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# Participatory systems modeling to identify and support gender-responsive agri-food system strategies

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There is a growing body of literature highlighting the need for increased focus on gender dynamics and inequality within agri-food systems, and in the design of policies that improve food and nutrition security while addressing climate change. Application of analytical tools that both (a) increase understanding of distinct gendered outcomes and constraints in these settings and (b) facilitate the development of policies that are gender-responsive and effective at mitigating climate change impacts is needed. Yet, identification of policies that improve or harm gendered outcomes is limited within many current analytical approaches by significant knowledge gaps about gender-specific realities, and by the lack of a systems perspective. We summarize these challenges in the context of agri-food supply chains under climate change and recommend Participatory Systems Modeling (PSM) as a method to address barriers to capturing “the gender variable” effectively and improving gender-responsive policy design. We discuss the methodology behind PSM and present examples of its usage in understanding agri-food supply chains as an integral component of global agri-food systems and determinant of food and nutrition security outcomes, where gender dynamics and climate change are important overarching system features and drivers. We recommend how PSM can be best utilized to improve the gender sensitivity of policy design for key agri-food system components like agri-food supply chains, and discuss ways that PSM itself can become more gender-responsive as a research and policy design tool.

## KEYWORDS

agri-food systems, climate resilience, gender, participatory system modelling, supply chain

# 1 Introduction

Global agri-food systems are experiencing increasing stress and volatility due in part to climate change and increased risks associated with climate shocks (Mirzabaev et al., 2023). A substantial literature has emerged examining myriad dimensions of climate change risk and vulnerability to our agri-food systems, ranging from: agricultural production shocks, food insecurity and nutritional vulnerability, food quality risks, transport system vulnerabilities and more. Better identification of how entire agri-food systems can be resilient to climate-related shocks is needed (Béné, 2020; HLPE, 2025).

Much of the work on the impacts of climate change on agri-food systems is focused on risks to crop and livestock productivity (Reardon and Zilberman, 2017). Far less research has focused on the potential vulnerabilities and current impacts of climate shocks on the rest of the agri-food system beyond the farm gate, including agri-food supply chains, which include all of the market relationships both upstream and downstream of the farm gate that link primary agricultural production to final end stage consumption [Institute of Medicine (IOM) and National Research Council (NRC), 2015]. Data gaps and a lack of a systems perspective on the rest of the agri-food supply chain has thus hampered efforts to improve climate resilience for all communities engaged in agri-food systems (HLPE, 2025). Climate resilience research and policy can benefit from methods that offer robust tools to develop a systems perspective on agri-food supply chain behaviour and vulnerabilities.

Research on agri-food systems has also identified distinct, gender-specific features and constituencies within them, and has engaged in efforts to document these patterns and apply a gender frame to the analysis of agri-food system behaviour, dynamics, outcomes and consequences (e.g., Lecoutere et al., 2023). Gender-specific features in the context of agri-food supply chains can include the division of agri-food supply chain segments or nodes into different gender domains. For example, women are dominant in local marketing and processing nodes in Nigeria fish value chains, whereas men are more present in international trade in this commodity (Adetoyinbo and Otter, 2020). Distinct gender norms around socially acceptable roles within supply chains may also lead to differential access to key resources, such as critical productive inputs or information. For example, McKune et al. (2021) document that strict gender norms impede access to livestock vaccines, leading to lower returns and higher risk for women livestock producers in Sénégal; and multiple studies find that female smallholder farmers are often underserved by agricultural extension (Nyberg et al., 2025). Climate risk is only likely to exacerbate these existing divisions and inequalities in roles, access and outcomes within global agri-food systems and their supply chains (Lecoutere et al., 2023).

Researchers applying a gender frame to agri-food system analysis have highlighted that there are many critical data gaps on gender distinctions across agri-food systems (Lambrou and Piana, 2006; UN Economic and Social Council, 2023) and that assessment of supply chain structures are appropriate [Institute of Medicine (IOM) and National Research Council (NRC), 2015]. Further, the nature of gender inequality itself varies widely across the multitude of agri-food supply chain settings, requiring context specific and detailed documentation of gender dynamics in each case. However, this documentation is scarce in the literature, particularly in low- and middle income country settings. Participatory research methods can offer a way to capture this gender variation directly from supply chain

stakeholders, in order to collect important baseline information on how agri-food supply chain properties and outcomes might diverge across gender and group identities (Soto et al., 2024).

In this paper we therefore present Participatory System Modeling (PSM<sup>1</sup>) as a methodology with high, but underexploited potential to explore and quantify gendered dynamics in the context of agri-food supply chains and climate change impacts from commodity production to food and nutrition security (FNS). Despite decades of recognition in the literature, “the gender variable” remains largely undocumented and thinly captured in dominant research methodologies used to analyze agri-food systems (Lambrou and Piana, 2006; Stephens et al., 2010; UN Economic and Social Council, 2023). Our primary research objective is to therefore discuss whether PSM can overcome these long-standing data and research gaps on gender and offer a productive approach to analyzing gender dynamics and climate resilience within agri-food supply chains. We do this as follows. In Section 1, we first present an overview of existing research on the gender and climate dimensions of agri-food supply chains and document data challenges in capturing these dynamics. We then introduce PSM and its potential applicability to analyzing these challenges, by highlighting its strengths as a methodology that links participatory system stakeholder engagement, which is needed to better capture “the gender variable,” with quantitative system modeling, that has been used successfully to uncover high leverage strategies to improve agri-food supply chain outcomes. We then argue that PSM can successfully advance the urgent research agenda to improve data collection and modeling of “the gender variable” (Lambrou and Piana, 2006) as a critical baseline step to increasing the gender responsiveness of agri-food systems and climate policy via PSM’s emphasis on connecting stakeholder system knowledge, which likely varies but can be captured in a PSM approach across gender lines, with identification of system drivers and high leverage interventions, that can then be potentially prioritized for gender specific outcomes with improved gender specific stakeholder knowledge capture. More specifically, we document how PSM can increase understanding of the intersections between food and nutrition security, gender and climate dynamics in supply chains via increased stakeholder participation and the application of quantitative system modeling tools and principles. In Section 2, we examine the current extent of usage of PSM in the context of climate resilience, agri-food supply chains and gender dynamics. We demonstrate that PSM is currently underutilized in this space, but has high potential to overcome challenges to the better representation of gender within agri-food supply chain research and contribute meaningfully to the development of gender-responsive climate resilience policy in agri-food systems. PSM therefore has the potential to improve policy design and support the necessary consensus building on gender-sensitive interventions (Mulema et al., 2022). We follow this presentation in Section 3 with recommendations for incorporating PSM into the research program on gender-responsive agri-food system strategies, and discuss specific concerns on power dynamics

1 The acronym PSM sometimes refers to Participatory Systems Mapping, a different approach. Participatory Systems Modeling can draw upon a variety of participatory and systems modeling methods, although we focus here on Group Model Building (GMB) and System Dynamics Modeling (SDM).

and equity that contextualize and pervade the study of gender dynamics using participatory methods. We then offer our conclusions in Section 4 on the potential for greater use of PSM to support gender-responsive agri-food system resilience strategies.

## 2 Background literature

We now present some important background literature on the gender dimensions of agri-food supply chains and the history and methodological approach of PSM. We next highlight how PSM has been used more specifically in the context of agri-food supply chains and highlight its potential to be usefully applied to analyze climate resilience and gender in this setting. This will be used as context to accompany the PSM literature review in Section 2.

### 2.1 Gender-specific features and outcomes across agri-food supply chains, and their intersection with climate

Agri-food supply chains, as critical components and structures within broader agri-food systems (AFS), are important sources of employment and livelihoods for women and men across low- and middle-income countries (LMICs), representing between 22% [Latin American Countries (LAC)] and 67% [Sub-Saharan Africa (SSA)] of women's employment (Costa et al., 2023). Globally, off-farm food system sectors, including agri-food supply chains and the food environment sphere, employ more women than men (Lecoutere et al., 2025). Both agriculture and off-farm employment are important for men and women across LMIC regions. Yet while we have greatly improved our understanding of gender dynamics in primary agriculture, particularly through the greater availability of sex-disaggregated farm data by country level, our understanding of gender dynamics and availability of sex-disaggregated data in off-farm employment (including in the broader agri-food supply chain) is much lower (Porciello et al., 2024). Obtaining data on activities between the farmgate and consumers in LMICs is challenging because much economic activity in this sphere is informal and temporal, including buying and selling of foods, artisanal processing, preparing and selling of prepared and processed foods often occurring in markets, on streets, in people's homes, and in small businesses. A recent review of market linkage between supply chains and small-scale producers found that interactions between farmers and markets are often not formal or contractual based (Liverpool-Tasie et al., 2020). Further, these sorts of interactions and employment numbers are much harder to capture because people often hold multiple jobs at the same time (Davis et al., 2023).

Data in general, let alone sex-disaggregated data, on what occurs between when food is purchased and consumed are even less available in LMICs, and these dynamics are less documented systematically, yet these include important decisions on how food is procured, stored, prepared, served and distributed between household members, shaping differential outcomes in terms of nutrition, health and wellbeing over time (Twyman et al., 2020; O'Meara et al., 2025). Recent landmark papers on food environments in LMICs have substantially brought these types of issues to light (Turner et al., 2018; Constantinides et al., 2021).

Women and men play different roles at different nodes of agri-food supply chains, and within households and communities with respect to food. These roles are shaped by cultural norms that are place-specific in terms of how they operate on women and men to shape participation and outcomes from agri-food systems (Njuki et al., 2022).

Cultural norms are local and diverse, varying between and within countries, as well as between and within communities and households. Gender norms interact with other social norms related to class, age, religion, ethnicity, even marital status that intersect and interact to collectively shape the experience of women and men in agri-food systems. Gender norms also play out differently in the food production versus food consumption spheres (Rietveld et al., 2023), and interact to shape the uneven AFS outcomes across gender lines. Capturing these dynamics is extremely complex, and participatory methods can be valuable in documenting the lived experiences of women and men in ways that can inform not only the research findings, but also the research process itself.

In addition to playing different roles in AFS, women and men experience different outcomes: women tend to earn less than men from their participation in AFS; women are on average more food insecure (FAO, 2022); and women are more likely to be overweight and obese and suffer from related health issues (Ambikapathi et al., 2025). AFS policies impact women and men differently, often in unintended and unpredictable ways, due to a lack of adequate knowledge of how gender norms operate at different scales and for different groups, especially marginalized groups, including poor women. There is also a lack of analytical tools and approaches like modeling tools to assess different policy alternatives and interventions.

The climate dimension adds another layer of complexity. Men and women have different exposure to and vulnerability to climate change that stems from multi-dimensional inequalities which shape differential risks. People who are socially, economically, culturally, politically, institutionally, or otherwise marginalized are especially vulnerable to climate change and also to some adaptation and mitigation responses. This heightened vulnerability is the product of intersecting social processes that result in inequalities in socioeconomic status and income, as well as in exposure. Such social processes include discrimination on the basis of gender, class, ethnicity, age, and (dis)ability (IPCC, 2014).

Gender norms, particularly in interaction with other social norms, shape women's climate adaptation strategies and outcomes (Rietveld et al., 2023). Gender norms shape participation in and the benefits from AFS, as well as climate responses, through their impact on women's access to assets, mobility, education, and the public sphere.

Given these complex interactions between gender, agri-food supply structures and outcomes and climate, as well as the significant data gaps on gender specific features of agri-food supply chains from production to consumption stages, system-based research methodologies are likely to be necessary to successfully model these interactions as well as identify intervention strategies that have leverage to address gender inequalities in agri-food supply chains that are robust to supply chain feedback effects and unintended consequences. There is reason to believe PSM could be a highly gender-sensitive tool for modeling gendered dynamics in AFS in the context of climate shocks, as it combines stakeholder engagement and qualitative insights with quantitative systems modeling, allowing for gender specific input on modeling agri-food supply chain

characteristics and gendered perspectives on policy design and consequences.

## 2.2 Participatory systems modeling as a research methodology

PSM is a systems methodological approach to identify priority interventions and assess their impacts. It is a modeling methodology particularly well suited to settings with multi-scale interactions like agri-food supply chains (i.e., between individual, household, regional, institutional, spatial scales), as well as one with potential data gaps and uncertainty (i.e., due to the absence of data or high variability in terms of impacts, for example across gender dimensions), dynamic complexity (where short- and long-term system behaviours might differ substantially, e.g., “worse before better” trajectories) and when stakeholder engagement, consensus building and policy prioritization are critical to ensure success in resolving persistent, problematic system outcomes. PSM currently comprises a suite of potential methods that combine system conceptualization and quantitative modeling. Qualitative systems mapping uses tools like Group Model Building (GMB), soft systems methodology, and fuzzy cognitive mapping. Quantification of these conceptual mappings can use a variety of related tools, including system dynamics modeling (SDM), agent-based modeling (ABM) and role-playing games based on them.

Involving stakeholders directly in system modeling processes has emerged over time as an important extension to original modeling paradigms. Initially, system modeling methods, such as system dynamics (SD), developed primarily as “hard,” quantitative modeling approaches, focused on mathematical structural representation to simulate and analyze system properties. Within SD, for example, quantitative stock-flow elements are linked by systems of differential equations and embedded within feedback processes, and can characterize a wide variety of system reference mode problem behaviours (Sterman, 2006), like exponential growth or decay of a key system outcome, or long term suboptimal outcomes (like persistently low incomes or long-term food insecurity for women in AFS, for example). Understanding how system structure generates such problem behaviours over time is crucial in SD modeling for identifying high-leverage policy solutions.

Two key insights in SD research were recognized by the mid 1990s and helped drive efforts to more directly solicit stakeholder input in modeling: (1) situations arise frequently in which input from stakeholders is needed to determine system structure and potential solutions, and (2) stakeholder engagement promotes learning and consensus for action to address the problem behaviour. Awareness of these issues coincided with the extension of SD modeling beyond its original applications in industry and private enterprise to analyze complex community and social concerns (Hovmand, 2013) and facilitated the development of broader PSM approaches.

Here, we focus on PSM that employs the combined application of GMB and SDM, recognizing that these comprise only one potentially useful combination of conceptual and quantitative modeling methods. One motivation for this focus is that the combination of GMB and SDM has a long history of development, with documented contributions to the identification and implementation of interventions to address problem behaviours in a wide variety of fields and settings (Vennix, 1996; Rouwette et al., 2002). This combination

often is relatively low cost to implement compared to alternatives, and can be applied with equal usefulness to identification, implementation, and the (ex post) evaluation of policy interventions (McRoberts et al., 2013; Mumba et al., 2017). PSM has conceptual similarities with frameworks for foresight analyses, including Theory of Change (TOC) (Thornton et al., 2017) and Program Impact Pathways (PIP) (Kachwaha et al., 2021) used in nutrition programming. PSM also integrates the “Three-Thirds” approach to facilitating action that comprises evidence, engagement, and outreach. The adaptability and systems approach of PSM allows it to link with larger research, action, and policy agendas such as the UN Framework Convention on Climate Change.

With GMB as the qualitative system conceptualization approach, the PSM process typically begins with facilitated discussions with six to 15 people from relevant stakeholder groups (Rouwette et al., 2002). In order to apply PSM to the development of gender-sensitive climate resilience strategies for agri-food systems, these stakeholder groups would need to be carefully identified, structured and facilitated to allow for free discussion and information gathering from system participants with diverse perspectives and experiences with agri-food systems across gender identities. GMB proceeds from these facilitated discussions to the development of a conceptual model based on feedback relationships<sup>2</sup> and focused on specific desired outcomes and potential intervention points. This conceptual model can then support subsequent quantitative model development using system dynamics modeling (SDM), which captures these feedback processes and the underlying stock-flow dynamics (Sterman, 2006). These quantitative systems models are then reviewed and tested with the stakeholders, and interventions are evaluated as a continuation of the group process begun with GMB.

PSM goes beyond eliciting knowledge from stakeholders; it involves negotiating “shared ownership” of which outcomes are determined by the group as focal priorities, how systems interactions result in those outcomes, and a shared understanding of the tradeoffs among different potential interventions and solutions (Antunes et al., 2015). Each stakeholder can be viewed as an expert in their domain of lived experiences in the food system, so this approach facilitates drawing from this decentralized knowledge. The PSM process provides a basis for further interaction among stakeholders as they move to implement interventions or policy change. In that sense, PSM can serve as a potentially powerful tool in carrying out and supporting processes of organizational and social change, such as those described in Scharmer (2009) and Drimie et al. (2018), which require presentation of the problem, understanding, discussion and testing and scaling of solutions among stakeholders. PSM’s emphasis on stakeholder engagement to facilitate group model building and quantitative model development, in the absence of sufficient context-specific information, thus seems well suited to the setting of closing data, research and policy gaps on gendered experiences and outcomes within AFS, and to improve gender-responsive policy development.

<sup>2</sup> Where conceptual frameworks relevant to understanding particular outcomes (such as FNS under climate change) have already been developed by other groups, these may be used to complement what is typically more context-specific stakeholder knowledge.

## 2.3 Why is PSM valuable for understanding agri-food supply chains, especially in the context of FNS and climate resilience?

Agri-food supply chains, particularly in LMICs, are rapidly expanding and are increasingly responsible for providing the bulk of consumer foods, both urban and rural, in many LMICs. Supply chain structures and interactions are now recognized as a key determinant of FNS, with developed conceptual frameworks (e.g., Fanzo et al., 2017) and efforts to implement “nutrition-sensitive value chains” (de la Peña et al., 2018). There is increased understanding of the importance of the impact of supply-chain actors (bridging the gap between producers and consumers) on the access and affordability of food for healthy diets. A supply chain perspective includes food processing (value-added) activities essential to assessing changes in livelihoods for people working in food systems, as about 70% of the value addition and related earnings within AFS occurs after farm-gate (Yi et al., 2021). The impacts of climate change on key FNS metrics like food utilization, loss and waste will be determined by the decisions of supply-chain actors and the dissemination of socio-technical innovation bundles across agri-food supply chains as a whole (Barrett et al., 2020; Nicholson et al., 2021). Assessing and improving climate resilience of agri-food supply chains depends on successfully capturing the distinct climate risks in input, farm level, wholesale and retail stages of supply chains and their transmissions across the chain (Reardon and Zilberman, 2017). A systems approach involving stakeholders and focused on value chains can fill critical knowledge gaps between climate change, FNS outcomes and effective interventions. Systems approaches can (a) consider interconnected and heterogeneous components of food systems across scales, (b) account for multiple complex interactions over time, (c) integrate existing knowledge, and (d) identify priority actions [Institute of Medicine (IOM) and National Research Council (NRC), 2015].

Dynamic complexity is a well-documented feature of agri-food supply chains, with interactions among multiple agents frequently resulting in unintended and unanticipated system responses to interventions. Because PSM is valuable for studying issues of dynamic complexity, it is particularly well suited for understanding how agri-food supply chains can play a role in promoting food and nutrition security under climate change. Climate change is acknowledged as a threat to FNS, especially for populations in low-income countries (Fanzo et al., 2017). The pathways linking climate change to FNS outcomes are complex and dynamic (Bizikova et al., 2020; Nicholson et al., 2020a, 2020b, 2020c; Fanzo et al., 2020) and FNS outcomes are likely to be affected by decreased food production and access, dietary diversity, and nutritional content as well as breakdowns in agri-food supply chains, particularly for those living in marginal urban and rural areas. Substantive gaps exist in our understanding of potential climate change impacts on FNS outcomes and assessment of interventions, especially at the scale of supply chains (Nicholson et al., 2020b; Slater et al., 2022). Moreover, the climate resilience of agri-food supply chains has received relatively little research attention in contrast to research on primary agricultural production (Reardon and Zilberman, 2017). Tools such as PSM are capable of describing and analyzing these complex agri-food supply chain structures and highlighting key leverage points that can influence system behaviour (Lie et al., 2017).

The above features all suggest that participatory systems analytical approaches like PSM can be key to analyze and address climate

change-driven negative agri-food supply chain outcomes. As highlighted previously in Section 1.1, there are also significant gendered dimensions to all of the above, including unequal FNS, climate risks and agri-food supply chain livelihood outcomes across gender lines, driven partly by gendered inequalities within the supply chains themselves. The PSM approach therefore, when focused on agri-food supply chains in the context of climate change, has several potential benefits deriving from: the application of well-developed quantitative systems modeling methods, like SD; the involvement of stakeholders to address data gaps that have previously hampered quantitative modeling efforts in this context; as well as flexibility, low cost and useful linkages to other conceptual frameworks for agri-food supply chains. These benefits are summarized in Table 1 and each category of benefits is described further below (Sections 1.3.1 to 1.3.3) with existing examples of these applications in the literature described in Section 1.4. The additional benefits of PSM when analyzing the layers of known gender-specific features and divergences across agri-food supply chains under climate change more directly are summarized later in Section 1.5.

### 2.3.1 Benefits of system dynamics modeling (SDM) as the quantitative modeling method within PSM

SDM has a long history of development and there is extensive documentation on modeling practices and model evaluation (Sterman, 2000). SDM models can readily incorporate diverse disciplinary perspectives, including biophysical effects but also economic and other incentives. PSM can draw upon previous quantitative SDM supply chain models to identify potential unintended consequences.

A systems approach combining GMB and quantitative SDM, focused on agri-food supply chains, can thus fill critical knowledge

TABLE 1 Potential benefits of participatory systems modeling applied to agri-food supply chains to address climate resilience and food and nutrition security outcomes.

Category	Key benefits
Use of system dynamics models	<ul style="list-style-type: none"> <li>Facilitates application of known methods for model development (including ‘systems archetypes’) and model evaluation</li> <li>Provides examples of value-chain models to streamline development in new contexts</li> </ul>
Involvement of stakeholders	<ul style="list-style-type: none"> <li>Broadens knowledge base to cover data gaps on supply chain system structure and model parameters</li> <li>Enhances learning by stakeholders about supply-chain system structure and underlying causes of undesirable outcomes</li> <li>Improves consensus about and motivation to implement priority actions</li> </ul>
Other benefits of PSM	<ul style="list-style-type: none"> <li>May be lower cost, more timely and more flexible than more resource-intensive agri-food system models</li> <li>Links supply-chain modeling to existing frameworks for foresight analyses (Theory of Change, Program Impact Pathways) used in nutrition intervention design and evaluation</li> <li>Integrates components of the “Three-Thirds” approach to facilitating action that comprises evidence, engagement, and outreach</li> </ul>

gaps between climate change, FNS outcomes and effective interventions. Participatory methods involving stakeholders in initial GMB exploration of problematic agri-food supply chain reference modes, drawn from supply chain model structures within the SD literature, can facilitate a more holistic understanding of agri-food supply chain systems, drawing upon both quantitative and qualitative information on how and for whom these systems work.

### 2.3.2 Benefits of involving stakeholders to analyze supply chain challenges

Agri-food supply chains are context-specific, with widely varied geographies and ecological, economic, and social conditions, so the subject matter knowledge of stakeholders can make important contributions to the model structures and the identification of potential interventions. The quantification of agri-food supply chain model parameters may be informed by stakeholder perspectives. Involvement of stakeholders can contribute to improved communication, understanding and motivation for action. This is particularly true when considering divergent experiences across gender lines within agri-food supply chains, where women's experiences are under-represented within the existing literature on supply chain behaviour, and direct engagement with women participants in supply chains is necessary to successfully model these systems. Rouwette et al. (2002) found that GMB applied in diverse contexts (for-profit businesses, non-profit organizations, and governments) increased understanding of the causes of undesirable outcomes and often resulted in the implementation of interventions identified by GMB. To address growing nutrition and environmental challenges, "focus will increasingly shift to how such change happens, [and] the extent to which such complex systems can be 'designed' (and if so 'by' and 'for' whom)" (Andrew et al., 2022). A clear understanding of the outcomes desired by supply-chain stakeholders is essential to the success of any change process. PSM can help identify desired or undesired outcomes through participatory scenario development and support group learning about dynamic processes of change and system design. PSM also aligns tools used in anticipatory governance (e.g., Muiderman et al., 2022).

### 2.3.3 Other benefits of PSM

PSM applied to agri-food supply chains can be undertaken relatively quickly and at a low cost, due to the integration of pre-existing quantitative agri-food supply chain models, such as those already developed within the SD literature. And, if the initial iterations of GMB and quantitative model building are not considered useful by a relevant set of stakeholders, the process can be relatively quickly repeated with appropriate modifications. This can provide a substantial benefit compared with large-resource global modeling tools developed over many years—tools not always appropriately applied because organizations become invested in their application and further development.

## 2.4 Examples of applying PSM to agri-food supply chains

PSM focused on agri-food supply chains complements analyses at meso-, macro- and global scales, and emphasizes the scale at which many climate adaptation interventions might most realistically be

implemented. Global agri-food system model analyses are relevant for some policy interventions (like international trade or multilateral climate agreements) but they can omit relevant context specificity, typically indicating little about how changes might occur through policy or other interventions or how food systems might respond to (adapt to) policies and interventions. PSM supply chain analyses can improve understanding of dynamic causal pathways, impacts on a broader set of food system metrics and the effectiveness of potential climate resilience interventions. They also can build on previously-developed conceptual frameworks (e.g., Tirado et al., 2009; Myers et al., 2017; Fanzo et al., 2020) and make use of prior PSM work on agri-food supply chains. Some recent examples for illustrative purposes are outlined in Table 2. These examples reflect the authorship team's subject matter knowledge on the existing applications of PSM to agri-food supply chains.

Using an example from Table 2 to demonstrate the potential of PSM more directly, Nicholson and Monterrosa (2021) used PSM to analyze fruit and vegetable supply chains in Nairobi, Kenya with the objective of assessing interventions to increase household consumption. Participants identified an undesirable "reference mode" behaviour: stagnant per capita consumption at levels below the recommended daily amounts. GMB participants also discussed the key drivers of consumption in Nairobi, including availability, affordability and desirability (including quality and safety dimensions) of fruits and vegetables. The participants then documented the different elements of the supply chain including linkages farmers, wholesalers, transporters and retailers (both formal ones like supermarkets and less formal vegetable stands often operated by women). Actions by stakeholders at each of these nodes interact across the entire supply chain, including through pricing, quality variation, or the timing of movement of horticultural commodities through the chain. The GMB process developed a systems mapping of the key elements of the supply chain that would affect availability, affordability and desirability. Participants also identified potential intervention points to increase consumption, including nutrition awareness campaigns, reduced perishability and higher crop yields. There were also significant data gaps about the capacity of local fruit and vegetable supply chains to implement these policy interventions. Stakeholders in the Nicholson and Monterrosa study thus also provided information to help parameterize the modeled fruit and vegetable supply chain, in

TABLE 2 Examples of PSM applied to agri-food supply chains.

Citation	Setting	Focus
McRoberts et al. (2013)	Mexico	Potential for development of value-added dairy supply chain through community cooperatives
Lie et al. (2017)	Nicaragua	Assessment of improvements of the dairy value chain to improve farmer incomes
Mumba et al., 2017	Zambia	Spatial dynamic modeling of animal health
Berends et al. (2021)	Myanmar	Ex-ante assessment of interventions to improve pork value chains
Nicholson and Monterrosa (2021)	Urban Kenya	Assessment of interventions to increase fruit and vegetable consumption

combination with prior descriptive studies and other relevant literature.

The result of this PSM process was a more consistent and quantitative comparison of the potential impacts of different policy solutions (i.e., nutrition campaigns vs. agricultural productivity increases). This approach allowed a ranking of solutions based on their overall influence on consumption even though the interventions would be implemented at different locations in the supply chain. The largest modeled impact on fruit and vegetable consumption in this study was assessed to be via increasing yields at the production node of the value chain, followed by improved consumer awareness at the consumption end of the value chain. Reducing fruit and vegetable losses in the transport and marketing nodes was projected to lead to lower fruit and vegetable consumption, because better storage and preservation in the middle of the value chain incurred higher storage costs, which raised consumer prices and reduced the quantity demanded by consumers.

This example illustrates how PSM is distinct from other value chain or agri-food system modeling methodologies in that it incorporates stakeholder-specific information about system structure and articulates undesirable outcomes and potential solutions. Other studies using PSM (Table 2) take a similar approach, directly accounting for stakeholder perspectives, building these viewpoints into model structure and identification of priority outcomes. The approach facilitates discussion with stakeholders about modelling results, which can inform appropriate modifications to model structure or parameters and promote group discussion and consensus about priority actions to take to improve outcomes.

## 2.5 What are the potential benefits of applying PSM to Agri-food supply chains to assess “the gender variable”?

In addition to being exposed to climate risks, representing significant consequences for global food and nutrition security, agri-food value chains are often highly gendered in terms of their structure, and distribution of economic returns across value chain nodes and the dominant gender groups that often occupy distinct market hierarchy positions (Adetoyinbo and Otter, 2020; Adam et al., 2024). Recent research building gender maps of key local food commodity value chains [Shrimp and fish value chains in Nigeria (Adetoyinbo and Otter, 2020)], gender typologies [Coffee value chains in Honduras (Soto et al., 2024)] and gender value webs [Cassava value chains in Tanzania (Masamha et al., 2018)] highlights the need to better document these gender patterns and mainstream consideration of gender in analyzing agri-food value chain analysis and policy design. A common thread across these analyses is the need for tools to conduct participatory research with under-represented groups in agri-food supply chains, such as engaging stakeholders across gender identities, like women engaged in marketing and processing of primary staple commodities, where they are often key players in this space [see for example the work on the “tomato queens” in Ghanaian horticultural marketing chains (Benabderrazik et al., 2022)].

Thus, given climate shocks and differential exposure and coping strategies across gender identities (Lambrou and Piana, 2006; FAO, 2022), there are many settings where poor socio-economic outcomes from agri-food supply chains are persistent and divergent by gender. This suggests the prevalence of system-driven dynamics that defy existing intervention efforts, for which a system analytical approach is

required to address. Thus, PSM, as one such approach, may be a valuable methodological tool in not only capturing stakeholder knowledge on agri-food system structure, climate resilience and critical gender specific features, but combining this diverse information into a quantitative model that can build consensus and facilitate shared understanding of the origins of problematic outcomes and potential interventions to address them.

## 3 Examining the use of participatory systems modeling at the intersection of gender, agri-food supply chains and climate resilience

The following section describes a review and classification of the PSM literature found within the Scopus database. The search results were narrowed down to works that employ PSM as we are referencing it, and then classify this research into the relevant subject areas of interest across gender, agri-food supply chains and climate.

### 3.1 Scopus literature search results on PSM used at the intersection of gender, value chains, and climate resilience

As outlined above, there are significant gender dynamics at work within every stage of agri-food supply chains that influence distinct, gendered outcomes for value chain participants, from farmers, to input suppliers, to traders, wholesalers, retailers, processors and consumers. In order to further examine the potential applicability of PSM to the challenge of uncovering gender-responsive climate resilience strategies across agri-food supply chains, we conducted a limited Scopus literature search for existing studies at the intersection of gender, agri-food supply chains, and climate that employ PSM as the primary research methodology.

In order to find the relevant literature, we first searched for any works using participatory system dynamics, with the following broad search string:

“participatory syste\* dynamics” OR “participatory syste\* model\*”

We then limited search results to published or in press articles or book chapters that are in English. This resulted in 1213 identified works across all research fields. We then narrowed this search to exclude domains outside of relevance to agri-food systems, such as engineering or other physical sciences.<sup>3</sup> We also filtered out review

<sup>3</sup> All searches excluded various engineering, physical science and other domains with the following string: (EXCLUDE (SUBJAREA,“IMMU”) OR EXCLUDE (SUBJAREA,“VETE”) OR EXCLUDE (SUBJAREA,“MATE”) OR EXCLUDE (SUBJAREA,“NEUR”) OR EXCLUDE (SUBJAREA,“CHEM”) OR EXCLUDE (SUBJAREA,“HEAL”) OR EXCLUDE (SUBJAREA,“CENG”) OR EXCLUDE (SUBJAREA,“NURS”) OR EXCLUDE (SUBJAREA,“PHYS”) OR EXCLUDE (SUBJAREA,“PSYC”) OR EXCLUDE (SUBJAREA,“BIOC”) OR EXCLUDE (SUBJAREA,“MATH”) OR EXCLUDE (SUBJAREA,“MEDI”) OR EXCLUDE (SUBJAREA,“EART”) OR EXCLUDE (SUBJAREA,“ENER”) OR EXCLUDE (SUBJAREA,“ENGI”).

papers and focused on primary research work. This reduced the returned search results down to 458 works.

Due to the variability in use and meaning of the terms ‘participatory modeling,’ we then examined the abstracts of the 458 manuscripts in more detail to identify which manuscripts utilized PSM as their main research methodology in the same manner as we are considering it: Group model building with key system stakeholders coupled with quantitative model building based on the SD paradigm, focusing on causal loop diagrams, feedback processes and stock-flow system structures. As a consequence, we thus filtered out some related stakeholder participatory modeling methods, such as fuzzy cognitive mapping and analytical hierarchy processes, as they are less focused on identifying key feedback processes and causal loops to help explain system behaviour. We also filtered out manuscripts that only used SD, without a participatory group modeling component, as well as manuscripts that included stakeholder engagement without a GMB element. We made a case by case judgement on some manuscripts with in-depth GMB that resulted in development of causal loop diagrams but did not continue on to the development of a fully quantitative SD system model. Out of these, we included those with considerable iterative research work between the GMB/causal loop diagram phase and analysis of system structure and drivers with stakeholder participants. This resulted in a further narrowing of the relevant PSM literature to 92 manuscripts.

Finally, we examined the full text of the 92 manuscripts to identify and classify those with a focus on either:

1. Agri-food supply/value chains
2. Climate mitigation or adaptation
3. Agricultural production or food systems and food security more broadly
4. Gender framing and analysis

In this exercise, we put manuscripts with a focus on agri-food supply/value chains in their own group, meaning that within the paper, there is a specific emphasis on the analysis of the connections between agri-food production, marketing, input supply, transport, trade and final consumption that is reflective of the supply chain literature. However, there were many additional PSM papers within the broader context of AFS, outside of the typical supply chain structural approach. This is the “agricultural production or food systems and food security” classification category “3” above. As indicated in [Reardon and Zilberman \(2017\)](#) this is the typical scale at which climate resilience work is conducted, and there are more works using PSM in this setting, as well as some work highlighting gender, so we retained these works. In the analysis below we contrast the application of PSM to agri-food supply chains to its application to AFS by way of further highlighting additional potential for PSM as well as existing underutilization.

A few of the 92 manuscripts did not employ PSM upon closer inspection, or they did not cover one of the above 4 topics and were thus further filtered out of our analysis, which left a final sample of 76 manuscripts. The full search flow is shown in [Figure 1](#).

Among the 76 manuscripts, the majority of these used PSM in the broad context of either agricultural production or food systems/food security (i.e., AFS) (64 out of 76). Climate was a major focus in 43 manuscripts, with many of these also within the broad AFS context (i.e., 36 out of 64 also considered climate).

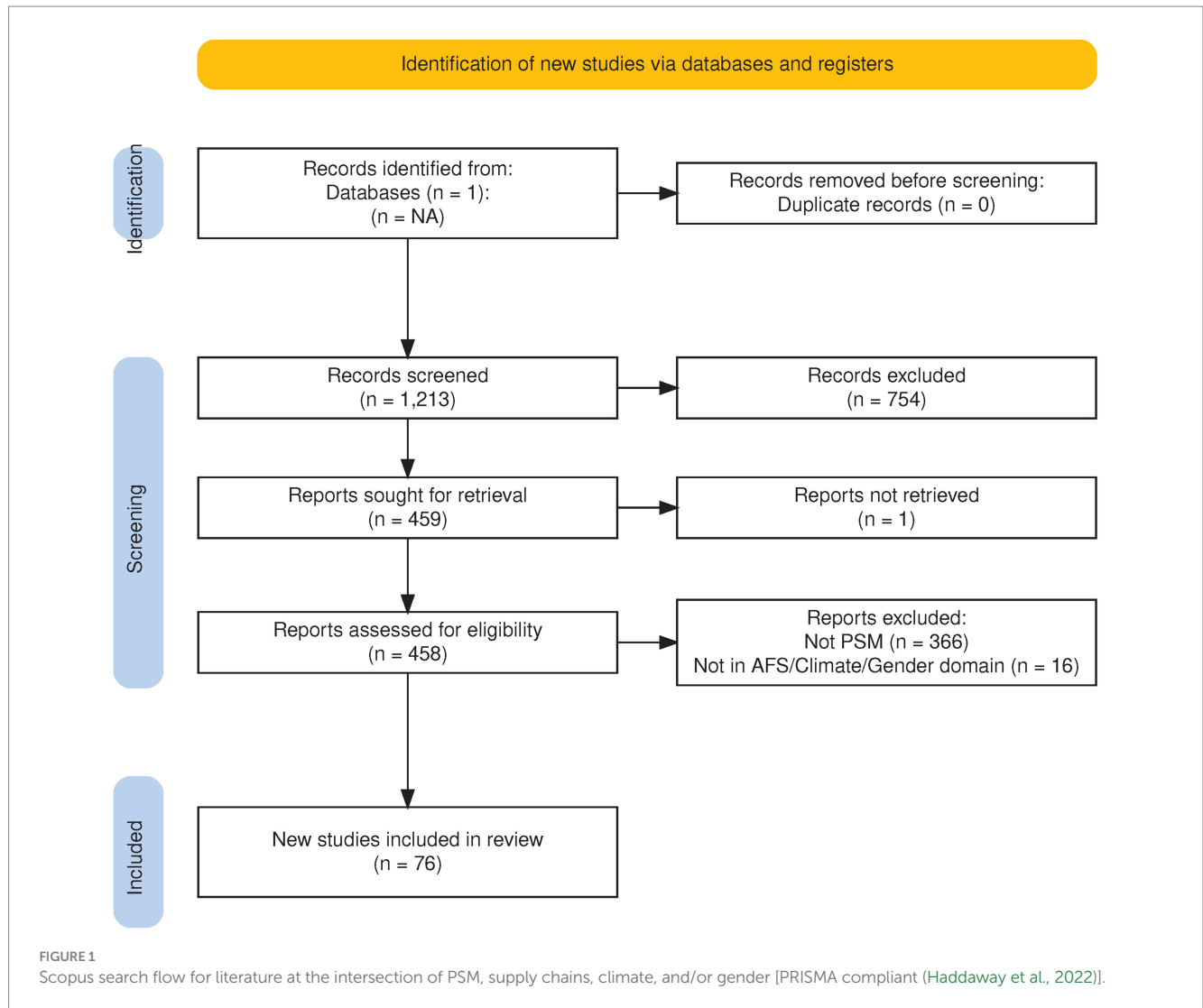
Agri-food supply chains were the focus of a subset of the AFS papers, with 23 manuscripts using PSM to analyze agri-food supply chains directly, and are included in the 64 AFS manuscripts. Likely due to additional variation in terminology for describing agri-food supply chains, only 3 of the papers identified by author team knowledge in [Table 2](#) were included in the Scopus search results on PSM used to analyze agri-food supply chains.

When considering gender analysis, only 11 of the 76 papers considered gender in their analysis, and not all of these to the same extent. In particular, of the 23 papers focused on agri-food supply chains, only 5 included any discussion of gender in the analysis. And, given the previous discussion on likely heightened exposure to climate change risks for women within AFS, it is also notable that only 5 papers focused on climate using PSM included gender as a component of their analysis. [Table 3](#) summarizes this initial content analysis of the literature using PSM. Some example references from the few works that included PSM, agri-food supply chains, climate and gender, along with some important paired categories, are described below. A full list of the PSM literature works and their major content categories are included in the [Appendix](#).

### 3.1.1 Literature using PSM in the context of food or agri-food supply chains, climate and gender (4 papers)

Only 4 of the identified papers from the Scopus review employed PSM methods and covered the full intersection of interest in this manuscript, between agri-food supply chains, climate and gender (i.e., within the agri-food supply chain set of 23 papers, only 4 out of the 5 that also consider gender could additionally be seen to discuss climate). These papers are summarized in [Table 4](#). As can be seen, these works used participatory systems modeling to address research questions concerning several key agri-food supply chains (seaweed, agro-forestry, tomato), as well as broader resilience and food security concerns, co-developed with engaged stakeholders and varying degrees of consideration of gender. [Benabderrazik et al. \(2022\)](#) use PSM to explore climate resilience of tomato farmers in Ghana, and incorporate broader agri-food supply chain drivers. They directly highlight the gender specific roles for women in the marketing nodes of tomato value chains (the Ghanaian “tomato queens” are highlighted in this work), but do not further analyze gender specific outcomes. [Muflikh et al. \(2024\)](#) highlight that they recruited a balanced representation of women and men in their stakeholder groups to build their models, but also do not further explore any differences across gender representation. [Santoro et al. \(2025\)](#) include “gender equality” as a modeled component of social dynamics influencing biodiversity losses, but do not go into further details beyond introducing it during description of the causal loop diagramming phase of the GMB work.

The [Gasparatos et al. \(2023\)](#) review comes closest to linking PSM, gender and climate and presents analysis of several participatory research projects examining the role of commodity crop production systems in food security. One project (the Belmont Forum) included “mediated modeling” or PSM as their participatory research approach. Gasparatos et al. highlight the importance of sensitivity to complex stakeholder dynamics and power imbalances, including by gender roles within commodity production systems, and identify some methods used to achieve better inclusivity in participatory research more generally, although they also indicate that they believe gender norms might be less of a barrier to



**TABLE 3** Scopus search results on research using participatory systems modelling, focused on agri-food supply/value chains, climate or gender/women.

Number of papers	“PSM” and Agriculture/ Food systems	“PSM” and “supply/ Value chain”	“PSM” and “climate”	“PSM” and “gender” or “women”
Total	64	23	43	11
Contains supply/value chains	23	(all)	11	5
Contains gender	7	5	5	(all)
Contains climate	36	10	(all)	5
LMIC setting	29	11	14	6

participatory research in the mediated modeling setting than in the other methods considered (expert interviews, focus group discussions, participatory mapping and scenario analysis). The broader recommendations for participatory work from Gasparatos include: in-depth research on local dynamics and inequalities before engaging in the research project itself, recruitment of stakeholder groups from specific communities, including women, and potential division of research teams (particularly for focus groups) by gender or other groups that may be disempowered in the local context to encourage freer and safer communication on

socio-economic challenges within the research settings of interest. They highlight that mediated modeling can have a significant positive impact on facilitating participatory research to address a transdisciplinary research space (in their case the links between food security and commodity crop production), and that commodity crop production and food security systems can be highly gendered.

Analyzing key subsets of literature from the Scopus search results is useful in its own right in order to better highlight the current gaps in the literature in terms of the state of use of PSM versus its potential

TABLE 4 Scopus search results at the intersection of PSM, climate, supply/value chains and gender.

Citation	Setting	Focus
Benabderrazik et al. (2022)	Ghana	Using PSM to understand climate resilience for tomato farmers, incorporating additional horticulture supply chain dynamics
Gasparatos et al. (2023)	Sub-Saharan Africa (review)	Assessment of best practices in participatory research on commodity production and food security, highlighting the benefits of PSM to uphold key participatory research principles, such as credibility and relevance
Muflikh et al. (2024)	Indonesia	Develop stakeholder mutual understanding through PSM of sustainability in seaweed supply chains
Santoro et al. (2025)	Brazil	Co-develop PSM to explore Biodiversity-Climate-Society Nexus and agro-forestry value chains (nuts, acai, cacao, palm, wood)

to be a valuable tool to incorporate “the gender variable” into analysis of agri-food supply chain climate resilience. Given the robust gender distinctions in participation and outcomes across agri-food supply chains described in Section 1, participatory research approaches will be needed to successfully describe and analyze these diverse experiences and improve the gender-responsiveness of agri-food supply chain policy interventions. However, in the Scopus search results described below, gender is mostly not addressed, despite the near certain existence of gender dynamics within each of the examples described below.

### 3.1.2 Literature using PSM in the context of AFS (64 papers)

From the broader group of AFS papers, which encompasses those focused more specifically on agri-food supply chains, the most manuscripts can be identified that use PSM (64 out of 76 papers). The bulk of the papers returned in this search utilized PSM with AFS stakeholders to model key features of the commodity of interest (e.g., poultry, dairy, tomato), and then analyzed the system behaviour in terms of its economic performance, delivery on key outcomes, such as sustainable livelihoods or food security, or environmental outcomes, such as land and water use. Benabderrazik et al. (2022) and Gasparatos et al. (2023) described previously, were both included in this broader search for literature on PSM in AFS (including agri-food supply chains) described in Table 3. Other works in this literature are similar to these two papers in that they do extensive work with stakeholders to co-develop a dynamic model of key agri-food systems for critical insights. But, this larger literature on PSM and AFS does not significantly mention gender in the analysis (7 out of 64 papers, 4 of which have already been discussed in section 2.1.1).

An example from this subset of this literature that does encompass some aspects of gender dynamics within AFS is Kopainsky et al. (2017). PSM is used with small-scale farmers in Zambia to develop a system model of their farms and farming outcomes, as well as identify important interventions, such as access to off-farm income and co-operation by men and women in the household, to improve important outcomes, such as food security. Workshops with stakeholders on the co-developed system dynamic model included assessment of how the system might respond to shocks, like climate change, as well as the emergence of shared understanding of the different roles of men and women within the system. Other works returned in this search also emphasized participatory approaches to understanding different agri-food systems settings and food security outcomes of these systems. Although learning about gender dynamics was an important outcome in Kopainsky et al. (2017), and is discussed to some degree in the other works returned in the “participatory

systems” and “AFS” search, gender is not explicitly highlighted as a research objective.

### 3.1.3 Literature using PSM in the context of climate change (43 papers)

Within this grouping, 36 papers are within an AFS setting, and 10 of these are further dedicated to studying agri-food supply chains<sup>4</sup>. As a representative example from this Scopus search, a paper found at the intersection of PSM, climate and agri-food supply chains, Olabisi et al. (2021) describes the application of PSM to assess climate change adaptation possibilities across the poultry value chain in Nigeria. This research team convened several workshops with a diverse set of poultry value chain stakeholders including producers, retailers, policy makers, veterinarians and input suppliers, maize producers (a main poultry feed) and climate and agricultural researchers across two regions. The stakeholders and researchers built a quantitative system dynamic model of the poultry sector and used it to discuss likely impacts of climate change and identify key climate adaptation strategies. This paper emphasized the importance of direct stakeholder engagement in developing climate adaptation approaches that are applicable to the local context, also noting that many existing climate adaptation policies in Nigeria are “top-down” and primarily at the national scale.

The PSM participants converged on an overall system picture of the poultry sector that is likely to be negatively impacted by climate change in terms of reduced availability of maize feeds as well as higher poultry mortality and disease, while concurrently expanding in scale due to high population and income growth in Nigeria driving increased consumer demand for poultry as a main dietary protein. Participants identified additional adaptation strategies including: switching to cassava as a more climate resilient poultry feed; investing in shade trees on poultry operations; switching to more climate resilient livestock breeds and improved communication with policy makers, about the negative impacts of these trade policies on stakeholder ability to adapt to climate change. The PSM approach used in Olabisi et al. (2021) resulted in the successful construction of a functioning system dynamic model of the sector, despite a noted lack of certainty or quantitative data about many of the value chain nodes or sensitivity to shocks and external drivers, like climate. However, gender was not a feature of the analysis presented, despite the substantial literature cited in Section 1.

<sup>4</sup> Other papers in this category are significantly outside the AFS context, with several on urban planning, hydrology and flood mitigation. Further details are outlined in the Appendix summary of these papers.

### 3.1.4 Literature using PSM with a direct focus on gender (11 papers)

Analyzing the Scopus search results that use PSM to more explicitly model gender provides a final perspective on the current state of usage of PSM within the context of climate resilience in agri-food systems that incorporates a gender framework. Within these 11 papers, 8 are in an AFS setting, and 5 of these directly analyze agri-food supply chains (including the 4 described in section 2.1.1). 5 others highlight climate, with the [Kopainsky et al. \(2017\)](#) paper described in 2.1.2 as the paper that looks at AFS, climate and indirectly discusses gender dynamics although it is not the main research objective. The papers in this classification represent works where gender is directly addressed as a research emphasis. As an example, [Prabhu et al. \(2023\)](#) directly focus on gender and agri-food supply chains (but not climate) to use PSM to identify specific adoption dynamics for women fish vendors of mobile phone based e-commerce technologies in India. They use the model to identify strategies to increase its adoption by women, revealing the importance of word of mouth as well as adequate training and support for women to facilitate investing in smartphones to take advantage of the technology. [Nguyen et al. \(2021\)](#) use a participatory modeling approach (without a quantitative SD model building component) to work with women smallholder farmers in Vietnam and Ghana to model their overall workload and quality of life concerns in these AFS contexts (but exclude climate and agri-food supply chains). The other search results for works using PSM with a direct focus on gender fall outside of agri-food systems, supply chains or climate resilience, into health and gender representation in science, among other topics.

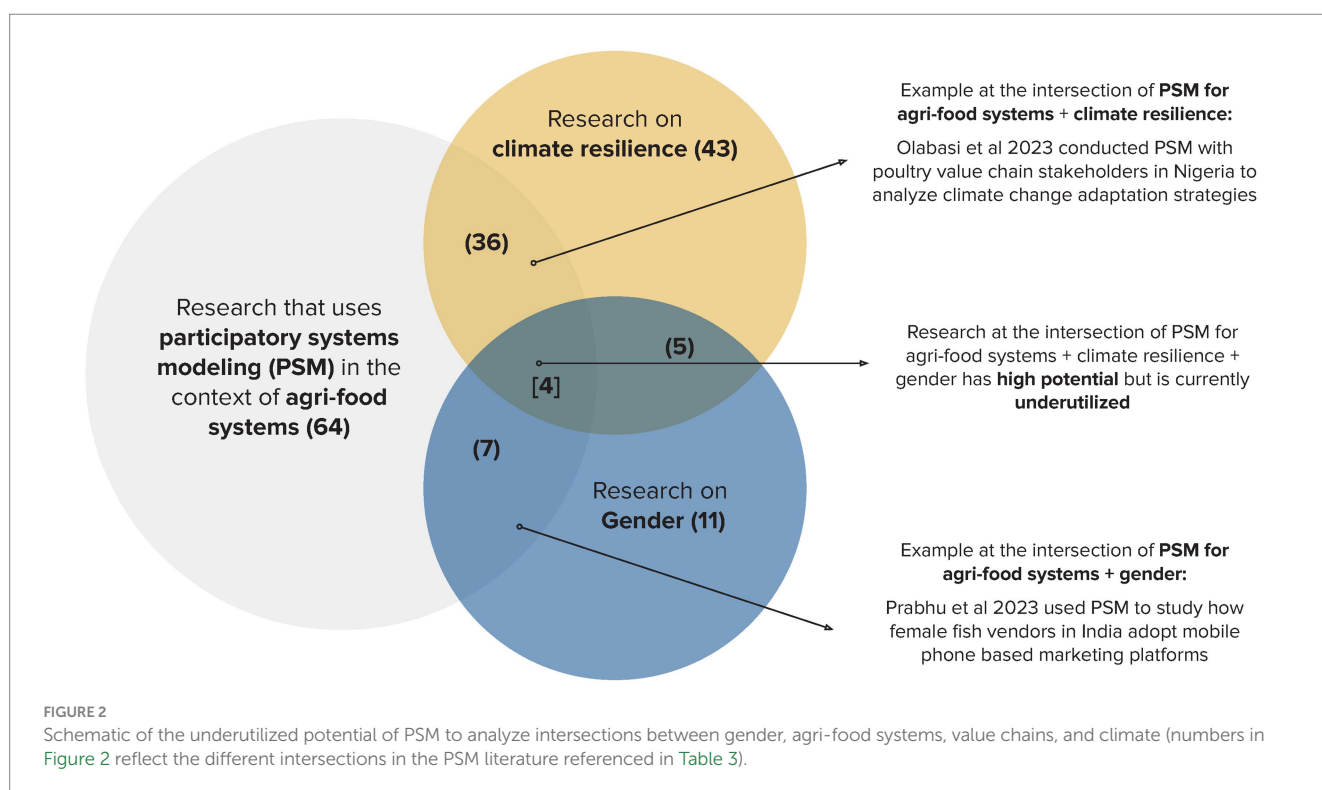
To summarize, as shown in [Figure 2](#), the above exploration suggests that PSM has *high potential* to be successfully utilized to improve gender-responsiveness in agri-food supply chain resilience

research, given the PSM and climate and supply/value chain literature identified in the pairwise Scopus searches, but the lack of findings in terms of existing use of PSM to encompass gender suggests it is currently *underutilized* as a research methodology in this space.

The lack of existing literature employing PSM in the context of agri-food system resilience with a focus on gender more directly might seemingly suggest the lack of applicability of this methodology to these topics. However, a feminist critique of Systems Theory in [Stephens et al. \(2010\)](#) references the near-absence of gender-sensitive approaches to systems modeling in general, and the need for more active strategies to consciously apply systems modeling to gender inequality in a wide variety of settings. This Scopus review suggests that PSM could thus represent an important new methodological tool to explicitly study gender sensitivity and responsiveness to interventions to address agri-food systems challenges under climate change, given the previous literature identified in [Table 3](#) that has successfully employed PSM for greater insights, yet is conspicuously missing a gender frame and lens.

## 4 Discussion and recommendations for using PSM at the intersection of gender, value, chains, and climate resilience

In this section we summarize the notable current underutilization of PSM in the context of gender, agri-food supply chains and climate found in the PSM literature review in Section 2 in contrast to our assessment of the potential of PSM from section 1. We then introduce some standing recommendations on mainstreaming gender from work within an AFS context to increase gender responsiveness in analysis and policy development. We then document how PSM can



support these recommendations, as well as some potential limitations in fully utilizing PSM to address these challenges.

## 4.1 Implications of the Scopus review findings

After reviewing the Scopus search results, a principal takeaway is that gender is not well represented in the PSM literature on climate and agri-food supply chains. As can be seen in [Table 3](#), PSM has successfully been used to understand gender dynamics in a few settings, but these do not seem to substantially cover agri-food and/or climate scenarios, even though we know (1) there are significant gendered divisions within agri-food systems, which impacts outcomes with differences across gender (cf. [Section 2](#)), (2) women are anticipated to be at higher climate risk overall ([Lambrou and Piana, 2006](#); [IPCC, 2014](#)) and (3) there is a significant lack of either quantitative or qualitative data on gendered systems and outcomes, which means that direct engagement across gender lines is necessary to analyze, and even just capture, these realities. To further understand this apparent underutilization of PSM, we draw next upon prior work that has been done to increase gender mainstreaming within AFS policy to look for potential guidance for increased use of PSM.

## 4.2 Recommendations on how PSM can support incorporating gender into analysis of agri-food supply chain resilience and promoting gender-responsive resilience strategies

Recognition of the need for participatory research methods to address agri-food system challenges emerged in the 1990s ([Johnson et al., 2004](#)) and has been steadily increasing [c.f. [Asare-Nuamah et al. \(2025\)](#) for documentation of these trends in Africa]. Alongside the increase in the use of participatory research methods have been documentation of the challenges in maintaining inclusivity in this work and ensuring that power dynamics are acknowledged and managed so that marginalization of stakeholders is not ignored or worsened by the participatory research process ([Hovmand, 2013](#); [Butler and Adamowski, 2015](#)).

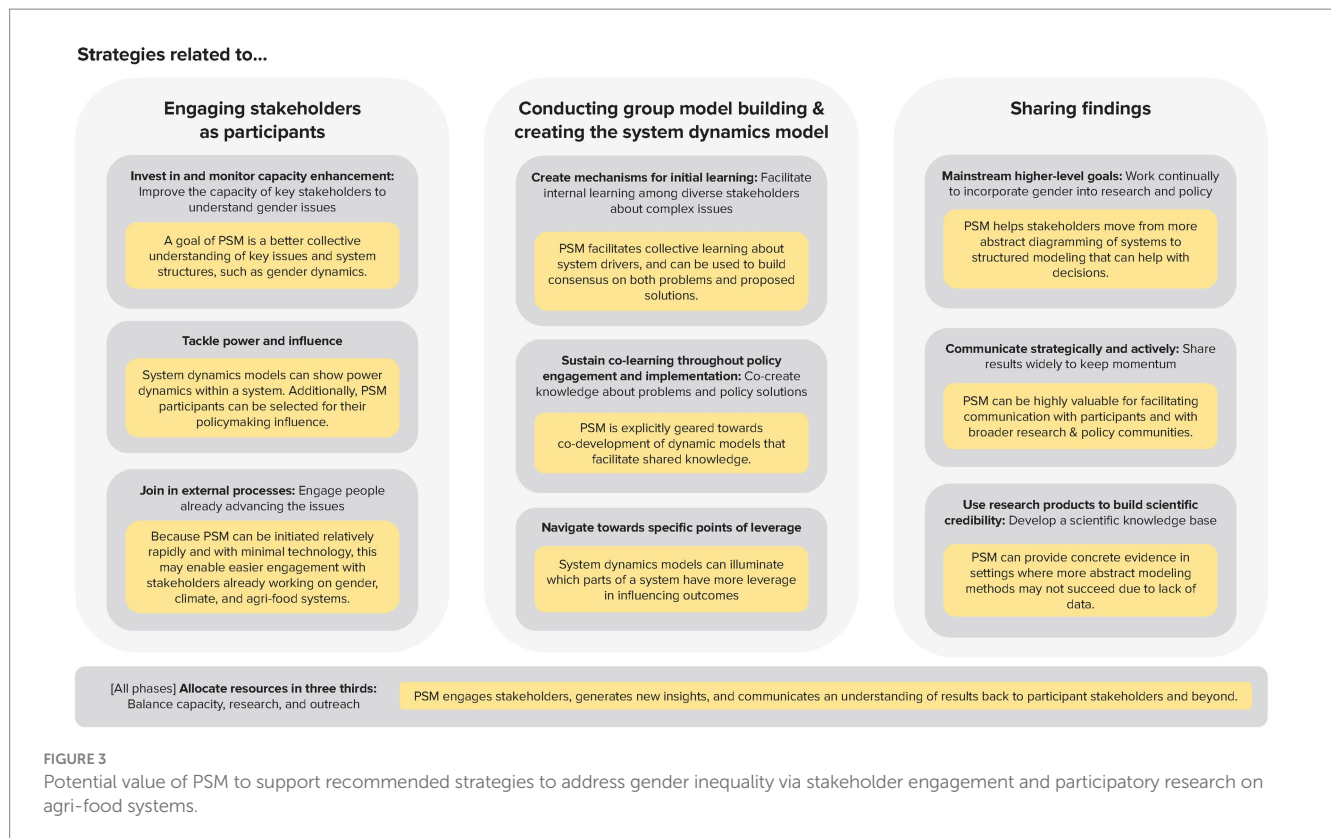
In consideration of how gender inequalities specifically might impact stakeholder engagement and policy processes in climate and agriculture and food security research, [Mulema et al. \(2022\)](#) analyze the outcomes of several projects designed to tackle gender dynamics in the agriculture/climate domain. They use the experiences in these projects to develop guidelines for increasing and mainstreaming gender within agri-food systems and climate change policy and research settings [2022, [Table 1](#), adapted from [Dinesh et al. \(2018\)](#)].

We have taken the recommendations of [Mulema et al. \(2022\)](#) as a baseline, and in combination with our summary of the potential of PSM as a mixed qualitative and quantitative systems research methodology from [Section 1](#) we present a breakdown of how PSM could support the recommendations in [Mulema et al. \(2022\)](#) in future research on gender-responsive climate resilience research. PSM as a research method has particular strengths in fostering 'shared ownership' of co-created knowledge about system dynamics, as well as in using model building to identify key leverage points for policy

intervention. PSM also emphasizes the use of transparent system modeling practices and documentation of modeling assumptions. These features of PSM speak directly to many of the critical recommendations from [Mulema et al. \(2022\)](#) and other researchers ([Gasparatos et al., 2023](#)) on best practices in participatory research overall and in fostering greater gender responsiveness in particular. [Figure 3](#) summarizes our suggestions on how PSM can help to achieve greater gender-responsiveness in agri-food supply chain resilience research and subsequent policy development. The outer boxes (light grey) show major phases of the PSM approach (stakeholder engagement, group model building, sharing findings); the middle boxes (dark grey) list and describe strategies to increase gender inclusivity in climate and agri-food system research and policy from [Mulema et al. \(2022\)](#); and the inner boxes (yellow) provide examples of how PSM can help to achieve these strategies.

For an illustration of the potential impact of these recommendations, we summarize the analysis of gender inequalities within an important agri-food supply chain in Nigeria as demonstrated in [Adetoyinbo and Otter \(2020\)](#) and then highlight how PSM could complement this research. [Adetoyinbo and Otter \(2020\)](#) use participatory qualitative research methods to create a gender value web for the shrimp sector across three States in Nigeria. The value web is an alternative framework for studying outcomes in agri-food value chains, that not only tracks agri-food commodity movement and transformation from suppliers to consumers for specific end products, but also documents all value-added processing options, and estimated margin value contribution to overall market values for agri-food commodities, and the identities of key participants in these value-added processes. With gender identity information, it then becomes possible to estimate the relative distribution of gains from agri-food value chains across gender lines. After completing the gender value web for the shrimp sector in Nigeria, [Adetoyinbo and Otter \(2020\)](#) determined that women dominate in the primary processing and local marketing of fresh shrimp, supporting product quality downstream in the value chain through preservation of a perishable commodity. However, the margins at the local nodes in the value chain are smaller than those from international trade as well as those for transport and industrial processing. Extending this gender value web analysis with PSM would add an additional method to not only represent this gender web but also assess possible interventions to rectify the persistent gender inequality in financial returns and the lack of mobility for women value chain participants from local processing into higher-return sectors. PSM can also examine systemwide consequences and benefits if gender equality in the sector improves. It is also possible to imagine a more explicitly gender-focused PSM approach to the poultry value chain work of [Olabisi et al. \(2021\)](#) described previously, potentially by more explicit recruitment of stakeholder groups by gender, and examination of gender specific differences in conceptualization and modeling of this value chain. PSM is thus not a substitute for the many existing research methods available to analyze and address gender inequality within agri-food systems, but is a potential complement to these existing approaches that can transform stakeholder information about system-driven problems into actionable insights for interventions.

PSM can be successfully utilized to analyze gender-responsiveness in agri-food systems and also support gender-mainstreamed policy interventions and overall learning about different system behaviours and consequences across gender lines. Gender responsiveness in



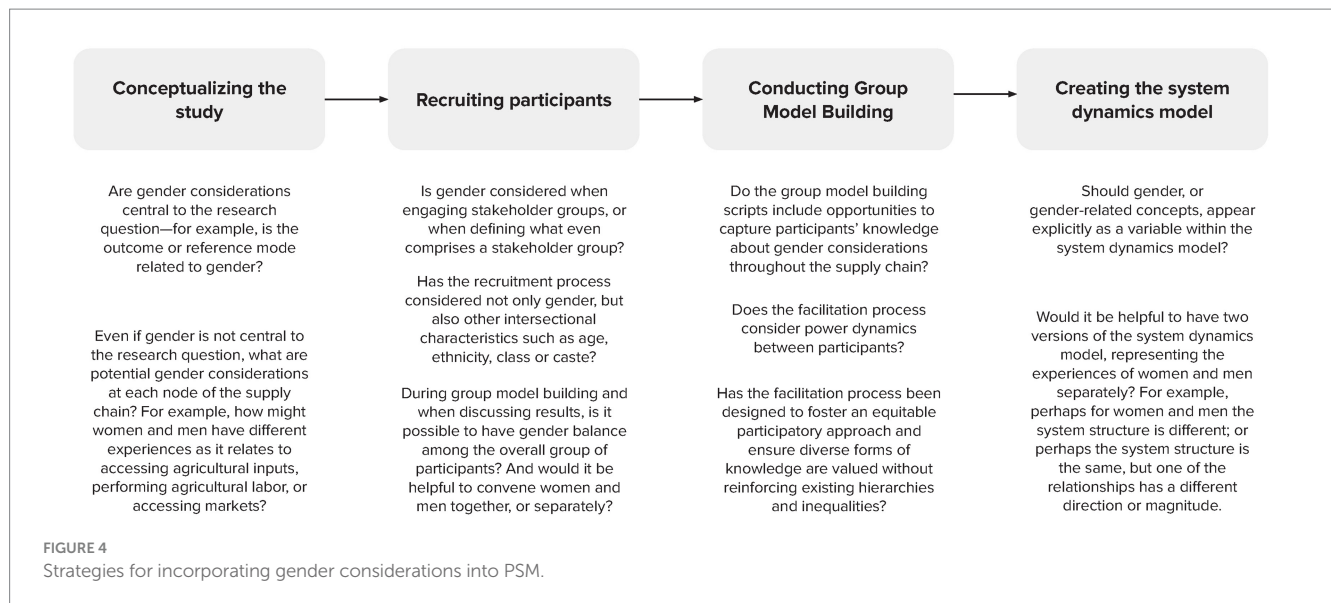
identifying intervention strategies within agri-food systems under climate change using PSM will likely require not just gender balance in participant recruitment, but gender focus for the modeling work to be successful [“valuing voices from the margins” Stephens et al. (2010)]. Our additional recommendations for future work with PSM in this sphere are summarized in Figure 4.

### 4.3 Limitations and challenges to greater use of PSM in the context of gender-responsive agri-food system climate resilience

PSM has been identified as a powerful participatory research methodology that fosters consensus, shared ownership and solidarity (Gasparatos et al., 2023; Hovmand, 2013) amongst stakeholders of key system-driven problematic outcomes, like supply chain and livelihood vulnerabilities (Olabisi et al., 2021), or food insecurity (Kopainsky et al., 2017). However, as evidenced in the Scopus review presented here (Section 2), it has not thus far been much employed to examine “the gender variable” that is likely ubiquitous and a critical system component and driver within agri-food supply chains, particularly in LMIC settings. Despite some evidence of growing attention to gender dynamics in participatory research in agriculture (Asare-Nuamah et al., 2025), Johnson et al. (2004), Stephens et al. (2010), and Mulema et al. (2022) all document a pervasive “gender-blindness” in participatory research on agriculture, as well as within the PSM research community as well as the systems theory and modeling research sphere. Mulema et al. (2022) also document that although improvements have been made in facilitation and mainstreaming of gender considerations in

agri-food systems and climate resilience work, there are additional barriers to challenging gender dynamics at the policy level that may not be easily overcome despite much greater explicit documentation and attention to these agri-food system features.

As documented in Table 1 and Figures 2, 3, PSM has *high potential* to support increased gender responsiveness through some key methodological features. It is a highly flexible system modeling method and through careful participant recruitment and facilitation [documented for participatory work overall by Johnson et al. (2004) and Gasparatos et al. (2023)], gendered features of agri-food supply chains can be uncovered through the combined GMB and quantitative model development. It also has high potential in terms of improved sharing of findings on effective, gender-responsive strategies with policy-makers, but communication is only one component of achieving system transformation. Power dynamics in the overall policy space that can improve gender-responsiveness may determine the ultimate level of impact of PSM approaches (Mulema et al., 2022). Diversity analysis prior to engagement in participatory work is suggested by Johnson et al. (2004) to ensure more balanced recruitment of diverse stakeholders, including women, as well as ‘triangulation’ across knowledge bases to improve representation and reflection of gender in particular in participatory research in natural resource management, a related research area to agri-food supply chains and climate. Context sensitive facilitation is highlighted by Butler and Adamowski (2015) as critical in ensuring full participation of marginalized groups, which in agri-food supply chain and climate resilience settings can include women. Due to the limited use of PSM thus far to directly address gender within research on agri-food supply chain and climate resilience, there is not much existing guidance in this research domain on best practices for consideration of gender. It may



thus be necessary to examine the research cited in Table 3 using PSM to understand gender dynamics in other research fields (public health, labour equity) and remain an area for future research on applying those lessons to improved consideration of gender within PSM work.

#### 4.4 Additional limitations on the use of PSM for impact and system transformation beyond the research domain

A further qualification of our analysis comes from acknowledging that PSM as a research methodology is not without downsides. It has been critiqued in terms of its potential high costs, especially in time, versus other analytical approaches (Gasparatos et al., 2023). There is often a trade-off involved in utilizing participatory approaches in terms of accessing relevant stakeholder perspectives to quantify important agri-food system features, and investment in time and other resources in group model building and analysis. Deutsch et al. (2024) provides an in-depth assessment of these trade-offs for participatory modeling, including: balancing qualitative system structure exploration and quantitative modeling boundaries; incorporating modeling uncertainty but still achieving greater system insights; recruiting a sufficiently diverse set of stakeholders and building in facilitation practices to integrate these potentially divergent perspectives; balancing investing time in model building and exploration with the urgency to find solutions to the complex problems under investigation (Thornton et al., 2017). Other agri-food system research methodologies handle these issues with different prioritized approaches. We believe in the context of improving gender-responsiveness in agri-food supply chains, PSM has high potential in this space, despite the above limitations.

## 5 Conclusion

PSM is a potentially powerful analytical approach that can be gainfully applied to better understand gender dynamics in the context of climate change shocks to agri-food systems. It combines stakeholder

engagement and co-creation of models of community-identified dynamic problems with rigorous quantitative modeling of these systems and reference modes to develop a better shared understanding of problems and identify key leverage points for policy interventions. PSM has previously been applied to tackle key problems within agri-food systems under climate challenges, such as improving the climate resilience of livestock value chains or developing improved locally relevant adaptation strategies. But PSM has not yet been widely applied to these settings alongside their broader intersection with gender, despite a large and growing body of evidence of gender differences and inequalities within agri-food systems and value chains. In this paper we have attempted to bring together these different literatures and introduce the PSM methodology to the broader research and policy community working at the intersection of gender, climate and agri-food system resilience, as well as offer suggestions on how PSM can be utilized to further collective understanding. We have demonstrated that PSM can support existing guidance on mainstreaming gender framing into agri-food systems research and policy work by providing a flexible and powerful systems modeling methodology that can well capture and model stakeholder perspectives on high-priority problematic outcomes. Such tools are needed in particular to capture the mostly undocumented experiences of women stakeholders within our agri-food supply chains, and there is therefore considerable scope to increase the utilization of PSM to identify high leverage gender responsive climate resilience strategies in these domains.

## Author contributions

ES: Conceptualization, Formal analysis, Supervision, Writing – original draft, Writing – review & editing. MS: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. RA: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. JW: Conceptualization, Writing – original draft, Writing – review & editing. EP: Conceptualization, Writing – original draft, Writing – review & editing. JG: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. DM-D'C: Writing – original

draft, Writing – review & editing. LC: Writing – original draft, Writing – review & editing. SY: Writing – original draft, Writing – review & editing. PT: Writing – original draft, Writing – review & editing. AJ: Writing – original draft, Writing – review & editing. DP: Writing – original draft, Writing – review & editing. RZ: Writing – original draft, Writing – review & editing. MW: Writing – original draft, Writing – review & editing. CN: Conceptualization, Formal analysis, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing.

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The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

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