MIXED

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Executive Summary

Crop-livestock collaborations beyond farm level are recognized as promising options to i) achieve environmental interest in crop-livestock systems regarding circularity in inputs while ii) overcoming work limit constraints at the farm level. Still, establishing exchanges (buying/selling of feed or manure) among farms can be rather complex in terms of logistics and collective organization. Co-design could thus be a relevant options to build scenarios with farmers considering their practices and context. The aim of Task 5.3 was to develop a landscape level participatory game, Dynamix, to help farmers develop crop-livestock integration scenarios farms.

The game is part of a six step participatory approach: (1) To assess the current situation, an initial collective meeting allows defining the problem situation. (2) Then, individual farmers are interviewed to gather their motivations, their resources and technical and economic farm data. (3) A co-design meeting is organized with the group of farmers using the serious game Dynamix combining a spatially explicit board game to a model allowing to design and evaluate crop-livestock integration scenarios among farms. (4) A multicriteria evaluation of these scenarios is led at the individual farm and at the group level and (5) The results of the evaluation are discussed collectively at a meeting and a scenario is selected. (6) The scenario implementation is then monitored. We implemented this approach with two groups of farmers in Southwestern France.

A prototype has been developed by INRAE and is detailed in the previous deliverable of task 5.3. (Prototype version of the game – Ryschawy et al., 2022). A major interest of Dynamix tool is because it provides a standardized method to co-design crop-livestock integration beyond farm level and is easily applicable to other case-studies. The participative approach has been scaled-out to three other MIXED landscape case-studies (Denmark, Scotland and the Netherlands).

Abbreviations

D	Deliverable
Dynamix	DYNamics of MIXed farming systems
EC	European Commission
WP	Work Package
WT	Work Task

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1 Introduction

Crop-livestock collaborations beyond farm level are recognized as promising options to i) achieve reduced environmental impacts through integrated crop-livestock systems in relation to circularity in inputs while ii) overpassing the potential work limit constraints at the farm level (Martin et al., 2016). However, establishing exchanges (buying/selling of feed or manure) among farms can be rather complex in terms of logistics and collective organization (Asai et al., 2018). Co-design could thus be a relevant options to build scenarios with farmers considering their practices and context (Ryschawy et al., 2019).

The aim of Task 5.3 was to develop the landscape level participatory game, Dynamix, to help farmers develop crop-livestock integration scenarios farms in the selected networks. A prototype was developed by INRAE and detailed in the previous deliverable of task 5.3. (D5. -3. Prototype version of the game). A major strength of the Dynamix tool is because it provides a standardized method to co-design crop-livestock integration beyond farm level and is easily applicable to other case-studies. The objective of this deliverable is to present the adaptation of the participative approach to the three other case-studies involved (Denmark, Scotland and the Netherlands).

2 A six-step participative methodology including Dynamix

2.1 General presentation of the participative approach, including Dynamix game

Before focusing on the adaptation of the game to the different MIXED networks, a recap on the participative methodology and game is provided in this section. The details on the game are provided in the previous deliverable on Dynamix game prototype (D5.3.). The participative approach consists of six steps which will be developed in more details in this deliverable :

(1) To assess the current situation, an initial collective focus group meeting is held to define the problem situation and potential scenarios to be tested.

(2) Then, individual farmers are interviewed to gather their motivations, their resources and technical and economic farm data.

(3) A co-design meeting is organized with the group of farmers **using the serious game Dynamix**, which combines a spatially explicit board game and a system model. The game allows the farmers to design and evaluate crop-livestock integration scenarios among farms.

(4) A multicriteria evaluation of these scenarios is undertaken at the individual farm and at the group level.

(5) The results of the evaluation are discussed collectively at a second collective meeting and a scenario is selected.

(6) The scenario implementation is then implemented in real life and monitored.

The participative approach is to be undertaken with small local groups of crop and livestock farmers. In each group there should be between 5 and 15 farmers. The methodology developed was inspired by Moraine et al. (2017), developing the first adaptive methodology to co-design scenarios of crop-livestock integration beyond farm level, *e.g.* selling grain and fodder within collectives of neighboring farmers. This method was a first step to support the design of sustainable collective crop-livestock systems considering both the technical specific constraints of agroecosystems and the objectives of farmers. The method was based on five steps that are inspired by Börjeson et al.'s (2006) guidelines for designing future-oriented scenarios (Figure 1).

The adapted assessment framework developed by Moraine et al. (2017) was used firstly to co-produce with farmers and advisers a diagnosis of strengths and weaknesses of farms using post-its. Then, technical and organizational options for change were suggested considering i) the objectives of the farmers (e.g. work management, economic viability,…) and ii) other sustainability indicators (biological regulation, social learning and capacity building, embeddedness of agriculture in the territory, integration in public policies).

This method allowed to identify the potential for new crop-livestock interactions between farms and to quantify the potential fluxes between farms through a collective need-offer balance but did not represent explicitly the fluxes on a map. We worked in continuity with this approach but improved it to co-design spatially-explicit crop-livestock integration scenarios between farms, while considering further the logistical aspects (e.g. storage, transportation, …). We thus adapted the Step 3 though the creation of Dynamix game allowing to co-design technical and logistical scenarios on a map of the collective and added a sixth step to address the implementation of changes.

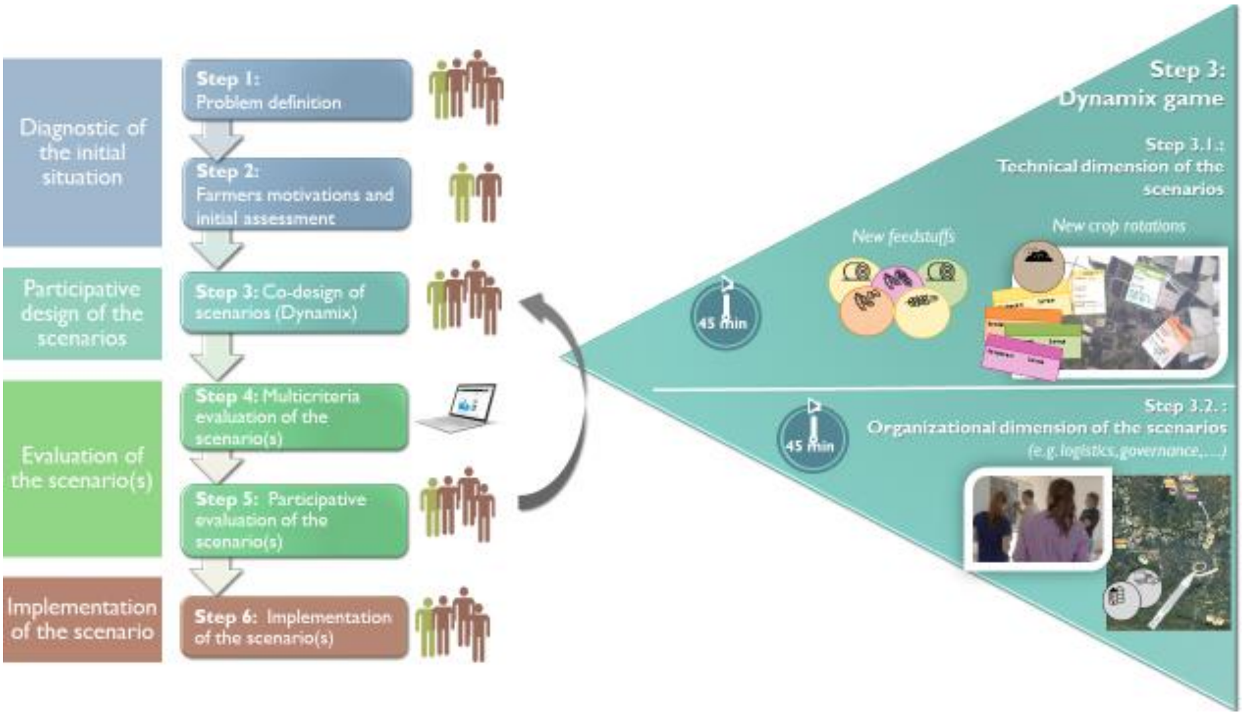

Figure 1. The six-step participatory approach including the serious game Dynamix (DYNamics of MIXed systems) to co-design crop-livestock integration among farms

2.2 Detailed presentation of each step

2.2.1 Step 1 – Problem definition

The first step consists of a group workshop to define the current problem to deal with regarding crop-livestock systems beyond farm level : "Which crops and grassland would be relevant to diversify crop rotations while limiting inputs, especially when feeding animals?". The question can be reframed regarding specific local objectives such as carbon-positive cropping, water quality management, increase of grassland in the area, etc. and especially as asked by farmers in WP1. For this first participatory meeting, a local advisor that is knowledgeable about the local area and farmers is contacting farmers and animating the debate with at least one researcher. The farmers invited are both reached through a mailing list of local farmer associations interested on the topic and directly for farmers, who already showed interest in the approach. Groups of 10-20 farmers could participate.

In a session using Post-it® notes, each farmer of the group has to think individually for 10 minutes to provide his/her main technical and organizational issues and expectations for the group reflection (this step could be based on WP1 issues and solutions) . Then a mind map is created collectively from these notes to classify the issues and levers into main categories and discussed for about an hour to prioritize issues to be considered in the participatory approach (Kelemen et al; 2013).

At the end of the meeting, we organized groups of farmers to follow the process collectively. For this, we relied on Pahl-Wostl and Knieper (2014) defining three types of governance regimes, which we adapted to crop-livestock exchanges beyond farm level: fragmented (one-on-one exchanges), polycentric (small interconnected groups) and centralized (*e.g.* cooperative). In agreement with our previous studies of this topic, we prioritize scenarios considering polycentric governance regime, as we considered an intermediary option between fragmented governance that would not allow in-depth redesign of farms and centralized governance, that was already existing locally through cooperatives and limiting the marketing options for crop diversification for the farmers. We thus build small groups of 10-15 farmers for next steps, being able to include/contact new farmers if recommended by participants, as snowball sampling allows to include neighbors and/or farmers with whom trust is already established. The distance between farmers in all groups had ideally to be under the 25 km recommended by Asai et al. (2014) to facilitate logistics.

2.2.2 Step 2 – Farmers' motivations and initial assessment

In the second step, researchers collect technical and economic data about each farm from Step 1. Based on a standardized interview guide, data are collected about farm resources (e.g. land area, soil types, animals, equipment, irrigation, workforce) and practices (e.g. grazing management, feeding management, tillage). More detailed questions on motivations are asked through an open-ended part of the interview to help researchers understand the farmer's motivations for exchanges, the products he/she would like to supply or demand and why, logistical aspects and the form of governance he/she would like the group to implement. Analysis of the interviews provide i) an initial "Scenario 0" of supply-demand for each product within the group, based on the products mentioned by the farmers as exchanged or sold and ii) comprehensive analysis of farmers' motivations.

2.2.3 Step 3 – Group design of scenarios using Dynamix

The third step is the effective co-design of scenarios using the serious game Dynamix. Dynamix help them design exchanges among themselves to achieve local self-sufficiency in inputs when self-sufficiency is not possible at the farm level. The technical objective of the collaborative arrangement beyond farm level was thus to balance the supply and demand of each type of product; for instance, crop farmers supply grain maize from their rotations, while livestock farmers can demand it to feed their animals. Dynamix combines a spatially explicit board game representing the collective area and the farms and a model allowing to evaluate the crop-livestock integration scenarios among farms. Farmers are first invited to suggest innovations on their farm in an individual step and then to design and discuss logistics during a collective step. A standardized game session using Dynamix lasts about 2 hours and will be detailed in the following sections. The prototype of the game will be detailed further in part 3 detailing the board game utilization and part 4 detailing the model and multicriteria evaluation.

Sub-step 3.1. – Technical dimension of the scenarios

In the first sub-step of the game session, farmers redesign their own farms using game pieces and cards that represent the products and by-products that they would sell or buy (Figure 2). Crop farmers redesign their cropping system with the help of the local advisor and/or researcher, who facilitate the session and help them identify the game pieces and cards. Crop farmers receive a map of their fields and are asked to suggest (new) crops or grassland that they would produce to sell the products to the livestock farmers and precise the area and yield expected. In return, they may expect manure and should quantify the volume they need. Each type of product is represented by a color so farmers can observe the increase in diversity visually: cereals in yellow, oilseed and protein crops in orange, grassland (and grass hay/silage) in green, mixed crops in rose, manure in brown and straw in light yellow.

Meanwhile, livestock farmers redesign their feeding systems using the boardgame of Forage Rummy (Martin et al., 2011), to ensure they will not decrease self-sufficiency in feedstuffs while sourcing more local grain and/or fodder. Each farmer receives a board representing 13 periods of four weeks, i.e. one year, on which they have to detail their own crops and grasslands with sticks marked with year-round grain or forage production and animal feeding requirements. The consequent need-offer balances at the farm level are calculated by the advisor through the computerized support system but the feeding system adaptation can be made without computer if the livestock advisor is able to adapt it properly and advise the farmers. This step lasts approximately 45 minutes and crop farmers are able to discuss options to implement with livestock farmers along the step.

Sub-step 3.2. – Organizational dimension of the scenarios

In the second sub-step of the game session, we proceed in a roundtable during which farmers successively place their game pieces and cards on a A0 poster representing a map of the area. They are invited to explain their technical proposals from Step 3.1. to the rest of the group (eg. adding a 3 ha of barley to sell grain to livestock farmers, …). The facilitator is meanwhile informing the collective need-offer balance table to give some quantifications for each product and help farmers adjust the exchanges and adapt their choices accordingly. Finally, farmers are invited to concretely consider logistics issues considering the map and fluxes of products planned previously. As detailed in Figure 2, they get storage and transport tokens to write the type of products they could store for the group and volume and/or specify lacking storage facilities. They consider transport issues the same way and imagine the better path looking at the map to facilitate transportation. They are invited to use a white felt tip pen to draw any important organizational element (weighbridge, possible route) but also other farmers who can join the group. This sub-step helps them organize the logistical aspects visually. They finally discuss the governance they would like to adopt (polycentral or more centralized or even hybrid with some 2-by-2 exchanges), several barriers to and mechanisms for implementing the scenarios and a future schedule to continue the work. This step lasts approximately 45 minutes.

Figure 2. Boardgame and boundary objects used in the serious game Dynamix

On the top corner left, the individual boundary objects for cereal growers: 1. On a map of their fields, the crop farmer is given square cards to detail crop "offer", corresponding to crops, grassland or cover crops to be inserted in their rotation and sold to the livestock farmers, they can detail all technical operations and *summarize major information (type of crops/area/yield expected) on 3. little square card to be used in the following stage an mentionning only the crops/grassland selected along with yield and area they plan to dedicate to this land-use and 4. They may use a round “demand” token to require manure.*

At the bottom left, the individual design supports the livestock farmers, e.g. 1. Forage rummy board and cards to detail animal types, feed requirement and feeding systems, 2. Model to test the balance between crop/grassland production on-farm and animal feed requirements, 3. Round tokens to write down the “demand” of fodder and/or grain to ask crop farmers to produce and 4. organic manures offered on brown "supply" circles.

On the right, the organizational dimension step is illustrated. This is based on 1. a map of the collective area including all the farms on which farmers will position the “offer” cards and “demand” circles they used on the previous step, e.g. x ha of alfalfa at y t dry matter per ha, at the location of their farm headquarters and then 2. design the logistics with specific storage and transport tokens, on which they state precisely the type of product to be stored/transported and volume and 3. At the end, they may add anything needed for next steps using a white felt tip pen, e.g. new farmer, local cooperative material, …

2.2.4 Step 4 – Multicriteria evaluation of the scenarios with Dynamix model

In the fourth step, scenarios are evaluated using Dynamix to i) quantify supply-demand balances of the crops, fodder and manure exchanged and ii) perform multicriteria evaluation at the farm and group levels. The multicriteria grid has been adapted from previous studies on farm sustainability and in particular sustainability assessment of crop-livestock systems beyond farm level (e.g. Moraine et al. ,2017; Ryschawy et al., 2019). The farmers have the possibility to adapt the multicriteria grid to their specific objectives and issues and thus choose and/or rank indicators within the full list. This is known to help them projecting themselves and make the scenarios more concrete (Lamarque et al., 2011). The detailed information needed and list of indicators will be detailed in part 4.

2.2.5 Step 5 – Group evaluation of the scenarios

In the fifth step, a participatory meeting is organized with the group to discuss the results of scenario evaluation. This step includes the initial group of farmers and involve new farmers, who were cited during the Dynamix game session in Step 3 and were interested. After having presenting the need-offer balance and evaluation for each scenario designed in Step 3, the limits and perspectives are discussed, especially trade-offs between individual and collective objectives and performances to identify the scenario offering the best compromise for each farmer and for the collective of farmers. The scenario can be adapted to include new farmers and new ideas since Step 3. The meeting last about 3 hours meeting that includes refreshments to foster ties among the farmers.

2.2.6 Step 6 – Implementation of the scenario

In the new sixth step, that we added in this study, we continue to work with the group to help the farmers implement the changes suggested in the scenario they had selected. We monitored the occurrence of expected and unexpected results through on-farm observation and discussions with farmers and their advisors. For each technical innovation (either new crop seeded, either new fodder or concentrate), a dedicated local advisor is visiting the farmer to help him, monitor the results and give him any needed technical information. The researcher is calling back every 2-3 months to discuss with the farmer about his/her needs and participating to any collective meeting organized locally with farmers and the Agricultural Chamber.

2.3 A focus on the model and data needs

The model of Dynamix is based on two main components : i) a need-offer balance tool considering the level of self-sufficiency in animal feeding and manure and other inputs for each individual farm and at collective levels and ii) a multicriteria evaluation. Figure 3 is summarizing the data needed as input for the simulation and outputs provided by the Dynamix model. Farmer interviews (step 2 and/or WP2) and national databases provide information to inform the model.

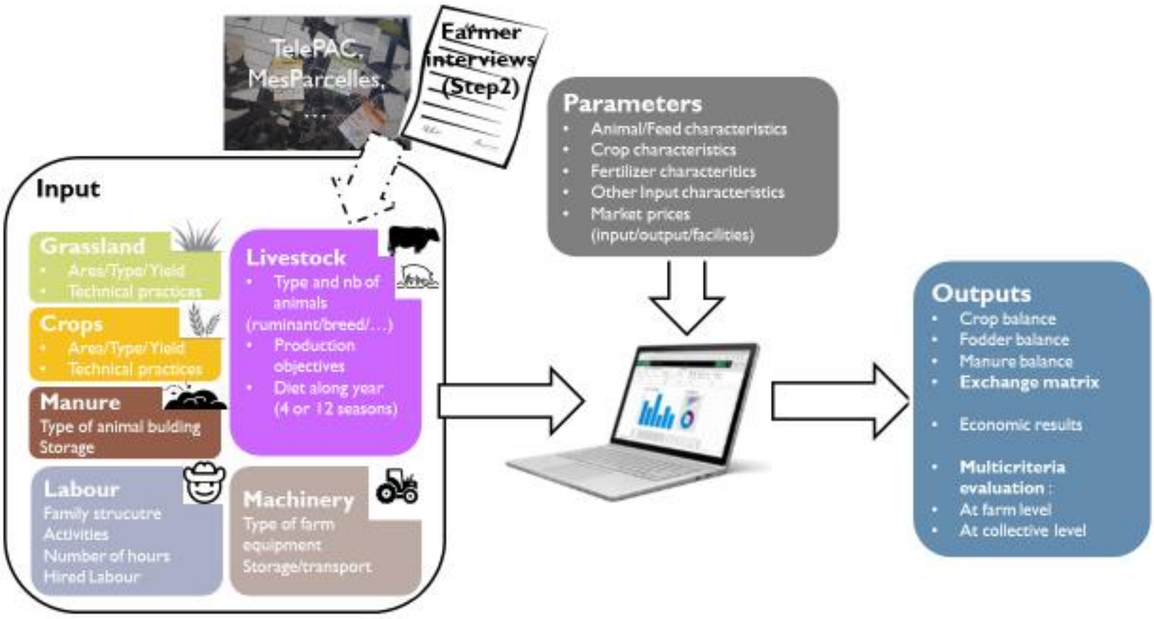

Figure 3. Data needed as input for the model of Dynamix serious game and output provided

2.3.1 Quantifying need-offer balances

The baseline scenario (S0) is calculated using the farm survey data in step 2 for each individual farm and at the collective level. For each farm, we entered animal feeding and crop production according to farm survey data. As individual and collective levels are dynamically interlinked, the sum of farm level needs and offers enables information regarding the needs and offers at the collective level. A synthesis table, with the farmers in rows and products in columns, can be used to summarise and assess the balance between supply and demand for each crop and grassland products (i.e., to feed animals) and for manure at the collective level.

To evaluate the scenarios designed, crops with potential to be exchanged (new or already present on farms) and their yields were estimated according to farmers' information and/or national or local database (e.g. Agreste, Terrunivia and Arvalis). Potential crop area and observed yields were considered for the crops and grasslands already produced on each farm. For crops that were not yet produced on the farms, we used either the yield of neighboring organic farms growing this crop or the regional reference yield published by the regional federation of organic farmers. Organic manure production and organic alternative crops suitable for animal feeding were quantified on the basis of local and national references on organic farming. Animal needs were based on a research database from INRA (2007) and fertiliser quantity and content were based on CORPEN (2001). Farmers were asked directly about their willingness to provide manure to crop farms. The costs of inputs were quantified according to values from farm surveys representing the current situation. At the collective level, we analyzed the consistency of the technical changes implied by each scenario with our supply– demand balance model for fertilizer and feed inputs (i.e., Moraine et al. 2017), using scenario 0 (current situation) as the reference.

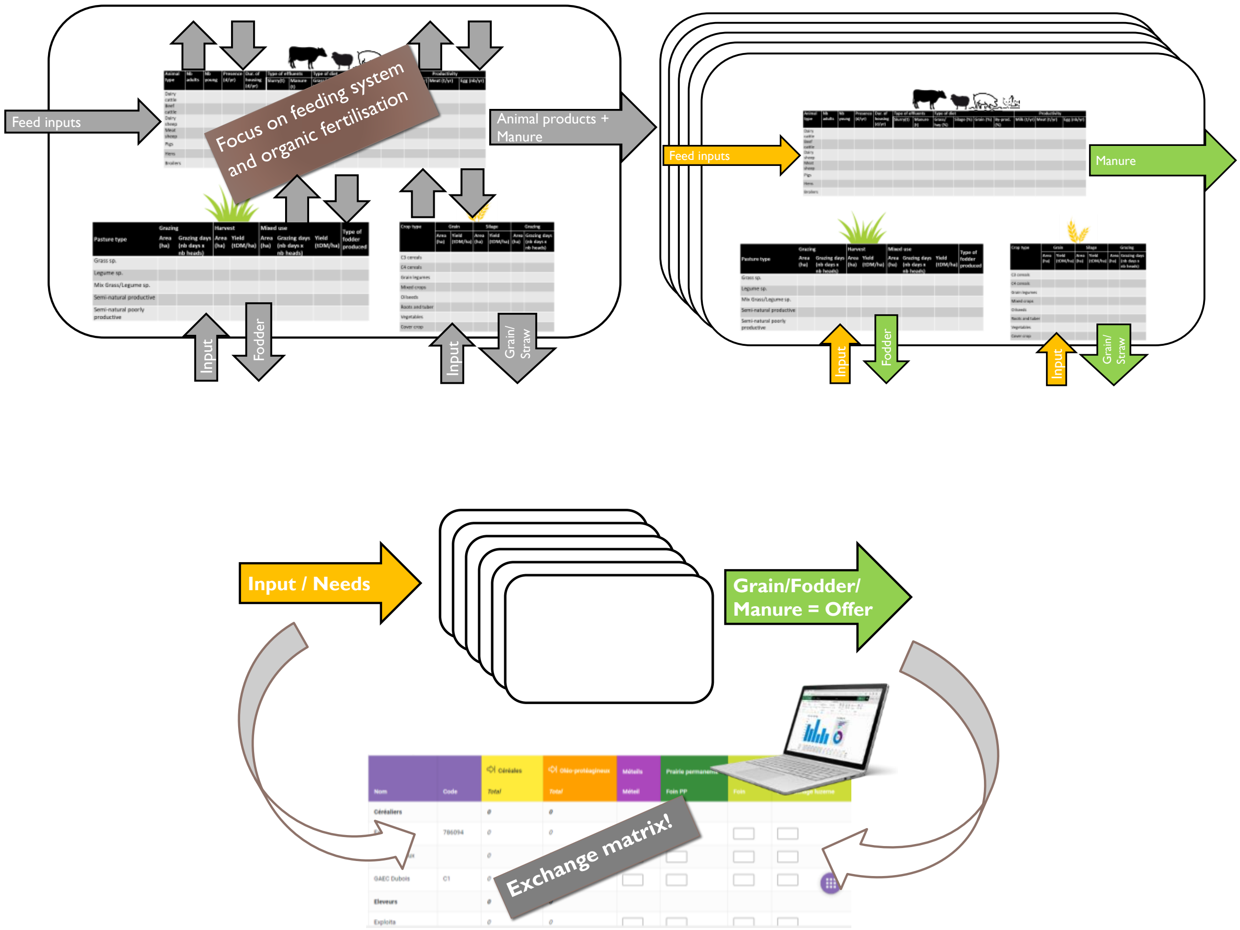

Figure 4. Fluxes considered in the Dynamix serious game model and interlinkage between farm and collective levels.

On the top left corner, the fluxes considered are represented at the farm level, e.g. within the farm between herd, grassland, crop and manure components and input and outputs from the fam. Then the farms are aggregated to keep only the needs and offers to scale-up to the collective level (top right corner). The information is summarized within the exchange matrix with all farmers in line and products exchanged in column.

2.3.2 A focus on multicriteria evaluation

Within the multicriteria assessment we considered four key domains to evaluate the scenarios i) efficiency of flows of products, nutrients and energy, conceptualized as the system metabolism; (ii) ecosystem services to agriculture; (iii) socioeconomic performances and knowledge management; and (iv) social embeddedness of farming systems. For economic, environmental and social dimensions, 24 indicators are calculated at the farm level (11, 10 and 3, respectively) and 7 are calculated at the group level (3, 1, 2 respectively). Table 1 details the full list of indicators available. Calculating all indicators requires approximately two hours per farm. For each group of farmers, a specific set of indicators can be selected to ensure relevance, within this large multicriteria grid.

Table 1. Multi-criteria analysis framework developed to evaluate scenarios of crop-livestock integration beyond farm level (adapted from Ryschawy et al., 2019 and 2022)

Dimension of sustainability	Category of criteria	Criteria considered	Indicator evaluated	Reference
Agro Environment	Biodiversity and biological regulations	Temporal diversity of landscape mosaic	Percentage of land dedicated to major land-use (%)	Joannon et al. (2008)
			Percentage of Utilized Agricultural Area (UAA) dedicated to grasslands (%)	Joannon et al. (2008)
			Percentage of UAA dedicated to monoculture (%)	Joannon et al. (2008)
			Percentage of UAA dedicated to legumes (%)	Joannon et al. (2008)
			Intra-field mixture (>%)	Joannon et al. (2008)
			Simpson Index	Sabatier et al. (2008)
			Crop Succession Index	Castoldi et al. (2008)
		Spatial diversity of landscape mosaic	Equitability between crops and semi-natural elements	Legendre et al. (2014)
			Density of semi-natural elements	Legendre et al. (2014)
			Connectivity of semi-natural elements	Legendre et al. (2014)
			Mean field size per crop type (ha)	Joannon et al. (2008)
	Fertilization management	Soil erosion management	Estimated soil losses (t/ha/year)	Witschmeier et al. (1985)
		Fertilization	Farm-gate nitrogen balance (kg/ha)	Simon et al. (2000)
			Farm-gate phosphorus balance (kg/ha)	Simon et al. (2000)
			Intermediate crop nitrate-trap (ha)	
	Energy dependence		Fuel consumed (€/ha UAA)	
Economic	Economic farm results	Efficiency of production process	Economic efficiency	Zahm et al. (2008)
		Economic margin	Gross operating profit – Earnings Before Interest, Tax, Depreciation and Amortization (EBITDA)	Zahm et al. (2008)
	Self-sufficiency	Economic self-sufficiency	Dependence on total inputs (%)	Zahm et al. (2008)
			Dependence on animal feed inputs (%)	
			Dependence on fertilizer inputs (%)	
			Dependence on public subsidies (%)	
		Use of local resources	Inputs from the local area (%)	Moraine et al. (2017)
		On-farm self-sufficiency	Self-sufficiency in forages (%)	Zahm et al. (2018)
			Self-sufficiency in concentrates (%)	
		Local inputs for animal feeding	Forage from the local area (%)	Moraine et al. (2017)
			Concentrates from the local area (%)	
Social	Work time	Work organization	Estimated time available (h/year)	Dedieu et al. (2000)

	Time invested in training	Knowledge sources	Amount of training (h/year)	Moraine et al. (2017)
	Time invested in the collective	Collective work	Time worked with/for the other farmers (h/year)	Moraine et al. (2017)

Self-sufficiency in inputs and nitrogen balance are calculated at both levels and used to analyze trade-offs between individual and group levels. As a previous study highlighted that operational costs and environmental impacts decrease while workload and logistical costs increase, the trade-offs between individual and collective benefits need to be considered in decision-making at the collective level (Ryschawy et al,. 2019). Considering trade-offs allows to encourage equity in the decision as a first step of trust establishment.

3 Application to the French farm network (NW 10)

The serious game has been developed and tested with two groups of French farmers from NW 10, including crop-livestock farmers and specialised crop or livestock farmers (Table 2; and published in Agricultural Systems : Ryschawy et al. 2022).

3.1 Context and short description of the network

In French mountainous and hilly areas, crop farmers are mainly located in the valleys and mainly grow cereals and oilseeds whereas livestock farmers are located in the Piedmont and in the mountains and raise mainly beef cattle. Crop farmers are dependent on synthetic fertilizers and livestock farmers are dependent on feed concentrate inputs.

INRAE works in collaboration with a network located in South-western France (Ariège) which involves three different groups of neighbouring farmers (10-15), including one group of organic farmers. These groups aim at developing crop-livestock integration beyond the farm level. Crop farmers are interested in diversifying their rotations and being supplied with cattle manure. And livestock farmers are interested in local and non-GM feed for their animals. These groups have been engaged in a co-design process for five years to achieve climate change mitigation, soil fertility and nutrient cycling.

Pictures of the case-study *(Credit : Julie Ryschawy, Txomin Elosegui)*

3.2 Adaptation of the participative method to the network

In the French network, crop farmers wanted to diversify their cropping systems and to use manure to improve soil quality. Livestock farmers were interested in local and non-GMO feed for their animals. The selected scenario considered i) the insertion of cereal-legume mixtures into crop rotations of arable farms and ii) transfers of manure from livestock farmers to crop farmers. In this scenario, overall gross margins increased and environmental impacts decreased, but workload and complexity increased.

Compared to other scenarios, the trade-offs between individual and collective benefits resulted in greater autonomy in inputs and decision-making at the collective level. In the two groups, discussions improved trust, a key ingredient for transitioning to crop-livestock integration beyond the farm level. Group discussions about establishing a price, or at least floor and ceiling prices, can increase equity in sharing the benefits of the integration planned in the scenarios. A future step could include sensitivity analysis of scenario outputs to price ranges for each product based on climate conditions and market trends. This analysis could help farmers to decide fair prices for the entire group.

New farmers were directly invited in step 5 to obtain information about the scenarios evaluated, their results, discuss technical aspects and suggest potential next steps. At this stage, the group decided to begin a new design loop at step 3. At this step the farmers adjusted and redesigned the scenarios specifically for organic livestock farmers wishing to collectively invest in a local feed processor. This will be co-designed with their cooperative and involve local organic crop farmers to sell local grain and fodder.

Table 2. Application of the six-step participative approach to the case-study

	Number and type of meeting	**Number and types of actors involved**	**Detailed schedule**
Step 1 – Problem definition	A focus group on carbon-positive crop rotations with the technical question asked: *"Which crops and grassland would be relevant to diversify crop rotations that can be carbon-positive while limiting inputs, especially when feeding animals."*	- 16 local crop farmers, - 5 livestock farmers - 4 advisers - 2 researchers Organized during the annual general assembly of Conser'sols association in March 2017	2-hour meeting into four sub-groups: - 30 minutes to list relevant crops/grassland on post-its - 30 minutes to insert them into relevant crop rotations - 15 minutes per group to present/discuss results with other groups
Step 2 – Farmers' motivations and initial assessment	- Volunteer crop farmers - Call through snowball sampling and agricultural chamber database to find neighbouring interested livestock farmers	17 individual interviews: - 9 crop farmers - 8 livestock farmers	It takes on average one hour for crop farmers and two hours for livestock farmers (having feeding systems to detail)
Step 3 – Group design of scenarios using Dynamix	Two groups defined to limit distance between volunteer farmers from Step 2: - Pamiers group in the valley - Mirepoix group in the pre-mountainous area	Pamiers group: - 5 crop farmers - 3 livestock farmers Mirepoix group: - 4 crop farmers - 5 livestock farmers For each group : 2 local advisors and 2 researchers.	A 2-hour meeting using the boardgame of Dynamix for each group : - Pamiers group (1 crop farmer and 1 livestock farmer present) - Mirepoix group consisted (2 crop farmers, 3 livestock farmers)
Step 4 – Multicriteria evaluation of the scenarios	Model used at the laboratory to evaluate the scenarios Detailed minutes sent to all farmers by email.	Farmers selected only one indicator for each dimension (economic, environmental and social) to have a quick overview of scenarios at the farm level: overall gross margin, the farm-gate nitrogen balance and workload, respectively.	The indicators were calculated by the researchers alone at the lab.
Step 5 – Group evaluation of the scenarios	Collective discussion to present the multicriteria evaluation of the scenarios	Pamiers group: - 3 crop farmers - 2 livestock farmers Mirepoix group: - 3 crop farmers - 3 livestock farmers For each group: three local advisors (in charge of crop, livestock, and organic production, respectively)	A 3-hour meeting to present the quantified scenarios, discuss them and prioritize one scenario to implement + distribution of papers on technical innovations and markets to answer questions from last meeting and have refreshments at the end to foster ties among the farmers.
Step 6 – Implementation of the scenario	New technical information collection + Involvement of more advisers and partners Monitoring on-farm implementation of the scenarios (farm visits once or twice depending farmer needs	The farmers involved in step 5 for both group	New rounds of interviews to follow-up + technical visits of the advisor to implement new crops and/or feeding systems

4 Application to the three other case-studies

4.1 Adaptation process to the three other MIXED landscape networks

In the specific case of the MIXED project, we focused on adapting the Dynamix game, (as the whole participative method was already implemented for each network considered within WP1 in the four field workshops planned to identify challenges and solutions with farmers and advisers). Thus, the first step of the process was always considered through discussions between researchers and advisors leading the networks and sharing reports and views on the two first Field Workshop. A specific satellite meeting was organized at the MIXED annual meeting, January 2023, to allow the identification of scenarios to be tested and to select the indicators which will be assessed.

The networks selected to adapt the Dynamix game were the landscape networks in Denmark, Scotland and the Netherlands. The tool is built to co-design scenarios with small local groups of between 5 and 15 crop and livestock farmers. This corresponds to the size of the networks involved in the project. These networks are detailed in the next section.

Considering data, most parameters that are already set in the model were considered valid for the other case-studies, e.g., animal feed requirements and feed characteristics, crop types, nutritional requirements, standard yields, fertilizer characteristics and market prices. Input data were collected already through the WP2 data collection. Maps of the parcels and farms were provided by network coordinators. For each of the three new networks, we will here present the context and objective of the participative approach and then focus on the specific adaptation of the serious game to each case-study, considering specifically the boardgame, data needs and multicriteria evaluation.

For each network considered, a thorough understanding of the case-study was essential. This involved compiling the information already available in the best practices report from WP1 called COLIN (COllation of Learnings, Innovative and Nature-based solution) and WP1 field workshop reports.

4.2 Application to the Danish Organic Agroforestry Systems (Network 1)

4.2.1 Context and short description of the network

The farmers in the Danish network 1 mainly have organic cattle and pigs for both milk and meat production. The trees are mainly used as energy crops. The group of farmers are incorporating trees/shrubs on their individual farms in combination with crops, cattle or pigs. The network had not initially been identified as a landscape network as farmers were aiming for self-sufficiency at farm level. The agroforestry systems established by the farmers on their land represent a huge diversity in age, function and spatial arrangement of trees/shrubs. The organic agroforestry farms are located in different parts of Jutland. Some of the farmers are part of a larger agroforestry network recently established by Organic Denmark. Integration of trees and shrubs with agricultural crops and animal husbandry is, however, not a common practice in today's organic agricultural systems. The drivers for the group of farmers that MIXED is working with is specifically to improve biodiversity, c-sequestration, animal welfare and environment. This has led the adviser and some of the farmers to rethink the system including a landscape approach to ensure that more ecosystem services and feed self-sufficiency would be achieved if the farmers viewed the hedgerows as collective resource to manage together, e.g. making hedges continuous to enhance landscape scale benefits for biodiversity (Kongsted, 2022).

Pictures of the case-study *(Credit : Søren Gammelmark, Julie Rohde Birk, Organic Denmark)*

Figure 5 highlights an example of pig farms involved in the network. Here this is interesting to see that lots of connectedness could be enhanced beyond the farm blackbox represented, in particular buying local feed from local farmers instead of a feed company and/or keeping grain or selling it to neighbouring farmers. Hedgerows would allow more ecosystem provision if beyond farm level connectedness was considered.

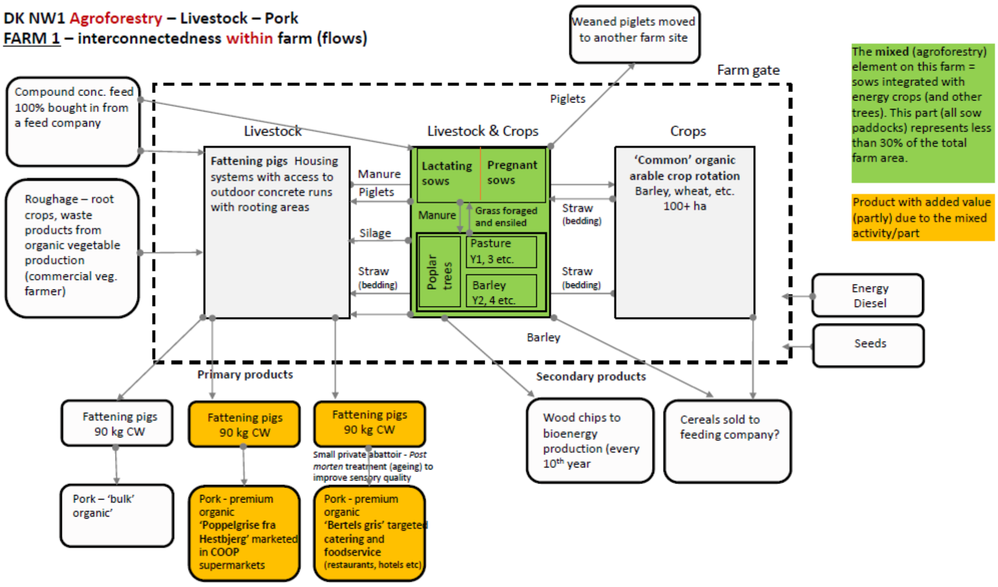

Figure 5. Graphical representation of the type of farms involved in the Danish network 1 (Kongsted, 2022).

The dimension of mixed farming differs between the different farms. On two (large) intensive farms, the agroforestry concept (poplar trees) is only implemented in lactating sow pastures (approximately 20 % of total farm area). On two extensive pig farms, trees are planted on the majority of farmland.

4.2.2 Application of Dynamix game to the case-study

Discussions with the adviser of Organic Denmark and farmers during a visit organized at the annual meeting of MIXED (April 2022) led to considering the network as relevant for adaption to the serious game Dynamix. Organic dairy farmers were involved in a local cooperative to transform and sell organic cheese and local self-sufficiency could be improved. Even more volume of local feed needs could be considered while involving local pig producers.

The **scenario tested** with Dynamix is related to enhancing local farmer collaborations to increase landscape continuity. This would cover both some animal feed saved through trees for the dairy cows and the ecosystem services which would be gained through an increase in the number of longer hedgerows and connectedness between the hedgerows.

The **boardgame adaptations** are easy as specific new circles with trees would allow consideration of both fodder and fruit production from the trees and grass undercover to be grazed. Regarding **the model parameters**, standard data for animal needs and feed values were retained. The specific nutritional value of green tree biomass (e.g., leaves, fruits) were inserted for the type of trees available. This had been already studied in the French case-study in relation to the provision of tree biomass for grazing during periods of summer drought. Maps of the farms also had to be collected.

The **indicators of interest** for the group were already considered within the ecosystem services (landscape mosaic as a proxy for biodiversity, share of semi-natural infrastructures including hedgerows, and nitrate leaching at farm and local levels). In this network, farmers were particularly interested in supporting livestock farmers' tree management and/or support "shared farming" by splitting the management of e.g. trees/livestock/arable crops between several actors. Workload balances are offered as an option in the Dynamix model so a specific shared workload table could be provided to the farmers.

Table 3. Detailed application of the six-step participative approach to the Danish case-study

DENMARK NW1	**Number and type of meeting**	**Number and types of actors involved**	**Detailed adaptation to the initial methodology**
Step 1 – Problem definition	A focus group meeting on introducing trees within organic systems to improve biodiversity, c-sequestration, animal welfare and environment.	- 9 local organic pig and dairy farmers, - 2 advisers from Organic Denmark - 2 researchers from AU - 3 Centres for Free-range livestock	The focus group to define the problem correponded to the second field workshop (WP1) where collaborations between farms were discussed
Step 2 – Farmers' motivations and initial assessment	- Farmers surveyed by Organic Denmark within WP2 data collection (Dynamix application requires a data subset only)	6 individual interviews: - 2 dairy farmers - 4 pig farmers	Interviews were led by the Danish team within WP2 data collection.
Step 3 – Group design of scenarios using Dynamix	A discussion based on the reports from the first two field workshops + training planned for Organic Denmark adviser in March	1 local advisor from Organic Denmark	Satellite session between advisers and researchers at the annual MIXED meeting Discussions with farmers and cooperative April 2022
Step 4 – Multicriteria evaluation of the scenarios	Model used at the laboratory to evaluate the first scenarios designed	1 researcher from INRAE France 1 local advisor from Organic Denmark	Indicator calculation focused on hedgerows continuity, feed saving costs through trees and shared labour
Step 5 – Group evaluation of the scenarios	Collective discussion to present the multicriteria evaluation of the scenarios and run the Dynamix game with farmers	- 8 local organic pig and dairy farmers, - 2 advisers from Organic Denmark - 2 researchers from AU	Planned for next 30th May to present first results and play Dynamix game to co-design scenarios
Step 6 – Implementation of the scenario	Monitoring on-farm implementation of the scenarios will be done by Organic Denmark as part of longer-term collaboration	The farmers involved at step 5 + 1 advisor	Technical visits of the advisor will be planned to implement new trees and/or feeding systems

To implement the game with the farmers, the INRAE team is training the Organic Denmark advisor in March. We are also providing support to help the Danish team organise the meeting (May 30th for the 3rd Field workshop).

4.2.3 Unexpected outcomes and next steps

The initial network plan was to adapt the Dynamix tool for the second Danish network, which is a landscape level network. The case of nutrient cycling and green biomass production through farm collaboration was relevant for the use of Dynamix and it was quite simple to introduce the biogas unit circles as relevant organisational structure to the boardgame. However, the participative approach was not at the right stage of development because some progressive farmers had already implemented the biogas units and other were not yet ready to design scenarios. This highlights that it is critical that the Dynamix game is introduced at the right stage of a participative process as the groups need to be advanced in their collective thinking and trust building but have not yet implemented the scenario to be assessed.

4.3 Application to the UK Scottland Graziers-arable network (Network 3)

4.3.1 Case study description and context

In the UK and in particular Scottish agriculture, there are many specialized arable farms (barley, wheat, etc.) where the farmer has lost the skills and also the boundary fences to keep livestock. Moreover, they rely on chemical inputs to maintain soil fertility. Reintroducing rotations and fodder/manure exchange in a cross-farm collaboration would thus be a relevant option to limit energy and labour costs for animal feeding and housing in the winter.

For the arable farmer, getting grass rotations back onto land would enable the natural fertility to be brought back into the soils, improving soil structure and reducing the inputs and labour for the crop farmer. Interest in crossover between specialized arable farms and specialized livestock farms is for mutual benefit. The network here includes 4 grazing/fodder exchanges between 2-by 2 farmers (Nicholas-Davis, 2022).

Pictures from the case-study *(Credit : Pip Nicholas-Davis / Christine Watson / Fergus Younger)*

The figure 6 is detailing an example of such collaborations. Here the livestock farm is a mixed farm with a diversified business including office/business centre, residential property and sheep and cattle (over 2000 ewes and 100 cows). The crop farm is a diversified business of 460 ha of cash crops including winter oil seed rape, winter wheat, winter oats, spring and winter barley. The herd comes to eat cover crops in between two major cash crops. The farms are only a few miles apart. This type of 2-2 interactions is at the core of the network but farmers liked to think about it collectively with the network advisor (Nicholas-Davis, 2022).

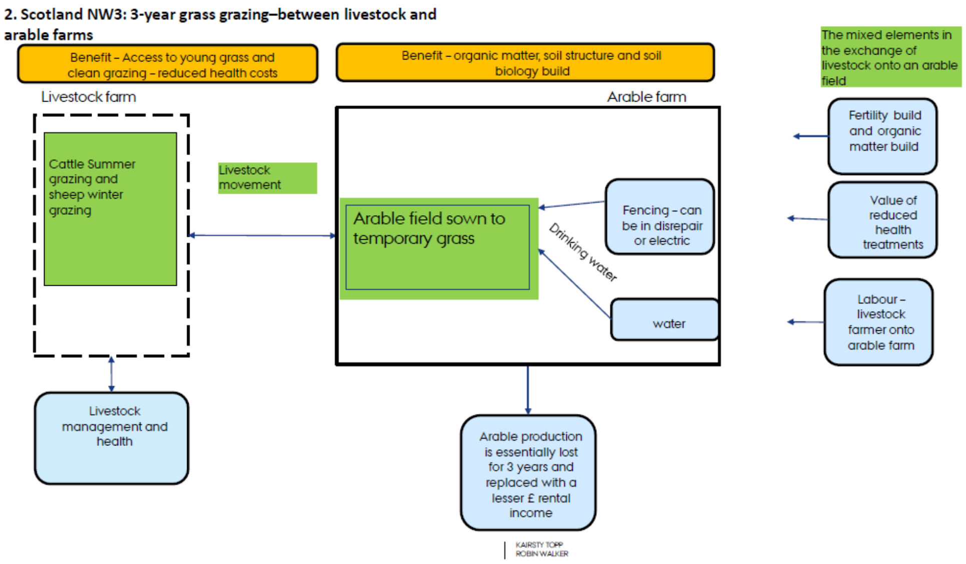

Figure 6. Graphical representation of the type of interfam collaborations involved in the Scottish network 3 (Topp K., Walker R., Younger F. 2022)

4.3.2 Application of Dynamix game to the case-study

The **main scenario** to be tested here at the collective level was enhanced collaborations to allow financial and environmental value of moving breeding cattle to lower cost natural resources. The major adaptation to be made to the **boardgame** was to include animal circles to represent animal lots, which would be transported from a livestock farm to an arable farm. The **model part** was already adapted to this as animal feeding and self-sufficiency are already included. Specific local breed needs and crop yields had to be inserted into a new Scottish database parameter file but were easy to find through local advisors and UK level data.

New indicators at the farm-gate had to be developed to allow quantification of the infrastructure costs of livestock on arable farms – e.g. fencing, water, handling facilities. Until now, Dynamix had only considered grain, fodder and manure flows to feed animals but not animal moving to get their feed on the fields. Farms were informed of the feeding costs savings as well as the balance of feed. The ecosystem services of soil structure and fertility had to be calculated, either directly or through proxies.. Finally, relevant indicators for the crop farmers were related to fertiliser savings thanks to animal grazing and labour saved in cover crop destruction.

Table 4. Detailed Application of the six-step participative approach to the UK case-study

UK Scotland (NW3)	**Number and type of meeting**	**Number and types of actors involved**	**Detailed adaptation to the initial methodology**
Step 1 – Problem definition	A focus group meeting on collaborations between arable and cattle and sheep farmers	- 9 local farmers, - 2 advisers (from SAOS and independant) - 3 researchers from SRUC	The focus group to define the problem correponded to the 2nd field workshop (WP1) on collaborations between farms
Step 2 – Farmers' motivations and initial assessment	Farmers surveyed by SAOS on NW 3 within WP2 data collection (Dynamix application requires a data subset only)	8 individual interviews: - 4 cattle farmers - 4 arable farmers	Interviews were led by the Scottish team within WP2 data collection.
Step 3 – Group design of scenarios using Dynamix	A discussion based on the reports of the two first fieldworkshops and between farms	- 1 local advisor from SAOS - 2 researchers from SRUC	Satellite session between advisers and researchers at the annual MIXED meeting Discussions with farmers and cooperative during the fieldtrip from February 2023
Step 4 – Multicriteria evaluation of the scenarios	Model used at the laboratory to evaluate the first scenarios designed	1 researcher from INRAE France 1 local advisor from SAOS 2 researchers from SRUC	Indicator calculation focused on feed saving cost, price grid between farmers, soil quality indicators and fertilizer savings
Step 5 – Group evaluation of the scenarios	Collective discussion to present the multicriteria evaluation of the scenarios and run the Dynamix game with farmers	- 8 local farmers - 2 advisers from Organic Denmark - 2 researchers	Planned in July with co-animation with the French team and play Dynamix game to co-design scenarios
Step 6 – Implementation of the scenario	Monitoring on-farm implementation of the scenarios will be done by SAOS as part of longer-term collaboration	The farmers involved at step 5 + 1 advisor	Technical visits of the advisor will be planned

4.3.3 Unexpected outcomes and next steps

The Scottish team has already gained experience on building trust and successful collaborative relationships. A cross network fieldtrip between French farmers and Scottish farmers was organized with the French farmers visiting Scotland in February 2023. During the field trip, the scenarios were discussed with Scottish farmers. Cover crop grazing and winter cereal grazing have been intensively discussed and data was collected on these innovations. Specific price grid and formal contracts for animal hosting on arable or mixed-crop livestock farms were inspiring for the game and in particular the Step 6 on implementation. A new meeting with farmers is planned in Scotland in June 2023 for the third MIXED field workshop (jointly with the ERANET MIBicycle project dealing of circularity scenarios for crop-livestock areas).

4.4 Application to the Netherlands (Network 12)

4.4.1 Case study description and context

MIXED network in the Netherlands refers to the cooperation between arable and dairy farms in the north-east of the Netherlands. The cooperation embraces the exchange of land, the application of manure, and the provision of 'contract work'. All involved farmers perceive the cooperation as enjoyable and it had already existed for many years. One of the advantages of the exchange of land is that it enables the farmer to reduce the intensity of crop rotations (Meuwissen, 2022).

Pictures of the case-study *(Credit: Miranda Meuwissen)*

Six farms are involved in two clusters (Figure 7). These clusters include potato producers needing to diversify their rotation to limit pesticide use and dairy farmers trying to extend their grass area to enhance self-sufficiency and use their manure. Despite the many years of cooperation, the farmers had never met as a group around the table before. The group meetings for MIXED are a unique moment to discuss future strategies at cluster level.

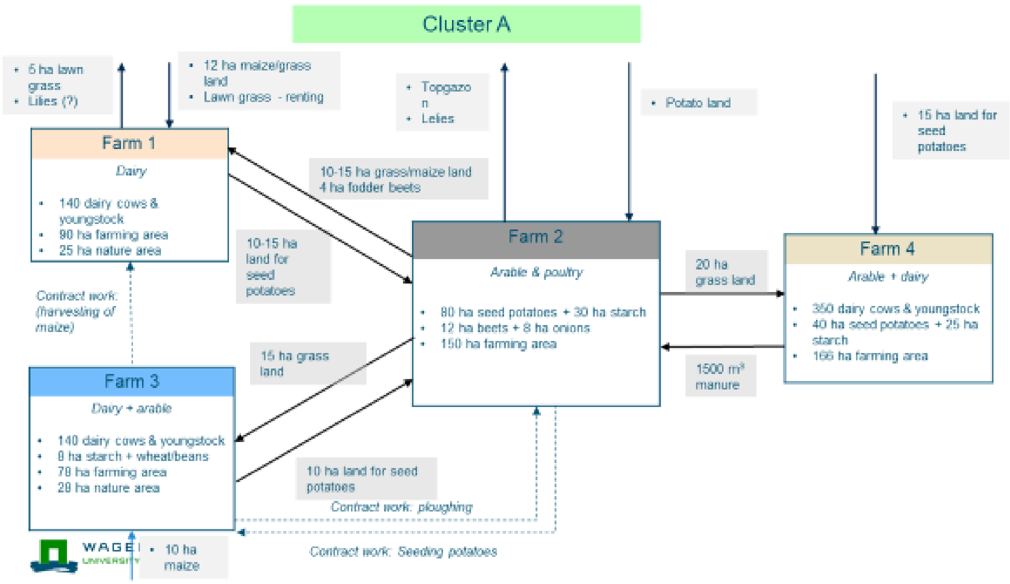

Figure 7. Flows quantified within a sub-cluster of four neighbouring farmers (Meuwissen, 2022)

4.4.2 Application of Dynamix game to the case-study

The second field workshop highlighted the interest of farmers to increase collaboration and in particular a need to estimate the implications of such crop-livestock collaborations (economic, soil quality). Netherlands case farmers were interested in land exchange to diversify crop rotations (grassland vs potatoes). This is an aspect that had not previously been represented in the game.

Regarding technical data, we only needed to obtain standardized data on crop types and yields (in particular including potatoes). In the collective part, we considered land exchange as an option within the organisational part of the boardgame and the model. We thus prepared in advance 'crop wish lists' per farm and a collective map to allow them to identify best patterns to increase the amount of grass and maize.

Table 5. Detailed Application of the six-step participative approach to the Dutch case-study

Netherlands (NW12)	**Number and type of meeting**	**Number and types of actors involved**	**Detailed adaptation to the initial methodology**
Step 1 – Problem definition	A focus group meeting on collaborations between potato and dairy farmer	- 6 local farmers, - 2 researchers from WUR	The focus group to define the problem correponded to the second field workshop (WP1)
Step 2 – Farmers' motivations and initial assessment	Farmers surveyed by WUR researchers - WP2 data collection (Dynamix application requires a data subset only)	6 individual interviews: - potato farmers - dairy farmers	Interviews will be led by the Dutch team within WP2 data collection.
Step 3 – Group design of scenarios using Dynamix	A discussion based on the reports of the two first fieldworkshops and between farms	- 1 researcher from WUR - 1 researcher from France	Satellite session between advisers and researchers at the annual MIXED meeting Training session planned end of April
Step 4 – Multicriteria evaluation of the scenarios	Model used at the laboratory to evaluate the first scenarios designed	- 1 researcher from INRAE France - 2 researchers from WUR	Price grid between farmers with optimization model and contracts
Step 5 – Group evaluation of the scenarios	Collective discussion to present the multicriteria evaluation of the scenarios and run the Dynamix game with farmers	- 6local farmers - 2 researchers from WUR	Planned in July/August 2023 (Fieldworkshop 3 – WP1) using Dynamix boargame to co-design scenarios
Step 6 – Implementation of the scenario	Monitoring on-farm implementation of the scenarios	The farmers involved at step 5	Not planned yet

4.4.3 Unexpected outcomes and next steps

The researcher team will be trained to use the game at the end of April and it will be used at the third collective field workshop during the summer. The last step of the game will be replaced by economic-optimization model which is planned within a PhD and will allow farmers to better evaluate the prices grid and equity to build formal contracts arrangements. Current policy discussions on the potential of regional collaboration to improve nutrient circularity is used to evaluate scenarios and to translate informal agreements to formal agreements.

5 Conclusion and next steps

The Dynamix game was quite easily adapted to other contexts for crop-livestock integration beyond the individual farm level: including cattle grazing cover crops in Scotland, parcel exchange between potato farmers and dairy farmers in the Netherlands and landscape connectiviy through hedges in Denmark.

Further developments to the tool were needed and summarized within Table 5. The main adaptations for the case-studies. included trees and tree undercover, vegetables and especially potatoes, animal transportation and winter cereal grazing in the Dynamix serious game. The boardgame and model adaptation were not time-demanding as the tool was already planned to be adaptable to other soil-climatic and market contexts. The challenging components of the Dynamix process, including the problem definition and data collection were made simpler through the existing work within the MIXED project. Issues and topics for discussion and scenario building had already been dealt with through the WP1 field workshops, whilst the detailed farm data had been collected through WP2.

Table 6.Transversal table to recap the adaptation fo the Dynamix game made in three networks

Country	**Denmark**	**Scotland UK**	**The Netherlands**
Network leaders	**AU – Organic Denmark**	**SRUC – SAOS**	**WUR**
Case-study	***NW 1***	***NW 3***	***NW 12***
Area	***Jutland main land***	***East-West Scottland***	***North-east of the Netherlands***
Main objective	Implementation of trees in organic pig and dairy cattle production	Linking grazing cattle/fodder exchange with arable farms	Identify scenarios of land and manure exchange within a network of arable and dairy farmers
Nb and type of farms	*6 farms – dairy and pig organic ICLS farms / one cluster*	*8 farms* *Cattle& arable farms – 2-2 interactions*	*6 farms in two clusters potato producers/ dairy farmers*
Scenarios to be tested with Dynamix	Increasing landscape continuity through farm landscape reconnexion	Collaborations and grid to save costs for both arable farmer and graziers	Land exchange to allow reconsidering crop rotations towards more fodder crops.
Indicators selected	Include hedgerows continuity and landscape mosaic heterogeneity indicator as proxies for biodiversity levels	Self-sufficiency at the local levels, energy and cost savings in winter feeding and housing	Better evaluate prices grid/ equity/ formal contracts arrangements through optimization model
Timeframe	March 30th (training) May 30 th (planned for FW 3)	Training already made along with MiBicycle June (to plan along with FW 3)	April 28th (meeting preparation) During FW 3 (Summer 2023)

Adaptation of the co-design tool			
Adaptation of the boardgame	Include trees and tree undercover (quantity and quality for feeding)	Include cover crop grazing + animal circles to move them to other farms	Include potatoes
Adaptation of the model	Tree production (tons of fruits and prices) Include hedges linear and type of indicators	Include cover crop grazing and winter cereal grazing in the database (baguettes cultures) + new types of animals like easycare sheep	+ include potatoes and technical-economic data for vegetables as well
Indicators of interest *(selection and/or addition)*	Linear of hedges / continuity analyses on the landscape and nitrogen balance to estimate risks of nutrient leaching	Price grid ?! Energy consumption to move animals Cost savings for housing and feeding animals in the winter	estimate implications (economic, soil quality) + labour constraints

The most challenging aspect of implementing the the Dynamix serious game has been to align the process with at the right stage of the participative reflections taking part within the MIXED networks. In fact, the interest of implementing the Dynamix tool in the three case-studies selected was not only depending on farm data availability and context specificities but on interactions with researchers-advisers and farmers within each network. For each network considered, a strong effort was made in understanding the case-study, compiling the information already in the field workshops reports. Discussing scenarios and relevant indicators with the network leaders ahead was a key part of the process.

A joint paper will be written 2023 with all colleagues involved in the networks and submitted to Agricultural Systems journal.

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