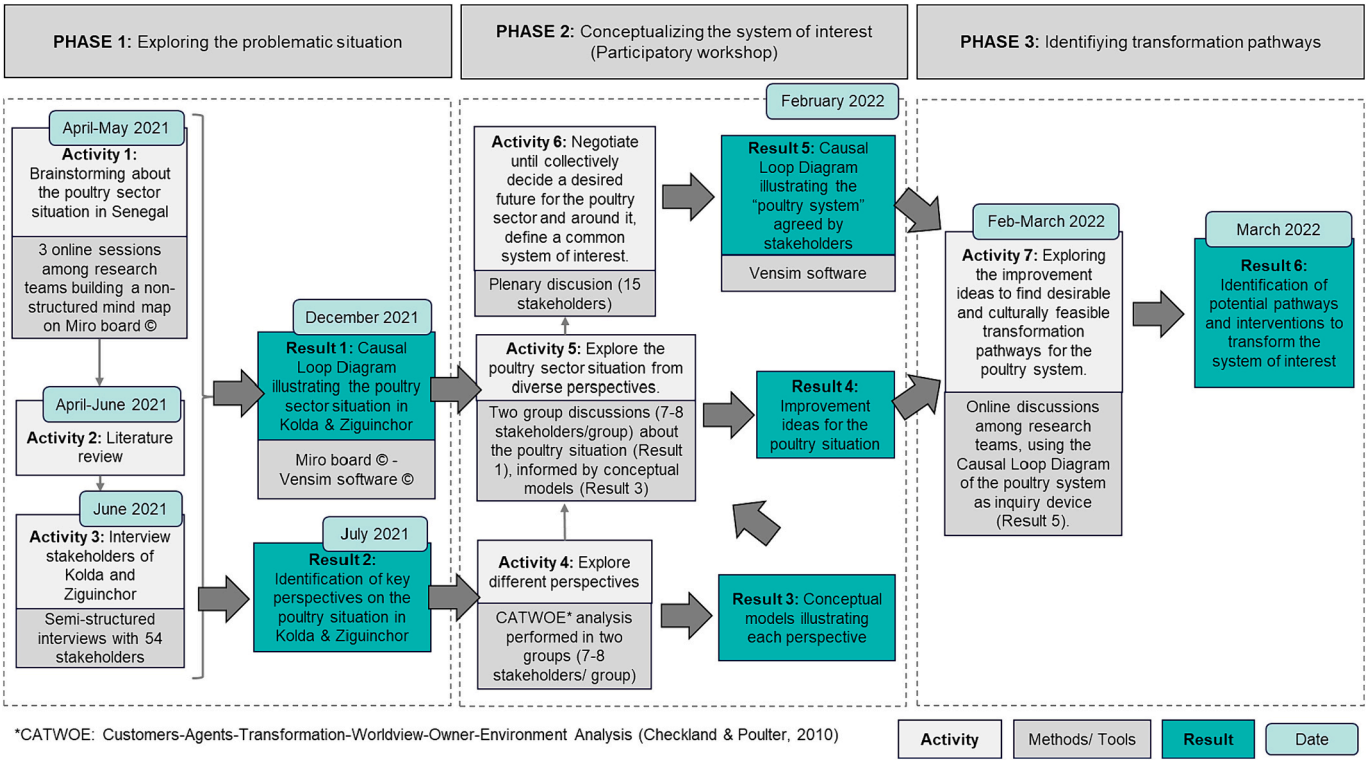

Fig. 3. Implementation of the Participatory Food Systems Modeling (PFSM) framework: phases, activities, and results.

Table 1
Key stakeholders involved throughout participatory food system modeling.

Role / Group	Interviewed stakeholders	Workshop participants
Small-scale farmers / Breeders	8 males	2 males
Breeders associated / Breeders	5 males	1 female; 1 male
Transformers / Transformation	2 females; 6 males	1 female
Researchers and ITA trainees / ISRA (online) Innovation	2 males	3 females; 6 males
Veterinarians / PVC regulations	4 males	1 male
Consumers / Consumption	5 females	–
Retailer and Seller/Consumption	6 females	–
Intermediaries	2 females; 8 males	–
Politicians / Politics	6 males	1 female
Total	54 people: 15 females and 39 males	15 people: 5 females and 10 males

participatory workshop conducted in Dakar in February 2022 to conceptualize the system of interest and to gain insights to support its transformation, stakeholders' participation sharply declined, which was due mainly to mobility and time constraints to travel to Dakar.

The activities and results of the three PFSM framework phases, as applied in the case study, are described below.

- Phase 1: Exploring the problematic situation.

In order to explore the poultry sector situation as comprehensively as possible, information was collected from different sources, agents and perspectives.

The brainstorming sessions held between researchers from ITA and UPM revealed the elements, processes, activities, and people involved in the poultry sector situation, and a preliminary view of it was obtained. The insights shared and discussed by the research teams during this preliminary exploration were compared and complemented with a literature review and interviews held with 54 stakeholders in the sector (Table 1), particularly from the Kolda and Ziguinchor regions. Interviewing stakeholders allowed their interests, expectations and concerns to be delved into. This revealed different ways of understanding and formulating the challenges and opportunities in the poultry sector, which were the main input to explore the distinct perspectives in Phase 2 of the PFSM.

A food systems approach guided the three activities carried out in this phase (see Fig. 3). The TEEB AgriFood framework (Eigenraam et al., 2020; TEEB, 2018), with its comprehensive description of the elements and interrelationships that should be considered to make sense of food systems behavior and outcomes, enabled the research teams to systemically explore the poultry sector situation. The valuable insights gained during the exploration allowed the poultry sector situation to be illustrated as closer-to-reality as possible in a CLD.

To build the CLD, the insights gained into the poultry sector situation were formulated as interrelated variables that form reinforcing loops that amplify trends and balancing loops that mitigate them (Williams and Hummelbrunner, 2009). The CLD was built on the Miro© collaborative board to allow research teams to revisit the diagram as many times as necessary to express the richness of the insights gained from different sources. The CLD set the groundwork for establishing a common language among stakeholders on the poultry sector situation, which is essential to foster discussions and debates on what needs to be changed and how to go about this in the forthcoming PFSM phases.

- Phase 2: Conceptualizing the system of interest.

In this phase, the perspectives identified when interviewing stakeholders in Phase 1 were further explored to shed light on the complexity of the poultry sector situation and, from enhanced awareness about it, to negotiate a future for the poultry sector that is a desirable, or at least acceptable, for all the involved stakeholders.

Before delving into the different perspectives of the poultry sector situation, a common language was set among stakeholders using the CLD created in Phase 1 as a device to increase their awareness about the complexity of the situation (Daniell et al., 2006). From the

interrelationships and feedback loops illustrated in the CLD, a narrative on poultry sector dynamics was created and shared with stakeholders during the participatory workshop held in February 2022. Fig. 4 exemplifies the diagrams generated from the CLD using Vensim PLE© to share the poultry sector situation with stakeholders. The causal trees show the interrelationships between the elements that make sense of the poultry sector situation, while the feedback loops shed light on its dynamic behavior.

The perspectives identified in Phase 1 were explored during the participatory workshop by inquiring into the transformation that each envisioned for the poultry sector (Checkland, 2000; Checkland and Poulter, 2010). To this end, the 15 workshop participants (Table 1) formed groups by perspective and performed a CATWOE analysis. The CATWOE analysis provides a mnemonic to think about the elements that will shed light on the transformation envisioned for the poultry sector from each perspective. These elements are the people affected by the transformation process, named Customers; the people who enable the transformation to happen, named Agents; the envisioned Transformation process; the Worldview or motivation behind transformation; the people who own the entity to transform, called Owners; and the factors that enable or prevent the transformation to happen, named Environment (Checkland and Poulter, 2010; Williams and Hummelbrunner, 2009).

The conceptual models resulting from the CATWOE analysis were used as inquiry devices for stakeholders to collectively explore the poultry sector situation from different lenses and to gain insights into its complexity (Checkland and Poulter, 2010). The emerging insights from stakeholders' dialog and sharing from different perspectives suggested ideas to improve the poultry sector situation (Williams and Hummelbrunner, 2009).

The discussions and debates with stakeholders when collectively exploring the problematic situation of the poultry sector broadened their knowledge and understanding of the various involved perspectives (Daniell et al., 2006). With enhanced awareness about 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 the involved parties (Checkland and Poulter, 2010). It is worth noting that, given the diversity of the perspectives involved in most complex situations, it is rarely possible to agree on a future that everyone desires with the same intensity. Nonetheless, stakeholders can reach accommodations to make a collective effort to move in the same direction.

To make progress toward the future they had agreed on, stakeholders conceptualized the system of common interest, referred to as the "poultry system." The poultry system was illustrated in a new Causal Loop Diagram, used as a device to identify in Phase 3 leverage points in the system and to explore transformation pathways toward the desired future (Checkland and Poulter, 2010; Eigenraam et al., 2020; TEEB, 2018).

- Phase 3: Identifying transformation pathways.

The improvement ideas shared by stakeholders in Phase 2 were explored in this stage by the UPM and ITA research teams using the Causal Loop Diagram of the poultry system that had been agreed on to identify transformation pathways that are both desirable and culturally feasible as follows: desirable, according to the model of the agreed poultry system, and built around a desired future and agreed on by the engaged perspectives; culturally feasible in the sense of being possible

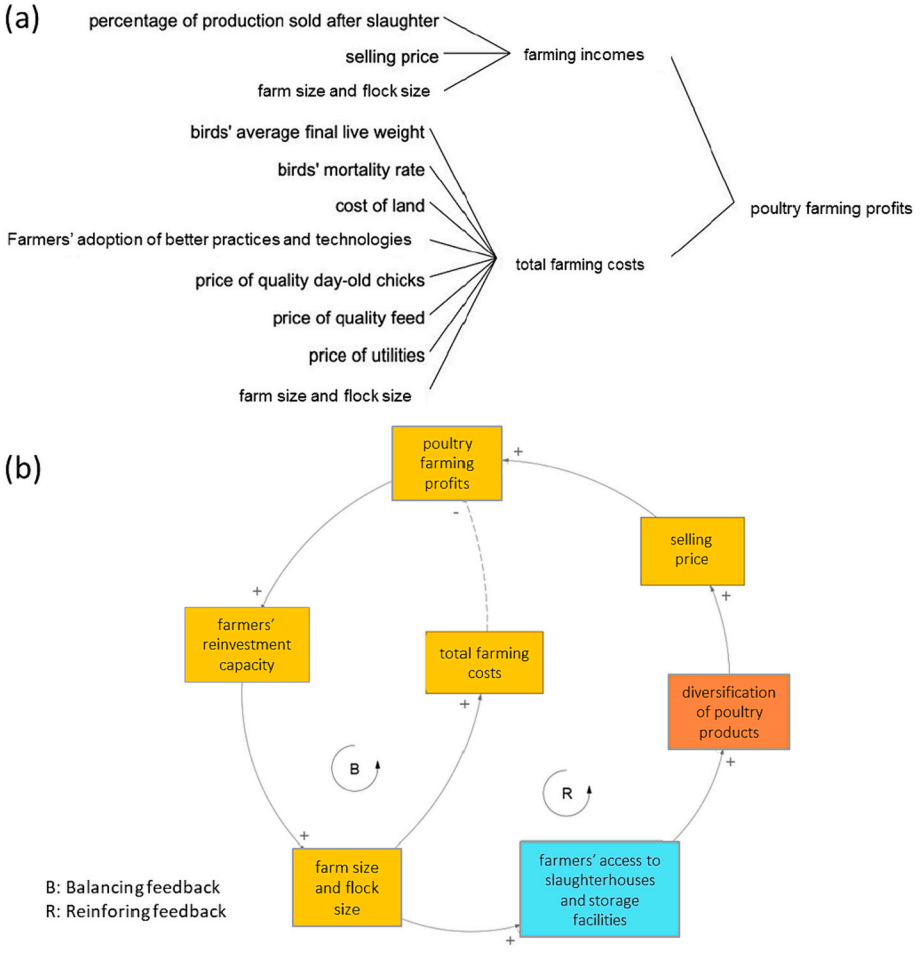

Fig. 4. Causal Trees (a) and feedback loops (b) to illustrate the poultry sector situation.

for the agents involved in the poultry system by considering the social norms, values, and power structures that guide their behavior and actions (Checkland and Poulter, 2010).

The ideas that emerged from an enhanced understanding of the poultry system's structure, complexity and dynamics informed the identification of leverage points in the system. These leverage points, when acted on, set in motion system-wide changes that ultimately contribute to make progress in the desired future that had been agreed on by stakeholders. Hence identifying leverage points in the poultry system was the basis for exploring pathways for its transformation. These pathways represent the changes triggered throughout the system when acting on the identified levers of change.

The livelihood strategies framework proposed by Dorward et al. (2009) guided the exploration of transformation pathways from a cultural feasibility lens. This framework describes three major livelihood strategies people follow to meet their requirements and aspirations in an evolving context: (i) maintaining livelihood levels in the face of adverse circumstances; (ii) increasing production and incomes to improve livelihoods and (iii) investing in diversifying activities to support financial stability.

3. Results and discussion

Below the main findings and results obtained throughout the three PFSM phases are described.

3.1. Exploring the poultry sector situation

Exploring the poultry sector situation from different sources allowed four different ways of framing the problematic situation in the poultry sector to be identified. Table 2 lists these four perspectives and describes their main focus of interest.

All the collected information, regardless of the source, people or perspective, was considered to illustrate the poultry sector situation as close to reality as possible in a CLD (Appendix 1). From this comprehensive view, a common language was set among stakeholders on the poultry sector situation. Moreover, sharing this systemic view with stakeholders in PFSM Phase 2 increased their awareness about the poultry sector's complexity by promoting individual and collective learning (Checkland, 2000; Daniell et al., 2006).

3.2. Conceptualizing the system of interest

An essential step for conceptualizing the system of interest was to explore how stakeholders understand and frame the transformation needed to address what they see as problematic within the poultry sector.

The results of the CATWOE analysis performed by stakeholders during the workshop held in February 2022 to illustrate their worldviews are shown in Table 3.

Using the conceptual models detailed in Table 3 as inquiry and learning devices, stakeholders discussed the current situation of the poultry sector, and became more aware of the diversity of perspectives involved, and the interests and concerns underlying them (Daniell et al., 2006). From these debates, valuable ideas emerged to improve the poultry sector situation (Appendix 2) and informed about the identification of levers of change in the system and the exploration of transformation pathways in Phase 3.

It is worth noting that during discussions, stakeholders elevated

Table 2
Perspectives of the poultry sector situation.

Perspectives	Main focus of interest
Perspective 1	Improve poultry farming performance.
Perspective 2	Enhance the quality of domestic poultry meat.
Perspective 3	Foster favorable political, financial and socio-economic conditions for poultry farmers.
Perspective 4	Adopt more efficient and sustainable poultry farming practices and technologies.

Table 3
Conceptual models illustrating different perspectives.

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, and in such a way that it improves the performance of poultry farming activities in terms of birds' growth rate and mortality rate. This transformation would be enabled by the companies supporting poultry farming (manufacturers, slaughterhouses, etc.) and the R&D and governmental institutions, by providing knowledge, and technical, economic and material resources.
Enhance the quality of domestic poultry meat.	A poultry system that allows poultry farmers, mainly small-scale farmers in rural areas, to make progress in the prevention and control of disease outbreaks and animal health issues on farms while procuring appropriate sanitary conditions for their products until they are sold to, thus, improve compliance with quality standards. To allow that to happen, governmental institutions should provide information to increase poultry farmers' awareness about regulations and standards, as well as economic and material resources to improve the sanitary and safety conditions along the poultry value chain; R&D institutions should encourage research, provide technical advice, and transfer knowledge and technology to take both preventive and controlling actions.
Foster favorable political, socio-economic, and financial conditions for poultry farming.	A poultry system that enables small-scale poultry farmers to boost their competitiveness on the domestic market by promoting political, socio-economic, and financial-related measures. By achieving this, governmental institutions should design and enforce policies and regulations that strengthen the domestic poultry sector; 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 act as a platform to better communicate with R&D and governmental institutions by 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 sustainable practices and technologies by improving their access to training that is 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 that monitor and evaluate the adoption results is essential. Financial institutions to finance this adoption are equally crucial. Stakeholders' associations also play a role in facilitating this transformation to happen.

power imbalances within the poultry sector by highlighting 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. They reported speculative practices with feed that cause shortages and price instability and prevent traditional poultry farming to maximize 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., 2013). As argued by Da Costa and McMichael (2007), power imbalances in poultry systems are associated with the dominant market-and-corporate-led regime.

With enhanced awareness about the complexity of the situation, stakeholders engaged in negotiations to envision a future for the poultry sector that is desirable, or at least acceptable, for all the involved parties (Checkland and Poulter, 2010). The agreed desired future was the following:

> "A poultry system that, on the one hand, improves the incomes of poultry farmers and other agents in the poultry value chain by, 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, stakeholders conceptualized the system of interest to everyone. Fig. 5 illustrates the poultry system conceptual model that they agreed on and offers a visual representation of the needed transformation to materialize the future for the poultry sector in Kolda and Ziguinchor, as agreed on by stakeholders.

Both reinforcing (R) and balancing (B) loops are depicted in Fig. 5 and are briefly described in Table 4. These feedback loops serve as a narrative tool to articulate poultry system dynamics. Shedding light on poultry systems dynamics laid the groundwork for identifying potential levers of change in the system.

3.3. Identifying transformation pathways for the poultry system

Based on an enhanced understanding of the poultry system's structure and dynamics and considering the ideas for improvement shared by stakeholders during the participatory workshop, four levers of change in the system were identified.

The identified levers of change were: "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 by interventions, such as those proposed by stakeholders during the participatory workshop, would set in motion system-wide changes to ultimately contribute to make progress toward the desired future that was agreed on by stakeholders. Thus, identifying leverage points in the poultry system was the basis for exploring pathways for its transformation.

The desirability of transformation pathways was evaluated based on their contribution to make progress toward the future agreed on 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 most poultry farmers in Kolda and Ziguinchor are smallholders who

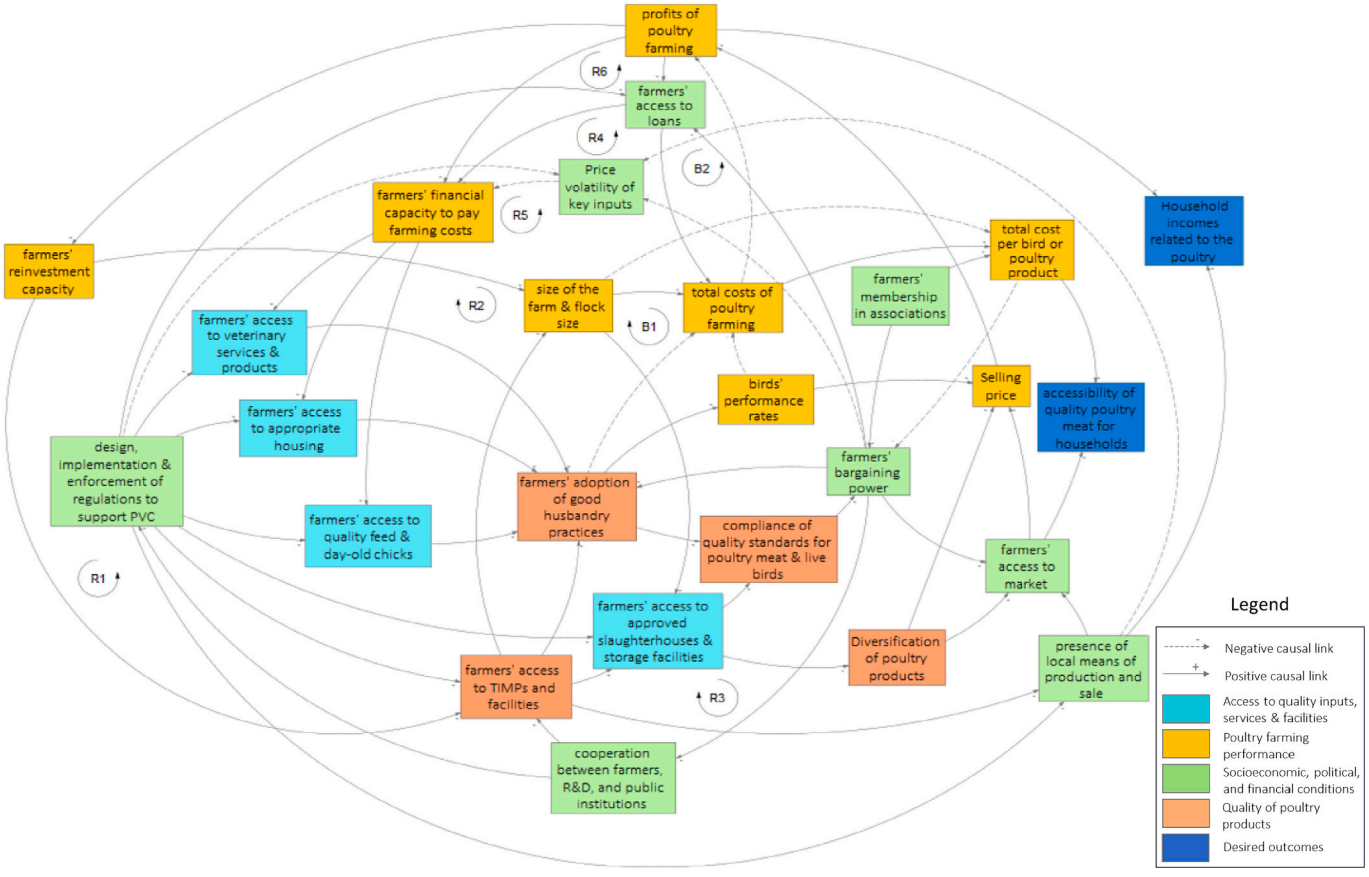

Fig. 5. Causal Loop Diagram of the poultry system in Kolda and Ziguinchor.

Table 4
Feedback loops in the poultry system conceptual model.

Feedback Loop	Description
(R1) Reinvestment – Access to TIMPs and facilities	Investing in Technology, Innovations, Management Practices (TIMPs), and facilities enhances birds' performance rates and the quality levels of poultry products. These enhancements translate into better profitability, thus reinforcing the reinvestment cycle.
(R2) Reinvestment – Farm size	Increasing flock size reduces the unitary costs of poultry products and improves farmers' access to approved slaughterhouses and storage facilities, which enhances their bargaining power to access markets with better selling prices. As they improve profitability, they can reinvest in their farms to increase flock size.
(R3) Farmers' bargaining power – Design & enforcement of regulations	Strengthening farmers' bargaining power fosters cooperation with R&D and government institutions. This cooperation promotes more support for the poultry sector, which translates into improved farm performance and better quality of poultry products, which reinforce farmers' bargaining power.
(R4) Farmers' access to loans – Financial capacity to afford farming costs.	Improving farmers' access to loans allows them to afford poultry farming expenses, thereby enabling the adoption of practices that enhance farm performance and product quality. These improvements strengthen farmers' access to markets, thus reinforcing their access to low-interest loans.
(R5) Price volatility of key inputs – Financial capacity to pay farming costs	Reducing the price volatility of the key inputs improves farmers' ability to pay farming costs, and to adopt practices that enhance product quality and reduce production costs. Quality improvements and expense reductions strengthen farmers' bargaining power and resilience to input price fluctuations, thereby reinforcing the cycle.
(R6) Profits of poultry farming – Financial capacity to pay farming costs.	Improving poultry farming profits boosts farmers' financial capacity to pay farm costs, and to adopt husbandry practices that enhance birds' performance, compliance with quality standards and market access, thereby reinforcing the cycle.
(B1) Farm size – Total poultry farming costs	Reinvesting in the farm, particularly in increasing flock size, introduces new production costs that balance farm profits and the reinvestment capacity of poultry farmers, thus creating a balancing loop.
(B2) Farmers' access to loans – Total poultry farming costs	Improving farmers' access to low-interest loans has associated costs that balance farm profits, thereby balancing their access to low-interest loans.

practice 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 group, as shown in Table 5, based on the categorization proposed by Dorward et al. (2009) to shed light on the diverse strategies that people follow to meet their goals and aspirations.

Discussions and reflections on the desirability and cultural feasibility of the transformation pathways were informed by systems diagrams, which were no more than simplifications of the poultry system's conceptual model (Fig. 5).

Four systems diagrams (Figs. 6 to 9) were developed to visually support the primary transformation pathways that arose from the strategic interventions on the identified levers of change in the poultry system. The desirability of the four transformation pathways is mapped according to their contributions to the outcome variables in bold:

Table 5
Poultry farmers' livelihood strategies.

Groups		Related type of livelihood strategy (Dorward et al., 2009)
Group I	Poultry farmers who do not have the financial or technical resources to improve their poultry farming activity, but that aim to maintain their livelihood levels with it.	Maintaining livelihood levels when facing adverse circumstances
Group II	Poultry farmers who are willing and able to adopt technologies and practices that improve their poultry activities in terms of yield and quality, this facilitating their access to broader diversity of markets.	Increasing production and incomes to improve livelihoods
Group III	Poultry farmers who are willing and able to diversify activities in the poultry value chain, upstream or downstream, thus being more competitive in the market and financially more stable (Barghouti et al., 2004; Heumesser and Kray, 2019).	Investing in diversifying activities to support financial stability.

"household incomes related to the poultry system" and "accessibility of quality poultry meat for households." Roman numerals indicate the paths that would be culturally feasible for all three groups of poultry farmers according to their livelihood strategies (Table 5).

Fig. 6 illustrates the first primary pathway to transform the poultry system, which resulted from enhancing farmers' financial capacity to afford poultry farming costs. This pathway is culturally feasible for all the farmers (Groups I, II and III).

By improving farmers' financial capacity by taking measures such as subsidies, price regulations on poultry inputs, access to grant capital, or other policies, a growing adoption of good husbandry practices is observed that positively impacts birds' performance rates and the quality of poultry products. These enhancements translate into improved selling prices and lower production costs and render poultry farming a more profitable activity to improve incomes in farmers' households. Moreover, they contribute to enhance the accessibility of quality poultry products for households.

Having a more profitable activity allows farmers (Groups II and III) to reinvest in poultry farming, which reinforces the cycle.

Fig. 7 illustrates the transformation pathways that results from reinforcing the policies and regulations that support the poultry system. Three distinct paths are outlined below.

The first path begins with the policies and regulations designed to improve farmers' access to quality inputs, services and on-farm facilities by addressing the price volatility of the key poultry inputs. These regulations also contemplate the creation or enhancement of local feed mills, hatcheries, storage facilities, slaughterhouses and local markets which contribute to reduce input price volatility. This pathway is culturally feasible for all the farmers.

The second path focuses on the policies and regulations that enable farmers to adopt the TIMPs that improve on-farm performance, compliance with quality standards and product diversification, which results in better access to markets and selling prices. This path is feasible for the farmers interested in diversifying activities in the value chain (Group III) because it contributes to engage farmers in decentralizing activities in the value chain. It is also feasible for the farmers who are able and willing to enhance on-farm activities (Group II), but only in the sense that it promotes the adoption of good husbandry practices.

The third path is shaped by the policies and regulations that foster the decentralization of poultry activities and services by 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 the poultry farmers (Groups I, II and III) by helping them to access markets with more competitive products.

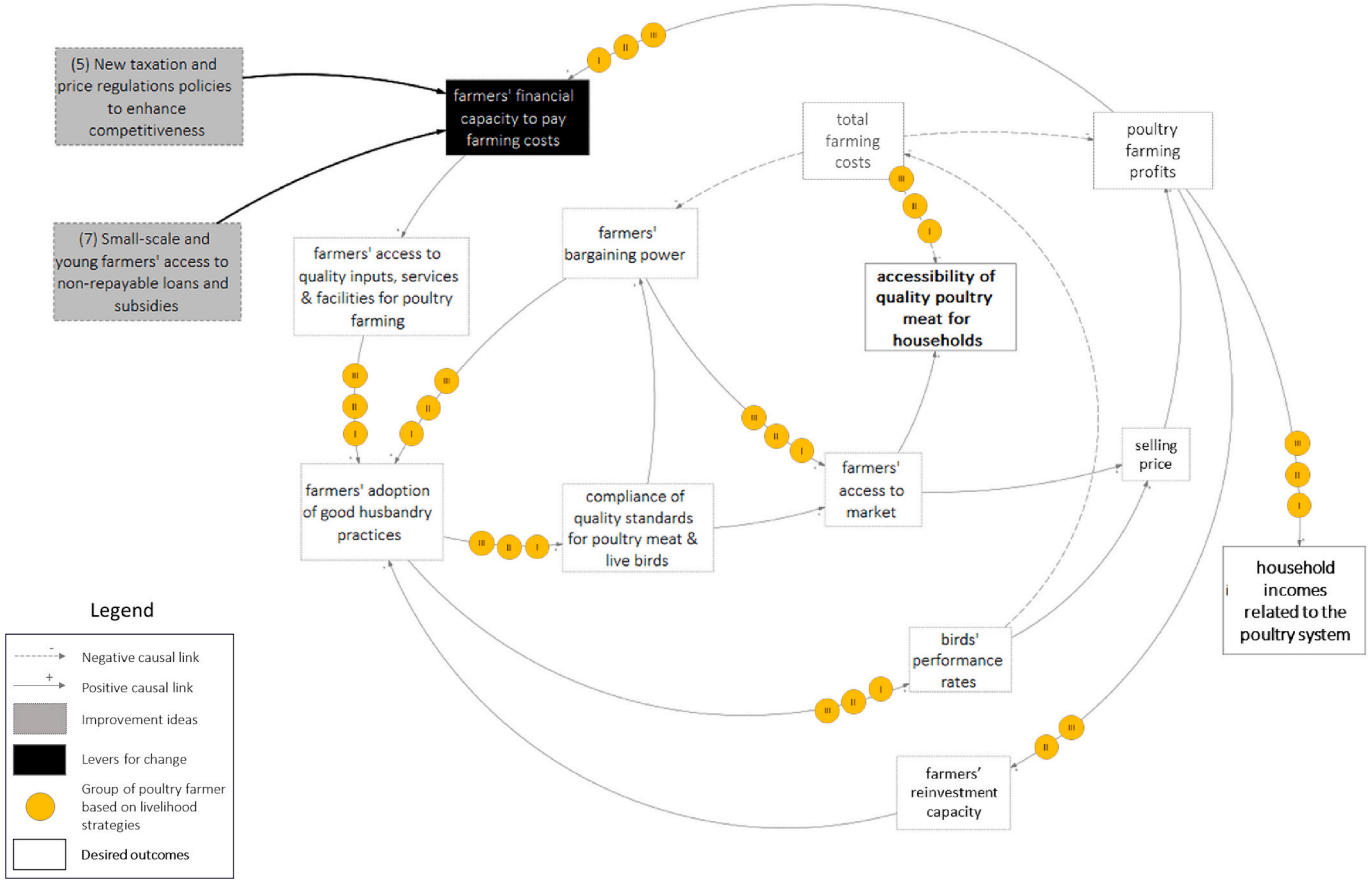

Fig. 6. First primary pathways to transform the poultry system.

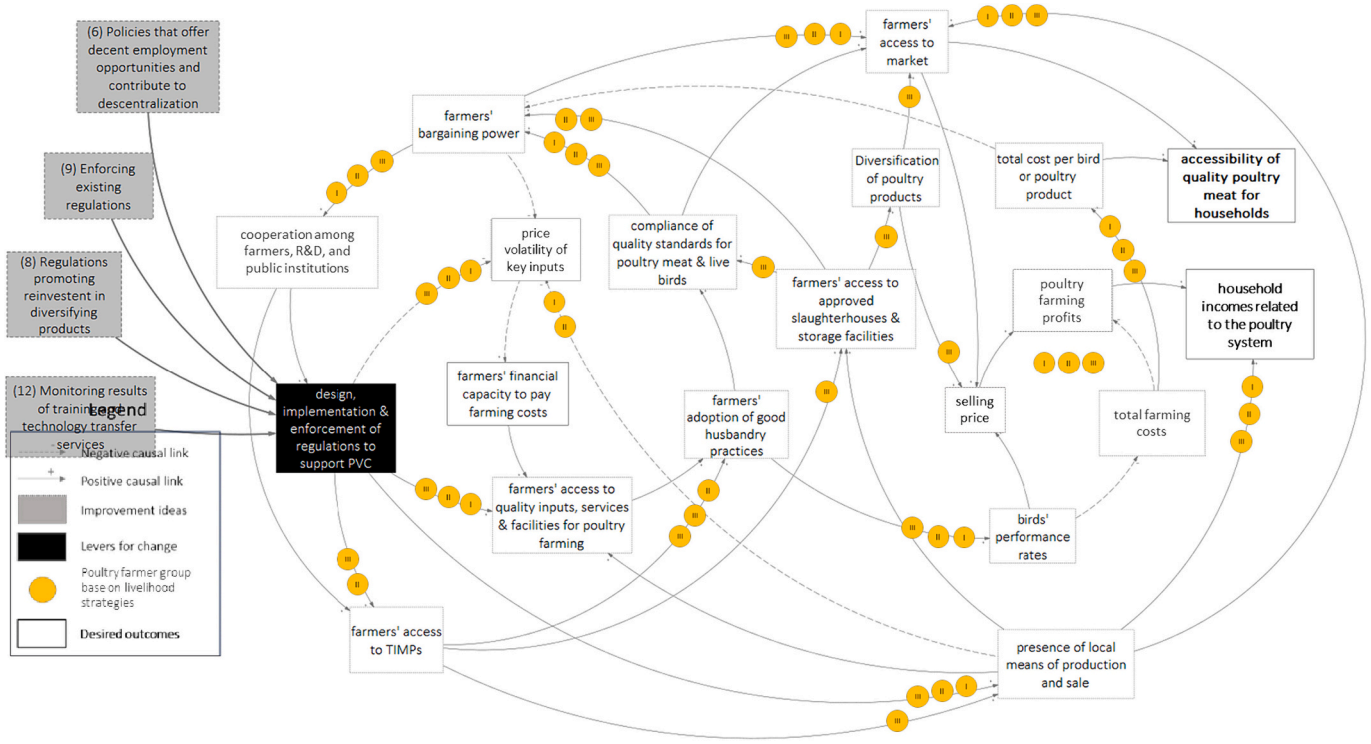

Fig. 7. Second primary pathway to transform the poultry system.

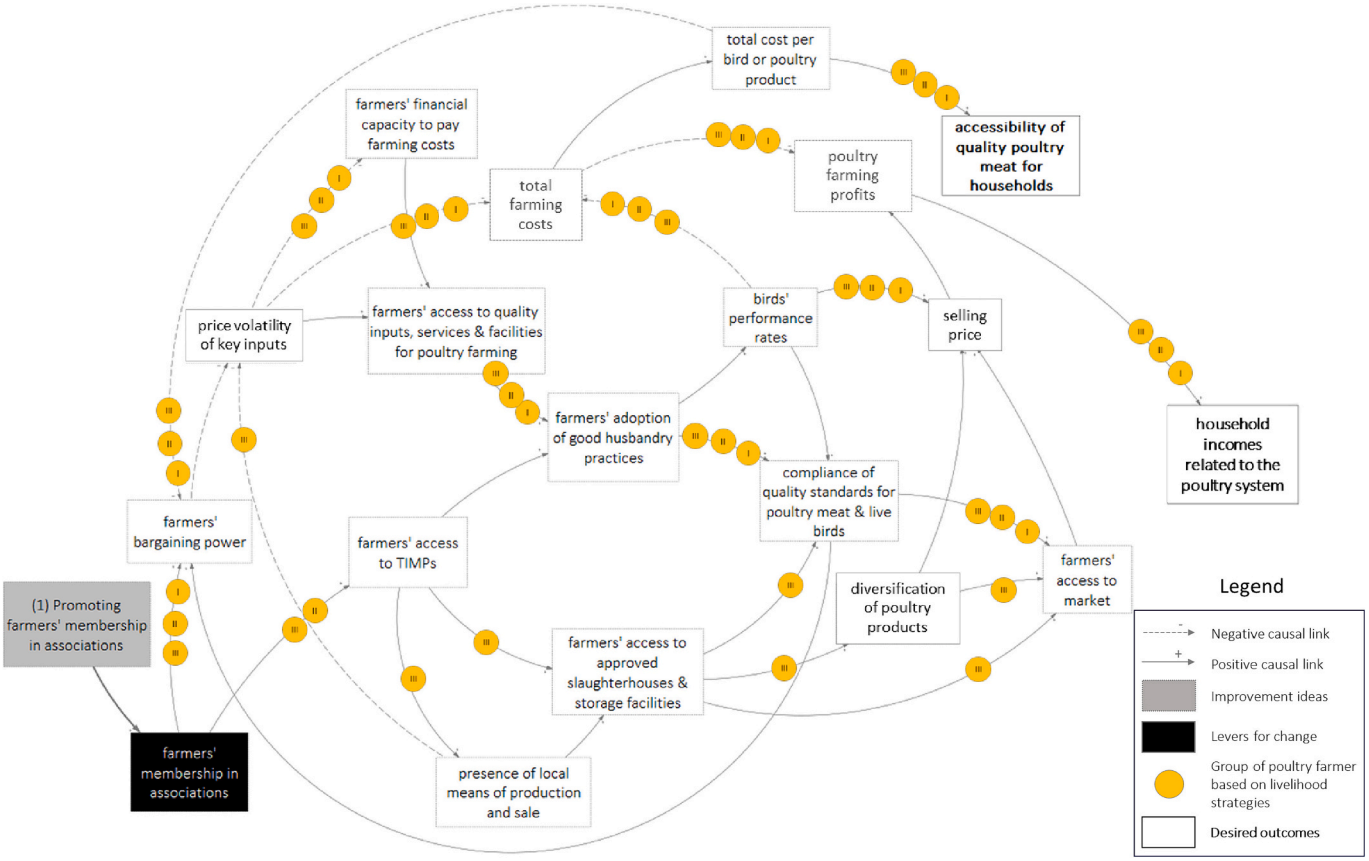

Fig. 8. Third primary pathway to transform the poultry system.

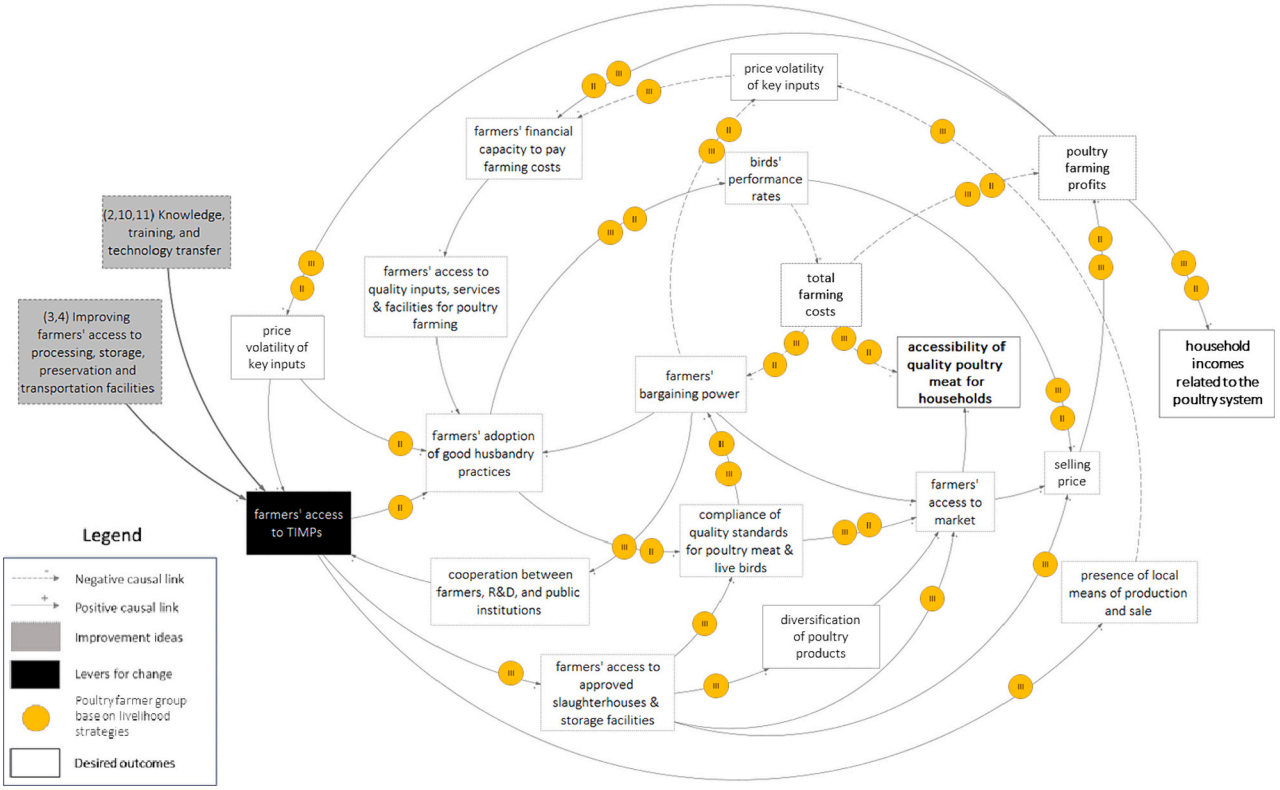

Fig. 9. Fourth primary pathway to transform the poultry system.

Furthermore, this path generates employment opportunities that improve the incomes of the households with poultry-related livelihoods in the region.

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

Fig. 8 outlines the transformation pathways that results from reinforcing farmers' membership in associations. Two paths were identified, as described below.

With the first path, membership in associations strengthens farmers' bargaining power by enabling them to negotiate favorable prices for farming inputs. This, in turn, enhances on-farm performance rates and the overall quality of poultry products and facilitates access to markets with better selling prices. This path is culturally feasible for all the farmers.

With the second path, membership in associations improves farmers' access to TIMPs. Accessing TIMPs can allow them to adopt better husbandry practices or gain access to approved slaughterhouses and storage facilities. Adopting better husbandry practices is culturally feasible for the farmers who are able and willing to enhance on-farm activities (Group II), and for those interested in diversifying activities in the value chain (Group III), which would imply improve on-farm performance and quality of poultry products. Accessing approved slaughterhouses and storage facilities is culturally feasible for the farmers interested in diversifying activities in the value chain (Group III) by 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 which, thus, contributes to the desired poultry system transformation.

Fig. 9 outlines the transformation pathways that result from the reinforcement of farmers' access to TIMPs by distinguishing three distinct paths.

With the first path, accessing TIMPs triggers farmers' adoption of husbandry practices to significantly increase on-farm performance rates and improve the quality of poultry products, which results on improved access to markets with higher selling prices. This path is culturally feasible for the farmers who are able and willing to enhance on-farm activities (Group II) and for those interested in diversifying activities in the value chain (Group III).

With the second path, access to TIMPs encompasses access to approved slaughterhouses and storage facilities, which enhances the quality of poultry products by adding value through diversification and allows farmers to store their products until the appropriate time to sell them. With the third path, accessing TIMPs empowers farmers to diversify activities downstream in the value chain by formulating their feed and own hatcheries to, thus, strengthen the local presence of local means of production. This strategy reduces farmers' dependence on the few companies that currently control the market and speculates with prices and availability of the key inputs. Lowering the volatility of input prices positively impacts farmers' access to these essential resources.

As both the second and third paths involve diversification of activities in the poultry value chain, they are culturally feasible exclusively for the 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, which all contribute to the desired poultry system transformation.

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

By delving into the intricacies of the four primary transformation pathways for the poultry system in Kolda and Ziguinchor from the cultural feasibility lens, valuable insights emerge to design tailored interventions that align with poultry farmers' unique circumstances and aspirations, expressed by the livelihood strategies that they choose to adopt. The aim of nuancing the interventions to poultry farmers' livelihood strategies is to maximize the benefits for poultry farmers, their families and society, as expressed in Table 6.

By acknowledging stakeholders' heterogeneity, particularly in the poultry farmers group, and considering their dynamic behavior influenced by an ever-evolving context, these interventions aim to be both culturally feasible and desirable.

4. Conclusions

The Participatory Food Systems Modeling (PFSM) framework serves as a dynamic instrument for engaging stakeholders with diverse perspectives in transformative processes within food systems. The framework guides the exploration of complex situations from diverse perspectives by fostering exchanges and facilitating collective learning. Additionally, it enables debate and negotiations, leading to a shared commitment to a future vision. Lastly, it aids in identifying desirable and culturally feasible pathways toward the future agreed upon by stakeholders.

Upon critical analysis, the PFSM framework reveals a nuanced landscape of strengths, challenges, and opportunities for improvement. Understanding these features is essential for its effective implementation in supporting food systems transformation. A significant challenge lies in maintaining stakeholders' engagement to recognize and understand diverse perspectives, comprehensively understand the complex situation, and foster informed discussions and decision-making.

The effectiveness of the PFSM framework also hinges on addressing power dynamics and imbalances in engagement strategies. Interviews and targeted group discussions have proven valuable in navigating power dynamics in the Senegalese poultry system case study, allowing stakeholders to freely share their interests, concerns, and expectations while decreasing distortions arising from power imbalances. However, the applicability of these methods may vary across contexts. Acknowledging that power imbalances are rooted in multiple systems of oppression, it is essential to recognize that the guidance offered by the PFSM framework is just a small contribution to empowering agents with different perspectives to meaningfully engage in discussions and

Table 6
Potential interventions for farmers with different livelihood strategies.

Livelihood strategy group	Potential interventions
Group I	Create an enabling environment that supports the poultry sector and focuses on smallholders. This approach comprises socio-political and financial measures to ensure smallholders in vulnerable positions can sustain their livelihood levels with poultry farming.
Group II	Facilitate the adoption of TIMPs by smallholders to enhance on-farm activities. This not only boosts their incomes, but also makes poultry meat more accessible regionally by improving their access to markets. Increased profitability allows farmers to allocate a larger portion of their production for self-consumption and reduces the need for urgent sales to cover basic needs.
Group III	Support farmers in diversifying their activities both upstream and downstream in the poultry value chain toward enhanced competitiveness and access to better market prices. Upstream diversification reduces farmers' vulnerability to input availability and price fluctuations and, thus, lowers production costs. This enables farmers to offer quality products at affordable prices to other families. Downstream diversification adds, on the other hand, value to their products, and opens doors to premium markets and improving overall incomes.

negotiation processes.

Concerning the modeling component, the qualitative approach adopted in the PFSM framework facilitates stakeholders' participation and reflections on desirable and culturally feasible transformation pathways. However, integrating quantitative or semi-quantitative methods could offer deeper insights into the system's dynamic behavior, allowing the exploration and comparison of different scenarios to inform decision-making. For instance, exploring interventions like addressing price volatility of key poultry farming inputs through quantitative modeling (e.g., Systems Dynamics Modeling) could provide valuable insights into poultry systems' behavior and outcomes under different action scenarios.

The PFSM framework features illustrate its potential to address two key barriers to food systems transformation: tensions and conflicts that emerge from contrasting perspectives (Béné, 2022; Caron et al., 2018; Hubeau et al., 2019; van Bers et al., 2019); and governance and power structures that lock-in transformations by marginalizing groups that could challenge the status quo, while prioritizing those who benefit from it (Blesh et al., 2019; Brouwer et al., 2020; FOLU, 2019; Garcia-Gonzalez and Eakin, 2019; Leeuwis et al., 2021; van Bers et al., 2019).

Applying the PFSM framework to poultry systems in southern Senegal provides further insights into its value for supporting and informing transformative processes in food systems by linking it with real-world situations. Besides illustrating the importance of empowering and engaging stakeholders on an equal footing during participatory modeling to foster insightful discussions that support transformations, the case study in southern Senegal highlights the importance of exploring transformation pathways from the cultural feasibility lens. This exploration involves considering the engaged stakeholders' particularities, the context's specificities, and the governance structures that condition their capacities to perform specific actions. Although these results are case study-specific, we believe that tailoring interventions to the livelihood strategies of the engaged stakeholders (Dorward et al., 2009), namely poultry farmers in this case, could be adopted as a strategy to maximize contributions to transformation for their own benefit, their families, and also society.

Considering the essential role that poultry farming plays in Senegalese households (Ly, 2020; RVO Netherlands Enterprise Agency, 2021) and rural communities in West African countries (Molina-Flores et al., 2020), the insights gained into transformation pathways for poultry systems in southern Senegal offer an enormous potential to improve food security and to supply economic support to rural communities and vulnerable populations (Faye, 2022; Hetherington et al., 2017), particularly the rural poor (FAO-GIEWS, December, 2021).

In conclusion, the PFSM framework proves its applicability and value in identifying sustainable food systems transformation pathways. Looking ahead, there is an opportunity for future research to focus on refining and integrating quantitative methods to enhance the framework's effectiveness in supporting stakeholders-driven decisions for sustainable development.

CRediT authorship contribution statement

María Bustamante: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation. **Carlota Rillo:** Writing – original draft, Methodology, Investigation. **Ibrahima Niang:** Validation, Investigation. **Lauren Baker:** Writing – original draft, Supervision. **Pablo Vidueira:** Writing – original draft, Supervision, Resources, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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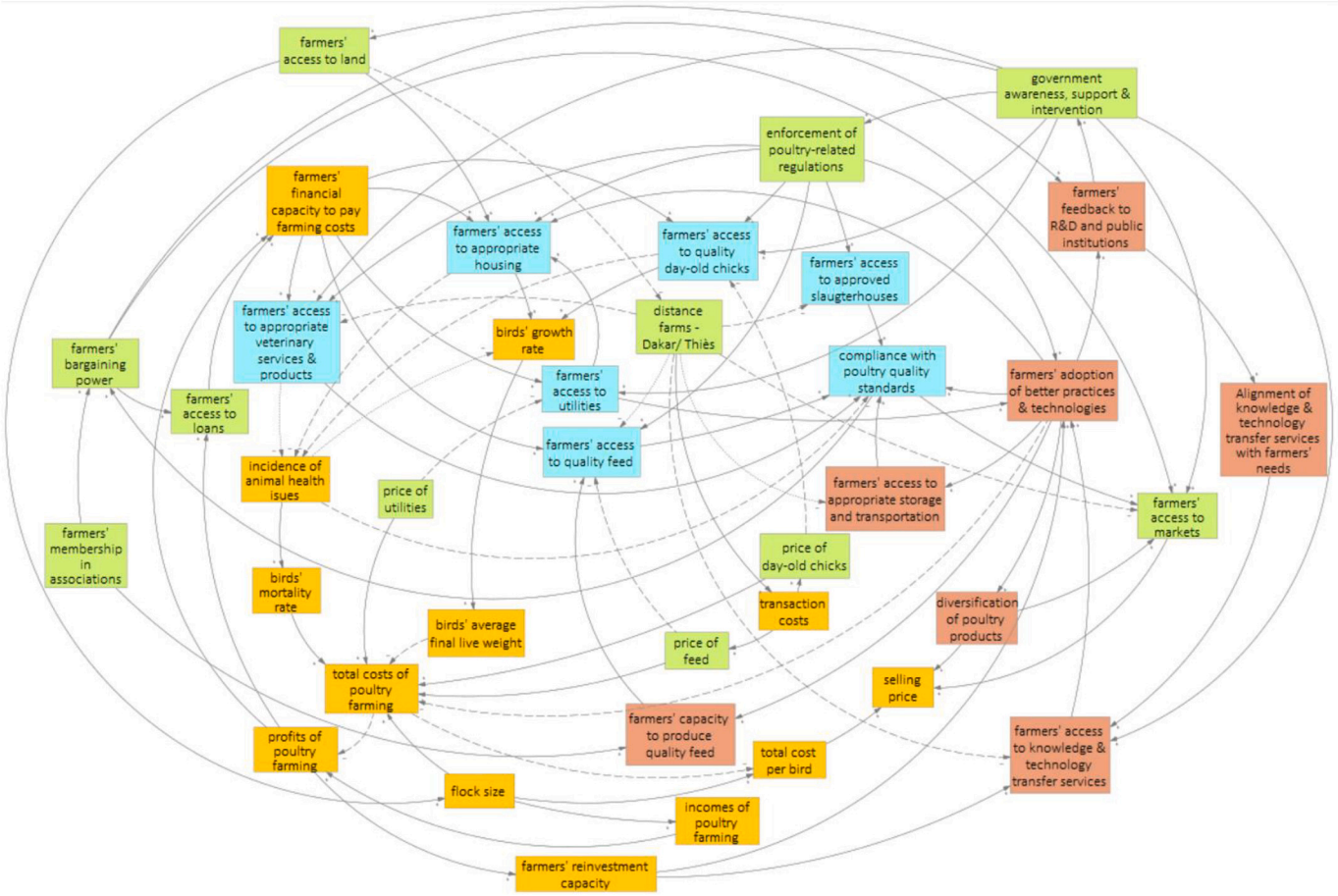
Appendix 1. Causal Loop Diagram of the poultry sector situation in Kolda and Ziguinchor



Appendix 2. 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

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(*continued*)

Ideas to improve the poultry sector situation		Justification
		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.	

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