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Factors to scale out innovative organic farming systems: A case study in Flanders region, Belgium

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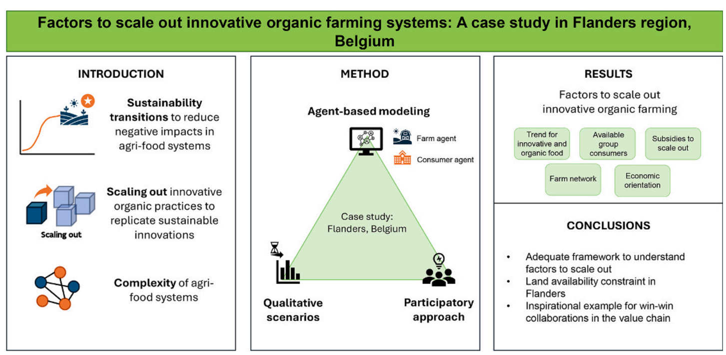
HIGHLIGHTS

- Agent-based models can identify factors to scale out innovations.
- A higher innovative organic food trend promotes collaborations in the value chain.
- Flanders expects limited scaling out of innovative organic farms.
- A scenario to connect local communities can encourage farms to collaborate.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Sustainability transitions in agri-food systems are expected to reduce their negative environmental and social impacts. On the other hand, Europe demands an increase in the agricultural land under organic farming by 2030. Innovations in agri-food systems, especially in the organic sector, could close the gap in sustainability transitions and the foreseen conversion to organic farming.
OBJECTIVE: In this study, we developed a participatory agent-based model combined with qualitative scenarios to understand which factors play a role in scaling out innovations in the organic sector and further study potential scenarios in the region of Flanders, Belgium.
METHODS: Agent-based modeling is a computational simulation environment able to represent complex systems where relevant actors behave and interact with each other. This modeling approach can be combined with qualitative scenarios to elucidate potential futures for a specific context.
RESULTS AND CONCLUSIONS: A strong trend for innovative and organic food, available groups of consumers in public institutions for collaboration, subsidies to start up, and a robust farm network can help farms to adopt a sustainable innovative collaboration with public institutions. However, land availability in the Flemish context may restrain this scaling out of farm innovation.

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SIGNIFICANCE: Combining agent-based models with qualitative scenarios in a participatory approach can integrate the expertise of different stakeholders for sustainability transitions. Pragmatically, it can illustrate how a sustainability transition may take place under potential scenarios.

1. Introduction

Recently, there has been a variety of noteworthy calls to transform dominant industrial agricultural production systems into sustainable systems that promote environmentally safe food production and consumption (European Commission, 2020; Springmann et al., 2018; Vermunt et al., 2022). There is a need for alternative and sustainable practices to be scalable to transform the agri-food system (AFS) combining different activities across multiple scales (Bonfert, 2022; Morgan, 2020). Currently, the topic of sustainability transition toward more sustainable production methods and consumption patterns is gaining attention in the research field (El Bilali, 2019; Markard et al., 2012).

In light of scaling processes to transform the AFS, scaling of innovations is defined as a set of strategies coming from innovations contributing to wider processes of systemic change (Schut et al., 2020; Wigboldus et al., 2016). In the literature, differences between scaling out and scaling up are pointed out (Moore et al., 2015; Wigboldus et al., 2016). Scaling up represents a cross-scale dynamic for the institutionalization of a specific innovation (Moore et al., 2015). On the other hand, scaling out refers to the geographical spread of a particular system innovation that becomes diffused in a greater area (Millar and Connell, 2010; Wigboldus et al., 2016). Replicating geographically sustainable initiatives facilitates knowledge sharing and the adaptation of these practices to a local context (Lam et al., 2020; Moore et al., 2015). Specifically, scaling calls for multilevel interactions between different scales e.g., farm, community, and region (Schut et al., 2020). Therefore, synergies and trade-offs of scaling an innovation require an approach that integrates different levels to consider the potential impacts of this process, involving thus changes in the decision-making of relevant actors (Schut et al., 2020; Wigboldus et al., 2016).

On the grounds that the environmental, social, and economic aspects of agri-food systems shape a complex system, suitable approaches for analyzing the potential of scaling out sustainability transitions are needed (Hatt et al., 2016; Méndez et al., 2013). In complex systems such as agri-food systems, linkages between elements need to be unraveled in order to understand systemic change (Vermunt et al., 2022). The concept of scaling aligns with the systemic change resulting from intertwined processes in complex systems (Hall and Dijkman, 2019; Schut et al., 2020). Thus, a better understanding of the drivers of systemic change could allow us to delineate policy interventions to implement and scale innovations (Ruben et al., 2018). In the literature, however, scaling concepts such as adoption do not always engage with complex dynamics in such systems (Shilomboleni and De Plaen, 2019; Wigboldus et al., 2016). In this line, Begimkulov and Darr, 2023 state that studying in-depth which mechanisms and factors are the most effective remains crucial for scaling processes.

Given the complexity of agri-food systems, it remains unclear how and which factors are influential in sustainability transitions. In order to deal with this complexity, agent-based modeling (ABM) arises here as a suitable method to simulate AFS and understand sustainability transitions (Kohler et al., 2018). Agent-based models are a computational resource that can represent interacting entities presenting a specific behavior and a defined purpose in the system (Railsback and Grimm, 2019). In the literature, ABM has been used to understand the potential of innovations to scale up pro-environmental practices (Bell et al., 2016) and factors influencing the adoption of circular technologies (Farahbakhsh et al., 2023a). To observe the scaling out of innovations, it is necessary to include elements that allow for the reconfiguration of the system, such as changing value chains, consumption patterns, and the decision-making change of relevant actors (Wigboldus et al., 2016). Furthermore, estimating variables that are difficult to measure could be eased by using simulation modeling approaches like ABM, especially when it involves the scaling out of an innovative farming practice across temporal and spatial scales (Martin et al., 2018).

Additionally, participatory modeling has been used to incorporate stakeholders' knowledge and to further investigate potential scenarios in a specific context (Joffre et al., 2015). This could help integrate valuable insights into the model regarding agents' behavior (Joffre et al., 2015). Participatory modeling approaches are proven to support transition pathways due to their integration of insightful discussions (Bustamante et al., 2024). In line with this, a participatory agent-based modeling approach seems advantageous due to the capacity of ABM to incorporate key characteristics of sustainability transitions (Halbe et al., 2020; Holtz et al., 2015; Köhler et al., 2018).

To tackle this gap, this study aims to develop a participatory ABM to understand which factors play a role in the scaling out of an innovative farming practice. We rely on the case of an organic farm in West Flanders (Belgium) with an innovative collaboration with a nearby hospital. By studying potential scenarios in Flanders in a participatory approach and performing a sensitivity analysis for the model, we show the interplay of mechanisms fostering a sustainability transition.

2. Materials and methods

2.1. Case study

As an approach rooted in sustainable principles, organic farming is oriented toward maintaining the health of soils, ecosystems, and people, relying on ecological processes and cycles adapted to local contexts (IFOAM, 2009; Oberč and Arroyo Schnell, 2020). Although organic farming only covered 9.9 % of agricultural land in the European Union in 2021, the European Commission aims to reach 25 % of the EU's agricultural land under organic farming area by 2030 (European Commission, 2020; European Environment Agency, 2023). Regardless of the rising consumer demand for organic products, farmers face several barriers to converting into organic producers (Xu et al., 2020). This change often implies strong inner motivations of the farmer as well as a change in their social networks (Sutherland et al., 2012; Xu et al., 2020).

Organic farming covers approximately 10,000 ha in Flanders in the year 2022, which comprises 1.6 % of the total Flemish agricultural area (Agentschap Landbouw en Zeevisserij, 2024). In the region of Flanders, a community-supported agricultural organic farm located in West Flanders was selected as a model case for this research. In 2017, this farm initiated a pioneering agreement with a nearby hospital to supply them with organic food. A farm that collaborates with a group of consumers in a public institution is categorized as an innovative farm within the organic sector.

2.2. Data

The present work uses quantitative and qualitative data from the European project FOODLEVERS (H2020 ERA-NET SUSFOOD2/CORE Organic Cofund, 2019). Quantitative farm data was extracted from public databases and the Public Goods Tool (den Herder et al., 2022; Gerrard et al., 2012). Qualitative data were retrieved from in-depth interviews with two main actors of the supply chain in the years 2021 and 2022.

3. Methodology

3.1. Agent-based model

In this study, we focus on the scaling out process of innovative organic farming practices. To explore the effect of varied sets of parameters in the scaling out of innovative farms, we use a participatory ABM that simulates how farms start a collaboration with public institutions. Although the model can simulate different regions, in this paper we focus on the Flanders region. The model is built in NetLogo 6.2.2. software (Wilensky, 1999). Following an ODD protocol (Grimm et al., 2020), a detailed model description is provided in the Supplementary materials.

The purpose of the model is to simulate the environment where farms interact with each other and decide whether to scale out into innovative organic production, imitating the Flemish case study. Scaling out in Flanders means that a farm will start a collaboration with a nearby group of consumers in a public institution, where organic food from the innovative farm will be delivered. Thus, one of the main outcomes of the model is the percentage of innovative organic farms to measure the scaling out. Additionally, outcomes for the economic, social, and ecological dimensions are integrated into the model.

3.1.1. Influencing factors

To determine which factors are essential to driving the scaling out of sustainable and innovative organic systems, following a participatory modeling approach, we conducted a Fuzzy Cognitive Mapping (FCM) exercise with stakeholders (Mehryar et al., 2020). Fuzzy cognitive mapping is a method that allows for the representation of the skateholder's knowledge of a specific issue (Papageorgiou and Kontogianni, 2012). During an exercise session held in March 2023, eight stakeholders i.e., policymakers, local farmers, advisors, and researchers, were asked to indicate the factors that play a role in the scaling out of innovative and organic farming systems in Flanders. The guiding question for the workshop was: "What drives or hinders the innovation in the organic agricultural sector in Flanders? What drives the conversion to organic farming? What drives the scaling out of organic farms?". Afterward, we bundled the main drivers into the influencing factor **trend for innovative and organic food** in the ABM, which represents the consumer demand, mindset of consumers toward organic farming, and researched and gained knowledge on the benefits of organic farming practices, that were indicated by stakeholders. This factor directly influences the number of outscaled farms. Consumers searching for agroecological and sustainable alternatives, and favorable policies for innovative agroecological practices are factors mentioned in the literature (Mier et al., 2018). The **farm network** parameter in the model was obtained from the stakeholders' input of collaboration between farmers, mindset of other farmers toward organic farming, innovativeness of the farmer, number of converted innovative organic farms, and successful farms influencing factors in the FCM. Furthermore, the ABM parameter of the **number of group of consumers** comes from the resulting FCM factors of collaboration within the food chain, which will enable the innovative collaboration between a farm and a group of consumers. Lastly, the **economic orientation** parameter in the ABM is the result of the factors of sales price off-farm and profitability obtained in the FCM exercise.

Other influencing factors such as the **opportunity window threshold** are derived from literature. The opportunity window threshold is a parameter that imposes the barrier at which the accumulation of pressures and trends causes the farm to change, that is, a breakthrough of the innovation to replace the current regime (Geels, 2011). On the other hand, **subsidies** for such innovative collaborations in the value chain have been recently approved in Flanders (Agentschap Landbouw en Zeevisserij, 2023).

3.1.2. Model structure

The model is divided into three main levels: **global**, **agents**, and **land**, the latter being represented by patch units in NetLogo software. Each level has its own parameters. Global-level parameters define the market prices, farming costs, and the conversion trend to organic farming. Market prices are parametrized to organic and conventional vegetable product prices in Flanders. Conversion to organic farming has been parametrized from real data in Flanders since 2005. Agent-level parameters represent the heterogeneity of farms based on their farming style, farming area, attitude toward innovation, innovativeness, consumers, and farm network. Farms are connected by a network of peers. They will only link themselves with similar peers based on their farming type, i.e., organic or conventional production. Based on these variables, farms will have different probabilities to scale out, propensity to scale out, and groups of consumers nearby, which will define their scaling out. On the other hand, consumers include the number of individual consumers present in each patch, the presence of groups of consumers, and consumers' preference toward organic or conventional food. Lastly, patches incorporate variables such as land use and species richness to represent the environmental dimension of the system and calculate the biodiversity index.

3.1.3. Model agents and main procedures

The main agents in the model are **farms**. Depending on whether they present a collaboration with a group of consumers or not, they can be labeled as either innovative or mainstream, respectively. Farms can have organic or conventional farming production. Hence, there are four types of farms represented in the model: (i) innovative organic farms; (ii) mainstream organic farms; (iii) innovative conventional farms; and (iv) mainstream conventional farms. For this research, we focus on organic farms, whereas conventional ones are only simulated to represent the whole sector. In addition, farms present three possible attitudes toward innovation: pioneer, follower, or risk-averse. Pioneer farms are those that are already innovative, while the decision-making of follower farms will be more influenced by social pressures. Lastly, risk-averse farms will need a higher pressure coming from both the social trend for innovative and organic food, and the peer pressure from neighboring innovative farms to consider scaling out.

The secondary type of agent, the **consumers**, buy their food at the farm that matches their food preference i.e., organic or conventional. There are two types of consumers: (i) group of consumers organized in public institutions e.g., a hospital; and (ii) individual consumers. Farms may have both types of consumers, however, only innovative farms can have groups of consumers.

On each step, farms produce yield and sell it to their market. The model includes a conversion rate to organic from conventional farms that is calibrated to the observed data in Flanders. Then, they assess the peer pressure to become innovative originated from innovative neighbor farms. Every two years, farms assess their economic performance to compare their revenues with the revenues earned in the last five years. Here, the economic orientation parameter determines how much they will tolerate economic losses. Farms also experience social pressures to become innovative through the trend for innovative and organic food in society. Thus, if the trend for innovative and organic food products is strong enough, if their revenues are sufficient, and if their area is reasonably small (as seen in our case study and validated with stakeholders), they will scale out and collaborate with an available and nearby public institution (Fig. 1). Otherwise, when the farm is already innovative, it can downscale back to mainstream production with a probabilistic approach, resembling the lack of interest or support to continue an innovative system. Although this concept was implemented in the generic ABM, the scenarios in Flanders did not consider this process, therefore this is not further included in this study.

3.2. Agent's decision-making behavior

The decision-making of agents in complex systems depends on a large number of factors aimed at pursuing diverse goals, adapted to a

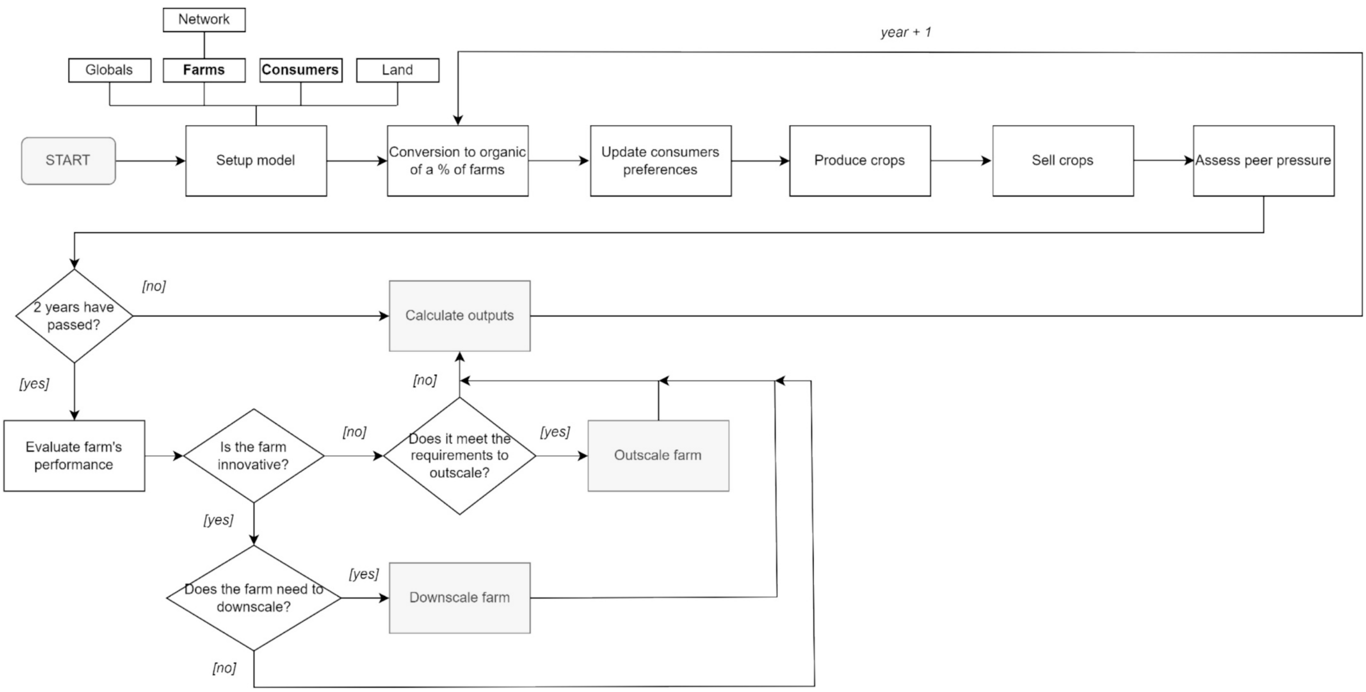

Fig. 1. Conceptual diagram of the agent-based model. The model starts setting up variables, and it follows the activity schedule of agents in one year. The main decision-making of farms refers to the scaling out into innovative farming.

dynamic environment (Tučník and Bureš, 2016). The multi-criteria decision analysis (MCDA) approach for decision-making is used to evaluate the sustainability among varied dimensions of a system representing agents' decision-making in complex systems (Wang et al., 2009). Furthermore, it has been applied to diverse research fields such as economic, agricultural, ecological, and social systems (Shaaban et al., 2019).

In our ABM, farms' decision-making is based on four parameters: (i) their economic performance, which will define their probability of scaling out, (ii) their social pressures coming from social trends for innovative and organic food, and peer pressure from fellow innovative farms, represented both in their propensity value, (iii) the availability of nearby groups of consumers in public institutions at a distance *D* between both agents, and (iv) their farming area. These parameters are shown in Table 1.

Every two years, farms evaluate their status regarding their economic situation by checking on their last revenues and their maximum expected revenue limit. The economic orientation of a farm represents how strong the influence of the economic performance is for the farm. Through this evaluation, farms will obtain a value for their probability of scaling out, which will be one of the factors involved in the scaling out later in the model. Their limit of revenues, under which revenues are considered too low for them, is calculated from their revenues from two years ago and it depends on their economic orientation. A higher value of economic orientation will imply that their limit of revenues will be closer to the revenues of the present year. When their current total revenues are lower than their minimum limit of revenues, their probability of scaling out decreases. On the other hand, if their total revenues are higher than the minimum limit of revenues, then their probability of scaling out increases. When the farm gets subsidies, their probability of scaling out drastically increases.

Table 1
Farm agent parameters involved in the decision-making of farms.

Parameter	Value	Unit	Description
Distance to consumers	n	km	How far does the farm provide food to its consumers.
Propensity value	[0–1]	index	How strong are the social pressures coming from social trends and peer pressure.
Farming area	n	ha	The size of the farming area.
Probability of scaling out	[0–1]	index	Probability of scaling out based on the economic performance of the farm.

After this, farms in the Flanders region will assess whether they want to **scale out** or **remain** the same. The conditions to **scale out**, based on literature, interviews with actors, and participatory sessions with experts, are:

- First, (i) there must be at least one available group of consumers in a public institution nearby whose food preference matches the food produced at the farm. This will lead to an agreement between the farm and the public institution. Besides, (ii) their farm area must be smaller than the average farm area of all farms.
- When the first two conditions that make the farms suitable to change are met, the farm decides whether it is convenient for them to scale out. Thus, (iii) their propensity value for scaling out, derived from social pressures of trends for innovative and organic food trend and peer pressure, should be higher than the opportunity window threshold; and finally, (iv) their probability of scaling out, derived from the economic performance, should be high enough.

If this set of conditions are met for a mainstream farm, then it will **scale out** and become innovative. Thus, the farm will start a collaboration with a nearby group of consumers. Also, their probability of scaling out will increase to its maximum value. In addition to this, since scaling out is a long-term investment, a delay of five years is set for farms that have recently scaled out. Otherwise, when the farms don't satisfy the requirements to scale out, they will simply **remain** the same.

Once the farms have assessed the change they want to experiment with, the model updates the farm network communities every five years. In this procedure, the links between organic farms get updated. Organic farms will have a more extensive network of farms than conventional ones, resembling the community-supported farm network in Flanders from the selected case study (Departement Landbouw and Visserij, 2011). Also, the model includes a stylized decision-making of consumers and updates consumer's preferences. Each year, 10 % of patches with consumers will update their food preferences. To update their preferences, they mainly rely on the economic factor, but also on social pressures. Consumers perceive the price gap between organic and conventional products as well as the trend for innovative and organic food.

The representation of how aspects from the three sustainability dimensions relate to the decision-making of farms is displayed in Fig. 2.

3.3. Model validation

The model was validated with a local network of experts i.e., policymakers, farmers, researchers, and advisors, from the organic sector in Flanders. A participatory modeling approach allowed all experts to be involved in giving input into the model, validating the model's outputs and dynamics, and defining scenarios. The stakeholders participated actively throughout the whole process.

From February 2021 to November 2023, seven participatory sessions were held in order to build up, validate, and discuss the modeling steps and the research progress. In March and September 2023, model parameters and preliminary results were validated by experts, respectively. For both participatory sessions, eight stakeholders were present, with the representation of local farmers, advisors, researchers, and policymakers. The main parameters for the ABM i.e., trend for innovative and organic food, opportunity window threshold, number of groups of consumers, farm network, economic orientation, and subsidies, were derived from the fuzzy cognitive mapping exercise, and the decision-making of farms was discussed during these sessions.

3.4. Sensitivity analysis

By performing a sensitivity analysis of the model, we obtained a better understanding of how sensitive the model is to parameter variations regarding model outputs (Thiele et al., 2014). The results from simulations are further analyzed with the R software (R Core Team, 2013). We explored the sensitivity of a set of parameters to the main output percentage of innovative organic farms in sets of three in a simulation with 50 runs (Table 2). The results of each set of parameters are presented in the total population of farms.

Table 2
Parameters tested for sensitivity analysis in Flanders case study.

Parameter	Units	Values tested	Description
Opportunity window threshold	index	0.1, 0.2, 0.3, 0.4, 0.5	The parameter defines when the threshold to scale out starts.
Economic orientation	ratio	0.75, 0.85, 0.95	The maximum ratio of revenues that the farmers would accept from which they would consider it an economically unfavorable year.
Farms links probability	index	0.05, 0.1, 0.2, 0.3	The parameter defines how dense are the links between farms that define the network.
Trend for innovative and organic food	index	0.1, 0.2, 0.3, 0.4, 0.5	The parameter defines the trend that is pushing toward organic and innovative food consumption through e.g., social media, demand, and the like.
Number of public institutions	n	25, 50, 100	Number of patches with public institutions as consumers in the simulation environment.
Subsidies for innovation	€	0, 1000, 20,000	Subsidies for farms that want to scale out to innovative.

3.5. Qualitative scenario modeling

Qualitative scenarios (QS) are used to delineate potential futures in a system, combining environmental, economic, and social systems (Schirrmeister and Warnke, 2013). In combination with quantitative modeling, they could allow identifying pathways toward sustainability in AFS (Shaaban et al., 2023). Combining ABM with QS offers advantages because it translates abstract agri-food future scenarios into concrete parameters, provides an accurate representation of the system behavior and decision-making process, and adds transparency to the participatory process (Shaaban et al., 2023).

For the present study, a regional-scale backcasting qualitative scenario modeling for Flanders in 2050 has been adopted. In backcasting approaches, future visions are drawn backward from the ideal future to the present time (Dreborg, 1996; Robinson, 1990), and they help to understand the influence of innovations in those futures e.g., through

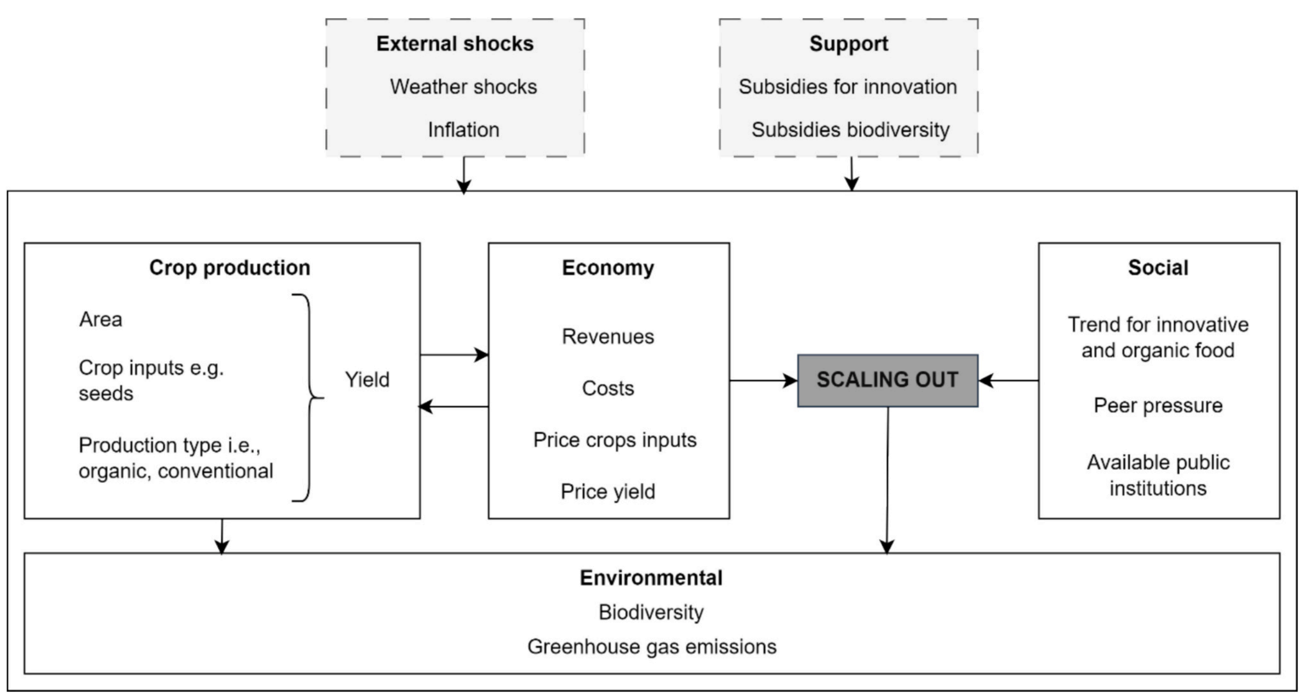

Fig. 2. Representation of aspects involved in the decision-making of farms in the ABM from sustainability dimensions.

technology or policy (Kishita et al., 2017). This qualitative scenario modeling workshop took place in September 2023 in Flanders with a group of local farmers, advisors, researchers, and policymakers. In this workshop, eight participants focused on three ideal scenarios for Flanders in the year 2050. Then, participants proposed pathways to reach these scenarios moving from the current situation in Flanders.

3.6. Baseline scenario and experimental design

The following scenarios for Flanders were described and examined during the workshop:

A. **Baseline scenario**: This scenario represents the current situation in Flanders, with no strong trend for innovative and organic food and no subsidies for similar innovative initiatives.
B. **Rural renaissance scenario**: In this scenario, innovation in AFS is fostered by increasing the number of available groups of consumers in public institutions for collaboration with local farms. The key driver of the rural renaissance is the food production that promotes small-scale farms. Therefore, the rural development of this scenario improves the connection of farms to other farms and consumers.
C. **Consumption scenario**: This presents a scenario where a high interest in innovative and organic food consumption is desired. Changes in consumer behavior lead to increased organic consumption from more sustainable and local sources. It also tests the possibility of increasing the number of innovative organic farms by giving them subsidies in the year 2023 to promote the scaling out of suitable farms.
D. **Biodiversity scenario**: Food production is aimed to enhance biodiversity for sustainable future development. The scenario for biodiversity represents a future where farms engage more in biodiversity-friendly farming. For this reason, governmental actors facilitate subsidies for biodiversity measures at the farm level.

First, to define the scenarios, the trend for innovative and organic food defines the trend that is pushing toward organic and innovative food consumption through e.g., promotion of organic food, and consumer awareness. The number of groups of consumers represents those public institutions that are willing to collaborate with nearby farms. Subsidies for susceptible farms to scale out are given in the year 2023 of the simulation. Similarly, subsidies for biodiversity per farm were introduced to maintain and enhance biodiversity in the farm through non-productive crops. This is only needed in the biodiversity scenario. Lastly, farm links probability defines how dense are the links between

Table 3
Parameter values used in simulation to define the scenarios.

Scenario	Parameter	Value	Unit
A	Trend for innovative and organic food	0.2	index
	Number of groups of consumers	50	n
	Subsidies for innovation	0	EUR
	Subsidies for biodiversity	0	EUR
	Farms links probability	0.05	index
B	Trend for innovative and organic food	0.3	index
	Number of groups of consumers	150	n
	Subsidies for innovation	0	EUR
	Subsidies for biodiversity	0	EUR
	Farms links probability	0.25	index
C	Trend for innovative and organic food	0.4	index
	Number of groups of consumers	50	n
	Subsidies for innovation	10.000	EUR
	Subsidies for biodiversity	0	EUR
	Farms links probability	0.05	index
D	Trend for innovative and organic food	0.2	index
	Number of groups of consumers	50	n
	Subsidies for innovation	0	EUR
	Subsidies for biodiversity	1.500	EUR
	Farms links probability	0.05	index

farms that define the farm network. These parameters are shown in Table 3.

As the main product of the farm, we selected zucchini for the Flemish case study. Scenario simulations and preliminary results were validated with experts from the organic sector in Flanders in a final meeting in November 2023.

4. Results

The main driver parameter i.e., the trend for innovative and organic food, and the main barrier i.e., opportunity window threshold, work as opposite forces, promoting or hindering the scaling out of farms, respectively (Fig. 3). We observed that the farm network parameter has a limited effect on the scaling out, only slightly promoting the transition when both the main driver and barrier are very similar. Despite this, subsidies can help when the driver parameter is not enough to overcome the barrier. Alternatively, high values of the economic orientation of farms slow down the scaling out. Lastly, the number of groups of consumers can significantly stimulate the scaling out, since more available groups of consumers allow for collaboration in the value chain. More detail on the sensitivity analysis is provided in the Supplementary Material.

After performing scenario simulations in 100 runs, we observed the percentage of innovative organic farms out of the total population. The percentage of organic innovative farms is the highest in the rural renaissance scenario, with close to 4 % of innovative organic farms in the whole farm population of Flanders (see Fig. 4A). Rural renaissance (B) and consumption (C) scenarios presented higher values of the trend for innovative and organic food, as well as more available groups of consumers and larger farm networks in scenario B, and subsidies for innovation in scenario C. This explains the increase in the percentage of innovative organic farms. On the other hand, the baseline (A) and biodiversity (D) scenarios present the lowest values of innovative consumer trends and therefore, the lowest percentage of innovative organic farms in the population.

The s-shape curve after 20 years of simulation could explain how farms are scaling out. Conventional farms are 98 % of the population at the beginning of the simulation, and after a few years, suitable conventional farms (i.e., with a smaller farming area and not risk-averse attitude) convert into organic mainstream farms. From this, they need time to evaluate their farm and increase their probability of scaling out.

For other outputs such as the area under organic innovative farms, we observe that the rural renaissance scenario estimates around 1 % of the agricultural land under innovative organic farming (Fig. 4B), following the same results as in Fig. 4A. Scenario B presents a higher trend for innovative and organic food as well as more available groups of consumers and a stronger farm network. The consumption scenario follows with 0.8 % of innovative organic agricultural land. Scenario C also presents a high trend for innovative and organic food, however, the number of available groups of consumers and the farm's network is low here. On the other hand, baseline and biodiversity scenarios show the lowest value for agricultural land under innovative organic farming both with 0.15 % of the total agricultural area.

The average total innovative organic food production in Flanders, based on zucchini production, is presented in the simulations for four potential scenarios (see Fig. 5). The rural renaissance scenario presents the highest food production with 4013 ton/year on average, while the biodiversity scenario presents the lowest food production with a value of 845.5 ton/year on average. The consumption scenario presents 3203 ton/year of total innovative organic food production on average, and finally, the baseline scenario has lower values of total innovative organic food production equal to 861.6 ton/year. Both scenarios B and C present a higher trend for innovative and organic food, which explains why they show higher average total food production. In addition, scenario B includes more available groups of consumers, increasing the number of collaborating innovative farms. Hence, in these scenarios, the number of

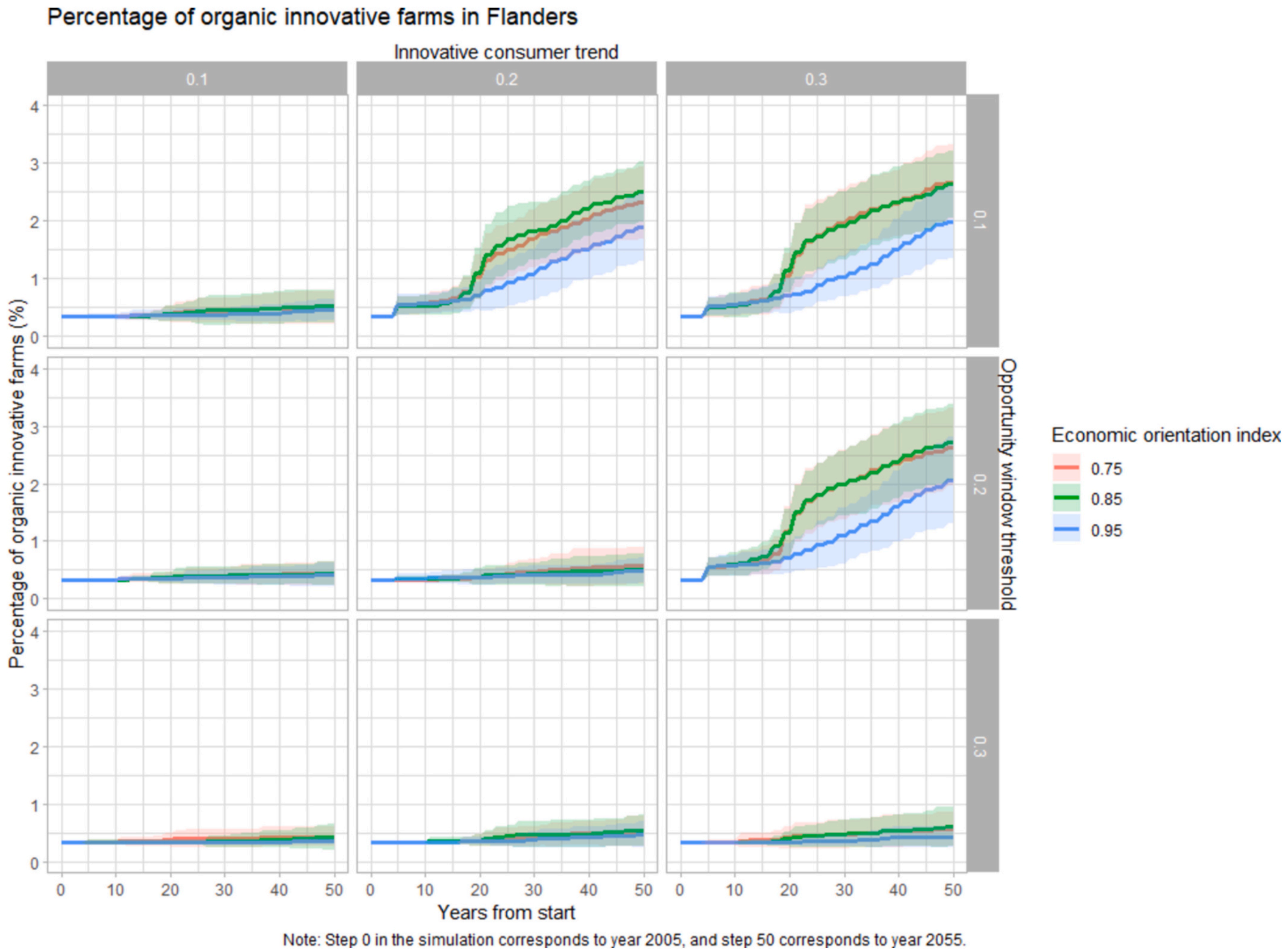

Fig. 3. Influence of the parameters of trend for innovative and organic food, opportunity window threshold, and economic orientation indew on the percentage of organic innovative farms.

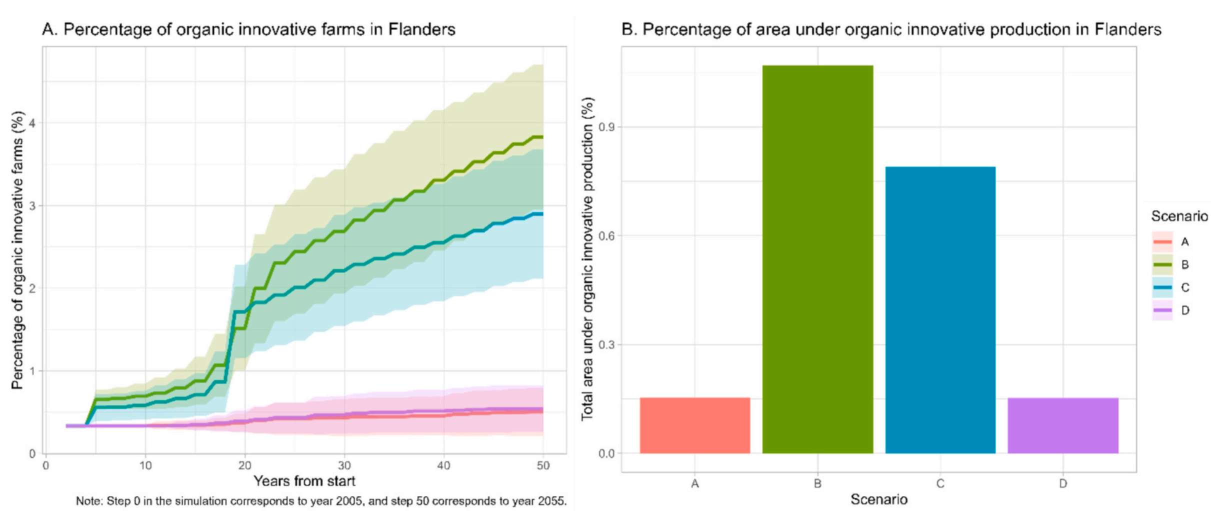

Fig. 4. Percentage of organic innovative farms for four potential scenarios in Flanders. Fig. 4A represents the change overtime, and Fig. 4B expresses this outcome after 50 years of simulation.

innovative organic farms is much higher than in scenarios A and D.

For the average innovative organic revenues per farm, the values vary among scenarios, between 19,000 and 26,000 €/year on average per farm. In scenarios A and D, the lower percentage of innovative organic farms produces a great standard deviation in the average revenues calculated per farm. Higher average values of revenues and

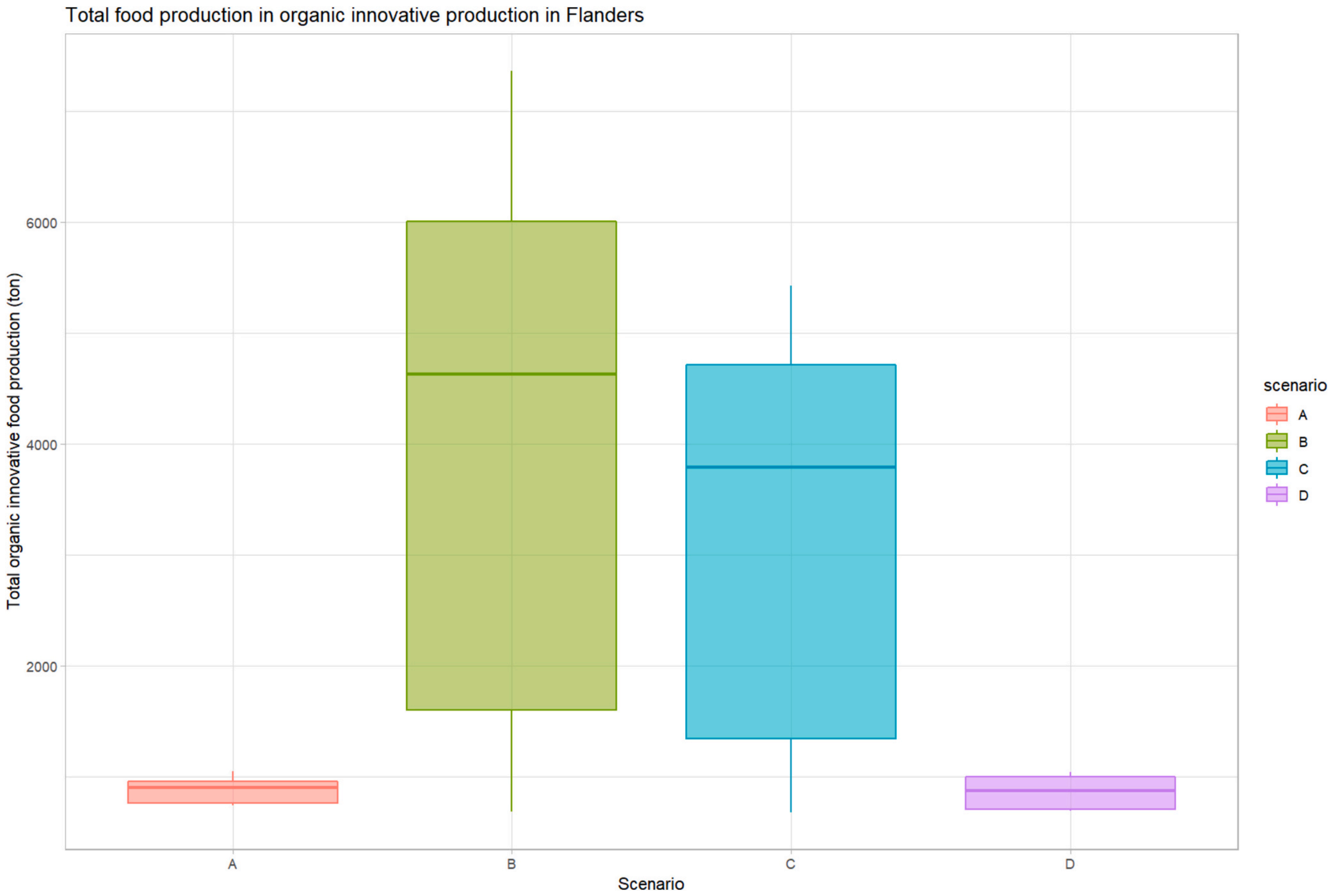

Fig. 5. Total innovative organic food production for four potential scenarios in Flanders.

variation are shown in the biodiversity scenario, with an average total revenue for innovative organic farms of 22,640 ± 7512 €/year, showing the greatest variation in total revenues from all scenarios. Because the subsidy for biodiversity is paid by area, larger farms would benefit more from this. When observing the results of the average total revenues per farm of innovative organic farms throughout the simulation, we observe that the peak in revenues corresponding to subsidies for innovation and for biodiversity can be observed in scenarios C and D around the year 2023, respectively (Fig. 6). While the subsidies for innovation in scenario C are paid once, subsidies for biodiversity in scenario D are yearly paid per hectare, which increases the revenues for this scenario.

Lastly, in Fig. 7, the average species richness representing biodiversity in the total agricultural land is shown. A, B, and C scenarios, where no measure for biodiversity is taken, show very similar values of average species richness. In the biodiversity scenario, subsidies for biodiversity are given to interested farmers, which results in a higher number of species in the community with a mean of 24.45.

5. Discussion

In this section, the results obtained from both the sensitivity analysis of the model and the scenario simulations for Flanders will be contrasted with literature. It starts by indicating the usefulness of the adopted approach. Subsequently, scenario simulation results are discussed in different subsections. Lastly, this section points out model limitations and offers future research pathways.

The agent-based model (ABM) was useful in understanding which factors play a role in the scaling out of innovative organic practices. First, the ABM is able to represent the decision-making of agents and explain key factors to scale out. A participatory ABM combined with qualitative scenarios (QS) shed light on the temporal and dynamic evolution of different elements of the AFS, as researched in Shaaban et al., 2023.

To explore challenges in scaling up alternative food networks, Kump and Fikar, 2021 used a qualitative approach through causal loop diagrams. This approach is broadly used for complex systems and offers a good overview of the system's feedback loops. However, it does not include a temporal dimension nor depicts emergent phenomena. Polita and Madureira, 2021 use a Multi-Level Perspective to capture trajectories of adopting innovations in sustainability transitions. Although this study can explain microscale transitions of winegrowers' innovations, our ABM-QS approach can understand dynamics in both micro and macro scales and simulate sustainability outcomes of potential scenarios.

5.1. Scaling out to innovative organic production

In complex systems, transitions and scaling processes usually arise from several simultaneous trends and influences in the system (Schut et al., 2020). Specifically in the context of Flanders, Borremans et al., 2018 highlights factors to scale out agroforestry as an innovation that were also identified in our simulations. First, engaging actors in agroforestry production is incentivized by facilitating farm-institution collaborations such as in our case study. Next, establishing a legal environment could be achieved with subsidies as support to scale out suitable farms. Furthermore, communication channels to familiarize actors with agroecology take part as the main driver of the model. Lastly, enhancing dialogue between influential groups to increase social innovation is fostered in this study by using a participatory modeling approach.

In our model, the trend for innovative and organic food was one of the main drivers of systemic change, as observed in the sensitivity

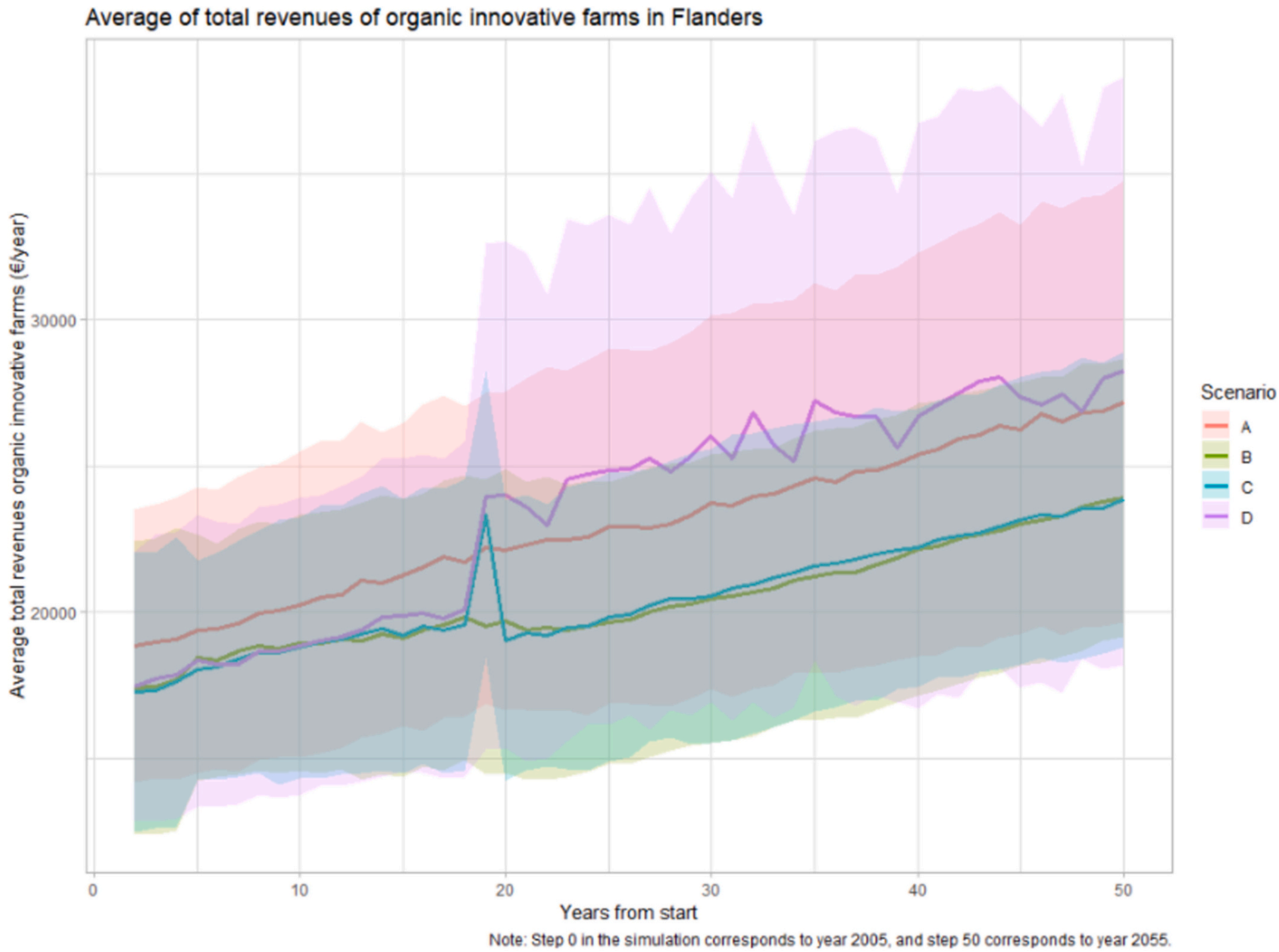

Fig. 6. Average of total revenues in organic innovative production per farm for four scenarios in Flanders.

analysis and in the scenarios with higher values for this parameter. Such a driver trend has been observed in other cases. For example, an increasing interest in local and organic food consumption, similar to our trend for innovative and organic food, promotes the exponential growth of short food supply chains in Spain (Yacamán Ochoa et al., 2020).

Nevertheless, we observe that this trend could be limited in Flanders, which could hinder the scaling out of innovative organic AFS. In Flanders, supermarkets are the main channel for the majority of organic consumers (Timmermans and Van Bellegem, 2022). Although the majority of Flemish consumers already purchase organic products, there is a predominant lack of awareness among consumers (Farahbakhsh et al., 2023b). Furthermore, a complex legal environment hampers these collaborations between institutions and food producers (Dessein et al., 2017). In the interviews we performed with relevant actors from the case study, they declared that such collaboration between an organic farm and a hospital did not exist before in Flanders.

On the other hand, the scenarios with more collaborating groups of consumers in public institutions resulted in increased scaling out of suitable farms. In our case study, the collaboration was initiated by the hospital's kitchen manager, who already knew the farmer and had a strong interest in reinforcing sustainability. Successful collaborations arise more often in win-win situations where partners work toward long-term common goals and share innovations (Wyborn and Bixler, 2013). Such successful collaborations depend on mutual trust and well-developed social networks built through personal relationships (Armitage et al., 2009). This was also the case with the scaling up of other local initiatives in Ghent, Flanders (Dessein et al., 2017).

Networking and cooperation among actors are essential in the scaling up of transition pathways (Friedmann, 2007), and they enhance the connection and engagement of farmers in the landscape (Vermunt et al., 2020). Harrington et al., 2001 examine the scaling out of results related to natural resource management. They identified scaling out easier when practices entail less risk and are more profitable, which was observed in our sensitivity analysis for less economically oriented farms. In our model, however, the farm network only has a modest effect when the main social driver and barrier values are similar. The proportion of risk-averse farms, which is a great percentage in Flanders, defines the farm network developed in this ABM. Including more pioneer or follower farms in the farm network could have made the scaling out more prominent. Nonetheless, larger farm networks seem to indicate the low innovativeness of organic farmers, while frequent interactions in smaller networks could promote innovativeness of farmers (De Cock et al., 2016; Gailhard and Bavorova, 2014).

Still, the present innovative case study is quite niche. In Flanders, with only 1.6 % of organic farming land and a very fragmented landscape, it is ambitious to foresee a massive scaling out of this specific innovation, which is also noticeable in the scenario simulations. In the literature, it is stated that scaling out strategies would reach a higher impact when used in conjunction with other scaling strategies such as scaling up or scaling deep (Butler et al., 2020; Moore et al., 2015; Nicol, 2020).

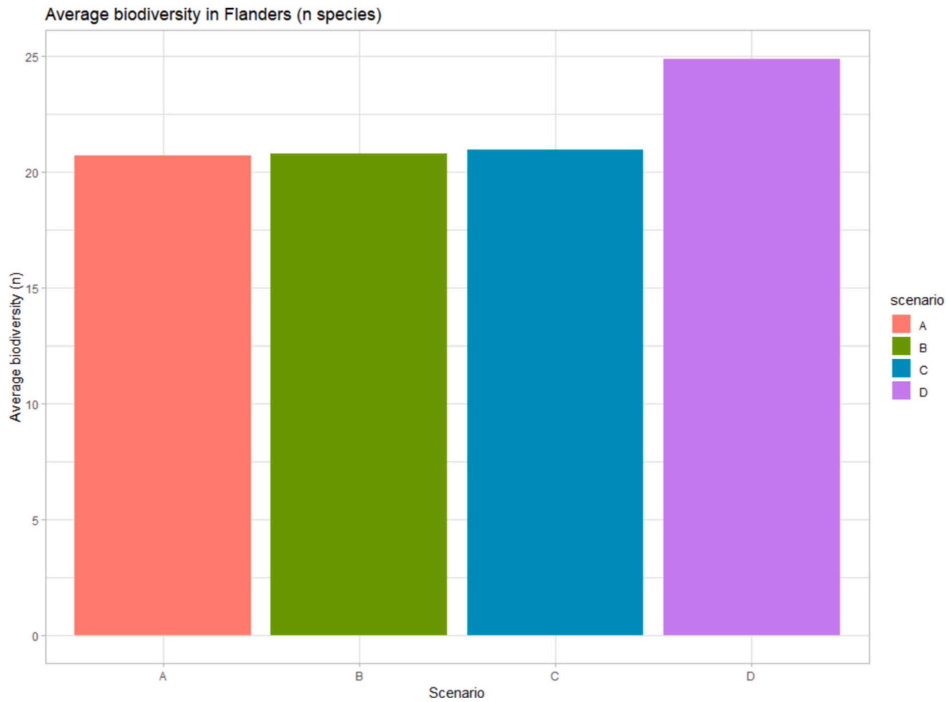

Fig. 7. Average biodiversity for four potential scenarios is Flanders.

5.2. Land availability and innovative organic food in Flanders

Our results showed a very limited percentage of land under innovative organic farming in Flanders, even under the most favorable scenarios. In Nicol, 2020, access to land for growing was one of the main challenges that agroecology is facing. In Flanders, available agricultural land is highly constrained and scarce (Lierman et al., 2015; Rogge et al., 2016), which may limit the future scaling out of innovative organic farms. By complementing simulation models with GIS, the performance and impacts of an innovation over space and time can be simulated (Harrington et al., 2001). A combination of ABM and GIS could analyze land availability as well as areas that are more prone to scale out.

As a result of limited available agricultural land, innovative organic food production was low in our simulations. Innovative organic food production increased for those scenarios with higher scaling out of farms, however, its impact is limited for the whole agri-food system. Moreover, the model developed in this study does not include the population growth of newcomer farmers. However, even though the agricultural land is constrained for newcomers, there is potential for conventional farms to convert into innovative organic farms. This can be detected in the results when observing the s-shape curve of how farms are scaling out.

5.3. Economic performance of innovative organic farms

In the simulations, the average revenues of farms were lower under the scenarios for rural renaissance and consumption. In these scenarios, we have more organic innovative farms due to a higher scaling out, whereas baseline and biodiversity scenarios only have a few innovative organic farms. Their variability in farm area, together with the scarce number of organic innovative farms could explain a huge standard deviation in farm revenues in scenarios A and D. Their high average revenues cannot be thus adequately compared to those scenarios that present higher innovative organic farms, which can be misleading. Economic sustainability must be guaranteed for farms in order to start collaborations in the value chain.

Additionally, subsidies were identified in our simulations as a factor that helps to start up the scaling out in farms. This economic incentive is more helpful for economically oriented farms when the barrier to scale out is still high. Nonetheless, ensuring a meaningful innovation with a long-term commitment requires planned strategies, rather than solely relying on farm incentives for adoption (Carter and Currie-Alder, 2006). In Lutz et al., 2017, farmers preferred start-up funding and straightforward cooperative schemes instead of permanent subsidies.

5.4. Biodiversity in innovative organic farming

Current Common Agricultural Policy greening measures aiming to address the biodiversity loss in Europe have had essentially no impact (De Keyzer, 2023). Agriculture in Flanders is also a major contributor to acidification, eutrophication, and habitat fragmentation, which are the main important factors for biodiversity degradation (De Keyzer, 2023). Due to the landscape aspect of biodiversity, collective subsidies to enhance biodiversity could be more effective.

Organic farming is oriented toward reducing environmental pressures from farming activities while enhancing biodiversity at the farm (FAO, 2018). In the simulations, however, due to a restricted proportion of innovative organic farms in Flanders, these did not result in more biodiversity. Only the scenario where biodiversity was specifically targeted through subsidies for biodiversity resulted in increased biodiversity. Policy support for effective biodiversity-friendly agriculture that also assures farm production would be crucial to improving biodiversity in Flemish fields.

5.5. Limitations of the study and future research

The model presents limitations that are worth considering. Due to a lack of data, assumptions were drawn up in the model. Proportions of farmers' attitudes, distance to consumers, economic orientation, and biodiversity dynamics are based on literature and participatory sessions with stakeholders. The limited heterogeneity in data due to the inclusion of data coming from only one surveyed innovative organic farm and limited data from the organic sector in Flanders might affect the uncertainty level of final results. The model is focused on zucchini production in Flanders, however, we use data from all organic vegetable farming in open air due to the lack of data on this crop. Furthermore, the farm network of the model can be improved and further calibrated.

The decision-making of farms takes into account only social (peer comparison) and economic factors (economic performance), while environmental factors are not taken into account. The probability of scaling out of farms should also consider values of job satisfaction, which was not included due to a lack of data. Moreover, a more developed decision-making of group of consumers would be interesting to study together with the decision-making of farms.

Empirically-based results such as biodiversity rely on results from the life cycle assessment performed in the project this study is based upon (H2020 ERA-NET SUSFOOD2/CORE Organic Cofund, 2019). Biodiversity studies should be performed in several organic farms in Flanders to provide more reliable results. Although other environmental and social outcomes such as quality of life or greenhouse gas emissions are present in the ABM, more data is needed to show significant results.

6. Conclusions

Factors that play a role in the scaling out of innovations in organic AFS can be identified with an ABM-QS approach. In this way, a higher trend for innovative and organic food could increase the scaling out of innovative collaborations between farms and institutions located nearby. Specifically, less economically oriented farms would be more suitable for this scaling out. When overcoming the barrier of opportunity window threshold, these innovations are more visible, and then, more farms will adopt this innovation. As a starting point, subsidies could work as a lift to have more innovative organic farms. In situations where both drivers and barriers are similar, strong farm networks could tilt the balance in favor of forming collaborations with a group of consumers.

Nonetheless, Flanders would expect a very modest scaling out of innovative farms under potential scenarios. The limitation in land available for an expansion in organic farming and supermarket dominance diminishes the potential for numerous innovative organic systems. However, a rural renaissance scenario in Flanders aimed at connecting local communities and promoting such collaborations could encourage suitable conventional farms to move in this direction.

Finally, this research further elucidates how scaling out processes in organic AFS may arise in the context of Flanders. This could also serve as an inspirational example for mutually beneficial collaborations within the supply chain. Moreover, policymakers could benefit from this research by studying potential scenarios in Flanders while observing outcomes in economic, social, and ecological dimensions.

CRediT authorship contribution statement

Alba Alonso-Adame: Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Siavash Farahbakhsh:** Writing – review & editing, Validation, Supervision, Software, Conceptualization. **Jef Van Meensel:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Fleur Marchand:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Steven Van Passel:** Writing – review & editing, Supervision.

Declaration of competing interest

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Relationships

Authors reports a relationship with Flanders Research institute for Agriculture, Fisheries and Food (ILVO) that includes employment and funding grants.

Patents and Intellectual Property

There are no patents to disclose.

Other Activities

There are no additional activities to disclose.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2024.104219.

Data availability

Data will be made available on request.

References

Agentschap Landbouw en Zeevisserij, 2023. VLIF-steun voor innovatieve investeringen (vanaf 2023) [WWW Document]. VLIF-Steun Voor Innov. Invest. Vanaf 2023. URL. https://lv.vlaanderen.be/subsidies/vlif-steun/projectsteun-voor-innovaties-de-landbouw (accessed 6.6.24).

Agentschap Landbouw en Zeevisserij, 2024. Landbouwrapport 2024 (LARA), Vlaamse landbouw in cijfers. Vlaamse Overheid, Brussel.

Armitage, D.R., Plummer, R., Berkes, F., Arthur, R.I., Charles, A.T., Davidson-Hunt, I.J., Diduck, A.P., 2009. Adaptive co-management for social ecological complexity. Front. Ecol. Environ. 7, 95–102. https://doi.org/10.1890/070089.

Begimkulov, E., Darr, D., 2023. Scaling strategies and mechanisms in small and medium enterprises in the agri-food sector: a systematic literature review. Front. Sustain. Food Syst. 7. https://doi.org/10.3389/fsufs.2023.1169948.

Bell, A., Parkhurst, G., Droppelmann, K., Benton, T.G., 2016. Scaling up pro-environmental agricultural practice using agglomeration payments: proof of concept from an agent-based model. Ecol. Econ. 126, 32–41. https://doi.org/10.1016/j.ecolecon.2016.03.002.

Bonfert, B., 2022. 'What we'd like is a CSA in every town.' Scaling community supported agriculture across the UK. J. Rural. Stud. 94, 499–508. https://doi.org/10.1016/j.jrurstud.2022.07.013.

Borremans, L., Marchand, F., Visser, M., Wauters, E., 2018. Nurturing agroforestry systems in Flanders: analysis from an agricultural innovation systems perspective. Agric. Syst. 162, 205–219. https://doi.org/10.1016/j.agsy.2018.01.004.

Bustamante, M., Rillo, C., Niang, I., Baker, L., Vidueira, P., 2024. Harvesting insights for transformation: developing and testing a participatory food systems modeling framework in Southern Senegal's poultry system. Agric. Syst. 217, 103941. https://doi.org/10.1016/j.agsy.2024.103941.

Butler, J.R.A., Rochester, W., Skewes, T.D., Wise, R.M., Bohensky, E.L., Katzfey, J., Kirono, D.G.C., Peterson, N., Suadnya, W., Yanuartati, Y., Handayani, T., Habibi, P., Jaya, I.K.D., Sutaryono, Y., Masike-Liri, B., Vaghelo, D., Duggan, K., 2020. How feasible is the scaling-out of livelihood and food system adaptation in Asia-Pacific Islands? Front. Sustain. Food Syst. 4, 43. https://doi.org/10.3389/fsufs.2020.00043.

Carter, S.E., Currie-Alder, B., 2006. Scaling-up natural resource management: insights from research in Latin America. Dev. Pract. 16, 128–140. https://doi.org/10.1080/09614520600562306.

De Cock, L., Taragola, N., Crivits, M., Dessein, J., 2016. Networks for a competitive and innovative organic horticulture in Flanders. ISHS Acta Horticult. 1137. https://doi.org/10.17660/ActaHortic.2016.1137.45.

De Keyzer, M., 2023. Tot de bodem. De toekomst van landbouw in Vlaanderen. Universitaire Pers Leuven, Leuven.

den Herder, M., Smith, L., Arguile, L., Dumper-Pollard, R., Borek, R., Syp, A., Pisanelli, A., Consalvo, C., Rois Díaz, M., Mignon, S., Eugen Gliga, A., Wustenberghs, H., Alonso Adame, A., Michel-Villareal, R., Tiilikainen, A., Orfanidou, T., Holzner, V., 2022. Incorporating Ecosystem Services in Evaluating the Sustainability of Innovative Organic Farming Systems Using the Public Goods Tool.

Departement Landbouw & Visserij, 2011. CSA-Netwerk [WWW Document]. URL. http://csa-netwerk.be/ (accessed 6.6.24).

Dessein, J., Crivits, M., Block, T., 2017. Hoe de korte keten opschalen?: Op zoek naar partnerschappen tussen landbouwers en grootafnemers in Gent en omstreken. Instituut voor Landbouw-, Visserij- en Voedingsonderzoek. Universiteit Gent, Rikolto.

Dreborg, K.H., 1996. Essence of backcasting. Futures 28, 813–828. https://doi.org/10.1016/S0016-3287(96)00044-4.

El Bilali, H., 2019. Research on agro-food sustainability transitions: a systematic review of research themes and an analysis of research gaps. J. Clean. Prod. 221, 353–364. https://doi.org/10.1016/j.jclepro.2019.02.232.

European Commission, 2020. A Farm to Fork Strategy: For a Fair, Healthy and Environmentally-Friendly Food System. European Commission.

European Environment Agency, 2023. Agricultural Area Under Organic Farming in Europe [WWW Document]. Eur. Environ. Agency. URL. https://www.eea.europa.eu/en/analysis/indicators/agricultural-area-used-for-organic#:~:text=The%

20UAA%20under%20organic%20farming,2012%20and%202021%20was%206%25 (accessed 1.26.24).
FAO, 2018. Scaling up agroecology initiative. Transforming food and agricultural systems in support of the SDGs. A proposal prepared for the International Symposium on Agroecology 2018.
Farahbakhsh, S., Snellinx, S., Mertens, A., Belderbos, E., Bourgeois, L., Meensel, J.V., 2023a. What's stopping the waste-treatment industry from adopting emerging circular technologies? An agent-based model revealing drivers and barriers. Resour. Conserv. Recycl. 190, 106792. https://doi.org/10.1016/j.resconrec.2022.106792.
Farahbakhsh, S., Wustenberghs, H., Lorenzoni, D., Petrangeli, E., 2023b. Deliverable 2.4: Report on consumer behaviour change (FOODLEVERS). ILVO.
Friedmann, H., 2007. Scaling up: bringing public institutions and food service corporations into the project for a local, sustainable food system in Ontario. Agric. Hum. Values 24, 389–398. https://doi.org/10.1007/s10460-006-9040-2.
Gailhard, İ.U., Bavorova, M., 2014. Innovation at rural enterprises: results from a survey of German organic and conventional farmers. Technol Innov 16, 3–17. https://doi.org/10.3727/194982414X13971392823190.
Geels, F.W., 2011. The multi-level perspective on sustainability transitions: responses to seven criticisms. Environ. Innov. Soc. Transit. 1, 24–40. https://doi.org/10.1016/j.eist.2011.02.002.
Gerrard, C.L., Smith, L.G., Pearce, B., Padel, S., Hitchings, R., Measures, M., Cooper, M., 2012. Public goods and farming. In: Farming for Food and Water Security. Springer.
Grimm, V., Railsback, S.F., Vincenot, C.E., Berger, U., Gallagher, C., DeAngelis, D.L., Edmonds, B., Ge, J., Giske, J., Groeneveld, J., Johnston, A.S.A., Milles, A., Nabe-Nielsen, J., Polhill, J.G., Radchuk, V., Rohwäder, M.-S., Stillman, R.A., Thiele, J.C., Ayllón, D., 2020. The ODD protocol for describing agent-based and other simulation models: a second update to improve clarity, replication, and structural realism. J. Artif. Soc. Soc. Simul. 23, 7. https://doi.org/10.18564/jasss.4259.
H2020 ERA-NET SUSFOOD2/CORE Organic Cofund, 2019. FOODLEVERS [WWW Document]. URL. https://www.foodlevers.org/ (accessed 1.30.24).
Halbe, J., Holtz, G., Ruutu, S., 2020. Participatory modeling for transition governance: linking methods to process phases. Environ. Innov. Soc. Trans. 35, 60–76. https://doi.org/10.1016/j.eist.2020.01.008.
Hall, A., Dijkman, J., 2019. Public Agricultural Research in an Era of Transformation: The Challenge of Agri-Food System Innovation. CGIAR Independent Science and Partnership Council (ISPC) Secretariat and Commonwealth Scientific and Industrial Research Organisation (CSIRO), Rome and Canberra.
Harrington, L., White, J., Grace, P., Hodson, D., Hartkamp, A.D., Vaughan, C., Meisner, C., 2001. Delivering the goods: scaling out results of natural resource management research. Ecol. Soc. 5, 19.
Hatt, S., Artru, S., Brédart, D., Lassois, L., Francis, F., Haubruge, É., Garré, S., Stassart, P. M., Dufrêne, M., Monty, A., Boeraeve, F., 2016. Towards sustainable food systems: the concept of agroecology and how it questions current research practices. A review. Biotechnol. Agron. Soc. Environ. 20, 215–224. https://doi.org/10.25518/1780-4507.12997.
Holtz, G., Alkemade, F., de Haan, F., Köhler, J., Trutnevyte, E., Luthe, T., Halbe, J., Papachristos, G., Chappin, E., Kwakkel, J., Ruutu, S., 2015. Prospects of modelling societal transitions: position paper of an emerging community. Environ. Innov. Soc. Transit. 17, 41–58. https://doi.org/10.1016/j.eist.2015.05.006.
IFOAM, 2009. Proceedings of the 1st IFOAM International Conference on Organic Animal and Plant Breeding. IFOAM, Bonn, Germany.
Joffre, O.M., Bosma, R.H., Ligtenberg, A., Tri, V.P.D., Ha, T.T.P., Bregt, A.K., 2015. Combining participatory approaches and an agent-based model for better planning shrimp aquaculture. Agric. Syst. 141, 149–159. https://doi.org/10.1016/j.agsy.2015.10.006.
Kishita, Y., McLellan, B.C., Giurco, D., Aoki, K., Yoshizawa, G., Handoh, I.C., 2017. Designing backcasting scenarios for resilient energy futures. Technol. Forecast. Soc. Chang. 124, 114–125. https://doi.org/10.1016/j.techfore.2017.02.001.
Kohler, J., de Haan, F., Holtz, G., Kubeczko, K., Moallemi, E., Papachristos, G., Chappin, E., 2018. Modelling sustainability transitions: an assessment of approaches and challenges. JASSS- J. Artif. Soc. Soc. Simul. 21. https://doi.org/10.18564/jasss.3629.
Köhler, J., De Haan, F., Holtz, G., Kubeczko, K., Moallemi, E., Papachristos, G., Chappin, E., 2018. Modelling sustainability transitions: an assessment of approaches and challenges. JASSS 21. https://doi.org/10.18564/jasss.3629.
Kump, B., Fikar, C., 2021. Challenges of maintaining and diffusing grassroots innovations in alternative food networks: a systems thinking approach. J. Clean. Prod. 317, 128407. https://doi.org/10.1016/j.jclepro.2021.128407.
Lam, D.P.M., Martín-López, B., Wiek, A., Bennett, E.M., Frantzeskaki, N., Horcea-Milcu, A.I., Lang, D.J., 2020. Scaling the impact of sustainability initiatives: a typology of amplification processes. Urban Transform. 2, 3. https://doi.org/10.1186/s42854-020-00007-9.
Lierman, S., Vandekerckhove, B., Huygebaert, B., Wellens, C., De Pau, J., Rogge, E., Dessein, J., 2015. Visie op landbouw in de stedelijke omgeving van Gent 2030 en de ruimtelijke vertaling ervan. Stad Gent.
Lutz, J., Smetschka, B., Grima, N., 2017. Farmer cooperation as a means for creating local food systems - potentials and challenges. Sustainability 9, 925. https://doi.org/10.3390/su9060925.
Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41, 955–967. https://doi.org/10.1016/j.respol.2012.02.013.
Martin, G., Allain, S., Bergez, J.-E., Burger-Leenhardt, D., Constantin, J., Duru, M., Hazard, L., Lacombe, C., Magda, D., Magne, M.-A., Ryschawy, J., Thénard, V., Tribouillois, H., Willaume, M., 2018. How to address the sustainability transition of farming systems? A conceptual framework to organize research. Sustainability 10, 2083. https://doi.org/10.3390/su10062083.
Mehryar, S., Schwarz, N., Sliuzas, R., van Maarseveen, M., 2020. Making use of fuzzy cognitive maps in agent-based modeling. In: Verhagen, H., Borit, M., Bravo, G., Wijermans, N. (Eds.), Advances in Social Simulation, Springer Proceedings in Complexity. Springer International Publishing, Cham, pp. 307–313. https://doi.org/10.1007/978-3-030-34127-5_29.
Méndez, V.E., Bacon, C.M., Cohen, R., 2013. Agroecology as a transdisciplinary, participatory and action-oriented approach. Agroecol. Sustain. Food Syst. 37, 3–18. https://doi.org/10.1080/10440046.2012.736926.
Mier, M., Gimenez Cacho, T., Giraldo, O.F., Aldasoro, M., Morales, H., Ferguson, B.C., Rosset, P., Khadse, A., Campos, C., 2018. Bringing agroecology to scale: key drivers and emblematic cases. Agroecol. Sustain. Food Syst. 42, 637–665. https://doi.org/10.1080/21683565.2018.1443313.
Millar, J., Connell, J., 2010. Strategies for scaling out impacts from agricultural systems change: the case of forages and livestock production in Laos. Agric. Hum. Values 27, 213–225. https://doi.org/10.1007/s10460-009-9194-9.
Moore, M.-L., Riddell, D., Vocisano, D., 2015. Scaling out, scaling up, scaling deep: strategies of non-profits in advancing systemic social innovation. J. Corp. Citizenship 67–84. https://doi.org/10.9774/GLEAF.4700.2015.ju.00009.
Morgan, K., 2020. Foodscapes of hope: the foundational economy of food. In: The Foundational Economy and Citizenship. Bristol University Press, Bristol, UK.
Nicol, P., 2020. Pathways to scaling agroecology in the city region: scaling out, scaling up and scaling deep through community-led trade. Sustainability 12, 7842. https://doi.org/10.3390/su12197842.
Oberč, B.P., Arroyo Schnell, A., 2020. Approaches to Sustainable Agriculture. Exploring the Pathways towards the Future of Farming. International Union for Conservation of Nature and Natural Resources, Brussels, Belgium.
Papageorgiou, E., Kontogianni, A., 2012. Using fuzzy cognitive mapping in environmental decision-making and management: A methodological primer and an application. International Perspectives on Global Environmental Change. InTech.
Polita, F.S., Madureira, L., 2021. Transition pathways of agroecological innovation in Portugal's Douro wine region. A multi-level perspective. Land 10, 322. https://doi.org/10.3390/land10030322.
R Core Team, 2013. R: A Language and Environment for Statistical Computing. Vienna, Austria.
Railsback, S.F., Grimm, V., 2019. Agent-Based and Individual-Based Modeling: A Practical Introduction, 2nd edition. ed. Princeton University Press, Princeton, NJ.
Robinson, J.B., 1990. Futures under glass: a recipe for people who hate to predict. Futures 22, 820–842. https://doi.org/10.1016/0016-3287(90)90018-D.
Rogge, E., Kerselaers, E., Prové, C., 2016. Envisioning opportunities for agriculture in peri-urban areas. In: Metropolitan Ruralities - Research in Rural Sociology and Development. Emerald Group Publishing.
Ruben, R., Verhagen, J., Plaisier, C., 2018. The challenge of food systems research: what difference does it make? Sustainability 11, 171. https://doi.org/10.3390/su11010171.
Schirrmeister, E., Warnke, P., 2013. Envisioning structural transformation—lessons from a foresight project on the future of innovation. Technol. Forecast. Soc. Chang. 80, 453–466. https://doi.org/10.1016/j.techfore.2012.10.008.
Schut, M., Leeuwis, C., Thiele, G., 2020. Science of scaling: understanding and guiding the scaling of innovation for societal outcomes. Agric. Syst. 184, 102908. https://doi.org/10.1016/j.agsy.2020.102908.
Shaaban, M., Scheffran, J., Böhner, J., Elsobki, M.S., 2019. A dynamic sustainability analysis of energy landscapes in Egypt: a spatial agent-based model combined with multi-criteria decision analysis. J. Artif. Soc. Soc. Simul. 22, 4. https://doi.org/10.18564/jasss.3906.
Shaaban, M., Voglhuber-Slavinsky, A., Dönitz, E., Macpherson, J., Paul, C., Mouratiadou, I., Helming, K., Piorr, A., 2023. Understanding the future and evolution of agri-food systems: a combination of qualitative scenarios with agent-based modelling. Futures 149, 103141. https://doi.org/10.1016/j.futures.2023.103141.
Shilomboleni, H., De Plaen, R., 2019. Scaling up research-for-development innovations in food and agricultural systems. Dev. Pract. 29, 723–734. https://doi.org/10.1080/09614524.2019.1590531.
Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Leon Bodirsky, B., Lassaletta, L., Vermeulen, S.J., Herrero, M., Carlson, K.M., Jonell, M., Troell, M., DeClerck, F., Gordon, L.J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., Godfray, H.C.J., Tilman, D., Rockström, J., Willett, W., 2018. Options for keeping the food system within environmental limits. Nature 562, 519–525. https://doi.org/10.1038/s41586-018-0594-0.
Sutherland, L.-A., Burton, R.J.F., Ingram, J., Blackstock, K., Slee, B., Gotts, N., 2012. Triggering change: towards a conceptualisation of major change processes in farm decision-making. J. Environ. Manag. 104, 142–151. https://doi.org/10.1016/j.jenvman.2012.03.013.
Thiele, J.C., Kurth, W., Grimm, V., 2014. Facilitating parameter estimation and sensitivity analysis of agent-based models: a cookbook using NetLogo and "R.". J. Artif. Soc. Soc. Simul. 17, 11. https://doi.org/10.18564/jasss.2503.
Timmermans, I., Van Bellegem, L., 2022. De biologische landbouw in 2021. Departement Landbouw en Visserij, Brussel.
Tučník, P., Bureš, V., 2016. Experimental evaluation of suitability of selected multi-criteria decision-making methods for large-scale agent-based simulations. PLoS One 11, e0165171. https://doi.org/10.1371/journal.pone.0165171.
Vermunt, D.A., Negro, S.O., Van Laerhoven, F.S.J., Verweij, P.A., Hekkert, M.P., 2020. Sustainability transitions in the agri-food sector: how ecology affects transition dynamics. Environ. Innov. Soc. Transit. 36, 236–249. https://doi.org/10.1016/j.eist.2020.06.003.
Vermunt, D.A., Wojtynia, N., Hekkert, M.P., Van Dijk, J., Verburg, R., Verweij, P.A., Wassen, M., Runhaar, H., 2022. Five mechanisms blocking the transition towards

'nature-inclusive' agriculture: a systemic analysis of Dutch dairy farming. Agric. Syst. 195, 103280. https://doi.org/10.1016/j.agsy.2021.103280.
Wang, J.-J., Ying, Y.-Y., Zhang, C.-F., Zhao, J.-H., 2009. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew. Sust. Energ. Rev. 13, 2263–2278. https://doi.org/10.1016/j.rser.2009.06.021.
Wigboldus, S., Klerkx, L., Leeuwis, C., Schut, M., Muilerman, S., Jochemsen, H., 2016. Systemic perspectives on scaling agricultural innovations. A review. Agron. Sustain. Dev. 36, 46. https://doi.org/10.1007/s13593-016-0380-z.
Wilensky, U., 1999. NetLogo. Northwest University, Evanston, IL, USA.
Wyborn, C., Bixler, R.P., 2013. Collaboration and nested environmental governance: scale dependency, scale framing, and cross-scale interactions in collaborative conservation. J. Environ. Manag. 123, 58–67. https://doi.org/10.1016/j.jenvman.2013.03.014.
Xu, Q., Huet, S., Perret, E., 2020. Do farm characteristics or social dynamics explain the conversion of dairy farmers to organic farming? An agent-based model of dairy farming in French cantons. JASSS 23, 4. https://doi.org/10.18564/jasss.4204.
Yacamán Ochoa, C., Matarán Ruiz, A., Mata Olmo, R., Macías Figueroa, Á., Torres Rodríguez, A., 2020. Peri-urban organic agriculture and short food supply chains as drivers for strengthening city/region food systems—two case studies in Andalucía, Spain. Land 9, 177. https://doi.org/10.3390/land9060177.