MIXED
EFFICIENT AND RESILIENT
MIXED FARMING & AGROFORESTRY

MIXED

GA no:	862357
Action full title:	Multi-actor and transdisciplinary development of efficient and resilient MIXED farming and agroforestry-systems
Call/Topic:	Climate-smart and resilient farming
Type of action:	Research and Innovation action (RIA)
Starting date of action:	1 October 2020
Project duration:	48 months
Project end date:	30 September 2024
Deliverable number:	D5.3
Deliverable title:	Test version – Prototype of the serious game available
Document version:	Ver1
WP number:	WP5
Lead beneficiary:	6-INRAE
Main author(s):	Julie Ryschawy (6-INRAE)
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Nature of deliverable:	Demonstrator (shown at AGM and with report as evidence)
Dissemination level:	CO
Delivery date from Annex 1:	M12
Actual delivery date:	30.09.2021 (M12) (resubmitted M24)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862357. Please note that this deliverable reflects only the authors' views and that the Commission is not responsible for any use that may be made of the information it contains.

Executive Summary

The aim of Task 5.3 was to develop the landscape level participatory game, Dynamix, to help farmers develop crop-livestock integration, through buying/selling of feed or manure between farms in the selected networks. Therefore, a prototype has been developed by INRAE (Task leader) and will be adapted to other networks by Month 30 (Participating: AU, WU, SRUC). The objective of the current deliverable is to present the prototype of the serious game Dynamix, a standardized method to codesign crop-livestock integration beyond farm level.

The approach consists of six steps. (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.

In the first sub-step (3.1) 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. 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. The consequent need-offer balances at the farm level are calculated by the advisor through the computerized support system. This step lasts approximately 45 minutes and crop farmers can discuss options to implement with livestock farmers during this process.

In the second sub-step (3.2), the organizational dimension of the scenarios we proceed in a roundtable during which farmers successively place their game pieces and cards on an 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 (e.g., adding a 3 ha of barley to sell grain to livestock farmers, etc.). 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. 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.

In a 4th step there is a focus on the model and multicriteria evaluation, using Dynamix, which 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. A web-platform is under development to allow further interoperability and automation between the components of the model, e.g., import online maps based on CAP declarations, technical practices from advisor tools or web-platforms when available, …

The prototype method was applied to the French farm network (NW 10), including crop-livestock farmers and specialised crop or livestock farmers, where the crop farmers wished 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 margin 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.

For the next steps the method will be applied on to other case-studies is planned in the MIXED project by Month 30. The application of the method may produce different results according to different cultural background and general contexts in the other case-studies. We assume that the method can be easily scaled-out to other contexts and is already being adapted to other cases of crop-livestock integration beyond farm level: cattle grazing cover crops in Scotland, parcel exchange between potato farmers and dairy farmers in the Netherlands and biogas production in Denmark. Further developments will be needed to include permanent crops, vegetables, and biogas plants in the Dynamix serious game, what will be challenging for the next steps.

In conclusion, the novel participatory process was successfully applied to a network in France, with a paper published describing the prototype and case-study application (Ryschawy et al., 2022). A second paper will be written to analyse the application of the game across the networks of four partners within the MIXED project.

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1. Introduction

The aim of Task 5.3 was to develop the landscape level participatory game, Dynamix, to help farmers develop crop-livestock integration, through buying/selling of feed or manure between farms in the selected networks.

A prototype has been developed by INRAE (Task leader) and will be adapted to other networks by Month 30 (Participating: AU, WU, SRUC). The objective of the current deliverable is to present the prototype of the serious game Dynamix, a standardized method to codesign crop-livestock integration beyond farm level.

2. A six-step participative methodology including Dynamix

Moraine et al. (2017) developed the first adaptive methodology to co-design scenarios of crop-livestock integration beyond farm level, e.g. selling grain and fodder within collectives of neighbouring 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.

The approach consists thus of six steps. (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.

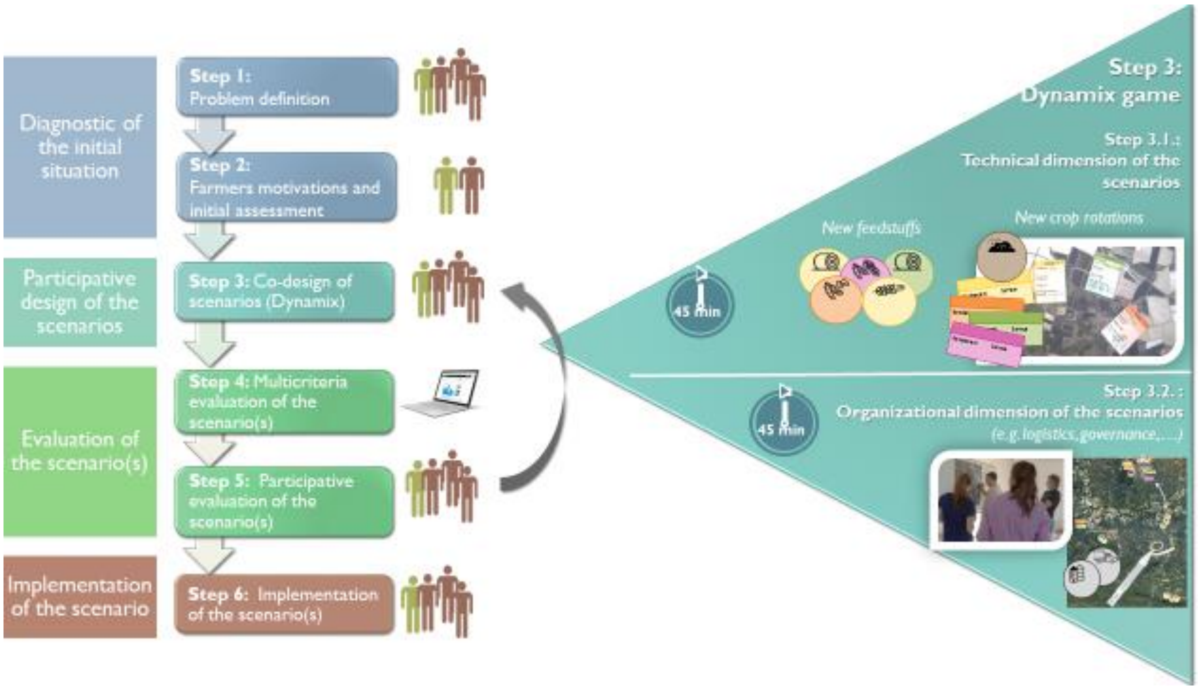

Figure 1 - The six-step participatory approach including the serious game Dynamix (DYNamics of MIXed systems) to co-design crop-livestock integration among farms

2.1. 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 contacts farmers and leads the debate with at least one researcher. The farmers invited are both reached through a mailing list of local farmer associations interested in the topic and directly for farmers, who already showed an 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 built small groups of 10-15 farmers for the next steps, being able to include/contact new farmers if recommended by participants, as snowball sampling allows to include neighbours 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 helps them to design exchanges among themselves to achieve local self-sufficiency for 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 an evaluation for 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 for around 2 hours and will be detailed in the following sections. The prototype of the game will be further explained in part 3 detailing the board game utilization and part 4 detailing the model and multicriteria evaluation.

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 project 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 may 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 was developed 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 sown, new fodder option or concentrate feed), a dedicated local advisor visits the farmer to help them, monitor the results and give 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.

3. A focus on the boardgame

a- 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 specify the area and yield expected. In return, they may expect manure in return and should quantify the volume they need. Each type of product is represented by a colour 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 during this process.

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 field parcels, 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 the crops/grassland, yield and area they plan to dedicate and 4. They may use a round "demand" pion to require manure.

At the bottom left, the individual design supports for 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 pins to write down the "demand" of fodder and/or grain to ask crop farmers to produce and 4. organic manures offered on round brown "supply" pins.

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" pins they used on the previous step, e.g. x ha of alfalfa at y t dry matter per ha, and near their farm headquarters and then 2. design the logistics with specific storage and transport tokens, on which they precise the type of product to be stored/transported and volume and 3. At the end, they may add anything needed for the next steps using a white felt tip pen, e.g. new farmer, local cooperative material, …

b- 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 an 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 (e.g. adding a 3 ha of barley to sell grain to livestock farmers, etc.). 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 receive 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 routes, etc) 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.

4. A focus on the model and multicriteria evaluation

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 enable information provision for the model. A web-platform is under development to allow further interoperability and automation between the components of the model, e.g. import online maps based on CAP declarations, technical practices from advisor tools or web-platforms when available, …

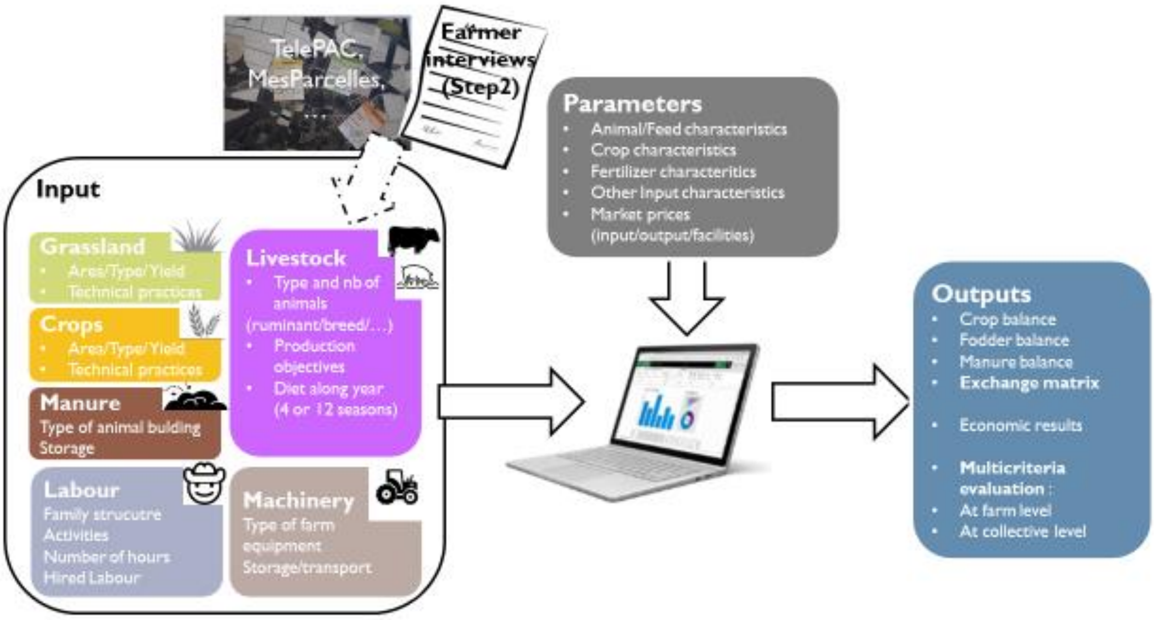

Figure 3 - Data needed as input for the model of Dynamix serious game and output provided

4.1. 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. At farm level, we use tools that were developed to focus on self-sufficiency in animal feeding and manure at a crop-livestock farm level (CLIFS (Ryschawy et al., 2014) and Forage Rummy (Martin et al., 2011). Figure 4 details the fluxes considered at farm level and the interlinkage between levels.

As individual and collective levels are dynamically interlinked, the sum of farm level needs and offers allows to inform the need and offer at the collective level. A basic table allows considering the farmers in line and product in column to 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 neighbouring 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 (FNAB 2014; ITAB 2011). Animal needs were based on a research database from INRA (2007). 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 analysed 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.

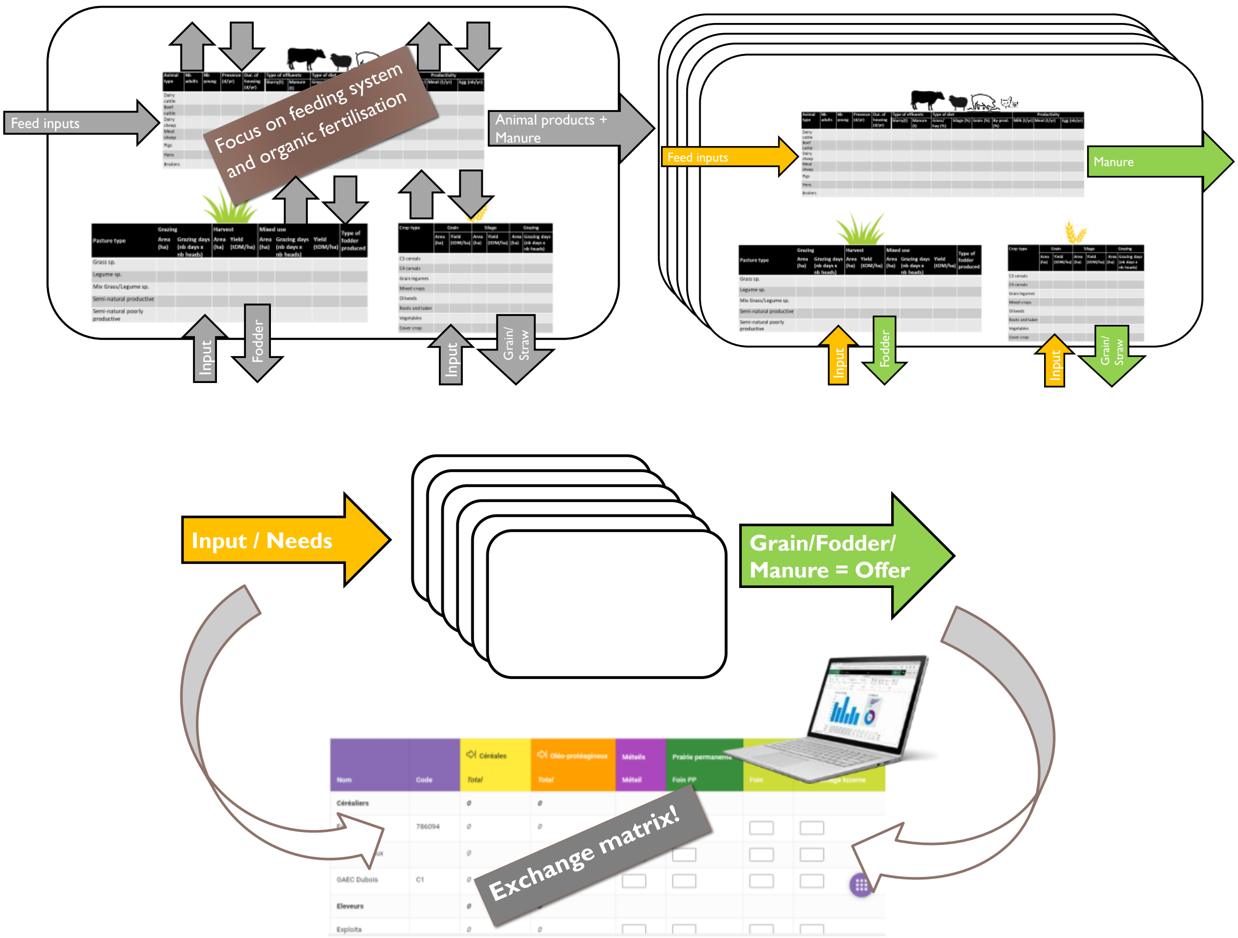

Figure 4 - Fluxes considered in the Dynamix serious game model and interlinkage between farm and collective levels.

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.*

4.2. Multicriteria evaluation

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.

Self-sufficiency in inputs and nitrogen balance are calculated at both levels and used to analyse 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.

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

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) Farm-gate phosphorus balance (kg/ha)	Simon et al. (2000) 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)

5. Application to the French farm network (NW 10)

The serious game has been tested with two groups of farmers from NW 10, including crop-livestock farmers and specialised crop or livestock farmers (Table 2).

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 a 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	In 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 on the needs of farmers)	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

Main results:

In the French network, crop farmers wished 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 margin 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.

6. Next steps

Up to now, the method has been only applied on case-study but its application to other case-studies is planned in the MIXED project by Month 30. The application of the method may produce different results according to different cultural background and general contexts in the other case-studies. We assume that the method can be easily scaled-out to other contexts and is already planned to be adapted to other cases of crop-livestock integration beyond farm level: cattle grazing cover crops in Scotland, parcel exchange between potato farmers and dairy farmers in the Netherlands and biogas production in Denmark. Further developments will be needed to include permanent crops, vegetables, and biogas plants in the Dynamix serious game, what will be challenging for the next steps.

- Application of Dynamix to three other networks (SRUC /AU /WUR):

    - **Main points of attention** after the presentation of Dynamix during the kick-off meeting in September 2021:
    - The cards and pins will be easily adapted to the other contexts (new crops/trees/grazing animals/new logistic pins, …)
    - The model may be used as it is and data collected in the MIXED project should be sufficient as model inputs.
    - The multicriteria evaluation needs to be shared and discussed with partners to adapt them to the different networks

    - **Scheduling the work**:

    - SRUC: 1st visit will be planned in Spring/Summer 2022 to meet farmers and understand their context. A second visit in Summer/Autumn will allow the adaptation and testing of the serious game.

    - AU: 1st visit during Spring/Summer to understand the farmer needs and select a collective and available model. A second visit may be needed.

    - WUR: not discussed yet but as data and models are already available, one visit 2022 may be sufficient. application will be developed after discussions around available models.

- The web-platform has been developed and is currently tested in NW 10 (link to be inserted).

- A paper has been published describing the prototype and case-study application:

  Ryschawy J, Moraine M, Pelletier A, Grillot M and Martin G. (2022) A participatory approach relying on the serious game Dynamix to co-design scenarios of crop-livestock integration among farms. Agricultural Systems. https://doi.org/10.1016/j.agsy.2022.103414

  A second paper will be written to analyse the application of the game across the network of four partners, transversally.

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