FOODLEVERS

Deliverable 3.2:
Generic Agent-based Model
ILVO, Belgium
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1. Objective

The aim of task 3.2 is **to provide a holistic view of the complex interplay between different socio-economic and behavioural aspects within the food value chain and sustainability goals**. To provide such analyses, Agent-Based Modelling (ABM) is one of the main methods used. The food value chain is considered as a complex system, with multiple interacting agents from farmers to consumers. These are adaptive systems since the decisions and interactions of agents along the chain may influence decisions of other agents. Interactions between agents results from behavioural rules extracted from literature and interviews along the different regions of FOODLEVERS project. In ABM, the behaviour of individual agents and the environment is modelled explicitly. With this approach, we can investigate how a system-level change toward sustainability can result from micro-level changes (e.g. changes in incentives, willingness to buy local products, value-chain length…).
ABM will incorporate data from previous tasks. To validate the used data and to gain expert view, this task requires all partners to be involved in the ABM development, to be able to provide insights and feedback for improving the model.

2. Modelling of case studies

To investigate the leverage points for sustainable and organic agri-food systems, FOODLEVERS project partners selected 7 main case studies in the different European partner countries. The selected case studies of the organic, innovative farms for FOODLEVERS project can be found in Table 1.

Table 1. Selected European case studies of innovative organic food systems.

No.	Innovative organic food/sustainable system	Study location
1	Biodynamic city-farm cooperating with a large network of regional organic farms, consumer-driven decision making, and innovative method of distribution	Frankfurt am Main, Germany
2	Organic farm managing silvopastoral systems where walnut plantations and olive orchards are grazed by laying hens	Orvieto, Italy
3	Network of local farms to strengthen market access and get a “grass-fed” standard for beef, to improve short value chains and create a joint shop for community farmers	Poland
4	Community supported farm with over 350 members and innovative governance structure	United Kingdom
5	Biodynamic farm cooperating with a large network of regional organic farms, consumer-driven decision making, innovative method of distribution, volunteer program, on site learning for local school children	Romania
6	Forest farming: Mushroom farms cultivating organic edible mushrooms in forests and indoors, more efficient use of forestry, agriculture and urban side products and waste streams (small diameter trees, grain husks, coffee	Region of Uusimaa and

	grounds etc.), courses to farmers and start-ups interested in mushroom cultivation	Southern Savonia, Finland
7	Community-Shared-Agriculture providing organic products for a local hospital kitchen	Flanders, Belgium

All of these case studies represent a specific mechanism that make them innovative and more sustainable in comparison with their mainstream organic counterparts. To compare the different case studies, they were grouped by three main mechanisms, which can also be observed in Figure 1. The **Circularity** scenario corresponds to the case studies of Italy and Finland. The case studies of Romania and Poland are represented in the scenario **Farm Network**. Lastly, the case studies of The United Kingdom, Germany, and Belgium are included in the scenario **CSA**.

Figure 1. Classification of the case studies of FOODLEVERS into one of the three mechanisms represented in the agent-based model.

The agent-based model for FOODLEVERS can represent all the seven case studies in one single generic model. That means that, in order to characterize one of the case studies, several parameters will be chosen in each simulation altogether with the correspondent mechanism (i.e. CSA, Farm Network, Circularity) of that case study (see Table 2). In that way, with one model we can capture all the main characteristics of each case study. Nonetheless, due to time constraints, we further performed simulations for one representative region of each of the three mechanisms, that is, for CSA in Flanders, for Farm Network in Poland, and for Circularity in Italy.

Table 2. Parameter values to define 3 regions in the agent-based model.

Mechanism	Case study	Main-product	Prop-org-inn	Prop-org-main	Farm-size-org	Farm-size-conv	Biodiversity-index	Mean-qol-lci	Farm-links-prob	Group-cons
Circularity	Italy	Eggs	0.005	0.08	24	8	1.101	2.3	0	0
Farm network	Poland	Beef	0.005	0.005	33	11	1.463	4.3	0.4	0
CSA	Flanders	Zucchini	0.005	0.005	8	26	1.407	4.2	0.05	50

3. Agent-Based Model

Agent-based modelling is a computational resource that has been widely used for modelling and simulating different scenarios within agriculture such as the implementation of a specific sustainable agricultural practice (e.g. organic farming), the decision-making of both farmers and consumers, and the effect of policy measures on agriculture (Bell et al., 2016). These simulations of uncertain, future scenarios can help to make decisions that lead to more sustainable agri-food systems. Additionally, a participatory approach, which is based on the co-creation with multidisciplinary involved actors, is essential to perform successful transformations in a system (Schot and Steinmueller, 2018). A combination of agent-based modelling with design-oriented approaches may be used to integrate information that could potentially provide leverage points for sustainability transitions (Gaitán-Cremaschi et al., 2019).

The decision-making of agents under risk and uncertainty conditions is a key issue for modelling. Farms, the main agents of agricultural models, are frequently facing diverse environmental, market and political risks (Huber et al., 2021). The decisions of farmers are also profoundly influenced by the decision-making of other actors that are part of the drivers of change in agri-food systems: the consumers (Allen et al., 1991). Hence, it is relevant to understand how consumers are actually making decisions towards more sustainable choices. As a theoretical framework, this research is also supported on the Theory of Planned Behaviour to understand the decision-making of agents in the models. This approach has been widely used in the agri-food context to investigate the relationship between attitude and action of adoption of certain farming practices or sustainable choices (Fielding et al., 2008).

Hence, agent-based models have been considered quite suitable in the agricultural sector for participatory research. This participation can occur for the conceptualization of the model to identify the roles of the stakeholders and their actions on resources and the analysis of simulation results. ABM simulates the decision-making process of individual agents in response to different scenarios and has a high capacity for the involvement of numerous stakeholders. Therefore, these ABM are a useful modelling approach to understand the dynamics of complex adaptive systems with self-organizing properties (Grimm et al., 2005). It allows us to study emergent behaviours that may arise from the cumulative actions and interactions of heterogeneous agents.

Furthermore, this tool can be used for modelling future situations of scenarios that incorporate multiple changes simultaneously (Delmotte et al., 2013). Hence, actors that aim to understand and support complex pathways towards more sustainable agricultural systems could benefit from ABM approaches. Stakeholders' meetings, focus groups, and role-playing games, among other participatory methods, have been widely adopted to organize the exchange of ideas and evaluate scenarios using ABM (Delmotte et al., 2013).

It is crucial to adapt agri-food production methods and state-of-the-art technologies to achieve current environmental quality goals as well as an enhanced sustainability in the system. Therefore, the objective of the task 3.2 of FOODLEVERS project is to understand the added value that a generic, yet highly useful agent-based modelling approach, can bring us to the development of sustainable pathways in agriculture. Eventually, the findings obtained during this project could also give value to the decision-making of involved actors in the agricultural sector.

3.1 Foodlevers' model

General purpose of the model

The main purpose of the ABM is to simulate the scaling out of **farms**, the main agent in the model, that can become more innovative, following the innovations seen in FOODLEVERS' case studies. Innovative farms are defined as those farms that are replicating the same business model as the innovative farm of reference in the FOODLEVERS project. That is, for CSA mechanism, innovative farms are CSA farms collaborating with nearby institutions with public kitchens; for Farm network mechanism, innovative farms are a network of farms connected to each other working for a common goal to be more sustainable; and for Circularity mechanism, innovative farms are reducing their costs by closing their cycles and being more sustainable. These farms can be either organic or conventional, although the focus is on organic farms, and innovative or mainstream. Innovative farms can follow one of the three mechanisms proposed:

- **Circularity**: Farms that adopt a circular production method, with no significant links to other farms.
- **Farm network**: Farms that develop a farm network with other farms pursuing a common goal.
- **CSA**: Farms that collaborate with public kitchens from institutions to deliver them food, also within a farm network of links with other farms.

The concept **scaling out** refers to the horizontal diffusion of the innovativeness that characterizes an innovative farm to a mainstream farm that becomes then innovative (Bonfert, 2022). Through scaling out, a mainstream farm can become innovative. On the other hand, **scaling down** means in this context that an innovative farm comes back to a mainstream production due to the incapacity to maintain an innovative system in their farm.

The farms scale out depending on factors like their economic performance, social pressures, and their farming area. Thus, the model is mainly focused on monitoring the percentage of innovative farms that arise in the simulation. Besides, representative outputs for sustainability in the economic, social, and environmental dimension are monitored in the model.

In Table 2 we describe the main variables for each kind of farm agent in Flanders:

Table 2. Values of farm variables for each type of farm agent.

	Organic innovative	Organic mainstream	Conventional innovative	Conventional mainstream
Production	Organic innovative	Organic mainstream	Conventional innovative	Conventional mainstream
Area	Small (8 ha)	Small (8 ha)	Medium (26 ha)	Medium (26 ha)
Attitude	pioneer	follower	pioneer	80% risk averse, 20% follower

Color	blue	green	magenta	orange
Probability outscale	1	0.7	1	0.1 risk averse, 0.3 follower

Farms can have two different production types, either **organic** or **conventional**. The area represents the total area owned by the farm. The attitude of the farm determines their perspective towards change, that is, towards scaling out. The color variable is helpful to visualize the farms in NetLogo environment. And lastly, the variable *probability-outscale* defines the probability of farms to scale out to innovative, being 1 for those farms that are already innovative. The values of the given parameters may change among regions, being calibrated to the specific environment of each country and case study. A model overview in NetLogo platform is shown in Annex 1. Moreover, a full list of all parameters included in the model is presented in Annex 2.

For more clarification of the main modelling concepts, see Annex 3. For further information and detailed overview of the main procedures and functioning of the model in NetLogo software, see the Documentation report and NetLogo file attached to this deliverable.

Model overview

The ABM of FOODLEVERS project is developed in NetLogo software 6.2.2. First, the model sets up the global variables, such as prices and data for calibration, the farms and their attributes and social networks, and the patches that represent the physical world i.e., the land. On each time step in the model that represents one year, the farms go through different processes. The simulation starts by (i) converting a specific percentage of conventional farms to organic ones, matching the organic trend for each country. Also, (ii) consumers update their food preferences, that is, they will prefer organic or conventional products. The farms start then (iii) producing crops or products, depending on their production type (i.e., organic or conventional). Then, they (iv) sell their produce to their market. By looking at neighbouring innovative farms that are linked to them, they (v) assess their peer pressure to scale out into innovative. When 2 years have passed, the farms (vi) decide whether or not to scale out if they are mainstream, or scale down if they are innovative. A diagram representing the main procedures of the model is shown in Figure 2.

The main social driver in the model for farms to scale out is represented in the parameter *inn-consumer-trend*, the **trend for innovative and organic consumption**. This parameter defines the trend that is pushing toward organic and innovative food consumption through social media, consumers awareness, etc. On the other hand, the parameter *change-threshold* represents the main social barrier to adopt innovative farming systems in the model. Also known as **opportunity window threshold**, this defines the threshold to scale out where the innovation becomes visible and known for farmers.

It should be noted that the present agent-based model developed for FOODLEVERS project is not intended to predict nor reproduce accurate future results. Therefore, this analysis must be taken with caution, as an interpretation for potential scenarios and measures to increase the amount of innovative organic farmers in Flanders.

For more information about model specifications, the ODD + D of the model is documented in an annex document where more model details are further explained. The ODD + D is a protocol to establish a standard in order to describe agent-based models which includes human decision-making elements (Müller et al., 2013). For more details about some NetLogo programming terminology, see Annex 3.

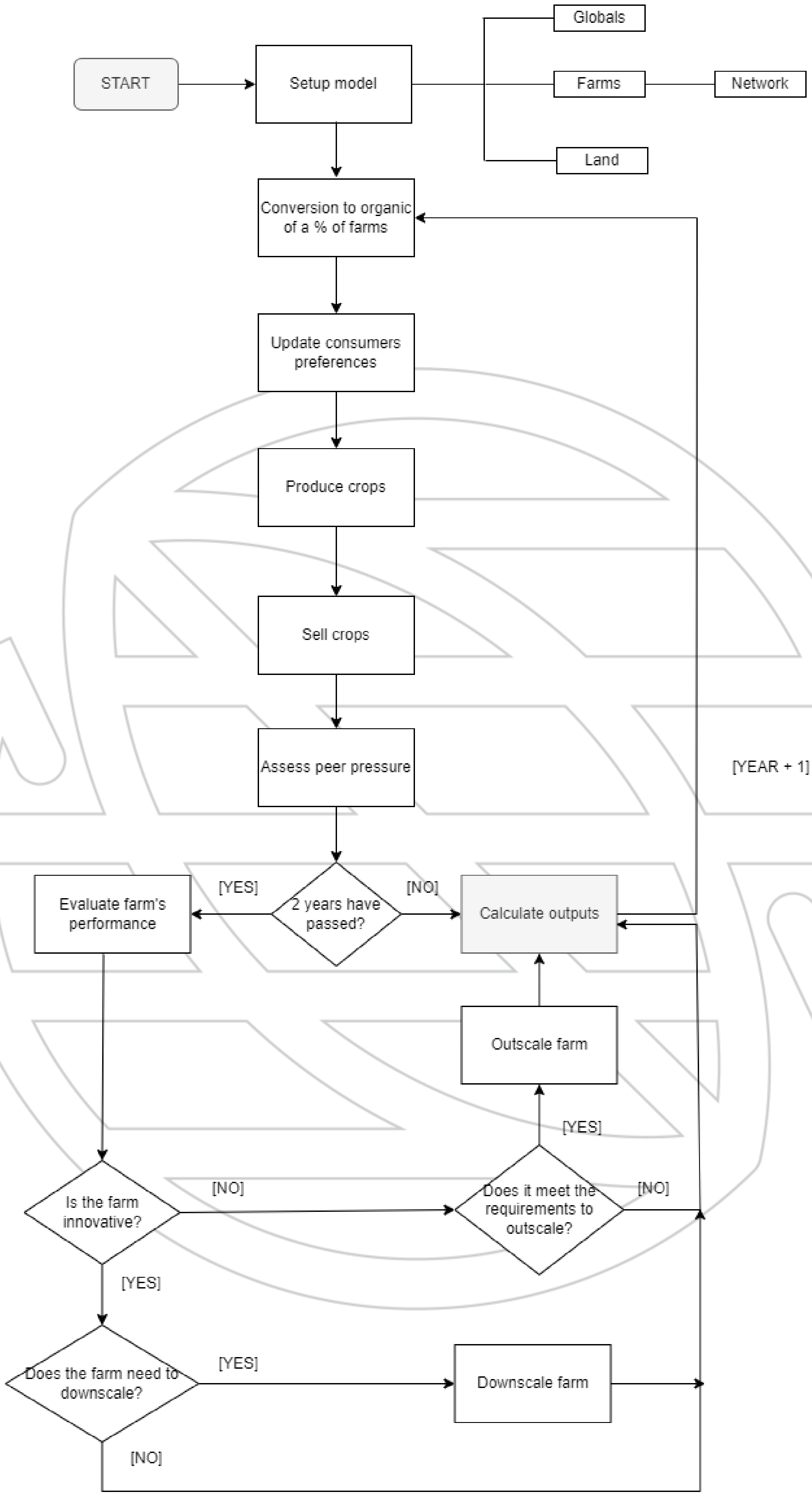

Figure 2. Diagram of the FOODLEVERS agent-based model.

Sensitivity analysis

By performing sensitivity analysis of the model, we can get a better understanding of how sensitive the model is to parameter variations regarding the model outputs (Thiele et al., 2014). As a showcase, we use Flanders case study in this document. The results from the performed simulations are further analysed with the R software (*R Core Team*, 2013).

We explored the sensitivity of certain parameters to the main output of the model of the **percentage of innovative organic farms**. The parameters selected for this sensitivity analysis of the Flemish case study are presented in Table 3.

Table 3. Parameters tested for sensitivity analysis in Flanders case study.

Parameter	Name	Units	Values tested	Description
Change threshold	*change-threshold*	index	0.1, 0.2, 0.3, 0.4, 0.5	Defines when the threshold to outscale starts, opportunity window threshold.
Distance to consumers	*Distance-consumers*	NetLogo unit	4, 8, 12	How far does the farm provide food to their consumers.
Economic orientation	*Economic-orientation*	ratio	0.75, 0.85, 0.95	Maximum ratio of revenues that the farmers would accept from which they would consider it an economically bad year.
Farms links probability	*Farms-links-probability*	index	0.05, 0.1, 0.2, 0.3	Defines how dense are the links between farms that define the network.
Innovative consumption trend	*inn-consumer-trend*	index	0.1, 0.2, 0.3, 0.4, 0.5	Defines the trend that is pushing toward organic and innovative food consumption through e.g. social media, demand,…
Number of group consumers	*Group-consumers*	n	25, 50, 100	Number of patches with group consumers in the simulation environment.
Subsidies	*subsidies*	€	0, 1000, 10000	Subsidies for farms that want to scale out to innovative.
Subsidies application time	*subsidies-time*	year	2023	Year in which the subsidies are being applied.

We tested different sets of 3 parameters indicated in the table above in a simulation with 50 runs.

Set 1 of parameters: inn-consumer trend, change threshold and economic orientation

In Figure 3, we observed that *inn-consumer-trend* needs to overcome *change-threshold* in order to increase the percentage of innovative organic farms out of the total population of farms. Also, having a lower *economic-threshold* (values = 0.75, 0.85) promotes a higher percentage of innovative organic farms, while being too economically-oriented may slow down the transition.

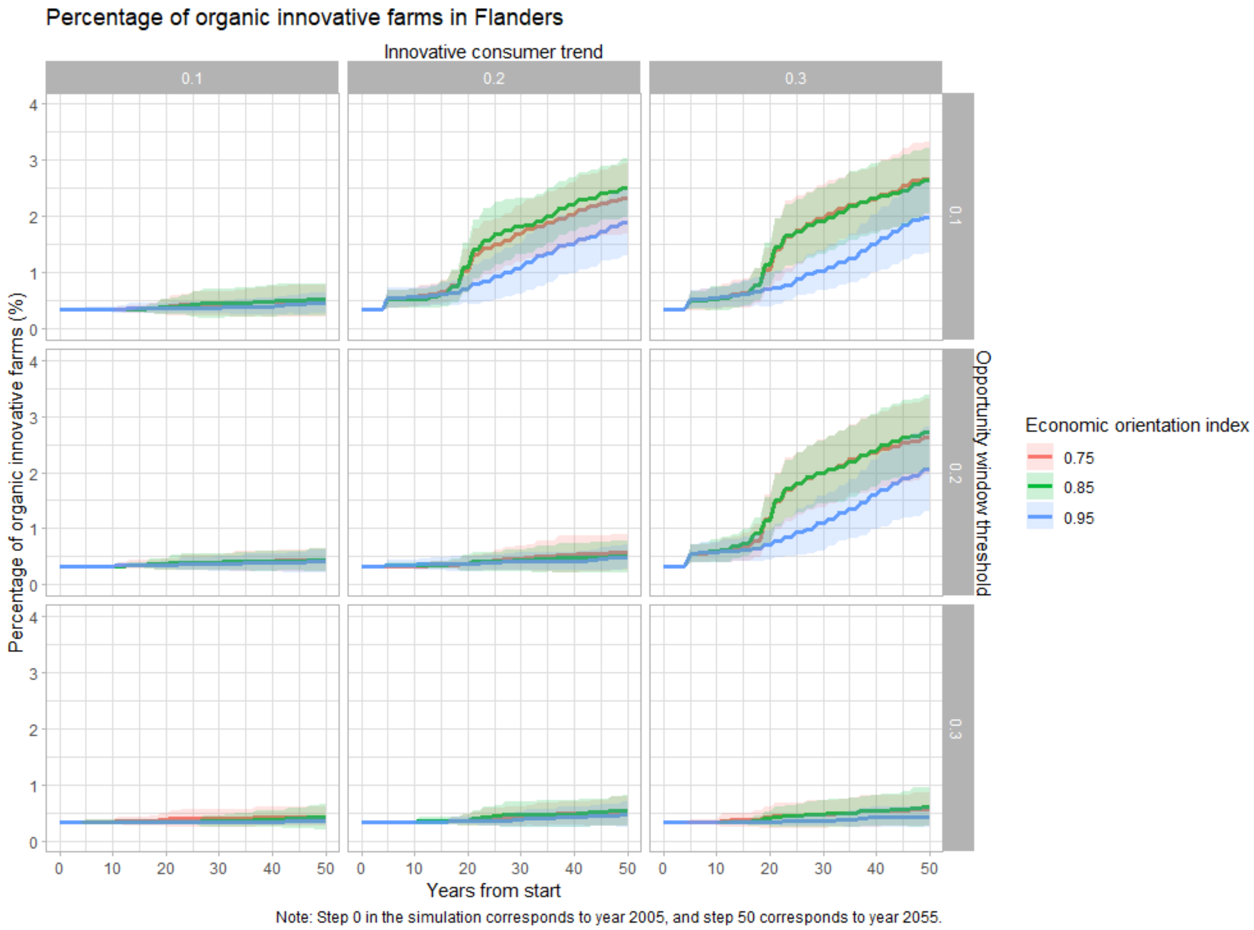

Figure 3. Influence of the parameters of innovative consumer trend, opportunity window threshold, and economic orientation index on the percentage of organic innovative farms.

In Figure 4, we observe the same results expressed in percentage out of organic farms. The simulation starts with only 1 innovative organic farm and another organic mainstream farm, and until the year 2015 there is only one innovative farm (grey area of stabilization). That is why we observe that the simulation starts at 50% (1 innovative and 1 mainstream organic farms), slowly descends because the organic farms are increasing and then, more innovative farms start to scale out. Here, the *economic-orientation* also plays a role in the scaling out, needing lower values to incentivize the scale out of farms. There is a peak of more than 60% innovative farms with low to medium *economic-orientation* values in the organic sector in the year 2025 that slowly declines because the organic trend keeps growing while the innovative farms are stabilized.

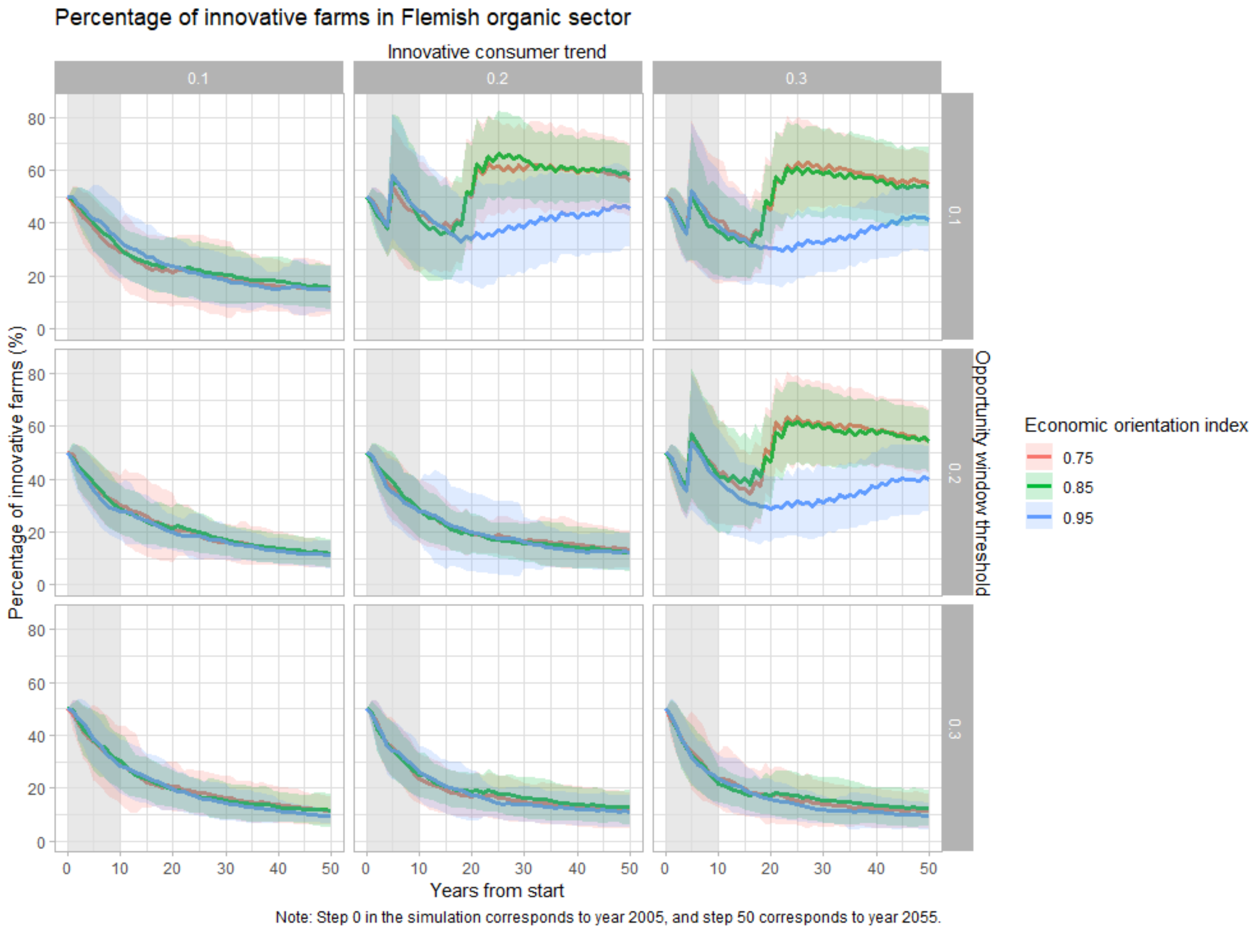

Figure 4. Influence of the parameters of innovative consumer trend, opportunity window threshold, and economic orientation index on the percentage of innovative farms in the organic sector.

Set 2 of parameters: inn-consumer-trend, change-threshold, and farms-links-probability

Having more links with other peer farms present an effect especially when *inn-consumer-trend* and *change-threshold* values are very similar (Figure 5). When *inn-consumer-trend* is higher than *change-threshold*, all farms will scale out regardless of their *farms-links-probability*. On the other hand, when *change-threshold* is higher than *inn-consumer-trend*, farms will not have enough pressure to scale out, therefore they will not scale out even if they have more *farms-links-probability*.

When focusing on the organic sector, we observe similar results. *Farms-links-probability* have more influence when *inn-consumer-trend* and *change-threshold* are very similar (see Figure 6). In these situations, we observe an increment around 20 years after the simulation started. However, higher values are reached when *inn-consumer-trend* is higher than *change-threshold*, that is, when there is more pressure from society for innovative and organic production and it's greater than the threshold to be aware of these innovations. Here, we observe a first peak around 5 years after the simulation starts. Around 25 years after the start of the simulation there is a second peak of percentage of innovative farms. At this point, the percentage of innovative farms stabilizes and slightly declines because the number of organic farms keeps growing.

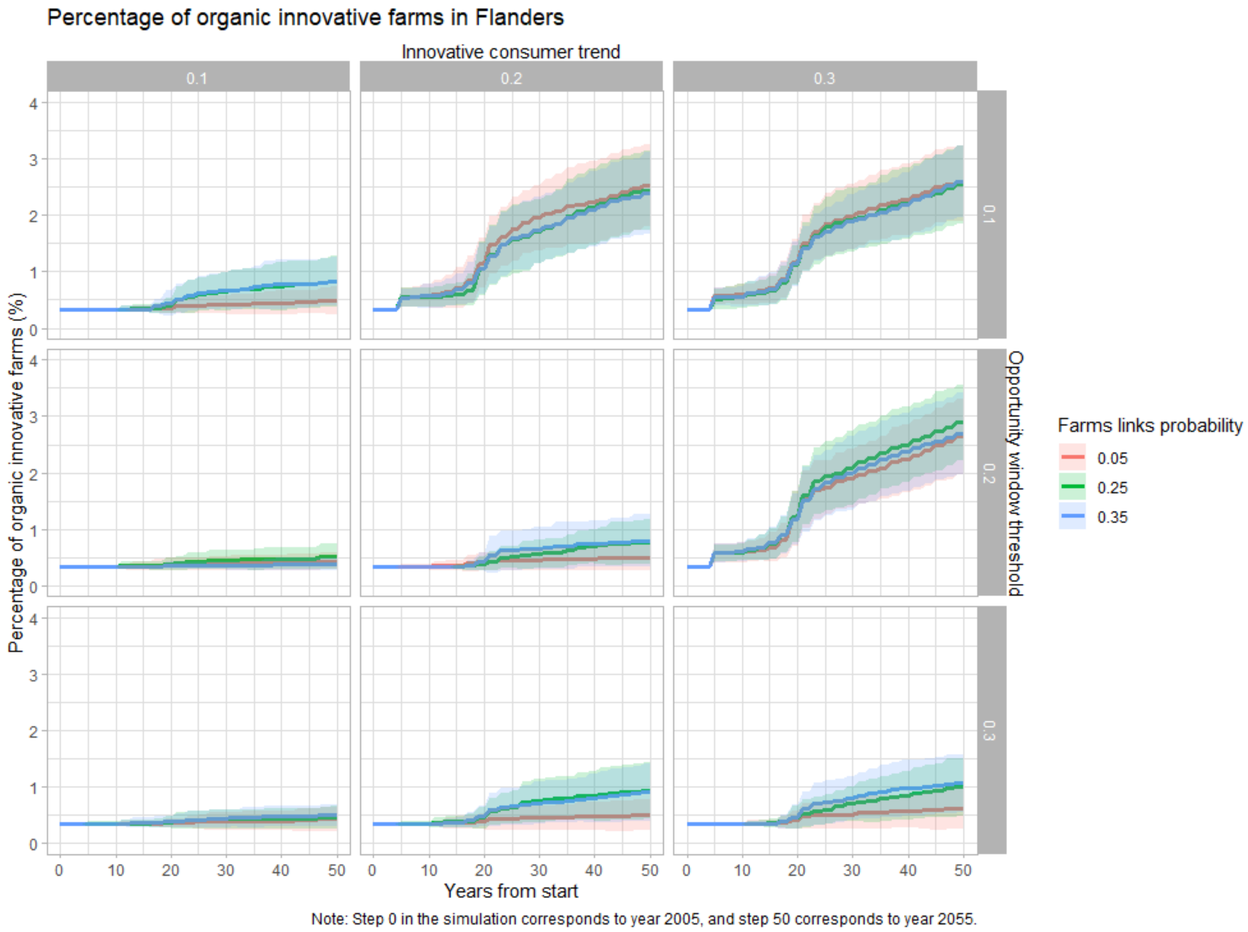

Figure 5. Influence of the parameters of innovative consumer trend, opportunity window threshold, and farms links probability on the percentage of organic innovative farms.

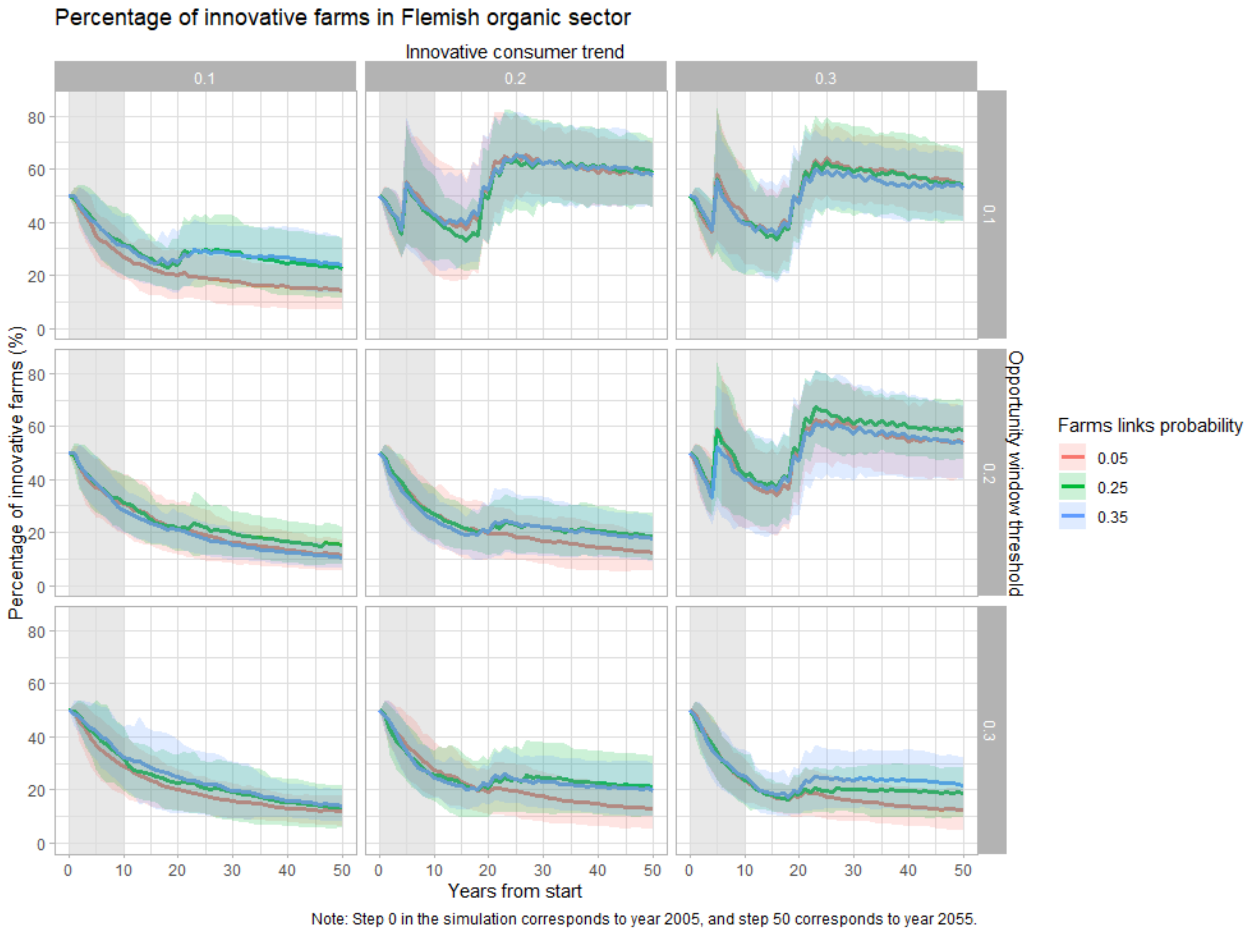

Figure 6. Influence of the parameters of innovative consumer trend, opportunity window threshold, and farms links probability on the percentage of innovative farms in the organic sector.

Set 3 of parameters: inn-consumer-trend, change-threshold, and subsidies

Subsidies in these simulations are set to be given to farms that want to scale out at time 18 years after the start of the simulation, which corresponds to the year 2023. Having *subsidies* helps to overcome *change-threshold* when *inn-consumer-trend* is not high enough (see Figure 7). However, there is not much difference between receiving 1.000€ or 20.000€.

Similar results are observed zooming in on the organic sector. A peak around year 18 after the start of the simulation is noticed, which means that the subsidies promote the scaling out of innovative farms (in Figure 8). Nonetheless, when the driver *inn-consumer-trend* is higher than the barrier *change-threshold*, *subsidies* don't have a strong influence on the percentage of innovative farms. From the year 18 after the start of the simulation onwards, the percentage of innovative farms is stabilized and begins to decrease slightly due to the increase of mainstream organic farms, following the trend for organic conversion in Flanders.

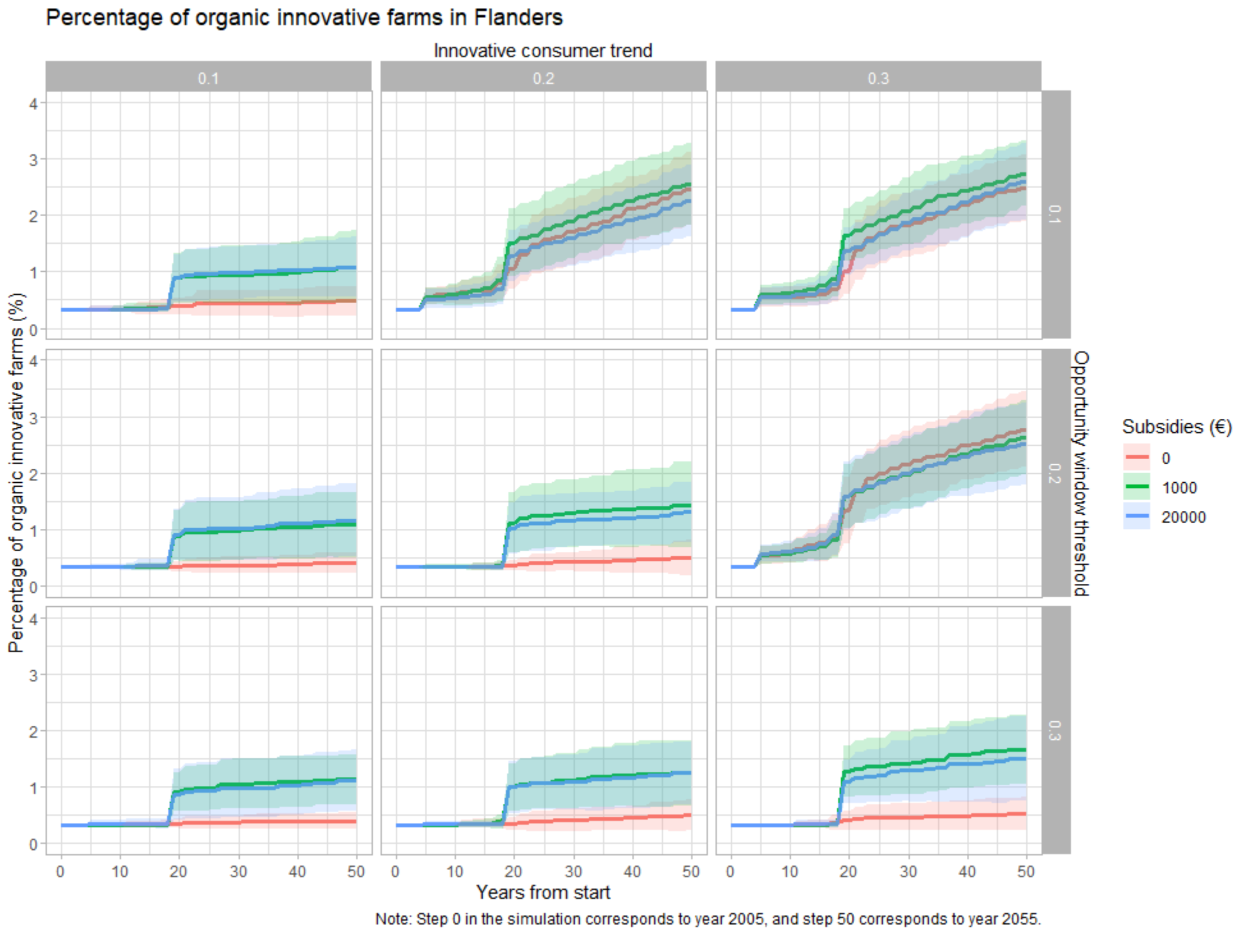

Figure 7. Influence of the parameters of innovative consumer trend, opportunity window threshold, and subsidies on the percentage of organic innovative farms.

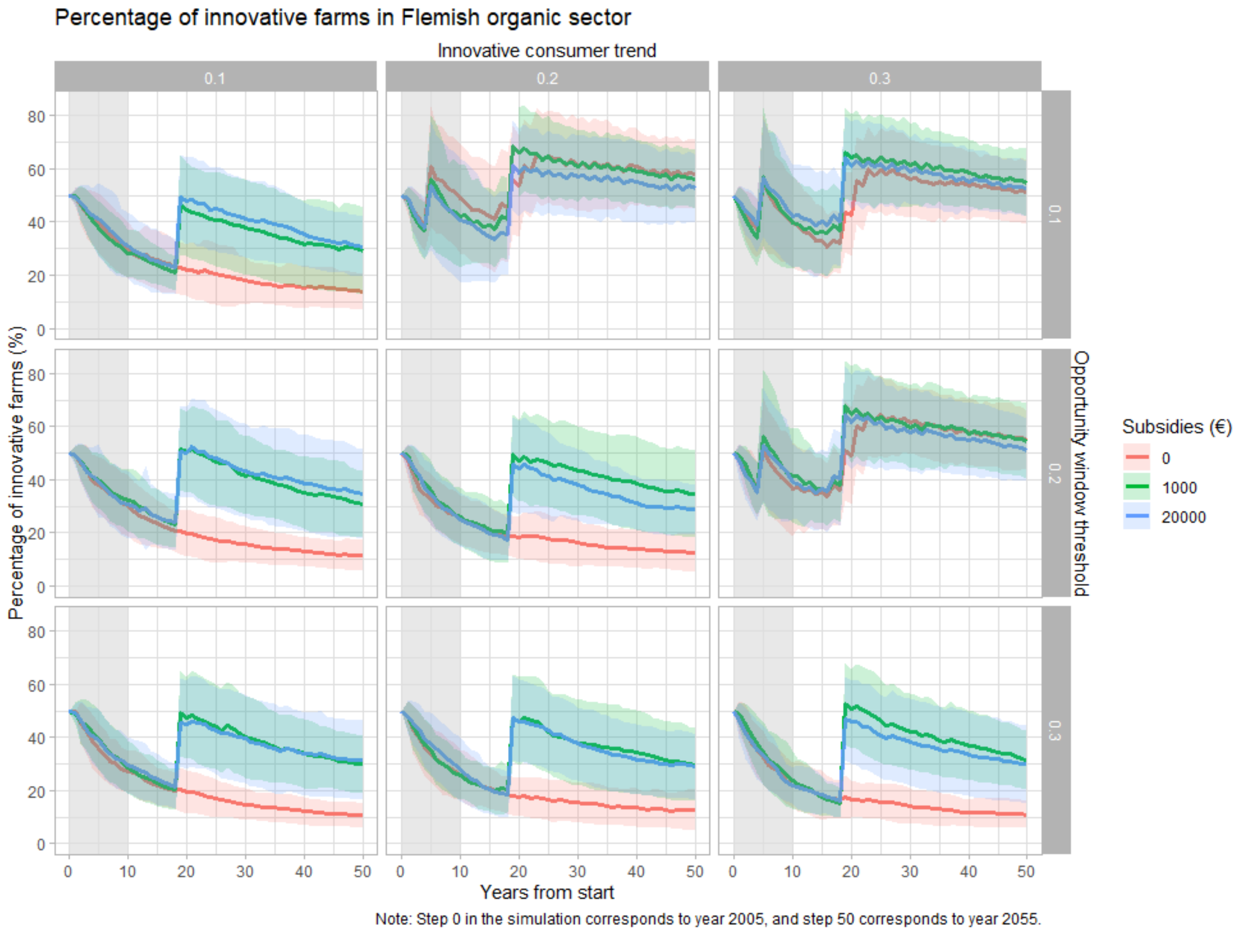

Figure 8. Influence of the parameters of innovative consumer trend, opportunity window threshold, and subsidies on the percentage of innovative farms in the organic sector.

Set 4 of parameters: inn-consumer-trend, change-threshold, and group-consumers

As expected, group-consumers, which represents the number of available public kitchens for collaboration, shapes the scaling out (in Figure 9). Having higher values of *group-consumers* increases the scaling out of innovative organic farms, with a maximum of 3.5%. The curve starts to increase in a S-curve shape from year 20 from the start of the simulation. However, *inn-consumer-trend* must be higher than *change-threshold* to be aware of these innovations and be able to scale out.

For the organic sector we observe similar results. When *inn-consumer-trend* overcomes *change-threshold*, the scaling out is present. Higher values of *group-consumers* promotes a higher percentage of innovative farms in the organic sector. Besides, having enough number of public kitchens (i.e., *group-consumers*) could promote the scaling out when *inn-consumer-trend* and *change-threshold* are similar (see bottom right quadrant in Figure 10).

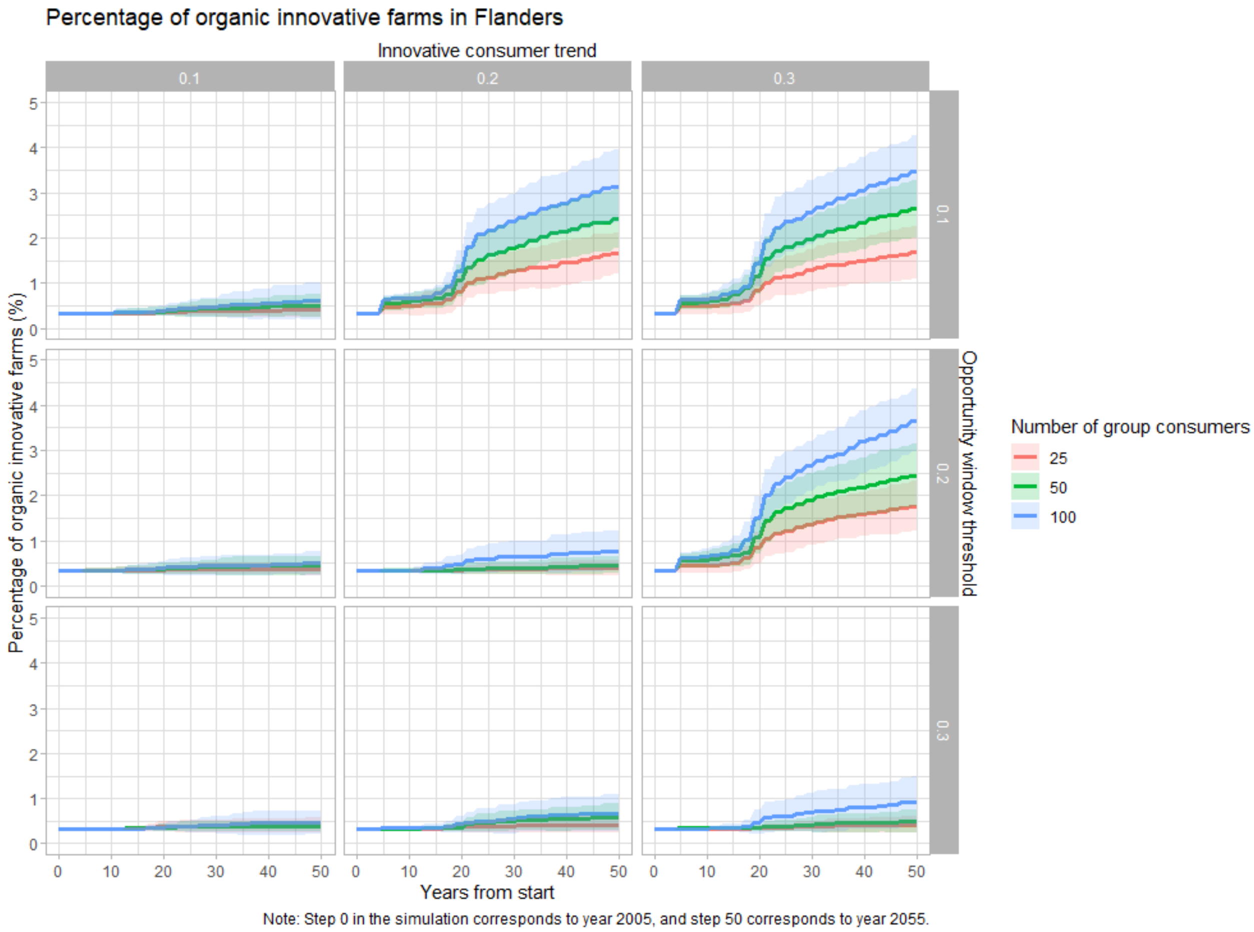

Figure 9. Influence of the parameters of innovative consumer trend, opportunity window threshold, and number of group consumers on the percentage of organic innovative farms.

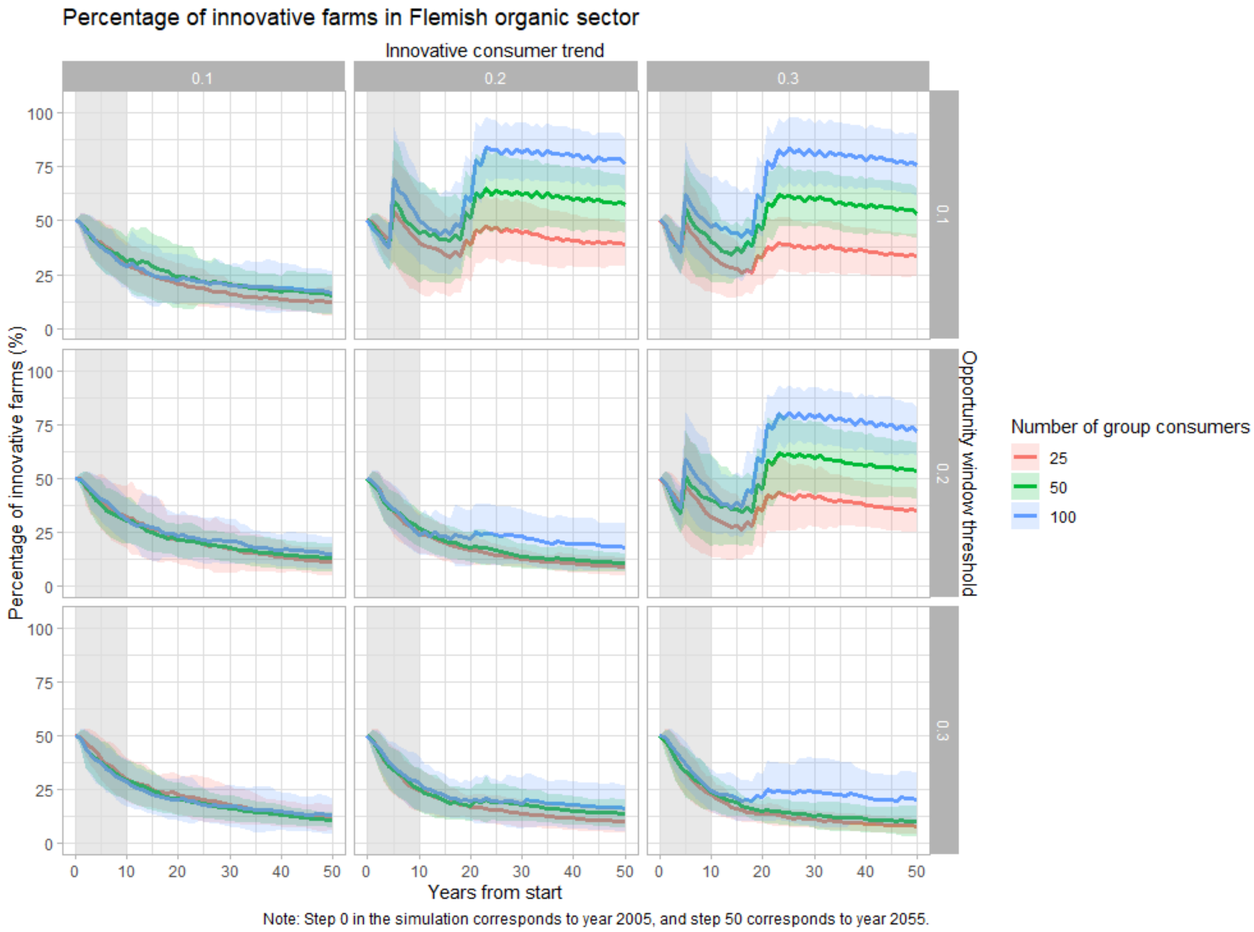

Figure 10. Influence of the parameters of innovative consumer trend, opportunity window threshold, and number of group consumers on the percentage of innovative farms in the organic sector.

Set 5 of parameters: inn-consumer-trend, subsidies, and economic-orientation

For these simulations, *change-threshold* barrier is set at the default value 0.2. When subsidies are present, and the *inn-consumer-trend* is too low to overcome the barrier *change-threshold*, being more economically-oriented increases the scaling out (Figure 11). Having no subsidies needs *inn-consumer-trend* to be bigger than 0.2 in order to observe an increase in the percentage of innovative organic farms. However, when the *inn-consumer-trend* is bigger than change-threshold (set at 0.2), *subsidies* have no effect anymore.

Looking only at the organic sector, subsidies help strong economically-oriented farms to scale out (Figure 12). However, when no subsidies are present and *inn-consumer-trend* overcomes *change-threshold* (set at 0.2), economically-oriented farms (*economic-orientation* = 0.95) lag behind. For situations where *inn-consumer-trend* is higher than *change-threshold* and with *subsidies*, these subsidies have no longer an effect. We can observe a peak in the percentage of innovative farms that corresponds to the time when the subsidies are applied, that is, 18 years after the simulation starts, corresponding to the year 2023.

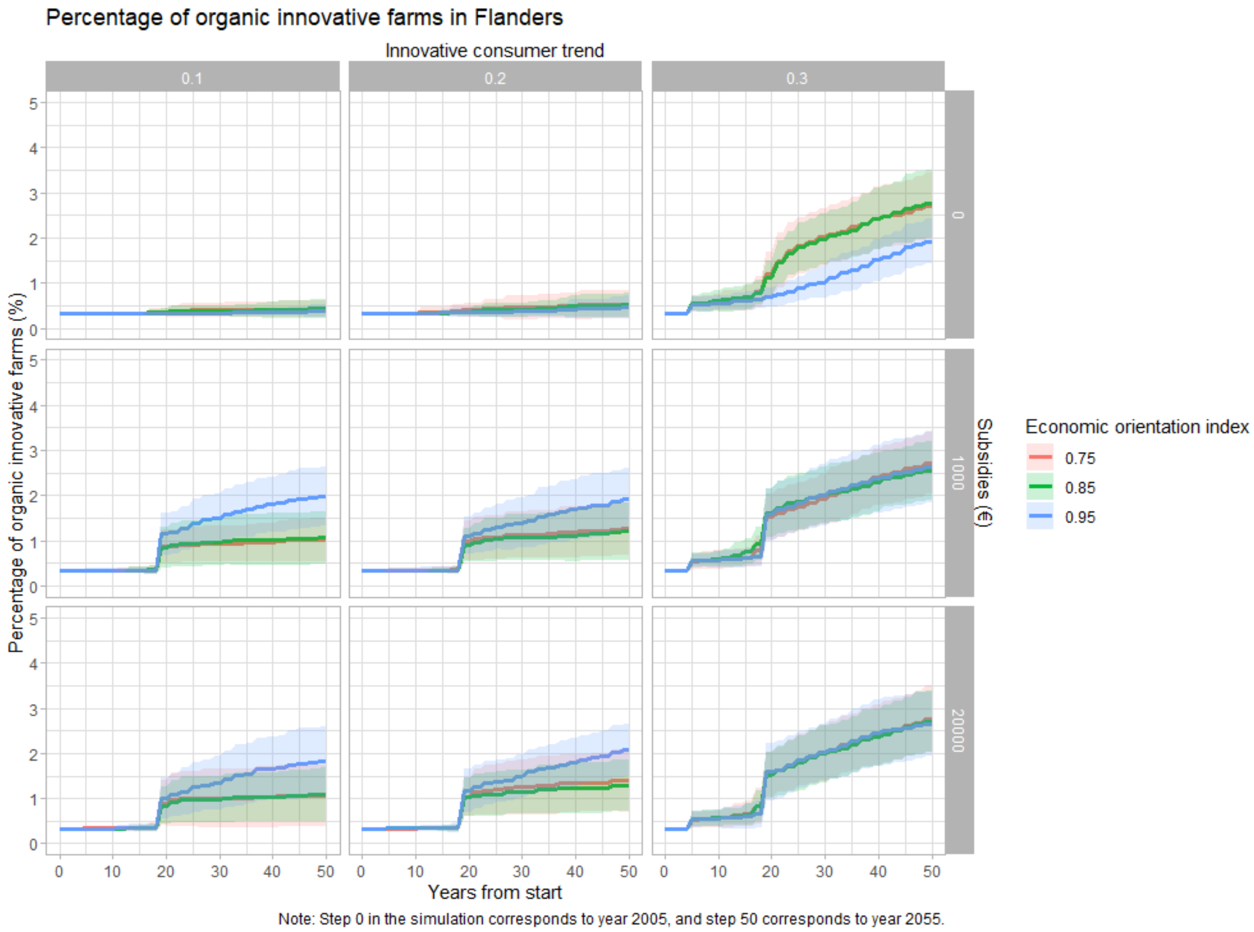

Figure 11. Influence of the parameters of innovative consumer trend, subsidies, and economic orientation index on the percentage of organic innovative farms.

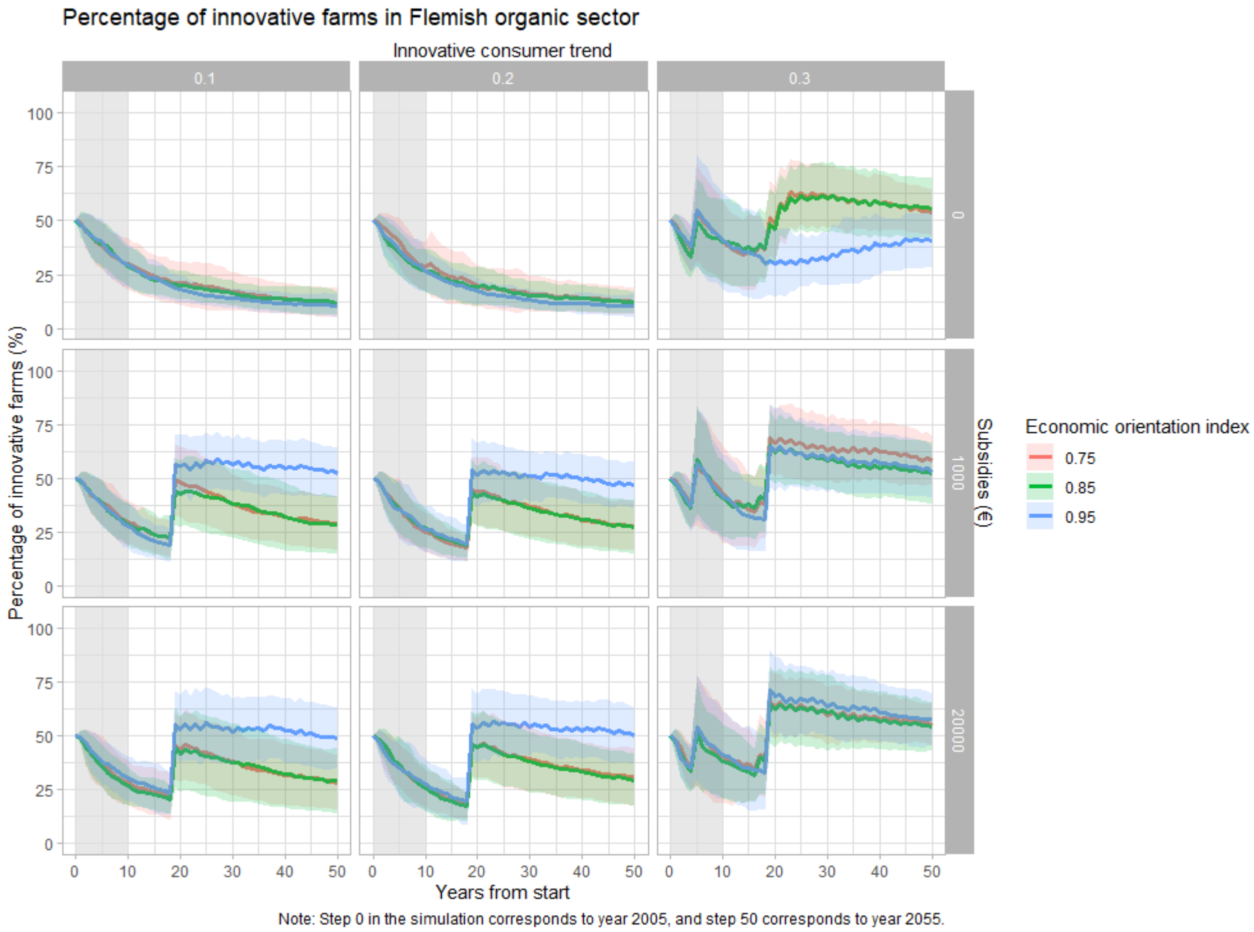

Figure 12. Influence of the parameters of innovative consumer trend, subsidies, and economic orientation index on the percentage of innovative farms in the organic sector.

Set 6 of parameters: inn-consumer-trend, subsidies and subsidies-time

Subsidies-time corresponds to the time when the subsidies were applied, that is, for the values 12, 18, and 25, it corresponds to the years 2017, 2023, and 2030, respectively[1]. Receiving early subsidies helps achieving higher percentage of innovative organic farms when *inn-consumer-trend* is not enough to overcome the barrier *change-threshold*, set at default value for these simulations at 0.2 (Figure 13). For subsidies applied at time 25 after the start of the simulation, it seems that the total simulation time is too short to observe an increase in the percentage of innovative organic farms. However, when *inn-consumer-trend* is bigger than the barrier *change-threshold* set at 0.2, the time to apply subsidies is not relevant anymore, but the equilibrium is achieved earlier than compared to later *subsidies-time*.

Similar results are expected for the organic sector. In Figure 14, receiving earlier subsidies promotes higher percentage of innovative farms among the organic sector. On the other hand, later subsidies in the year 2030 does not present a peak in the percentage of innovative farms as observed for lower values of *subsidies-time*. Furthermore, when *inn-consumer-trend* is higher

[1] The year 2017 was selected as the year where the Flemish CSA case study started the innovative collaboration; the year 2023 corresponds to the present time when VLIF subsidies in Flanders are available; and 2030 was chosen as a common future target.

than *change-threshold* (set at 0.2 for these simulations), *subsidies-time* does not influence anymore, although presenting early subsidies achieves the equilibrium earlier.

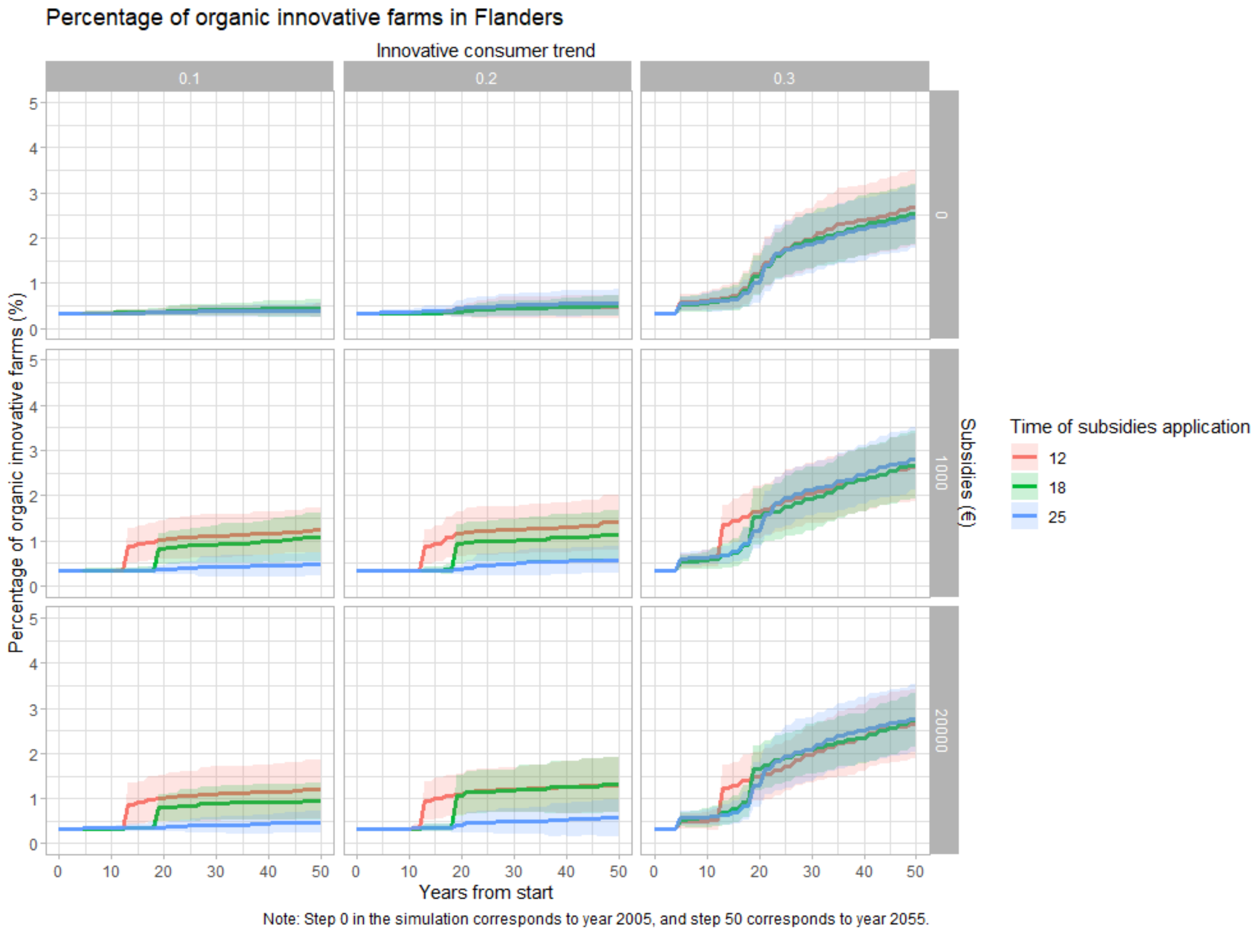

Figure 13. Influence of the parameters of innovative consumer trend, subsidies, and time of subsidies application on the percentage of organic innovative farms.

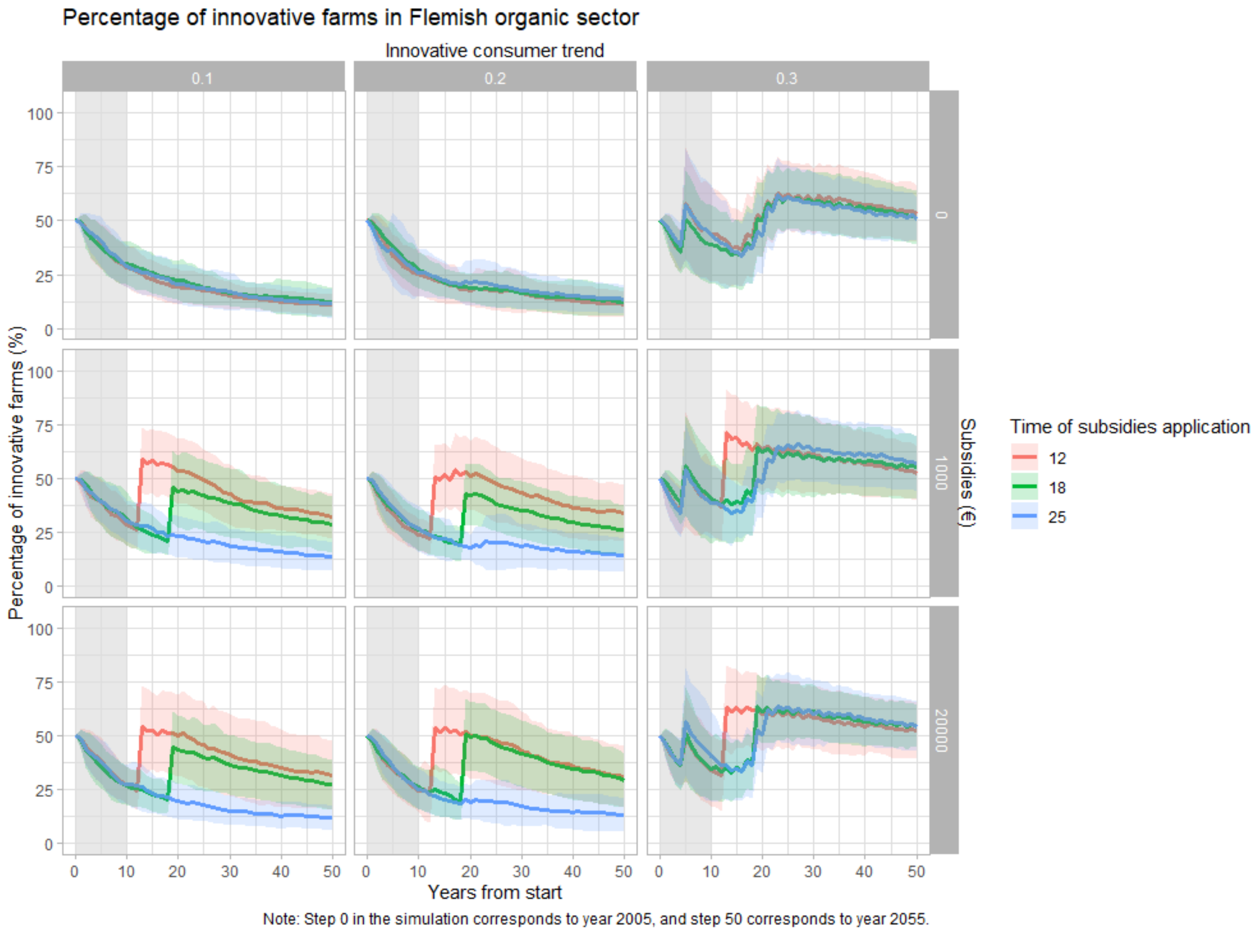

Figure 14. Influence of the parameters of innovative consumer trend, subsidies, and time of subsidies application on the percentage of innovative farms in the organic sector.

Scenarios simulations

We explore the baseline scenario (A) and three potential scenarios in Flanders (B, C, and D). The baseline **scenario A** is representing the current situation, with no strong trend for organic and innovative products and no subsidies for these innovative initiatives. On the other hand, scenarios B, C, and D represent potential future situations for the future. In **scenario B**, innovation in agri-food systems is fostered by increasing the number of available kitchens for collaboration, and a rural development that better connects farms to other farms and to consumers. **Scenario C** studies a scenario with a high interest for innovative and organic food from consumers. It tests the possibility to increase the number of innovative organic farms by giving subsidies in the year 2023 to promote the outscaling of interested farms. Finally, **scenario D** represents a future where farms engage more in biodiversity-friendly farming. For this reason, subsidies for biodiversity measures at farm-level are provided.

The parameters that characterize the scenarios are shown in Table 4. Different main products characterises the innovative farms of each region in FOODLEVERS project. As the main product of the farm, we selected zucchini for Flanders case study.

Table 4. Parameter values used in simulation to define the scenarios.

Scenario	Name	Parameter	Value
A	Innovative consumption trend	*Inn-consumer-trend*	0.2
	Number of group consumers	*Group-consumers*	50
	Subsidies (€)	*Subsidies*	0
	Subsidies for biodiversity (€)	*Bio-subsidies*	0
	Probability of links in the farm network	*Farms-links-probability*	0.05
B	Innovative consumption trend	*Inn-consumer-trend*	0.3
	Number of group consumers	*Group-consumers*	150
	Subsidies (€)	*Subsidies*	0
	Subsidies for biodiversity (€)	*Bio-subsidies*	0
	Probability of links in the farm network	*Farms-links-probability*	0.25
C	Innovative consumption trend	*Inn-consumer-trend*	0.4
	Number of group consumers	*Group-consumers*	50
	Subsidies (€)	*Subsidies*	10.000
	Subsidies for biodiversity (€)	*Bio-subsidies*	0
	Probability of links in the farm network	*Farms-links-probability*	0.05
D	Innovative consumption trend	*Inn-consumer-trend*	0.2
	Number of group consumers	*Group-consumers*	50
	Subsidies (€)	*Subsidies*	0
	Subsidies for biodiversity (€)	*Bio-subsidies*	1.500
	Probability of links in the farm network	*Farms-links-probability*	0.05

After performing simulations of the selected scenarios in 100 runs, we obtained some results for different scenarios. For the outcome percentage of innovative organic farms, we observed this percentage out of the total population (including both conventional and organic farms), as well as out of the organic sector, where only organic farms, mainstream and innovative, are represented.

First, we observe that the percentage of organic innovative farms is the highest in scenario B, with close to 4% of innovative organic farms in the whole farm population of Flanders (see Figure 15). On the other hand, the scenarios A and D which present the lowest values of innovative consumer trend also show the lowest percentage of innovative organic farms in the population. Similarly, scenario B shows the highest value for the percentage of innovative farms considering only the organic sector (see Figure 16). The lines in this graph decrease because the number of organic farms keeps growing, therefore decreasing the percentage of innovative farms.

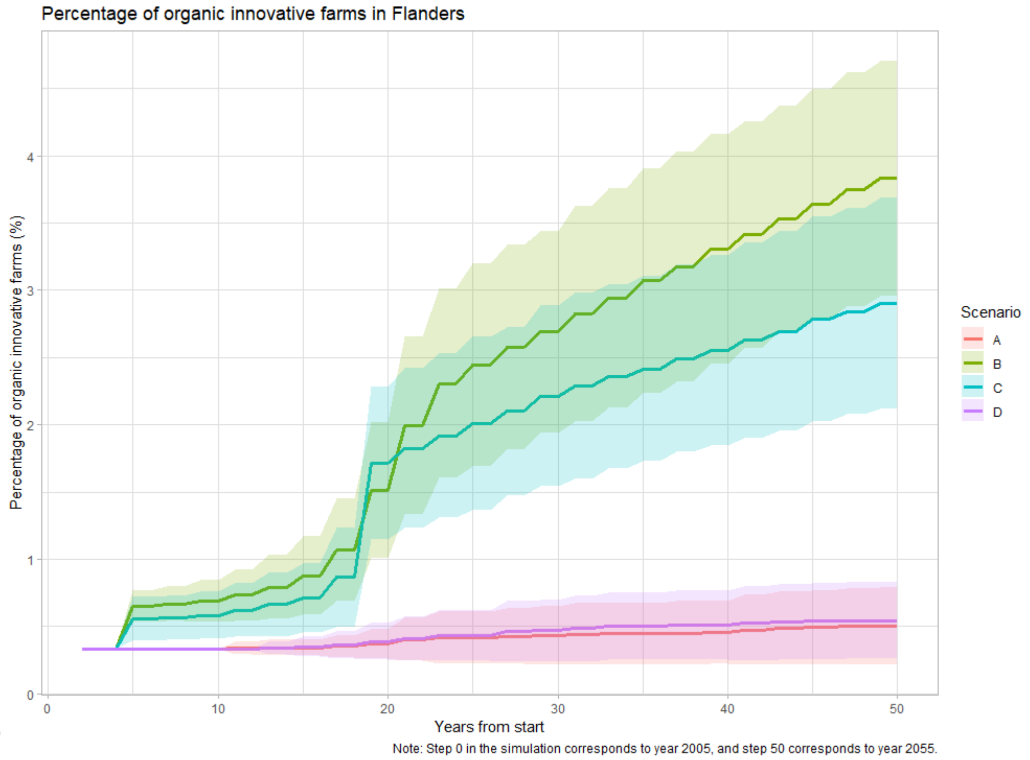

Figure 15. Percentage of organic innovative farms for four potential scenarios in Flanders.

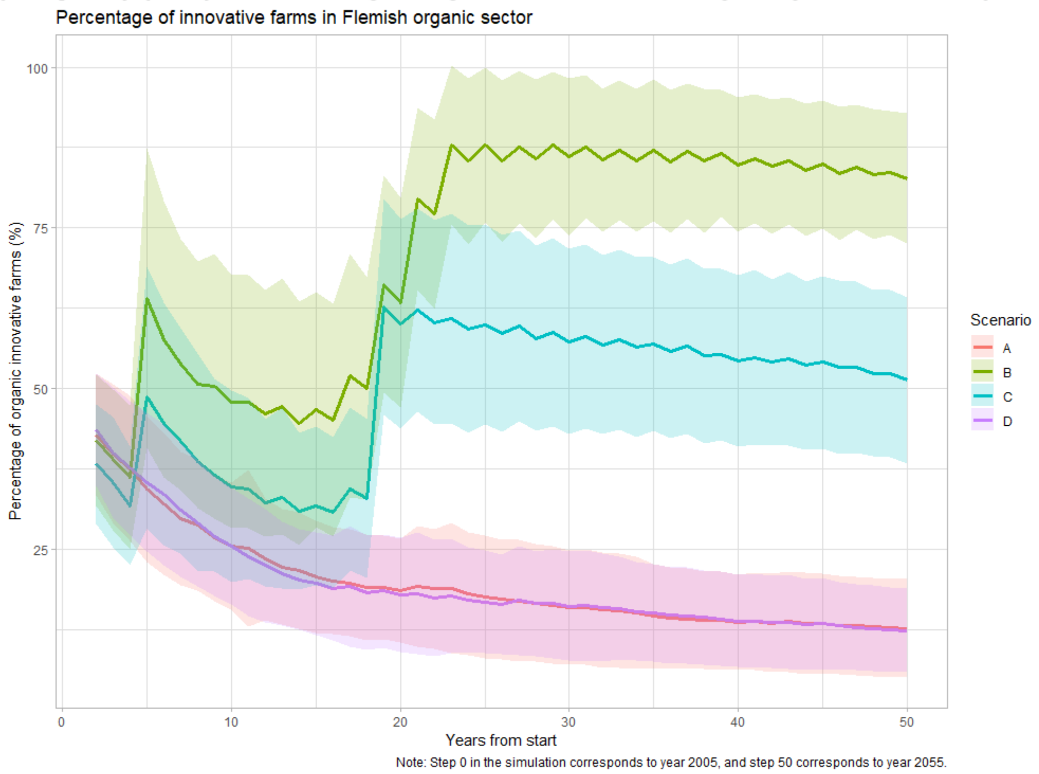

Figure 16. Percentage of innovative farms in the organic sector for four potential scenarios in Flanders.

For other outputs such as the area under organic innovative farms, we observe that scenario B estimates more than 1% of the agricultural land under innovative organic farming (Figure 17). Scenario C follows with 0.8% of innovative organic agricultural land. On the other hand, scenarios

A and D show the lowest value for agricultural land under innovative organic farming both with 0.15% of the total agricultural area.

The total food production in Flanders, based on the main product zucchini, is presented in the simulations for four potential scenarios (see Figure 18). Scenario B, the rural development scenario, presents the highest food production of zucchini with 4013 ton/year on average, while scenario D presents the lowest food production with a value of 845.5 ton/year on average. Scenario C presents 3203 ton/year of yield on average, and finally scenario A has lower values of yield equal to 861.6 ton/year. However, in scenario B and C, the number of innovative organic farms is much higher than in scenario A and D, which implies that there is more variation for the total food production due to the high amount of innovative organic farms that vary in farm sizes.

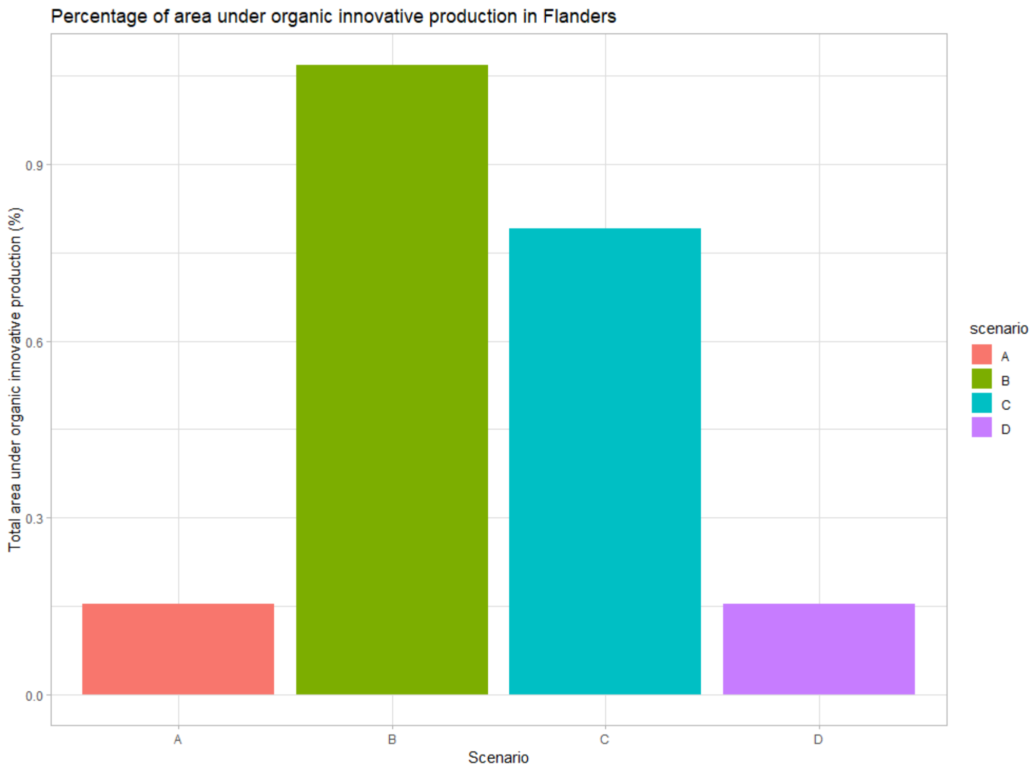

Figure 17. Percentage of area under organic innovative production for four potential scenarios in Flanders.

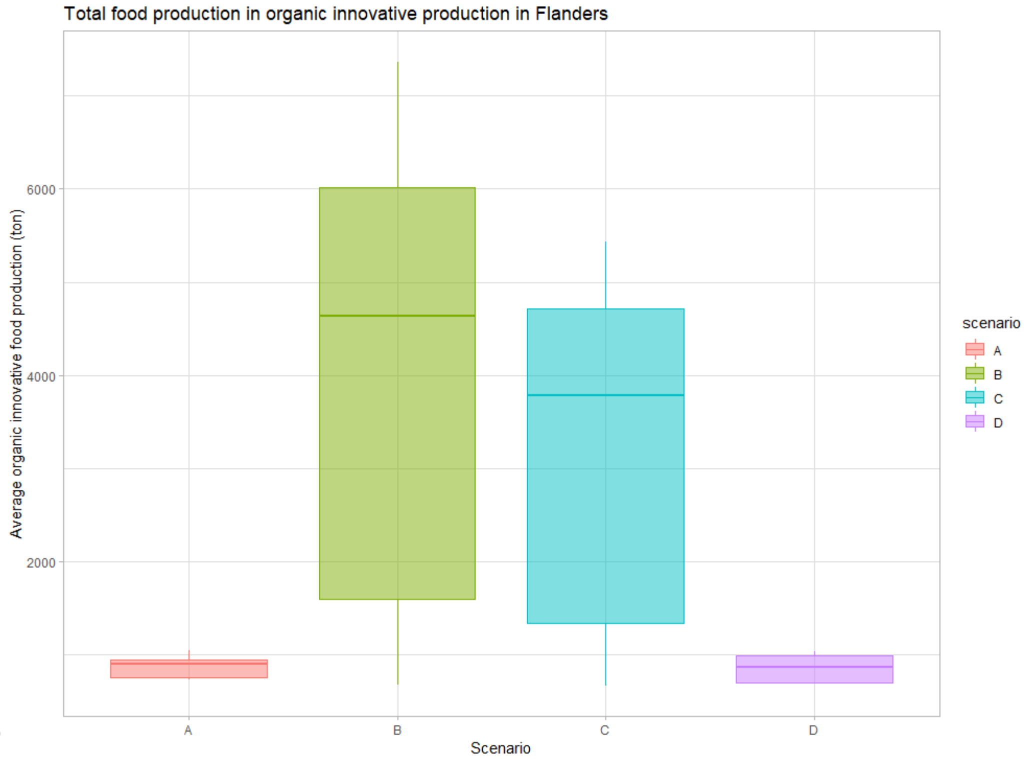

Figure 18. Total innovative organic food production for four potential scenarios in Flanders.

For the average total revenues, the values seem to present some variability among the four potential scenarios, between 19.000 and 26.000 €/year on average (see Figure 19). However, higher values and variation are shown in the biodiversity scenario D. Scenario D presents an average total revenues for innovative organic farms of 22.640 ± 7.512 €/year, showing the greatest variation in total revenues from all the scenarios. When observing the results of the average total revenues of innovative organic farms throughout the years of the simulation, we observe that although scenarios B and C are very similar, the peak in revenues corresponding to the subsidies can be observed in scenario C and D around the year 2023 (Figure 20).

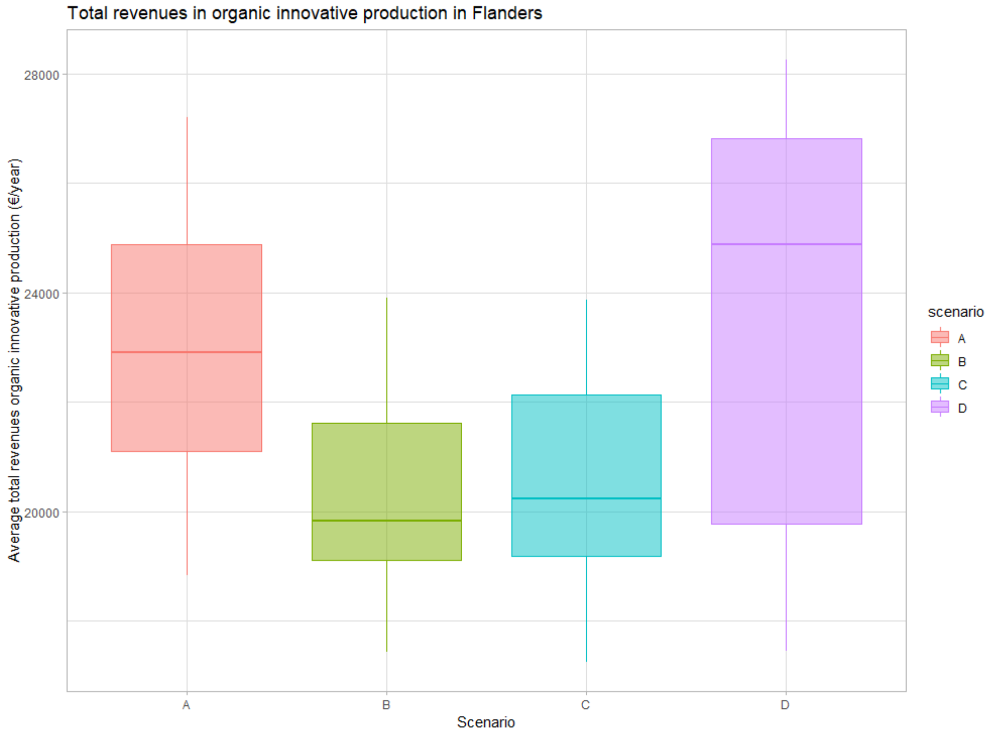

Figure 19. Average of total revenues in organic innovative production for four potential scenarios in Flanders.

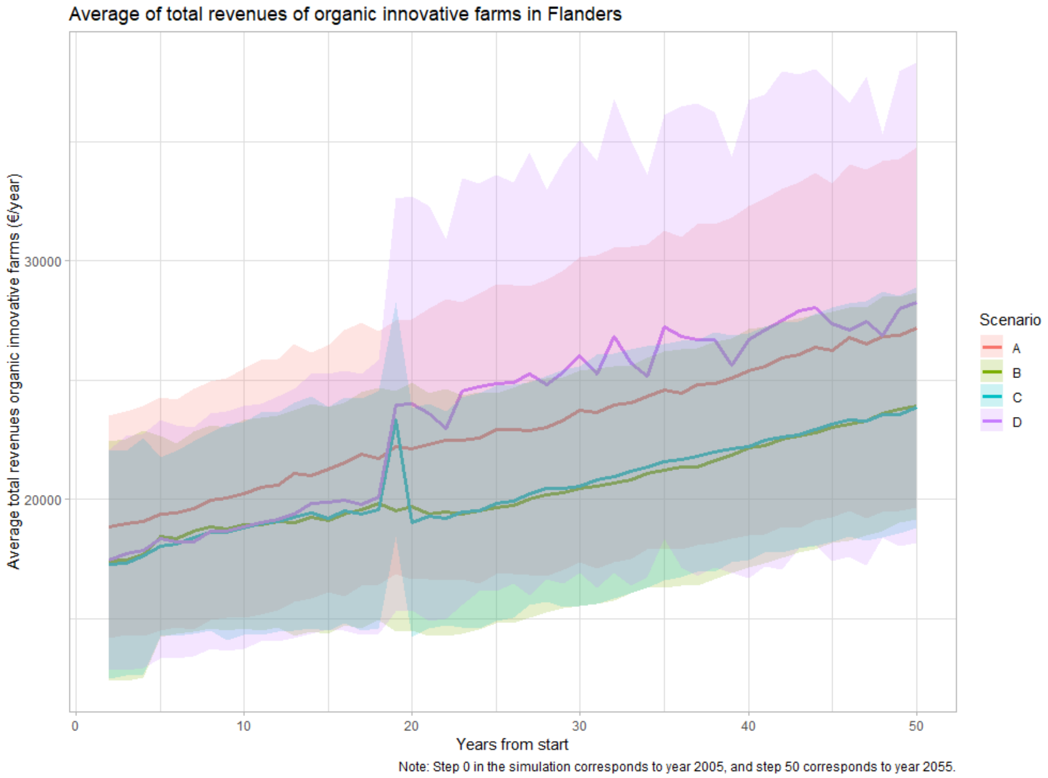

Figure 20. Average of total revenues of organic innovative farms for four potential scenarios in Flanders.

Lastly, in Figure 21, the average biodiversity measured in species richness in the whole environment is shown. Scenarios A, B, and C, where no measure for biodiversity is taken, show very similar values of biodiversity. In scenario D, subsidies for biodiversity are given to interested farmers[2], what results in an increase of the number of species in the community with a mean of 24.45 number of species.

[2] In the model, an assumption of 30% of farms interested in this subsidy is used.

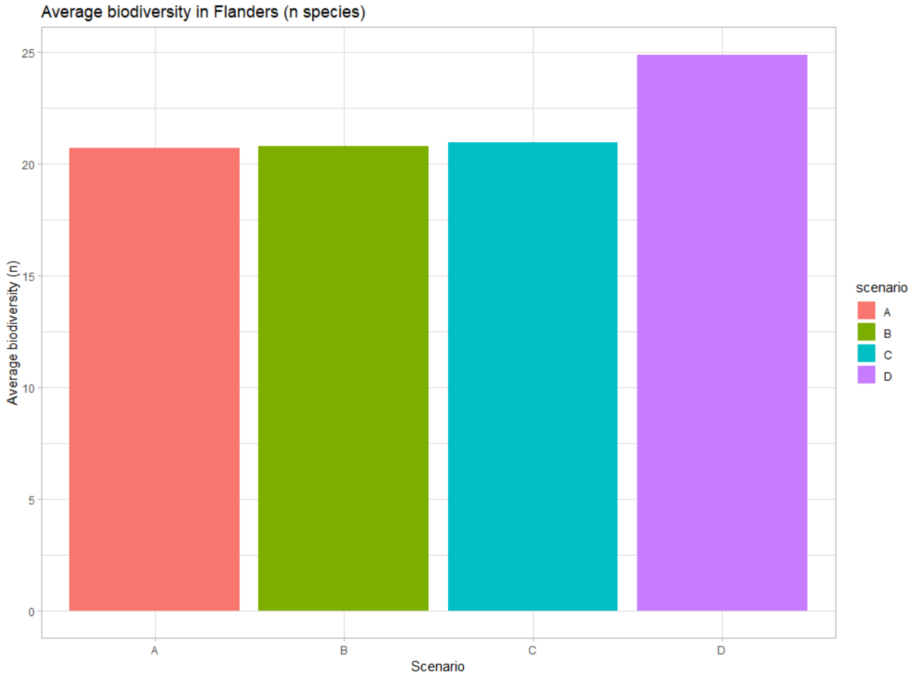

Figure 21. Average biodiversity for four potential scenarios is Flanders.

Limitations of the study

The limitations of the model as well as the analysis reported in this document are highlighted below:

- The non-homogeneity in data due to the inclusion of only one innovative farm and limited data coming from mainstream organic farms in some regions might affect the uncertainty level of the final results.
- Innovation criteria is quite varied among regions due to the diversity of organic farms and initiatives in the countries of study. This analysis is based on one sole case study in each region, therefore results must be taken with caution.
- Following the showcase of Flanders, we focused on zucchini production. However, in the model we use data from all organic vegetable farming in open air due to the lack of specific data in one single crop.
- Empirically-based results such as biodiversity rely on results for biodiversity in other project tasks such as the LCA analysis. Biodiversity studies should be performed in several innovative and mainstream organic farms in each region in order to provide more reliable results.
- Other environmental and social outcomes such as Quality of Life (QoL) and greenhouse gas (GHG) emissions need more data to be fully implemented in the model. Although these submodels are present in the ABM, more development is needed for them to show significant results between innovative and mainstream organic farming.

Scenario analysis conclusions

From the studied scenarios in Flanders as a showcase, we can extract some conclusions:

- Promoting the outscaling to innovative production by increasing the amount of available kitchens for collaborations with innovative organic farms and the connections between

farmers seems more effective than just giving subsidies for farms that would be suitable for scaling out even when there is a higher trend for innovative and organic production.
- Innovative organic food production increases in a scenario for rural development or with an increased awareness of consumers.
- The total revenues are higher and more varied in the biodiversity scenario because the subsidy is applied per hectare.
- A scenario with increased biodiversity presents benefits for revenues at the farm and number of species. However, it does not promote the scaling out to innovative organic farms.

4. Final conclusions

With this FOODLEVERS deliverable 3.2, we define the generic agent-based model developed to study three mechanisms (i.e., CSA, Farm network, Circularity) in three representative countries or regions (i.e., Flanders, Poland, Italy). Agent-based models and other computational models have been widely used to identify the most influential parameters in complex systems such as socioeconomic and climate sustainable scenarios (Moallemi et al., 2022).

As a showcase, we run simulations based on Flanders case study for the sensitivity analysis of the parameters as well as a scenario analysis. The results from the other two countries represented in the agent-based model simulations are also reported in different documents.

The generic agent-based model was able to represent three regions with different mechanisms, as well as to shed light into the understanding of sustainability transitions processes for innovative and organic farming. Complementary to other tasks within FOODLEVERS project, this ABM can recognize and include the leverage points from varied contexts that would help to scale out innovative organic initiatives. Identified leverage points to scale out innovative organic food systems are: **innovative consumption trend** for this kind of production, **low opportunity window threshold**, and engaging **more public kitchens** in such collaborations.

Due to the innovative nature of the selected case studies in the project, the model already includes re-thinking of sustainable farming systems, re-structuring of a shorten value chain, and re-connecting consumers to farming processes. Besides, ABM incorporates deeper issues in sustainability transitions such as structures, goals, and values in the decision-making process of farms. In other studies such as in (Pérez-Ramírez et al., 2021), they explore the understanding of factors that drive human-nature connectedness applying the leverage points perspective. In this article, the research goes beyond farm- or region-level to a more deep individual level. This aspect, although better capture through other methodologies, was included in the model from the interviews to innovative farms and discussions with experts.

The scenario analysis, set up from the qualitative scenario workshop held in the project, could outline some conclusions for future scenarios where these innovative organic farms are promoted.

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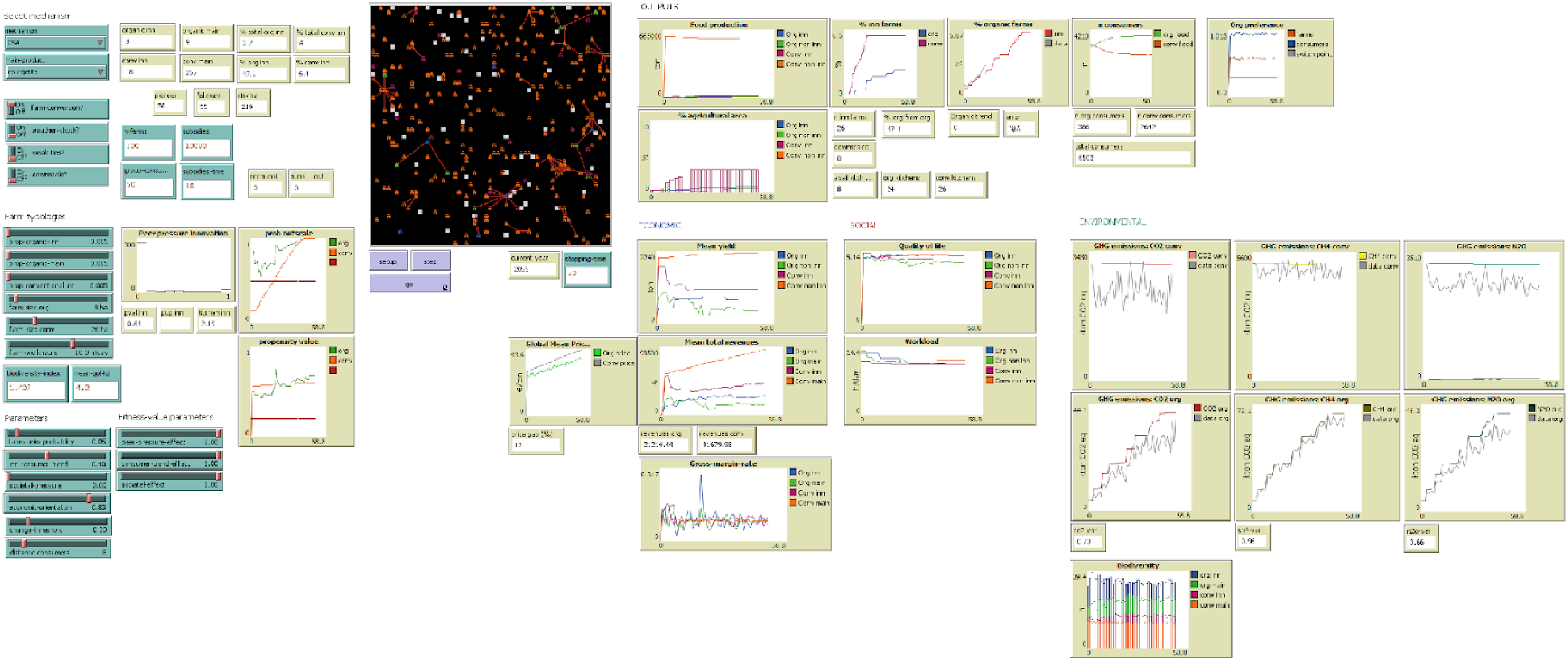
Annex 1

Overview of the model for FOODLEVERS project in NetLogo platform.



Annex 2

Table with parameters of the model.

Table 2- Parameter, name, range, value, description

Parameter	Name	Scale	Range	Units	Value	Description	Source
Number of farms	*n-farms*	regional	[0, 1000]	n	300	Number of farms in the simulation environment.	-
Proportion of innovative organic farms	*prop-organic-inn*	regional	[0, 1]	index	0.005	Ratio of farms that are innovative organic.	Inferred from total n farms, organic farms are approx. the 3% of total farms in Flanders.
Proportion of mainstream organic farms	*prop-organic-main*	regional	[0, 1]	index	0.005	Ratio of farms that are mainstream organic.	Inferred from total n farms, organic farms are approx. the 3% of total farms in Flanders.
Proportion of innovative conventional farms	*prop-conventional-inn*	regional	[0, 1]	index	0.005	Ratio of farms that are innovative conventional.	-
Organic farm size	*farm-size-org*	regional	[0, 100]	ha	8	Mean size of organic farms.	Excel data DLV
Conventional farm size	*farm-size-conv*	regional	[0, 100]	ha	26	Mean size of conventional farms.	LARA 2020
Farm links probability	*farms-links-probability*	regional	[0, 0.5]	index	0.05	Defines how dense are the links between farms that define the network.	Parameter to test
Innovative consumption trend	*inn-consumer-trend*	regional	[0,1]	index	0.1	Defines the trend that is pushing toward organic and innovative food consumption through e.g. social media, demand,…	Parameter to test
Change threshold	*change-threshold*	global	[0, 1]	index	0.2	Defines when the threshold to outscale starts, opportunity window threshold.	Parameter to test
Distance to consumers	*distance-consumers*	regional	[0, 50]	NetLogo's distance unit	8	How far does the farm provide food to their consumers.	Parameter to test
Workload of the farmers	*farm-workhours*	regional	[1, 15]	h/day	10	How many hours does the farmer work at the farm.	Literature
Mechanism of the farm	*mechanism*	regional	[CSA, Farm network, Circularity]	-	Depends on the represented region	Which one of the three observed mechanisms in FOODLEVERS project is the simulation environment representing.	FOODLEVERS project participatory sessions

Main product of the farm	*main-product*	regional	[“carrot”, “zucchini”, “beef”, “egg”]	-	Depends on the represented region	Main product produced at the farm.	FOODLEVERS case study
Farm conversion to organic	*farm-conversion?*	regional	boolean	-	true	Allows farms to convert to organic farming under predefined circumstances.	Statistiek Vlaanderen
Weather shock to crops	*weather-shock?*	global	boolean	-	false	Allows weather shocks to randomly happen in the simulation.	"Analysis of CC in Europe by 2050", JRC EECC. In North Europe, 1-14% crop reduction, and in South, 4-22% crop reduction (for maize). Thus, 1-22% crop loss as general first approach for this model. IPCC losses of more than 25% IPCC 2022 chapter 5.
Weak ties	*weak-ties?*	global	boolean	-	false	Allows weak ties in the farm network.	Parameter to test.
Price of the organic product input	*crop-input-org-farm*	regional	-	€/ton	Depends on *main-product*	Cost of the organic input for the farm. Calculated from data.	Landbouwcijfers, FOODLEVERS’s tasks, literature.
Price of the conventional product input	*crop-input-conv-farm*	regional	-	€/ton	Depends on *main-product*	Cost of the conventional input for the farm. Calculated from data.	Landbouwcijfers, literature
Number of group consumers	*group-consumers*	regional	-	n	50	Number of patches with group consumers in the simulation environment.	Parameter to test
Subsidies	*subsidies*	regional	-	€	0	Subsidies for farms that are susceptible to outscale.	VLIF 2023
Subsidies application time	*subsidies-time*	regional	[0, 50]	year	18	Year from start in the simulation in which the subsidies are being applied.	18 ticks in NetLogo model correspond to the year 2018, since the simulation starts in 2005.
Economic orientation	*Economic-orientation*	global	[0, 1]	ratio	0.83	Maximum ratio of revenues that the farmers would accept from which they would consider it an economically bad year.	LARA 2020

Annex 3

Modelling concepts

Innovative: We define as innovative farm those farms that are replicating the same business model as the innovative farm of reference in the FOODLEVERS project for each region. That is, for CSA mechanism, innovative farms are CSA farms collaborating with nearby institutions with public kitchens; for Farm network mechanism, innovative farms are a network of farms connected to each other working for a common goal to be more sustainable; and for Circularity mechanism, innovative farms are reducing their costs by closing their cycles and being more sustainable.
Mainstream: We define as mainstream farm those who follow the conventional or organic farming production types.
Mechanism: This defines the innovative business model employed by the farm, and it was validated throughout FOODLEVERS project. To cluster the seven case studies from the project, we came up with three main mechanisms that can represent the mentioned case studies. These are further explained in Figure 2.

Figure 2. Studied mechanisms in FOODLEVERS project, included in the agent-based model.

Scaling out/outscale: That means that a mainstream farm changes their business model and adopts the innovation as it is defined per mechanism.
Scaling down/downscale: That means that an innovative farm does not longer want to keep the innovation method of production and become mainstream again.

NetLogo specific coding therminology

Agent: Agents are the main entity in agent-based models that represent anything that can have decision-making and are defined by different attributes. In our model, agents are farmers and consumers.
Ask: It allows us to ask one or more agents (i.e., turtles, links, patches) to follow a provided set of rules.
Boolean: A binary variable or parameter that can have 2 possible values: false (0) or true (1).

Grid: A framework of spaced bars that are parallel to or cross each other. In NetLogo, it is defining the physical space to represent and visualize the agents, the patches and their links.
Let: This creates a new local variable and sets its initial value.
Parameter or variable: A numerical or other measurable factor forming one of a set that defines a system or sets the conditions of its operation. The parameters that can be changed between simulations are displayed in NetLogo interface. Variables with ? represent Boolean variables.
Patch: Patches are a special kind of stationary agents in NetLogo that make up the world of a model, forming the grid to visualize the agents. More specifically, patches are as the squares that make up the grid in NetLogo.
Set: This sets the specific variable to the given value.
Tick: A tick is a measure that represents time in NetLogo models. In our model, we define each tick as a year.