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THEME 2 – THE INTERSECTION OF SCIENCE AND PRACTICE: FARMING SYSTEM PERSPECTIVES

Agricultural sciences have to operate at the interface between technological, economic, political, natural, social and different knowledge systems. At the farm scale, science also has to intersect with the complex decision making environment, which presents certain challenges, risk and responsibilities.

Agricultural science can provide benefits of systematic observation, measurement and experiments, rigorous replicable methods, large data sets and analysis, however, how to make the outputs relevant to different production and management/decision contexts is a persistent question. Criticisms of uncertainty, lack of transparency are particularly pertinent to science supporting climate change adaptation.

Given the increasing reliance placed on science advancements, the need to understand how science intersects with practice is becoming more pressing; whether with respect to sophisticated modelling and big data, the promotion of concepts such as smart farming, sustainable intensification and ecological modernisation, or supporting farmers' adaptation to climate variability and resource challenges.

ADAPTING VITICULTURE TO CLIMATE CHANGE: A PARTICIPATORY SCENARIO DESIGN WITHIN A MEDITERRANEAN CATCHMENT

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Abstract

In a context of climate change, water management is considered a determinant factor for the agricultural sector, including viticulture. Grape is highly climate-sensitive, regarding both quantitative and qualitative production, making consequently climate change challenging. In France, vineyards are usually rainfed, although irrigation tends to develop, particularly in the Southern regions. However, many concerns remain: sharing the resources between uses and users, water shortage, salinization, etc. Various growing practices contribute to the grapevine adaptation to water shortage under rainfed situations: plant material, planting density, training system, soil management, etc. Adaptation strategies may combine these adaptation levers, through considering current and future water resource, cropping and farming systems.

This paper lays out a methodology aiming at exploring the following hypothesis: "the *combination of growing practices at the plot and farm level, and their spatial distribution in a catchment could give significant leeway to adapt a perennial crop such as grapevine to climate change"*. In a typical Mediterranean catchment (Rieutort, 45 km²), a group of stakeholders, involved in viticulture and water management, is mobilized to design and evaluate adaptation strategies, built as alternative spatial distributions of cropping and farming systems. A chain of models is used for producing indicators, measuring the impact of the different adaptation strategies under future climate. The originality of this multidisciplinary approach lies in the coupling of (1) a participatory approach (data collection, scenario design, integrated assessment), and (2) modeling tools allowing multi-scale quantitative assessment (plot, farm, and catchment). The methodological framework is illustrated by the results of the first step: the initial local diagnosis, and a shared conceptual scheme of the studied systems. The two next steps, scenario design and quantitative modeling, will be based on these preliminary results.

Introduction

Climate change is one of the major sources of concern in the Mediterranean, as the hotter and drier climatic conditions threaten agricultural production (IPCC et al., 2015). A good example is viticulture as the growth conditions of the grapevine are moving away from the optimum (Jones et al., 2005). The increasing occurrence of extremes, such as drought and heat waves (Giorgi, 2006), threatens the grapevines quantitative and qualitative production (Schultz, 2010). As a perennial plant, grapevine production requires producers to plan far ahead when taking vineyard management decisions (Lereboullet et al., 2013).

Water resource management will be increasingly determinantal for the viticulture sector (Santillán et al., 2019). Despite the recent development of irrigation systems, many limitations and concerns remain. From sharing the resources among uses and users, to water shortage and salinization, the hurdles are numerous. However, various growing practices contribute to the grapevine adaptation to water shortage under rainfed situations (Medrano *et al.*, 2015): plant genetics (Duchene, 2016), planting density (Van Leeuwen et al., 2019), soil management (Bagagiolo et al., 2018), canopy management (Palliotti et al., 2014), etc. Local adaptation strategies should combine those technical levers, considering current and future water resources, cropping and farming systems (Nicholas and Durham, 2012).

So far, the scientific community does not reach an agreement to propose adapted cropping system to climate change that consider local-context feasibility (Ollat and Touzard, 2014). Two challenging issues could explain this situation. First, building an adaptation strategy requires massive data collection about the local context (Ollat and Touzard, 2014), including the technical aspect and the adaptation capacity of individuals (Lereboullet et al., 2013). Second, design and selection of effective adaptation strategies requires quantification of the possible impacts of climate change and the damages avoided by adaptation (Diffenbaugh et al., 2011). In other words, *ex-ante* assessments of adaptation strategies require a quantification of multi-criteria indicators. Above all, multi-scale evaluations are necessary to identify detrimental or beneficial effects of a plot adaptation when applied at larger scale. For example, irrigation strategies at plot scale will impact the overall water availability in the catchment.

On the one hand, participatory sciences support activities of knowledge engineering, prototyping and assessment, that is adapted to a design process (Loyce and Wery, 2006). In viticulture, such an approach has been mostly implemented in designing and assessing cropping systems with low pesticide use (Lafond and Métral, 2015; Thiollet-Scholtus and Bockstaller, 2015). This approach is doubly helpful: by selecting and collecting locally relevant data from various sources of knowledge; and by fostering a shared assessment of complex and multi-scale systems. On the other hand, the development of process-based models allowed to better quantify the climate change impacts on grapevines (Moriondo et al., 2015), and to evaluate adaptation options (Fraga et al., 2018; Garcia de Cortazar Atauri, 2006). But, those process-based models hardly reproduce adaptation strategy impacts, as they do not consider the local-context feasibility, the supra-plot scale impact and the spatial combination of technical operations. To the authors' knowledge, there exists no study until now dealing with the adaptation to climate change, combining a participatory design and process-based modeling tools in order to evaluate adaptation strategy at different scales. Therefore, we proposed to lead a participatory modeling approach (as defined by Voinov *et al.* 2018) to build and assess relevant adaptation strategies.

This work, as part of the continuation of the LACCAVE project (Ollat and Touzard, 2014), aims at exploring the following hypothesis: "*the combination of adaptation at the plot and farm levels and their spatial distribution in a catchment could give significant leeway to adapt a perennial crop such as grapevine to climate change*". The proposed framework tries to overcome the two identified methodological challenges – local relevance and quantitative evaluation – by coupling (1) a participatory approach (data collection, scenario design, evaluation criteria), and (2) modeling tools allowing multi-scale quantitative assessment (plot, farm, and catchment). More precisely, we co-design and evaluate different adaptation scenarios. We define an adaptation scenario by the combination of a climate scenario and an adaptation strategy intended by the local stakeholders. We expect to identify trade-off between water resource uses and grapevine production under present and future climate, for the different studied scale.

In this paper, we first outline the methodological protocol, divided into three steps: the conceptualization, the scenario building and the quantitative modeling. We focus on the interactive process between stakeholders and researchers. We then present the results of the first step: stakeholders identification, initial diagnosis, and conceptual scheme of the studied system, collectively built with local stakeholders. Finally, we conclude by explaining broader implications of our results and we consider future prospects.

Material and methods

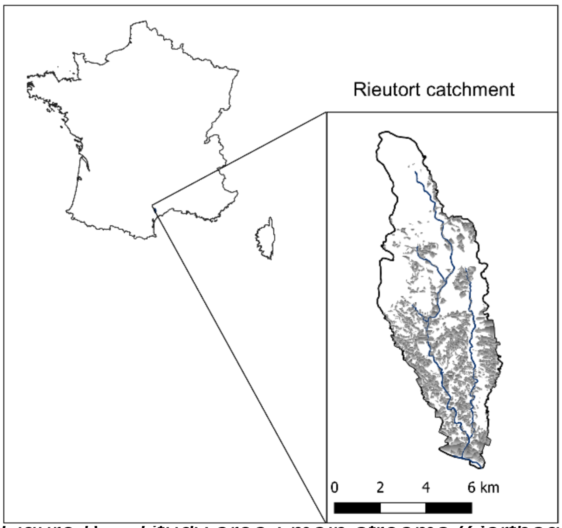


Figure 8 — Study area : main streams (Carthage BD) and vineyard plots (RPG 2017) in grey

The study area is the Rieutort catchment (45 km², 43° N, 3° E), a tributary of Orb River (Figure 8), located in the Languedoc vineyard. Grapevines represent 80% of the agricultural area of the catchment (1,500 ha). This catchment illustrates the regional wine-growing system diversity, notably with two Protected Designation of Origin areas (PDO) in the north, and a non-certified production area in the south.

Figure 9 shows the methodological general framework. The chronological structure is divided in three steps (Leenhardt et al., 2012; Voinov et al., 2018). First, the conceptualization phase aims at identifying, articulating and representing the relationships among the study system according to the stakeholder concerns (Voinov et al., 2018). The study system could be composed of crops (vine, cover crop or other productions), landscape elements (forest, rivers, reservoir, etc.), economic structure (cooperatives, PDO syndicates, etc.). Second, the scenario exercise tends to explore possible solutions to adapt to climate change. A scenario is defined as a combination of a climate scenario and an adaptation strategy, regarded as a spatial distribution of adapted cropping system in the catchment. The scenario exercise includes a representation of the initial situation, a description of changes and a description of an image of the future (Alcamo, 2009). Third, the quantitative modeling simulates the co-designed scenarios. The two last steps will be repeated allowing an increased confidence in the model and more creative and complete solution proposals (Voinov and Bousquet, 2010).

Methodological step		Step 1 Conceptualization			Step 2 Scenario Building		Step 3 Quantitative evaluation	
Intermediary production		Stakeholder identification	Initial diagnostic	Conceptual model	Climate scenario	Baseline + Adaptation strategies	Simulations	Evaluation
How ?	Who ?							
Individual interview	SH+R	X						
Climate modelling	R				X			
Workshop 1 (WS1)	SH+R	X	X		X			
Model library exploration	R			X				
Workshop 2 (WS2)	SH+R		X	X		X		
Model implementation	R					X	X	
Workshop 3 (WS3) and more	SH+R					X		X

Figure 9—Methodological general framework (R: researcher, SH: Stakeholders)

Stakeholders and researchers interact through a succession of workshops and model development (Voinov et al., 2018). Stakeholders are mobilized early in the process. The numerical model is determined after the conceptualization phase, reducing the gap between model and stakeholder representation of the system. The intermediary productions (initial diagnosis, conceptual model, climate scenarios, adaptation strategies) are presented or updated with stakeholders at least twice during the process. The repetition gives a better understanding and transparency of the process and the possibility to update the collected information and choices.

Step 1: Conceptualization Phase

First, we identified and selected the study participants through individual interviews. The first concern lay in involving a diverse group of stakeholders representing a variety of interests: farmers, institutional representatives of viticulture and of water management, vine collectors, extension services, etc. 21 semi-directives interviews were dedicated to: (1) identify the cropping and farming systems; (2) characterize the perception of climate change issue; and (3) identify the implemented or intended adaptations from different stakeholders. At least, the final work group gathered 24 persons, including four researchers that are considered as "neutral" and not stakeholders.

Then, the initial diagnosis has been constructed on the basis of the 21 interviews and the first workshop (WS1). Diagnosis aimed at identifying the different cropping and farming systems, as well as their local sets of constraints (Loyce and Wery, 2006). We divided the diagnosis into three parts: (1) description of the system (biophysical units, cropping and farming systems), (2) climate change perception (climatic events and impacts), (3) the adaptations to climate change (diversification, irrigation, variety, etc.) and their key variables and processes to consider building an effective adaptation strategy.

Finally, a conceptual model has been built in order to represent the system components and processes and their interactions. Indeed, the initial diagnosis being a static image of the current situation in the catchment, conceptual model will give the hierarchical and causal relations between elements that are required to assess the impact of a change in the system. Furthermore, the conceptual model is used as an "artefact", that is helpful for building and explaining the upcoming numerical model with the stakeholders (Barreteau et al., 2014). We relied on the initial diagnosis, completed by workshop discussion, to build the conceptual model: system inputs (climatic phenomena, adaptation and their sets of constraints), system processes, and expected outputs (impacted variables by climate change). Therefore, the researcher plays a role of translator transforming the narrative information of the first workshop into a conceptual model (Leenhardt *et al.,* 2012). The conceptual model is discussed and updated with the stakeholders in the second workshop (WS2).

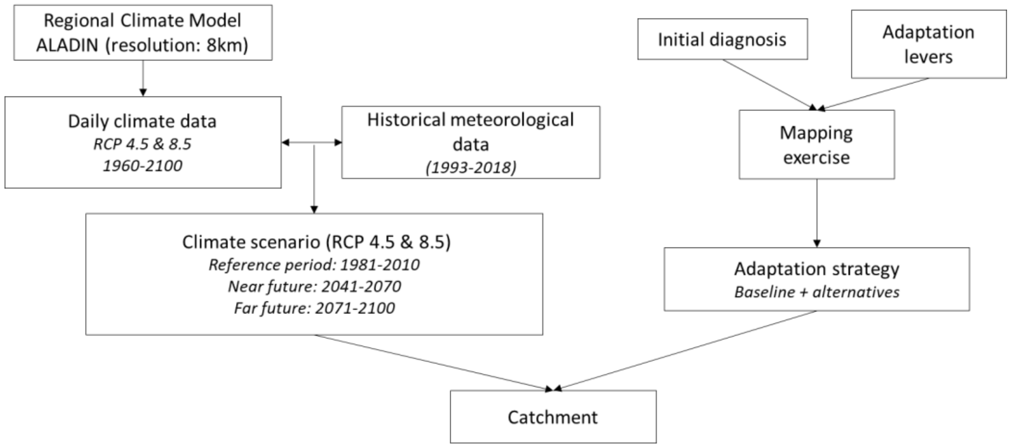
Step 2: Scenario Building

For the purpose of the study, we combine two types of explorative scenarios, as described by Alcamo (2009) (Figure 10):

Climate scenarios are provided by the Intergovernmental Panel on Climate Change (IPCC) and are considered as inquiry-driven scenarios,

Adaptation scenarios represent the spatial distribution of adaptation levers in the study catchment and are considered as strategy-driven scenario. Adaptation scenarios are also qualified as adaptation strategies as we do not *a priori* consider external factors of changes (e.g., regulation, market, etc.) (Börjeson et al., 2006).

Figure 10—General scenarios' framework



We considered two climate scenarios that represent a contrasted climate evolution for three 30-years-periods: one with a stabilization of the greenhouse gases emissions around 2050 (RCP 4.5) and another one without emission reduction (RCP 8.5) (IPCC et al., 2015). Climate data are provided by the Regional Climate Model ALADIN, developed by Meteo France. Daily-weather data are calibrated using 25-years meteorological data from Roujan station, located 16 km away from our study site (Molénat et al., 2018).

Adaptation strategies are alternative spatial distributions of cropping and farming systems, and landscape infrastructures. They are designed with stakeholders during WS2, through a mapping exercise. Although participation approaches engage more time, it ensures a better contextualization of the proposed solutions and the dissemination of the results (Van den Belt, 2004). The use of participatory approach when dealing with quantitative and modelled scenario requires a smart use of both qualitative and quantitative information (Leenhardt et al., 2012). In fact, adaptation strategies correspond to model inputs value, as a set of parameters. Knowing this, each input of the numerical model (e.g. soil type, slopes, practices management, commercialization, etc.) was translated in quantitative information through a participatory mapping exercise (WS2). Baseline scenario results from the mapping of current situation. Next, alternative future situation of the catchment are mapped through changes in cropping systems (e.g. irrigation, soil management, canopy management), farming systems (e.g. yield objectives, farm area) and landscape infrastructures (water reservoir, hedges). It is noteworthy that the pathway to reach the alternative image is not described in this exercise.

Step 3: Quantitative Modeling

Selecting the appropriate modeling tool is critical for any modeling exercise (Adam et al., 2012). The model selection should be driven by the participants' goals, the availability of data, the project deadlines and funding limitations (Voinov and Bousquet, 2010). We chose to use dynamic models because it keeps the causal effect of the climatic conditions on the variables of interest (Lane, 2008). For our purpose, the model is constructed by the researcher on the basis of the shared conceptual model. We select among current models only modules that can help in representing the current system and its evolution. The key model modules, selected by the modeler, are presented and discussed with stakeholders. The originality of our modeling approach is that we propose to couple different scales of the catchment, considering inter-relations between the biophysical processes at catchment scale (e.g. run-off), with the management strategies at field or farm scale (e.g. soil management). The coupling of models is executed on the OpenFluid simulation platform (https://www.openfluid-project.org).

Quantitative modeling allows the quantification of a given number of model outputs, that are discussed with the end-user (i.e. stakeholders) to generate model-based indicators (Bockstaller et al., 2008). Regarding stakeholder's selection, indicators concern mostly the productive system (yield, wine quality, diseases, etc.) and resource management (water use, water use efficiency, etc.). As far as we can tell, the assessment process will address more the changes in the system performances but not the performances *per se*, which could be too ambitious in such a complex and uncertain system.

The indicators of evaluation are not necessarily the raw model outputs (i.e., the indicators can be a simplified representation of the outputs (mean, median, distribution… through time and/or space)), but to some extent, they are closely limited by the model: how to quantify unmodelled processes and variables? We might not be able to model some key elements (e.g., biodiversity, carbon sequestration, effects of extreme temperature), because of missing data, unknown processes, or time calculation limitations. In that case, more qualitative assessment will be carried out thanks to data external from model calculation: input data, empirical knowledge, etc.

Preliminary results

Stakeholders identification

Table 8 — Involved stakeholders

Type of Stakeholders	Interview	WS1
Viticulture:		
Wine grower		
Cooperative	3	2
Particular cave	5	1
PDO syndicate	3	2
Cooperative cellar representative	1	1
Technical organization	5	—
Water:		
Agro-environmental animation	1	1
Regional policy maker	2	1
Local policy maker	1	—
Researchers	—	4
Total	*21*	*12*

Local stakeholders clearly expressed their concerns about climate change. Due to recent yield reduction and water shortage related to climatic incidents, they engaged solutions for maintaining their productive systems (irrigation projects, variety changes, hedges plantation).

Two types of local stakeholders were interviewed (Table 8): the vine growing system stakeholders (wine-growers, institutional representatives, cooperative cellar, and extension services) and the water management stakeholders (local facilitator, local and regional policy makers).

The participation to the first workshop was satisfying, despite the absence of some organizations. After the workshop, all stakeholders received the workshop detailed reporting and missing organizations' representatives were contacted for an update.

Initial diagnosis

The initial diagnosis was divided into three parts: (1) description of the system (biophysical units, cropping and farming systems), (2) climate change phenomena (drought, extreme temperatures, etc.) and impacted processes or variables (yield, wine quality, river flow, etc.), (3) a description of possible adaptations (diversification, irrigation, variety, etc.).

Three main types of cropping system are present in the catchment – describing the three main "terroirs" of the area:

vineyards located in the alluvial plain, characterized by high yields and availability of irrigation water;

vineyards located in slight hillside ("*côteau*"), characterized by a clay-limestone *terroir* and rain-fed;

sloping vineyards located in shale *terroir*, hardly mechanized and producing lower yields but higher-quality wine.

Concerning climate change, the main source of concern for stakeholders is the drought issue (Table 9). They reported frequent yield reductions, mostly due to the irregularity of rainfall during the year: extreme precipitation events and longer and unpredictable drought periods. They also noticed a general annual rainfall decrease. Second, the extreme temperature in summer is another source of concern. This climatic event, which had not been highlighted in interviews, was raised in the workshop. This directly referred to a climatic event that occurred few days before the workshop: an outstanding heat wave took place in southern France, with temperatures reaching more than 42°C in June 2019. In some parts of the vineyard, damage was clearly observed (leaf and fruit sunburn, desiccation). It is noteworthy that yield quality was not a major concern expressed during the workshop, despite the abundant literature about wine quality under climate change (Jones et al., 2005). In our study area, the solutions for limiting yield reduction seem to be more critical than increasing the yield quality, and thus it could be considered easier to maintain.

Table 9—Critical climatic events assigned to climate change and their impacts (X represent the occurrence of the climate change impact during interview or workshop)

Climate change perception	Climate change effects	Interviews	WS1
Annual rainfall decrease	Yield reduction	X	X
	Plant mortality	X	X
	Lower stream flow	X	X
	Economic impact	X	X
Rainfall intra-annual variability increase	Yield reduction	X	X
	Lower predictability of pest pressure	X	
Extreme rainfall	Flood		X
	Lower rainfall efficiency	X	X
Wind	Accentuation of dryness	X	
Higher temperature	Early harvest	X	
	Lower wine quality	X	
Extreme temperature in summer	Sunburn on fruit		X
	Leaf and plant desiccation		X
No cold in winter	Higher rate of mortality	X	

The third part of the diagnosis deals with adaptation options. A collective brainstorming session highlights the intended levers to adapt to climate change. The levers were arranged along the management plan of a vineyard (Figure 11). The stakeholders specified, for each of them, the biological or physical processes that could be targeted for adaptation and the climatic incident that can be tackled.

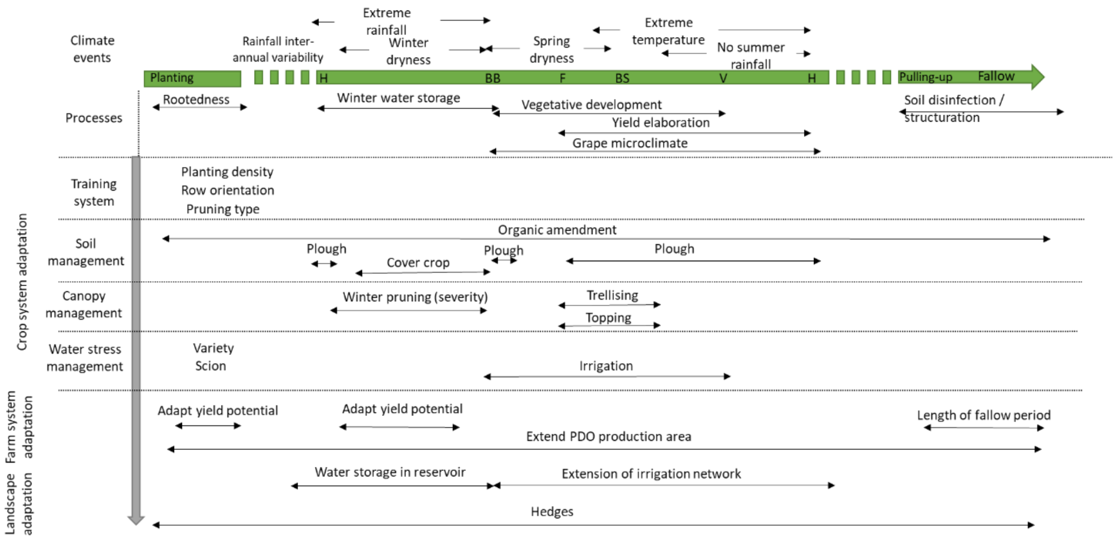


Figure 11—Adaptation options proposed by the stakeholders along grapevine cycle : BB = bud break, F = flowering, BS = berry set, V = veraison, H = harvest

The critical climatic events, illustrated in Table 9, were reported in the phenological cycle of vines. The processes (mentioned by the stakeholders) involved in the climate change adaptation were: the rooting of the vines during early years, the winter soil water storage typical of Mediterranean climate, the vegetative development and grape microclimate, the yield formation and the soil management during fallow periods (after vines have been pulled-up).

Figure 11 also confirms the implication of three scales for adaptation, from crop to landscape. These scales are closely interconnected. For instance, the extension of the irrigation network may influence the irrigation possibilities at the field scale. In addition, the extension of certified high quality wine area (PDO) may also influence the planting choices (imposed density, variety choice) and the productive period (yield limitation, irrigation rules, etc.).

As far as the adaptation timing was concerned, different levels of adaptation were highlighted. Stakeholders considered both planting choices and seasonal management as critical to plan a long-term adaptation strategy. On the one hand, fallow management (length, amendments and soil preparation), plant material and training system choices (row orientation, density, pruning system) have an impact on the global plant dryness tolerance. A good soil-plant adapted system ensures a long-term adaptation to climate change. On the other hand, seasonal management like soil management, canopy management and irrigation strategy allows an adaptation to specific climatic conditions of each year. It should be noted that most of the adaptation strategies have contrasting effects under different climatic conditions. For instance, topping should be more severe in wet years, preventing pest dissemination, but lighter in other hot years, preventing eventual damages caused by the sun. Stakeholders emphasize the necessity of a flexible adaptive capacity to specific climatic conditions of the year.

Conceptual Model

The design of the conceptual model was divided into three parts: model inputs, model components and associate processes, and model outputs. Model inputs are the climate variables, the management practices, which are those highlighted as adaptation levers and the context underlying adaptation feasibility. Model components are objects on which climate change, or its adaptation, have an impact. These components are in interaction (competition, services, management, etc.). Model outputs are the variables of interest impacted by climate change (yield, income, water use, etc.). The resulting conceptual model (Figure 12) represents the functioning of the catchment and the identified adaptation levers as described by stakeholders during the first workshop.

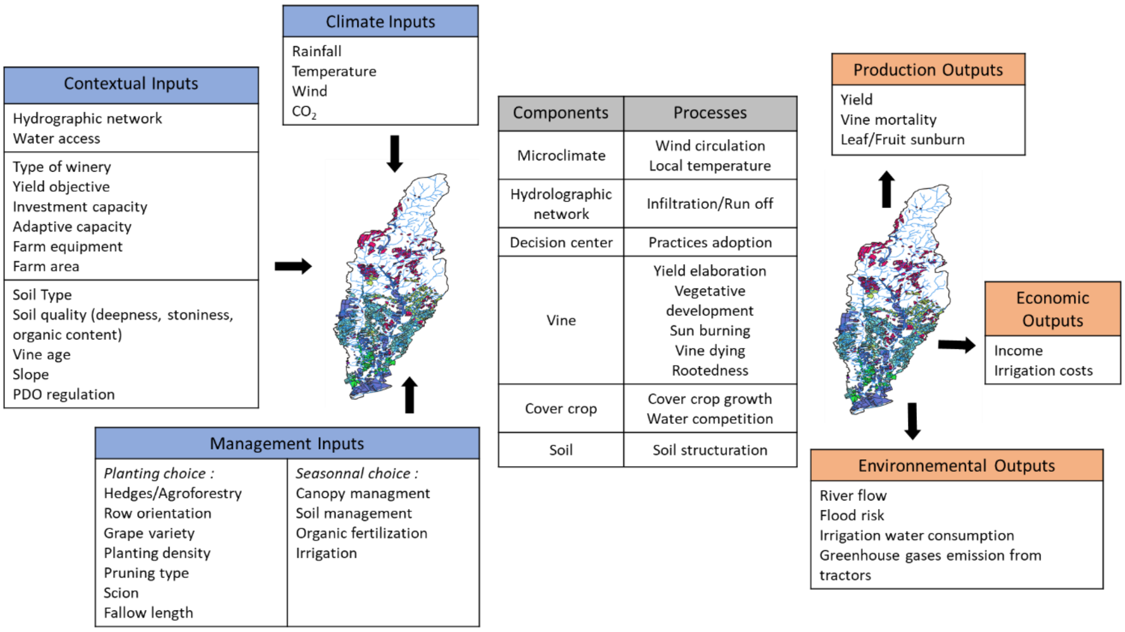


Figure 12—Conceptual model of a viticulture catchment under climate change. On the left, model inputs. In the middle, the model components with associated processes. On the right, model outputs.

The conceptual model brings out the nested and interrelated spatial scales. Each field unit depends on a specific set of parameters (climate, soil, practices, etc.), themselves depending on its specific location in the catchment and on the characteristics of the farm they belong to. Consequently, we can expect to represent a large range of situations in the catchment. Field scale remains the more detailed scale in which adaptation levers are numerous, but their feasibility can depend on the upper scales. Farm level is only described as the decision center, since wine-growing systems being monoculture systems, there is no other cropping system to consider. The choice of seasonal practices includes soil management (number and date of plough), organic fertilization, irrigation management and canopy management (topping, trellising). Adaptive capacity is defined by stakeholders as the level of knowledge and training of the wine-grower, which allows a well-adapted cropping system to plot specificity. Catchment level is characterized both by water circulation and availability, and by microclimate specificities.

Ideally, the numerical model should closely reproduce the catchment as described in Figure 5. However, we will not be able to model all the identified processes, neither than inform all the input variables. So, the decision will be taken by the modeler to be as close as possible to this first scheme, keeping in mind the predictive capacity of the final model. For example, high temperature effects on vine yield (sunburnt, desiccation) are poorly considered in current models. As a consequence, modeling results could alleviate climate change impacts, especially in the hottest years. The illustrated gap between conceptual model built from stakeholders' point of view (Figure 12) and conceptual scheme of the definitive model (to be constructed) will be explicitly presented and discussed during second workshop. Through stakeholder's empirical knowledge, completed by scientific literature, we could be able to integrate qualitative effects of unmodelled phenomena in our analysis.

Discussion

The proposed methodological framework is based on a first hypothesis: neither the modeler himself, nor stakeholders themselves, know how to assess numerically climate change impacts and the effects of adaptation strategies. In the present study, a model is constructed by coupling existing models to fit, at best, the stakeholders' representation of the system. Mobilizing the stakeholders early in the process improves the value of the resulting model in terms of its usefulness to decision makers, its educational potential for the public and its credibility within the community (Voinov and Bousquet, 2010). Therefore, the first difficulties arise from the confrontation of this representation, and the modeling capacities of existing models. In other words, even if stakeholders take part in the modeling process by expressing their expectations, the modeling exercise remains on the hand of the researcher. The influence of stakeholders on modeling choice can be questioned. Our participatory modeling still addresses three methodological advances. First, the participation of stakeholders is helpful in giving priorities to the processes to be considered. These processes can be already modelled or not, and with enough or too much detail. In a certain extent, stakeholders questioned the modeler on his own models and development perspectives; and in the other extent, the modeler shares scientific model-based knowledge with stakeholders. Second, participation is crucial to parameterize the model so as to fit to local conditions. The level of data details depends on the time and willing of stakeholders. Third, the validation of such a coupled model is a difficult task, because it mixes different epistemological references. Some modules of the model, which represent the natural and biophysical dynamics, may be validated with traditional methods in similar context areas. But the complete model cannot be validated in this way due to the absence of experimental design in the catchment and to the simplification of the input data. Stakeholders participate to the validation of the complete model through baseline simulation analysis (Bockstaller and Girardin, 2003).

Maintaining the level of participation is crucial, and efforts on clarity and transparency are necessary. Intermediary objects that support the interactions between researchers and stakeholders (conceptual model, scenario narratives, model simulations) need to be simple and consensual. It is not necessary to multiply the artefacts. For example, a conceptual model can be used both as front-end model conceptualization and as a back-end tool for communicating about the model outputs behavior (Lane, 2008). A clear and shared translation between narrative qualitative facts and quantitative model components facilitate the scenario interpretation assessment (Leenhardt *et al.*, 2012). The clarity of the general method (objectives, limitations) and the transparency of the model ensure production of plausible, consistent, creative and relevant scenarios (Alcamo, 2009).

Participative modeling is used here to undertake a spatialized simulation-based assessment in order to identify the trade-off between water consumption and vine productivity, but not the pathway to reach the alternative solutions. Scenario analysis is helpful in comparing the performance of various combinations of adaptation levers considering their socio-technical feasibilities in space. However, we cannot assume that it will be sufficient to support a decision making process. Indeed, further investigation should complete this scenario design by external factors, both climatic and socio-economical, promoting or limiting the situation described in the future. An integrated assessment of each strategy also suggests inclusion of a greater number of indicators and of people, including more producers, inhabitants, elected representatives, etc. For this reason, the analysis of the first simulated scenarios is a first step towards a more integrated assessment, which could be performed through the remobilization of this modeling platform.

The present study could have implications for both research and policy. Our first results already raised questions that could guide further research, e.g. on the processes reducing water demand, favoring water use efficiency, decreasing temperature locally that would be favored, according to stakeholders, by hedges, goblet pruning or grafting techniques. Future investigations would require experiments and modelling development to quantify those possible effects. Then, the results that will be produced all along our study could help to design local policies. For instance, we will quantify the impact of developing new water reservoirs on vine production and water consumption. Such quantification is necessary to assess *ex ante* part of the impacts of those expensive infrastructures. Policy makers may also be interested in other beneficial adaptations we would highlight, which they could encourage and support through subsidies. The originality of our study is to consider the regional vineyard diversity, which could help policy specifications according to the different production systems.

Conclusion

The paper presents a conceptual and operational method describing the main steps of a participatory design approach coupled with modeling tools exploring the adaptation of viticulture to climate change. This method contributes to the achievement of the project objectives into two ways: (i) it considered the local conditions and feasibility of each adaptation lever in diverse viticulture systems, and (ii) it takes into account different scales, from field to catchment, in order to identify in a quantitative way, wine-growing systems adapted to future climate. A local diagnosis and a shared conceptual scheme of the studied system were the first steps settled for the co-design and co-assessment processes, and will be used all along the work. Based on the shared conceptual model, a modular model will be developed. Then, adaptation strategies, built as alternative distribution of cropping system in space, will be simulated and assessed under present and future climate. We mobilize participatory and modeling methods to propose and assess relevant adaptation strategies to climate change, locally adapted to wine-growing systems of a typical Mediterranean catchment, for better informed decision making from farmers and local stakeholders.

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THE ROLE OF SCIENCE IN FACILITATING A SUSTAINABILITY TRANSITION OF THE SMALL RUMINANT FARMING SYSTEM ON THE GREEK ISLAND OF SAMOTHRAKI.

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Abstract

Sedentary extensive small ruminant farming systems are highly important for the preservation of High Nature Value (HNV) farmland. Both the abandonment of grazing, and overgrazing, have led to environmental degradation in many Mediterranean regions. On the Greek island of Samothraki, decades of overgrazing by sheep and goats have caused severe degradation of local ecosystems. The present study highlights the role of socio-ecological research in facilitating a sustainability transition of the small ruminant farming system (SRFS) on the island. By utilizing a mixed methods approach based on the conceptual framework of social metabolism, we show how long-term transdisciplinary research can achieve valuable scientific results and at the same time initiate a practical outcome. Sociometabolic results indicate clearly a regime change of the SRFS after 2002, and during the time period of our research. Between 1929 and 2016 the livestock and land-use system of Samothraki transformed from a diverse system towards a simplified system, solely used for small ruminant production. Total livestock units increased from 2,200 in 1929 to 7,850 in 2002, declining to 5,100 thereafter. The metabolic analysis conducted for the years 1993-2016 shows that the feed demand of small ruminants exceeded local available grazing resources at least for a decade. Monetary data shows that local small ruminant farmers generate 50% of their revenue through subsidies and have an income of 5,000€ per year per farmer on average. We discuss the role of science in the transdisciplinary research approach that shifts from mainly analytical, with the aim of understanding current problems and challenges, towards participatory with the aim of creating a space for knowledge co-production and preparing for change.

Introduction

Livestock represents a key element in society nature interactions and is responsible for more than a third of global land use in a wide range of ecosystems and 15% of global human induced GHG emissions (Gerber et al. 2013; Erb et al. 2016). Since ancient times, livestock plays an important role for human societies for the provision of food, working power and manure (Krausmann 2004). Livestock also represents a capital and nutrient stock and serves therefore as an important risk reduction strategy for vulnerable communities (Herrero et al. 2009). Since the onset of global agricultural industrialization in the 1950s, livestock successively lost its multifunctional purpose. Through the use of machinery and fossil fuels, draft animals vanished almost entirely, and animal manure got replaced by petrochemical fertilizers. Positive factors of industrialized livestock production, like higher feed to food conversion efficiencies and increased production output for a lower price, should not detract from the negative environmental, social and animal welfare consequences caused by this transformation. Industrialization of agriculture is among the most important reasons for the decline of small-scale farming and the abandonment of rural regions. The way animals are kept in industrialized production systems does not conform to their needs and must be questioned from an ethical point of view. Through industrialization of livestock production, grain became not only for monogastric species but also for ruminants an important external feeding resource. Thus, more than one third of global cropland is currently used for feed production (Steinfeld et al. 2006). The conversion efficiency of feed to livestock products was low in traditional farming but compared to industrialized systems they were more sustainable because animals mainly lived from feed not edible for humans (Krausmann 2016). Still, extensive, grazing-based ruminant and mixed crop-livestock systems provide globally 69% of milk and 61% of meat and are responsible for land use on 80% of all agricultural land (Herrero et al. 2015).

The Mediterranean represents one of the regions where semi-nomadic ruminant herding, mainly sheep and goats for dairy production, has a long tradition since antiquity. The specific environmental conditions in these regions limited intensive and specialized farming, why ruminant herding, often in combination with various forestry practices, still prevails in many regions until today. These characteristic landscapes, dominated by heterogenous plant communities of forests, bushes, herbaceous undergrowth and grassland, have undergone a long co-evolutionary process which generated "resilient ecosystems with a high species diversity, productivity and utility to society" (Kizos et al. 2013). This form of agriculture has in general lower production outputs than intensified forms and is classified in Europe as high nature value (HNV) farmland as it contributes to landscape level biodiversity and plays an important role as a repository of genetic resources (Plieninger et al. 2015). 40% of Greece's land area consists of mountainous, semi-mountainous and agriculturally least favored areas (Hadjigeorgiou 2011). These areas mostly represent HNV farmland on which rough grazing biomass is transformed into high value products, mainly by sheep and goats. The average small ruminant farm in Greece is mixed and rather small with 70 sheep and 40 goats. These farms represent mainly sedentary extensive systems in which a relatively small area is cultivated, the age of farmers is high and technical advances are limited (Hadjigeorgiou 2014). The socio-economic importance and multiple challenges faced by the sheep and goat sector in Greece and other Mediterranean regions call for a comprehensive research approach, focusing on environmental, social and economic aspects in the same time (Psyllos et al. 2016).

Since the publication of "Livestock's Long Shadow" (Steinfeld et al. 2006), research on the environmental implications of livestock has far progressed. The increased knowledge of problems and potential solutions are but only implemented on a small scale, why future research should increasingly focus on the practical implementation of proposed changes (M. Herrero et al. 2015). With the present study we aim at filling this research gap by focusing on the role of science in fostering a sustainability transition of the small ruminant farming system on the Greek island of Samothraki. The ongoing long-term research project facilitates since 2008 continuous exchange between scientists and citizens from various fields (Fischer-Kowalski et al. 2011; 2020). The conceptual framework of this approach is based on a socio-metabolic understanding of society-nature-interactions (Haberl et al. 2004; 2019) and combines analytical and management aspects towards sustainability transitions (Fischer-Kowalski and Rotmans 2009). In section (2.1) we introduce the study site, in section (2.2) we describe the conceptual framework and methodological approach and in section (3) we report on the main results. The discussion in section (4) is divided into the socioecological implications of the past transformation of Samothraki's livestock farming system and its main socioeconomic drivers (4.1) and the role of science to achieve a sustainability transition of sheep and goat farming on Samothraki (4.2). The conclusions are provided in section (5).

Material and Methods

The island Samothraki

Samothraki stretches over 178 km2 and is one of the very few hotspots of preserved archaic wilderness among the Greek islands. Its remote location in the north-eastern Aegean Sea, the pebbly nature of most beaches and often unclear land ownership averted economic exploitation and mass tourism on the island. The 1,611m high mountain range Σάος gives Samothraki its geomorphological character and shapes the distinct microclimates. While the northern side presents itself in lush green with old forest cover and numerous streams of drinkable water, the southern and western sides are shaped by a rather typical dry-summer Mediterranean climate and vegetation. A large proportion of the island's terrestrial area is part of the Natura 2000 network and since 2012 the island has been a UNESCO MAB candidate (Fischer-Kowalski et al. 2011; Petridis 2013). The island community of Samothraki is officially registered as 2,840 people but is subject to high fluctuations because many people leave the island in winter months or visit the island as tourists, seasonal workers or second homeowners. Of the 1,000 economically active residents, 40% work as livestock herders and small-scale farmers. The secondary sector is relatively underrepresented at 12%, while the tertiary sector employs 40% and consists mainly of tourism services.

The development path of recent decades has led to a wide variety of environmental but also social problems the island community currently must face. One of the major threats to local ecosystems was triggered by the transformation of the local agricultural system. Decades of overgrazing by sheep and goats resulted in biodiversity reduction and wide-spread soil erosion (Biel and Tan 2014; Panagopoulos et al. 2019; Noll et al. 2020). Since the mid 20th century, farms and farmers are declining, while the small ruminant population increased to unprecedented levels (Fetzel et al. 2018). Increasing feed prices, dependence on subsidies, the lack of marketing opportunities and little cooperation among themselves, have caused local farmers to find themselves in an economic deadlock situation that now threatens the very existence of agriculture on the island.

The conceptual framework of the socio-ecological research project on Samothraki

The point of departure for research was personal experience. Samothraki fascinated as a place of overwhelming archaic, natural and cultural beauty. Features that also appeared threatened. What followed was a transdisciplinary process involving scientists and experts from various fields and local citizens. This process aimed at creating a vision and an identity for the island community that would frame the local conditions not as "backwardness", poverty and lack of modernity to be overcome, but as a worthy heritage and asset to be developed in a targeted way. One result of this process was the idea that Samothraki becomes part of the world network of UNESCO Biosphere Reserves[31], a process that is still ongoing. Across the years, the many strands of research were guided by a basic systems model as outlined in Fig. 1.

[31] Biosphere Reserves are areas that encompass valuable ecosystems and social communities that wish to combine the conservation of ecosystems with their sustainable use. They are nominated by national governments and remain under sovereign jurisdiction of the states where they are located but become internationally recognized by UNESCO. Biosphere reserves form a world network under the protection of UNESCO. Within this network, exchange of information, experience and personnel are facilitated. At present, there are about 700 biosphere reserves in over 120 countries (See: http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/).

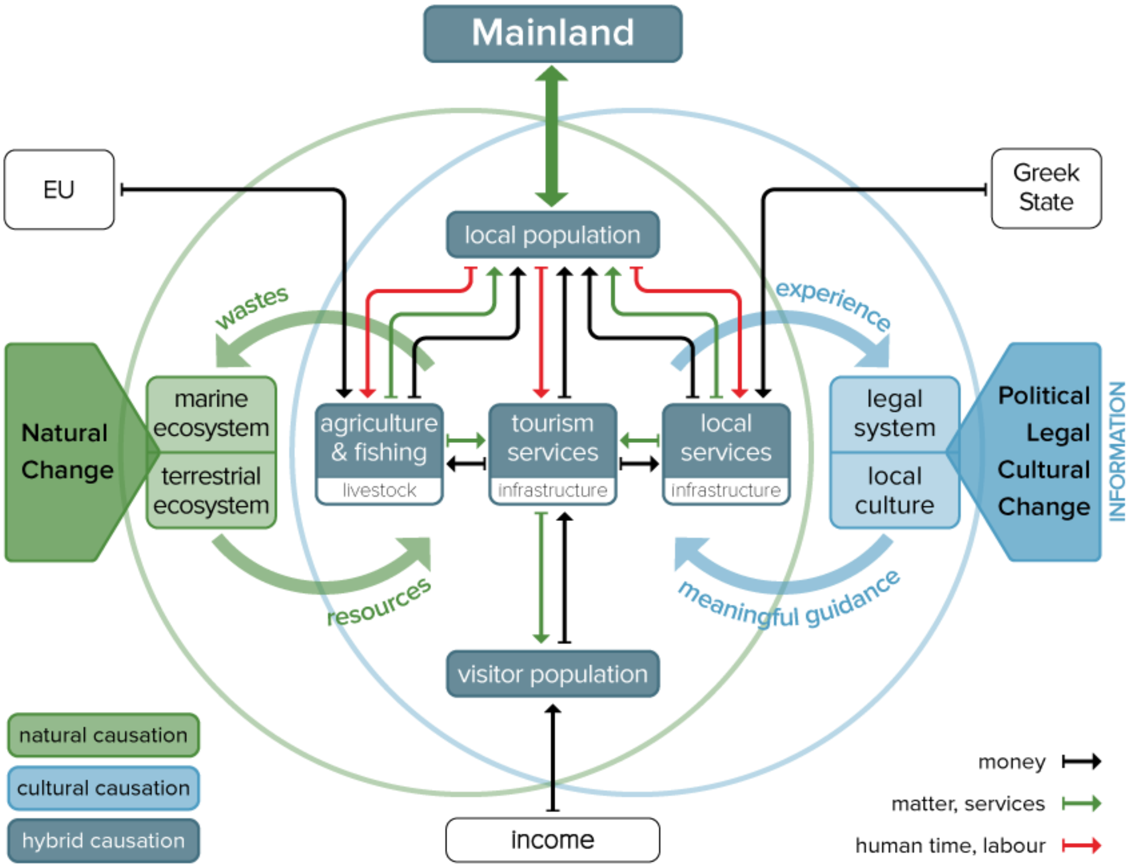

Figure 13: Sociometabolic system model for the relevant stocks and flows within and between the local society and its natural environment, required to identify critical social and/or environmental tipping points in the process of socio-ecological interaction.

According to this model, the sustainability of a socioecological system depends on whether flows required for maintaining societal stocks (humans, livestock, artefacts) can be organized. When critical stocks cannot be reproduced, the system might 'collapse' (Petridis and Fischer-Kowalski 2016). The reproduction of societal stocks requires flows of energy and material between societal systems and nature, referred to as social metabolism (Haberl et al. 2004; 2019). To strive towards sustainability, in this context, means to develop and maintain a social metabolism that serves the needs of the people without destroying the ecological balances of the natural environment, while being resilient to changing contexts. This implies to not increase socio-economic stocks excessively, to use natural resources carefully and efficiently, to create effective synergies between the sectors of the economy, and to develop a culture of social responsibility, collaboration and fairness (Petridis et al. 2017).

In the context of the current study we focus on the small ruminant farming system (SRFS) and its interconnections with its social and natural environment. The SRFS is defined as the small ruminant population (sheep and goats), its metabolic requirements, its material output in terms of products, the small ruminant farmers and their monetary economy. Terrestrial ecosystems provide the net primary production (NPP) consumed by small ruminants. The SRFS exchanges goods and money with the local population, including visitors and tourists. The political, legal and cultural framework is represented by rules and regulations of the Greek state, and the EU and local traditions. The EU provides agricultural subsidies through the Common Agricultural Policy (CAP) and the Greek state pays pensions to retired farmers. The local and visitor population receive money from external markets and through income from external sources (e.g. work or pensions). Wastes are not explicitly assessed in this study but are a relevant factor, especially regarding slaughtering residues and emissions.

The transdisciplinary research approach as applied in the present study

The transdisciplinary research approach is guided by a combination of analytical and management principles for sustainability transitions that aims at achieving both, academic output with a practical outcome (Fischer-Kowalski and Rotmans 2009). Applied to the small ruminant farming system (SRFS) this results in a dynamic research process (Figure 2) in which we improve our knowledge base of the local (livestock) farming system and increasingly engage farmers into a collaborative co-learning process. Blue arrows represent information flows between different stages of the research process.

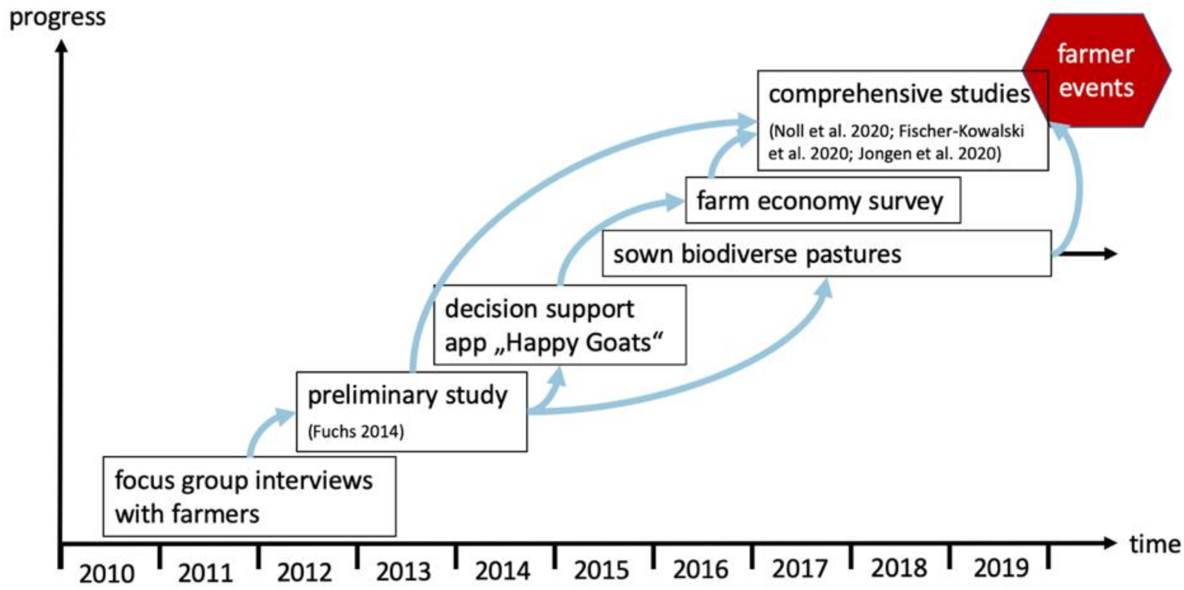

Figure 14: The transdisciplinary research process on the small ruminant farming system as applied in this project.

To enable the integration of data from various sources and thoroughly analyze the current socioecological crisis of small ruminant farming on the island, we utilize a mixed methods approach (Johnson et al. 2007; Kelle 2017). Focus group interviews with farmers and fishermen marked the beginning of research on the agricultural system of the island. Focus group interviews benefit from group interaction that can yield data which might otherways remain hidden (Ho 2006). Focus groups also allow for a discussion among participants and are therefore highly suitable for the co-creation of a transdisciplinary research process. In these meetings the researcher took over the role as moderator, initiating different topics of the discussion. We chose to use 1-2 moderators, including a translator. Students of the first Samothraki summer school helped to prepare questions and interpreting the outcome. During the interviews, some students were present and took notes. For a more detailed description and results of focus group interviews with various groups see Petridis et al. (2013). After these interviews in 2013, a preliminary study on the small ruminant farming system (SRFS) was conducted. Fuchs (2015) applied a combination of expert interviews and analysis of official statistical data to assess the environmental and socio-economic sustainability of small ruminant farming on Samothraki. This research led to the development of a decision support app which was then used to outline a survey to collect economic data from 23 local small ruminant farmers. This app is based on an agronomic model that combines metabolic data on the herd level with monetary data on the farm level. Simultaneously we initiated an experiment to apply a special seed mixture (sown biodiverse pastures - SBPs) that can store more carbon and is more resistant to grazing. We further conducted numerous expert interviews with farmers and other stakeholders between 2012 and 2018. An analysis of the transparency database for EU agricultural subsidies and public statistical data on demographics and agricultural production enabled the integration of official data. Annual summer schools enabled the involvement of numerous international students that helped to show our presence on the island and collect data. This approach has so far resulted in the completion of 4 scientific publications with a focus on livestock. Fetzel et al. (2018) uses land-use methods to estimate the grazing pressures on local ecosystems. Noll et al. (2020) utilizes a mixed methods approach, combining a metabolic livestock model with statistical and qualitative survey data to analyze the current socio-ecological crisis of small ruminant farming on the island. Fischer-Kowalski et al. (2020) provides a concise description of the socioecological transition of the island since antiquity and reports on the ongoing transdisciplinary research process. Jongen et al. (2022) uses vegetation and interview data to report on the social, economic and environmental implications of the ongoing experiments with sown biodiverse pastures. Students further completed 3 Master's Theses with a focus on the SRFS on the island. As an important next milestone, we drafted farmer events that would enable us to provide feedback from our research to farmers and local stakeholders and engage them further into the collaborative process. The COVID-19 pandemic had put this incentive at hold. A more detailed analysis of the outcome of this research approach is provided in section 4.2.

Results

Results are mainly focused on our sociometabolic and monetary assessments, as this data provides a good empirical foundation for the discussion of our transdisciplinary research approach. In section 3.1 we present the transformation of the local livestock farming system in changes of species composition from 1929 to 2016. In section 3.2 we plot the nutritional demand of small ruminants from 1993 to 2016 against the net primary production (NPP) of local ecosystems to assess environmental pressures associated with grazing. In section 3.3 we present the current economic situation of small ruminant farmers and show the low production output in comparison to the fairly high population numbers. For a more detailed description of these results and underlying methods refer to Noll et al. (2020). Results from qualitative interviews are integrated into the discussion sections and build the context for the sociometabolic results.

Development of total livestock units on Samothraki 1929 - 2016

Figure 3 shows the increasing significance of small ruminants in relation to other livestock species on the island from 1929 to 2016. Total livestock is expressed in livestock units [LSU], which express the nutritional requirements of each species. In 1929 the island had 490 [LSU] cows, 430 [LSU] pigs, 1,250 [LSU] Equidae (horses, mules and donkeys), 3,026 [LSU] poultry, 1,672 [LSU] sheep and 2,892 [LSU] goats. Small ruminants represented only 21% of all [LSU] in 1929, compared to cows (22%), pigs (10%), Equidae (45%) and poultry (2%). In 2016, small ruminants represent 93% of all LSU (2,276 [LSU] sheep; 2,428 [LSU] goats), while cows are reduced to 0%, pigs to 5% (277 [LSU]), Equidae to 1% (56 [LSU]) and poultry remained at 2% (77 [LSU]). Total [LSU] for small ruminants increased from 456 in 1929 to 4,478 in 1992 before reaching their peak at 6,735 in 2002, declining to values between 4,100 and 4,800 thereafter.

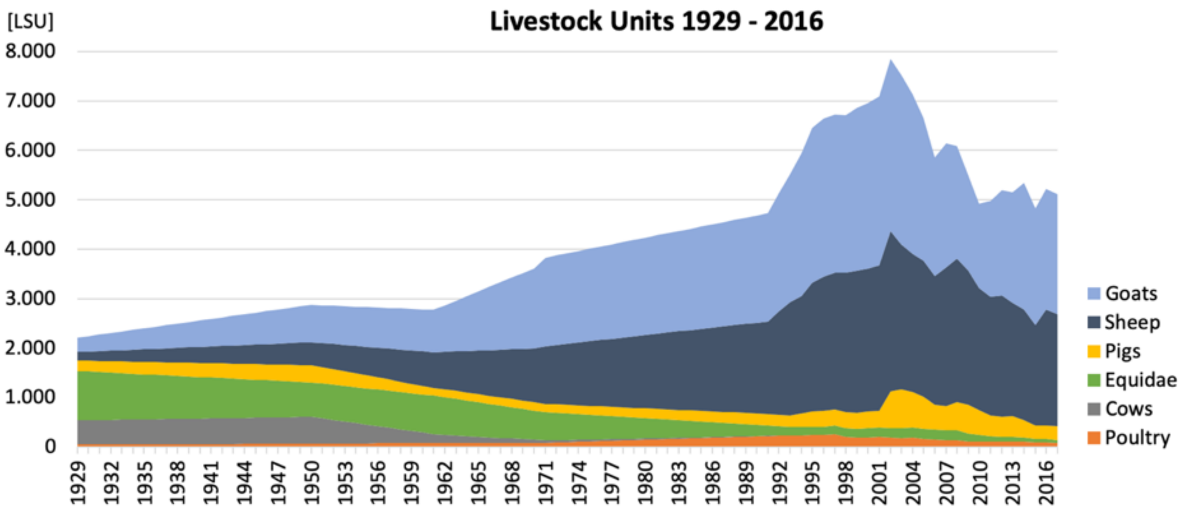

Figure 15: Development of total livestock units [LSU] on Samothraki from 1929 to 2016 (source: Noll et al. 2020).

Overutilization of grazing resources by the small ruminant population

Figure 4 plots grazing demand of the small ruminant population against the available NPP for grazing. In 1993 the grazing demand of the small ruminant population was 9,900 tC/yr, increasing to 13,700 tC/yr in 2001 and declining to values between 7,000 and 8,000 tC/yr thereafter. Herein we use two boundaries of the net primary production of biomass available for grazing (NPP) to assess the potential overgrazing and therefore degradation of local ecosystems. These two boundaries are based on the range of ±27% with regard to an uncertainty assessment for MODIS and NDVI data sources, derived from Jia et al. (2016). We find that the upper grazing boundary was exceeded for at least 10 years between 1995 and 2005, while the lower boundary was exceeded for almost the entire period.

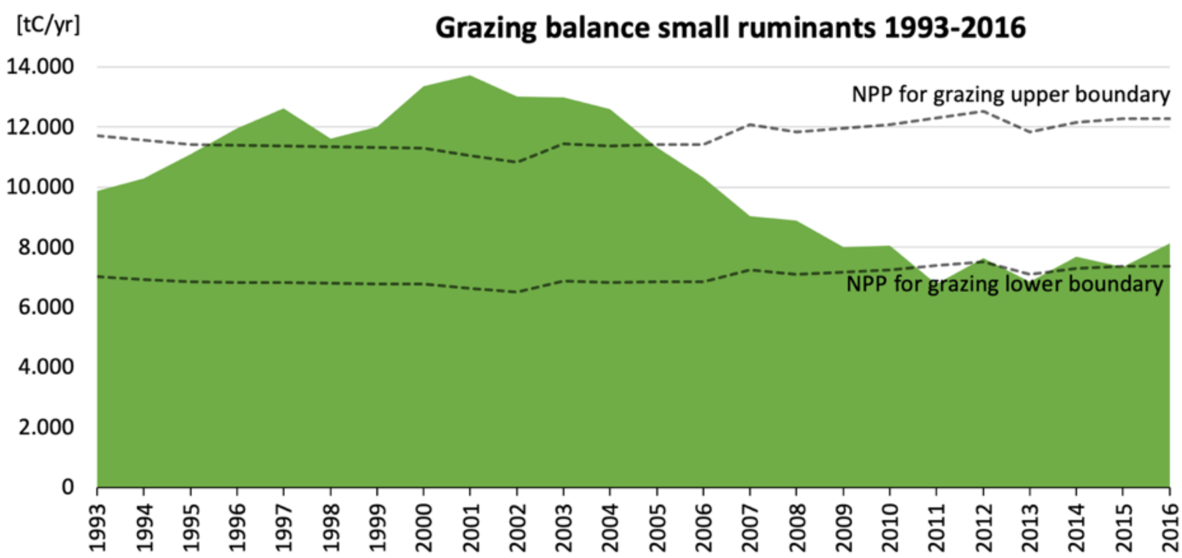

Figure 16: Grazing balance for the small ruminant population in tons of carbon from 1993 to 2016 (source: Noll et al. 2020).

The financial situation of small ruminant farmers in the light of underutilized production potentials

Figure 5 plots revenue against expenses to estimate the annual income for the average small ruminant farmer on Samothraki in 2016. One farmer generates a revenue of 25,000 €/yr through milk and milk products, meat and subsidies, which represent almost 50% of the revenue. Expenses for farm utility, processing, transport, land and animal maintenance were 20,000 €/yr, resulting in a net annual income of approximately 5,000 €/yr.

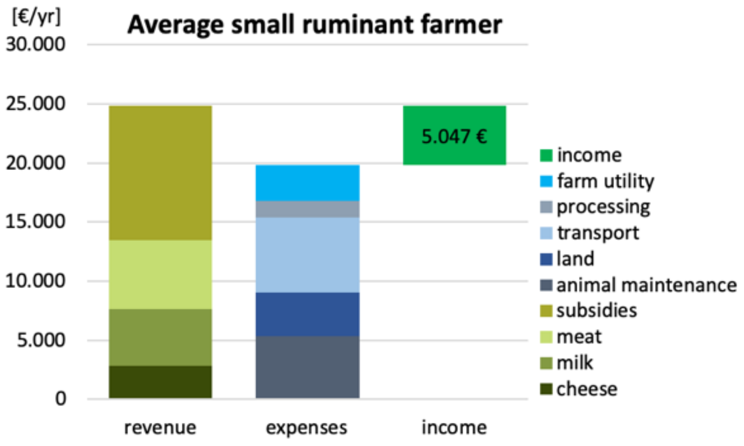

Figure 17: Revenue, expenses and income of the average small ruminant farmer in 2016 (source: Noll et al. 2020).

Figure 6 indicates the relatively low production output per animal if compared to potential production numbers. Actual production numbers for milk (blue solid line in secondary axis) and meat (red solid line in primary axis) are far below the potential production numbers (dashed lines and standard deviation bars of same color and axes) for the entire period. While potential production of meat and milk increases with the livestock population increase between 1993 and 2002, actual production of milk declines and meat stays constant. The increase of the actual milk production after 2003 can most likely be attributed to the reopening of the local dairy. This means that the increase of animals did not result in higher production output or higher income from products, hence leaving the farmers expectation of rising subsidies with rising animal numbers as the only plausible explanation.

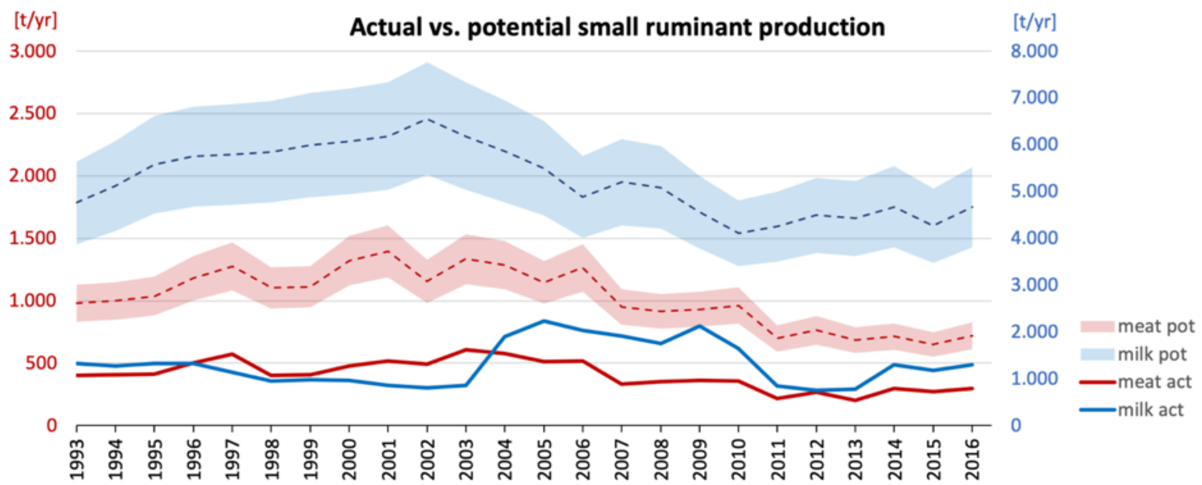

Figure 18: Actual vs. potential production of milk and meat from 1993 to 2016 (source: Noll et al. 2020).

Discussion

The integration of biophysical, monetary and qualitative data, in combination with results from previous studies analyzing changes in local ecosystems, enables us to comprehensively describe the current sustainability crisis of the small ruminant farming system (SRFS) and its socio-economic drivers in section 4.1. In section 4.2 we reflect on the applied transdisciplinary research approach in order to achieve a sustainability transition of the agricultural system on the island.

Socioecological implications of the past transformation of Samothraki's livestock farming system and its main socioeconomic drivers

Samothraki is a perfect example for the vicious effects of global industrialization on remote agriculturally shaped regions. The construction of the new port in the 1960s represents a key event for the development for the island, as it enabled transport of people and goods in larger quantities (Noll et al. 2019). The transformation of the local livestock farming system becomes evident in the changing composition of livestock species shown in Fig. 3. While there are only moderate changes before 1960, it is the time after that led to a complete transformation of stocking rates and species composition. In 1929 the livestock system had only 2,000 livestock units [LSU], was relatively diverse and dominated by Equidae (horses, mules and donkeys). The growth to almost 8,000 [LSU] in 2002 occurred almost exclusively in the small ruminant population. While the number of animals has been reduced since then to approximately 5,000 [LSU], the livestock system today is still dominated by sheep and goats. Expert interviews confirm the shift in the local livestock system. Up until the 1960s sheep and goat herders had a special position on the island. People who produced meat and had meat in abundance were considered rich by the community. Back then nobody possessed more than 100 animals and everything from the animals like meat, milk, wool and skins, was processed and used. Herds of goats grazed in the mountains in the summer and were chased down to the lowlands in winter and for slaughtering. In the past, animal numbers were kept below the carrying capacity of the island's ecosystems, as there were no feed imports. Despite the lack of statistical data on land use before 1993, the results of the present study clearly indicate that the land use system of Samothraki must have experienced a similar shift as described by Kizos et al. for the island of Lesvos. In their case study the authors show how since the 1960s "complex and multifunctional agrosilvopastoral land use systems were simplified to a pure livestock raising system" (Kizos et al. 2013). As evident from statistical data and confirmed by expert interviews, Samothraki's crop production is almost exclusively used for livestock feed today, while this was not the case prior to 1960. Initially farmers benefitted from good prices for their products, lush pastures and subsidies. Since recently the islands' ecosystems but suffer from overgrazing and erosion and farmers are caught in an economic deadlock.

Biel and Tan (2014) reported in their extensive survey about the flora of Samothraki that intense grazing and repeated "slash-and-burn" practices for obtaining pastureland, contributed to fundamental ecosystem changes and threats. A study conducted on the mountainous oak forests in 2017 assessed a sample of 940 trees and found no tree with a younger cambial age than 47 years. The authors concluded that 86% of the island's forests are currently threatened by overgrazing and have high regeneration priority (Heiling 2018). An analysis of the Normalized Difference Vegetation Index (NDVI) based on satellite images from 1984 to 2015 revealed a 40% reduction of large parts of Samothraki's landcover up until 2002 and only a partial recovery in the decade after (Löw 2017). A development that perfectly matches the increase of the small ruminant population prior to 2002. Grazing demand surpassed the upper boundary of the estimated NPP between 1995 and 2005 and the lower boundary from the 1980s until today (Figure 4). Thus, the small ruminant population seems to have overutilized grazing resources for at least a decade, or otherwise animals were severely undernourished. In reality, it was most likely a combination of both. The social and economic crisis of the system is reflected in multiple aspects. Of the 23 farmers interviewed for the farm economy survey, 22 have said that they see no future in farming on Samothraki and they advise their children to leave the island. The main reasons given were the increase in prices for feed, high taxes, reduction of subsidies and the declining market prices for products. For farmers in the north-east of the island the only local dairy is too far away, so they produce only small quantities of dairy products for their own consumption or in some cases their restaurants. Milking is largely done by hand and as prices are so low, it is not profitable for most farmers. The dairy can only process milk between April and July/August and 80% of their production is exported. According to the owner, in recent years they have needed to shut down the production in the middle of July as they cannot sustain their business over the summer. In Mediterranean regions many dairies stop taking milk during summer, as during the later stage of lactation, the coagulating properties of milk deteriorate, which has negative effects on yogurt and cheese production (Caroprese 2015). Many of the farmers interviewed claimed that the low capacity of the dairy is the main reason why they cannot generate any income from milk. Animals are often exported alive as they are purchased by external traders who take care of the transport and the slaughtering. If slaughtered locally, it can legally only be done in the slaughtering house. For many farmers, use of the slaughtering house is inconvenient and too expensive, so they slaughter by themselves and distribute the meat informally or may sell it in their own restaurants. The selling price per kilo is usually lower if the animals are sold alive for export. In the last 5 years, meat prices on Samothraki have dropped by 40% as traders agree on a price among themselves before negotiating with individual farmers. Traders benefit from the lack of farming cooperatives on the island that would allow a joint price policy on the part of the farmers. The partially coupled subsidy payments, or as stated by local experts, at least the perception that there is a strong correlation, continuously prevent farmers from minimizing their herds (Noll et al. 2020). The island is disadvantaged in free market competition as transport costs are high, processing facilities are lacking, and the market is flooded with cheap products, mainly from New Zealand and Australia. These difficulties are reflected in the current financial situation of local small ruminant farmers (Figure 5). Almost half of their revenue is generated through subsidies and main expenses are for transport and animal feed. This leaves the average small ruminant farmer with an income of about 5.000€ per year, too little to sustain their business and family. As stated by most farmers and local experts interviewed, without additional income it is not possible to live from small ruminant production on Samothraki today

The role of science to achieve a sustainability transition of sheep and goat farming on Samothraki

How could a successful sustainability transition of the small ruminant farming system on Samothraki look like and what did many years of research achieve so far? Samothraki needs to escape from the deadlock of the dysfunctional traditional farming system that can hardly secure an income for the farmers but destroys the vegetation cover and the landscape of the island. Exactly this landscape provides the core recreational and economic attractions for tourism. Ways of mutual support must be established between the island's core economic sectors, instead of mutual neglect, destruction and contempt. There are some ongoing processes that point to this direction: farmers are getting older and their overall numbers are diminishing; younger farmers see their chances in collaboration and finding new ways. Still, market conditions for agricultural produce are lacking, several legal regulations stand in the way of direct economic transactions between farmers and the tourism industry, and traditional political clientelism stabilizes large livestock numbers. With insight spreading, new European CAP regulations ahead, and the urgency of effective nature conservation becoming ever more apparent to everyone and being publicly declared by an application to UNESCO, chances are that the deadlock can be overcome.

Our transdisciplinary research approach aims at observing and describing the transformation processes of the livestock system on Samothraki, while "simultaneously increase societal capacity to reflect on them" (Schneidewind et al. 2016). This approach can be conceptualized as transformative as "by careful systemic analysis, it explores, together with the people involved, the realistic option space as well as the constraints of more sustainable alternatives" (Petridis et al. 2017). The research process therefore shifts from a mainly analytical starting point towards a participatory process with the aim of creating a space for knowledge co-production (Figure 2). At the beginning of the process it was important to gain an understanding of past and current conditions for small ruminant farming on the island. The sociometabolic approach proved to be the ideal conceptual framework for this goal as it enables us to generate consistent and comprehensive biophysical accounts for livestock systems, which can then be linked to other socio-economic processes (Erb et al. 2016). It goes much further than the often-applied focus on food to product conversion efficiencies, which has often been criticized as too narrow (Weis 2013). Most importantly, it provides an empirical basis for the definition of policy and management recommendations in order to overcome sustainability problems (Dumont et al. 2013). Through its strong focus on the assessment of biophysical processes within and between systems, it provides a complementary tool to various soft systems approaches in farming systems research (Darnhofer et al. 2012). The focus group interviews with local farmers and fishermen we conducted in 2012 (Petridis et al. 2013) set many of the guiding paradigms for our future research. We could identify major obstacles such as the degradation of pastures and high cost of supplementary feed, the crucial role of agricultural subsidies, the lack of information of marketing and production and the lack of cooperation between farmers. What followed after the focus group interviews in 2012, was a comprehensible study on small ruminant farming on Samothraki (Fuchs 2015). The author of this study highlighted for the first time the role of EU Common Agricultural Policy (CAP) subsidies for the increasing population of small ruminants on the island since the 1980s. It further provided an insight into the monetary economy of small ruminant farmers on the farm level and identified ways forward. This study led to the collaboration between the Greek IT-firm *Integrated ITDC*, the *Aristotle University of Thessaloniki*, and the *Leibnitz Centre for Agricultural Landscape Research (ZALF)* in order to develop the decision support app *Happy Goats* (happygoats.eu), which aimed at providing digital planning support for sheep and goat farmers in Greece and the EU. The initial goal was to use the app as a tool to encourage farmers to engage with their farm economy, especially in regard to small ruminant numbers and available pastures. The leading question during the development phase was: under current circumstances, how many animals would be an optimum for farmers' income while in the same time preserving their pastures? Farmers were supposed to use the app in collaboration with other farmers. During the development phase it turned out that the app required much more input parameters than initially planned for. Therefore, it became too complex to be used by farmers themselves but required an expert for data entry and processing. The app was then used during the farm economy survey conducted with 23 small ruminant farmers on Samothraki from 2016 to 2018 and proved to be a suitable tool for approaching farmers on Samothraki. In 2015 we initiated a collaboration with the University of Lisbon spin-off *Terraprima* (terraprima.pt) in order to provide a special seed mixture to interested farmers. The sown biodiverse pastures (SBP) system is based on sowing up to 20 species/varieties of legumes and grasses that are self-maintained for at least 10 years, with all species used native to the island. The legumes, being 'natural factories' of nitrogen, minimize the need for synthetic fertilizers. SBP result in on average 30% higher biomass production and higher grazing resistance, is currently applied on 13 plots on Samothraki and is still ongoing. This experiment has proven to be highly useful to approach farmers and interest them for our research. At this point it is important to mention the role of local facilitators who build a bridge between scientists and local farmers. These facilitators must speak both languages and are vital for the whole project.

Since the beginning of the project we conducted numerous additional qualitative interviews with farmers and local stakeholders. Recent studies on the agricultural system of the island summarize and analyse this process (Fetzel et al. 2018; Noll et al. 2020; Fischer-Kowalski et al. 2020; Jongen et al. 2022). Recently a farmers' cooperative was founded on the island and the olive oil cooperative resumed its work. These cooperatives are crucial for farmers to achieve a better bargaining position with traders, and for the exchange with researchers such as in the farmer events envisaged. Our knowledge of the small ruminant farming system of the island has far progressed and represents a solid empirical foundation for assisting farmers in finding a shared vision and initiating change in a sustainable direction. Important was also the recognition that there is a big difference between older and younger farmers regarding the future of farming on the island. Younger farmers were much more willing to invest into this transdisciplinary process, as they were desperately looking for ways to improve the situation. From this group came the suggestion of additional frequent meetings that would enable continuous communication between farmers, researchers, and other stakeholders. Set as goal in our research agenda, we refer to these frequent meetings as *farmer events* in Figure 2 and were organizing the kick-off meeting for spring 2020. Then the COVID-19 pandemic put the whole process at hold, and we are currently working on its continuation. This co-created space should enable social learning processes for which it is central to combine "co-construction methods that explicitly address normative agendas and orientations, and appropriate governance amongst social actors and scientists" (Herrero et al. 2019). This means that these events should be open for farmers, scientists, politicians and other stakeholders to enable a collaborative climate in which we can define our common agenda.

Conclusions

This study shows vividly that effects of industrialization and national as well as EU agricultural policies on remote regions require special attention. The socio-ecological transformation of recent decades pushed the island community into a deadlock between economic development and preservation needs. Agriculture plays a key role in this process, as the increase of the small ruminant population triggered environmental and social problems which pose threats to the entire island community. The reasons for this development are manifold but are strongly associated with structural land use changes, global industrialization of agriculture and the agricultural market and finally the regional implementation of the EU Common Agricultural Policy (CAP). To enable a recovery of the local ecosystems, animal numbers must decline substantially. Local socio-economic contexts must be much better taken into account for a new CAP legislation after 2020. Direct payments should reach those who implement measures for sustainable small ruminant production. The flexibility on a national or regional level should be adapted in a way that a situation such as that reported in the present study can be prevented.

Herrero et al. (2015) point out that many ideas look great on paper but are only implemented by 10-20% of farmers, for a wide range of reasons. The authors further state that the understanding of environmental implications of livestock systems and factors that need to change has progressed substantially, while little is known of how to practically implement these changes. Transdisciplinary science can play a crucial role in facilitating this process on a local level, by engaging farmers in the scientific process and foster collaboration among and between farmers and experts from various fields. Our activities seem to have kicked off some real-world changes already, such as encouragement to form cooperatives, a reduction of livestock numbers by 40% and positive experiences with a new type of sown biodiverse pastures. Nevertheless, such changes require more patience and insistence from the part of researchers than they can easily afford

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INVOLVING STAKEHOLDERS IN THE DEFINITION OF PATHWAYS FOR MORE SUSTAINABLE BEEF FARMING SYSTEMS

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Introduction

Agriculture faces many challenges, in particular ensuring food security for a growing human population, while facing resources depletion – resources that are also limited at the outset – in a context of uncertainty related to climate change. In addition, agriculture is objected to many criticisms, especially coming from media and society. Among the criticisms addressed to livestock farming in particular, the low conversion efficiency of livestock and the feed-food competition that livestock farming induces play an important role. However, recent works shed new light on this debate (Wilkinson 2011; Ertl et al. 2015; Mottet et al. 2017; Laisse et al. 2019), especially in the case of ruminant farming. Indeed, ruminants have the advantage of a diet essentially based on resources that are not edible by humans (e.g. grass). However, the evolution of the beef production towards systems relying on the use of concentrate feeds, much of which also have potential as human food, undermines this advantage.

The paper at hand presents the results of a still ongoing project that focuses on the decrease of the feed-food competition in beef production systems in several regions of Europe. The aim of the project is to identify scenarios for more sustainable beef farming systems, i.e. less competitive with human food systems while remaining viable, liveable and fair. This identification work relies on a participatory approach that includes the stakeholders of the beef sector and the use of the *FarmDyn* modelling tool. This paper focuses on the participatory approach.

We chose to invite stakeholders to be a part of our research because we assume that the decrease of the feed-food competition can lead to a re-design of the whole socio-technical system of beef production. The objective of this approach is therefore to better bridge the gap between science and practice, between research and action, in a transformational goal, although the project is limited to the proposal of scenarios.

In this paper, we describe and discuss both how we implement the participatory design, i.e. the methods we used to include stakeholders in our research, as well as the results this participatory process produces. We also analyze how our approach promotes the intersection of science and practices, focusing on our learning, as researchers, rather than on the learning of the stakeholders. Our purpose is therefore above all reflexive-oriented.

Methods

This paragraph reports on both the methods used to implement the participatory approach (1) and the conceptual frameworks used for the analysis of the data produced and of the participatory design (2).

By stakeholders of the beef sector, we mean breeders, farm advisors, up and downstream value chain actors, public authorities, but also scientists. The latter were the first to be included into our research by participating – through open-ended interviews – in the identification of innovations likely to reduce the feed-food competition. By innovation, we mean:

“The introduction of something new or improved into something that has a well-established character, such as products, processes, marketing or organizational methods. In other words, it means applying ideas, knowledge or practices that are new to a particular context with the purpose of creating positive change that will provide a way to meet needs, take on challenges or seize opportunities. Innovation is generally synonymous with risk-taking” (French, Montiel, et Palmieri 2014; Directorate General for Research and Innovation (European Commission) 2013; Centre National de Ressources Textuelles et Lexicales 2012).

We developed this definition following the interviews with the experts, who questioned the concept of “innovation”.

Thanks to these interviews, and a classic literature review (scientific as well as grey literature), we obtained a list of innovations that we then characterized on the basis of the Eco-efficiency – Substitution – Re-design (ESR) approach (Hill et MacRae 1995). This conceptual framework is designed to characterize farmers' transition towards sustainable agriculture following three stages: eco-efficiency (E), substitution (S) and redesign (R) (Estevez, Domon, et Lucas 2000). In our case, efficiency refers to innovations that improve the effectiveness of fodder production or animal feeding practices and limit waste. Substitution refers to the replacement of the part of the feed competing with human food by less competitive feeds. Finally, the re-design stage occurs when the causes of the problem are recognized, allowing to develop solutions at the farm or regional level to modify the system and make it more self-sufficient.

These innovations were then discussed with other stakeholders of the beef sector using the method of focus groups. These focus groups involved breeders, farm advisors and up and downstream value chain actors, i.e. feed manufacturers, actors from genetic selection, veterinarians, cattle traders, slaughterhouses, retailers and consumers’ associations[32]. To avoid risk of self-censorship[33], we organized two kinds of focus groups: with breeders and farm advisors on the one hand, with value chain actors on the other hand. The groups were artificial groups (i.e. created by us specifically for the period of our research). We used the snowball-sampling technique to recruit breeders. Farm advisory structures and other organizations were involved as relay-actors. The purposes of the focus groups was to gather the opinions of the participants on feed-food competition in general, and on the innovations identified through literature review and experts’ interviews in particular, in order to identify and characterize the barriers and levers to their implementation at the farm, territorial and value chain scale.

To achieve these goals, we used facilitation techniques, namely the moving debate and voting techniques. The moving debate – also called “positioning game” – is a facilitation technique where the facilitator presents a statement or asks a closed-ended question, and participants must position themselves in space according to their opinion (Evrat-Georgel et Kling-Eveillard 2018). The room is divided in two parts: on one side, people who agree with the assertion, on the other side, those who disagree. The middle symbolizes the space for people with no opinion. The facilitator invites each participant to express oneself and explain his/her position/opinion. Other participants can move through space as they hear each other's arguments. As it is experienced as a “game”, this technique helps to temper the debate. We used this technique to gather the opinions of the participants on the general objective of reducing feed-food competition in beef farming systems. We also organized votes on the innovations in each focus group. The breeders and advisors could vote for as many innovations as they wanted. They voted in two phases: first,

[32] However, some of them cancelled their participation the D-Day.

[33] Indeed, focus groups require both sufficient social homogeneity but also diversity within the group in order to encourage interactions (Duchesne et Haegel 2004).

the relevance, then the feasibility of the innovations, using labels of different colours (one for the relevance, another one for the feasibility). In the focus group with the value chain actors, we used the technique of Régnier Abacus (Balle-Beganton et Philippe 2018), which we adapted. For each innovation, participants had to choose the degree of their support, ranging from "total support" to "radically opposed", by way of "support", "mixed", "no support", "do not know" and "no answer", each position corresponding to a colour (see below).

The data collected through focus groups were then analysed thanks to the multi-level perspective (MLP), which provides a framework to understand *"how transitions to a new system take place"* (Geels 2006). According to (Geels 2006), the multi-level perspective distinguishes three levels:

The meso-level formed by socio-technical regimes. These regimes *"are actively created and maintained by several social groups"*.

The micro-level formed by technological niches, i.e. *"protected spaces"* and *"incubation rooms" "where it is possible to deviate from the rules in the existing regime [...]. Niches provide space to build the social networks that support innovations"*.

The macro-level formed by the socio-technical landscape, *"which refers to aspects of the wider exogenous environment, which affect socio-technical development (e.g. globalization, environmental problems, cultural changes)"*.

These *"three level interact dynamically over time"* (Geels 2006), which leads to transitions and system innovations. The dynamic of the interactions follows four phases:

Emergence of novelties within the micro-level, while problems in the current landscape and regime occur.

Improvement of the novelties by a growing network of actors (i.e. engineers, producers) revolving around them.

Dissemination of the novelties, which compete with the current regime.

Replacement of the old regime by the new technology, *"which is accompanied by changes in wider dimensions of the socio-technical regime"* (Geels 2006).

However, transitions do not occur without difficulties. Indeed, existing regimes generally put up some resistance to change due to inertia, but also to socio-technical lock-in mechanisms and path dependency. According to (Baret et al. 2013) *"lock-in is defined as a situation where a dominant technology prevents the development of alternative trajectories. The origin of lock-in is most often multifactorial, social and technical (we will speak of socio-technical lock-in) and linked to the dependency on the path of most innovations*".

Finally, we characterized our participatory design based on a recent review by (Lacombe, Couix, et Hazard 2018). In this paper, the authors analyse participatory processes used in research projects aiming at designing innovative farming systems, i.e. agroecological farming systems. They identify five main co-design approaches, i.e. the "de novo design" (1), the "case-study design" (2), the "niche innovation design" (3), the "co-innovation" (4) and the "activity-centered design" (5). Depending on the approach, the role that the farmers play *"can range from simple knowledge providers to co-designers"* (Lacombe, Couix, et Hazard 2018). This analytical framework is built around four questions: who designs and who participates in the co-design? What is the object of the design? Where does the co-design take place and when does it end? How is the design implemented, mainly in terms of knowledge management?

Results

The innovations and their characterization according to the ESR framework

We identified 21 innovations likely to address feed-food competition in beef production systems (see

Table 10). The 21 innovations were sorted, according to the ESR framework.

Table 10 – List of innovations identified to adress feed-food competition and their characterization based on the Eco-Efficiency – Substitution – Re-design (ESR) framework (Hill et MacRae 1995)

	Innovations	ESR characterization
1	Cattle fattening on pastures	R
2	Dynamic rotational grazing	E
3	Alfalfa and red clover as protein supplements in rations for young beef cattle	S
4	Hay dried in barn	S, R
5	Production of fodders through cover crops	E
6-8	Use of by-products coming from the agri-food industry: oil seed cakes used dried stoned olive pomace whey	S
9	Conservation of local pulps and by-products in a single silo	E
10	Use of insect meal as a source of protein in cattle diets	S
11	Use of algae as a substitute for corn or soymeal in the grower and finisher cattle diets	S
12	Crossbreeding (continental breed x breed with an early maturity, more adapted to be fattened under grazing) (e.g. Salers x Angus)	E, S
13	Spring calving for a better use of grass resources	R
14	Genomic selection: measuring and favouring the milk production of suckler cows	E, R
15	Genomic selection for food efficiency	E
16	Terminal crossbreeding with beef breed, on dairy herd, for commercial beef production	E, R
17	Precision livestock farming: connected plate pasture meters	E
18	Precision livestock farming: infrared analysis of fodder	E
19	Integrated crop-livestock systems	R
20	Agroforestry	S, R

21	Limiting meat production to non-competitive feed	R

The opinions of the farmers, advisors and up and down value chain actors on feed-food competition

These innovations were then discussed with farmers, advisors and value chain actors in eight focus groups (three in France, two in Italy, three in Belgium) between September 2018 and February 2019. The focus groups involved 66 participants, half of whom were farmers. Seven focus groups gathered breeders and advisors, one focus group gathered value chain actors[34].

As we mentioned in the introduction, the request for less feed-food competition in beef farming systems comes from society and research. We therefore wanted to gather the opinion of the participants on the object of our research: do they share the objectives of the project? Under what conditions? Through the technique of moving debate, we asked to the stakeholders the following question:

“In the beef production sector, one of the avenues envisaged for more sustainable beef farming systems is to increase the share of resources non-edible by humans in cattle diet. Do you agree with this avenue?”

While most participants agreed with the objective per se (their positions varied from simply “agree” to “totally agree”), they questioned it and, at the same time, questioned the foundations of our research. Indeed, some participants expressed that they felt the project as an additional attack of cattle farming. They raised the following questions in particular: why focus on ruminants farming while feed-food competition is higher in other production systems? (1) Why focus on competition between feed and food in a situation where fuel exerts a pressure - even greater according to some of them - on the production of food and feed? (2) What resources are exactly inedible by humans? (3) They also mentioned the following elements as many pressures on European beef farming systems:

The globalization and the imports: the trade agreement between the Mercosur and the European Union (seen as a threat) was especially mentioned;

The changes in consumption patterns: the growing consumers’ preference for minced beef (coming from culled dairy cows) than for “noble pieces” of meat (coming from meat breeds);

The changes in the human-animal relationship: they mentioned in particular the increased visibility in society of anti-speciesism, veganism, and anti-meat activism[35].

Finally, they pointed out the lack of incentives for less feed-food competition (from decision makers, value chain, consumers) and the soil and climate conditions (cattle farming being the only option in some area) as brakes on the decrease in the feed-food competition.

If most participants agreed with the objective of reducing feed-food competition, the means used to this end led to more divergence within and between groups. Indeed, some participants were opposed to the use of by-products (considered as waste or which could conflict with the search for autonomy at farm scale), while others feared that grass-fattening may be done at the expense of performance. Finally, while most participants shared the objective of reducing feed-food competition for the breeding phase, some were sceptical about the fattening phase, especially

[34] Walloon value chain actors (BE).

[35] Several actions carried out by anti-meat activists in France made the headlines at the same time as the focus groups.

considering the carcass conformation standards being in force in the value chain, as expressed in the following excerpt:

"When a young bull comes fat from pasture, I don't say it [editor's note: to the cattle trader]*, I don't brag about it, because the cattle trader will remove it* [editor's note: from the batch]*. He will say: « the fat is not the right colour, the carcass doesn't hold the same way, ...». And it's a practical matter!"* (a Walloon breeder-fattener leading a maize-based system)

We also observed that the reduction of feed-food competition seems rather a secondary benefit of other approaches (such as the search for autonomy, forage efficiency or decrease of the herd) that an objective per se: no participant acts specifically in this direction.

The opinions of the farmers, advisors and value chain actors on the innovations

After presenting them with the list of innovations identified, we asked the participants to express their preference through a vote. Table 11 shows the ranking of the innovations according to their relevance from the breeders and farm advisors point of view. They are sorted from the most relevant to the least relevant. Table 12 shows the ranking of the innovations according to their degree of support by the value chain actors. They are sorted from the most supported to the least supported[36].

In the focus groups with breeders and farm advisors, among the most relevant innovations, none of them really reaches consensus: when there is a consensus within a group, there is not systematically consensus between the groups, and vice versa. The different profiles of the breeders involved can partially explain these divergences[37]. On the other hand, they seem to agree more on the least relevant innovations.

Within the focus group with value chain actors, there is a consensus on more innovations, both among the most supported and least supported innovations. But there are divergences of opinion too.

If we compare the two types of focus groups (i.e. breeders and advisors on the one hand, value chain actors on the other hand) there are also differences: if stakeholders agree on innovations receiving little support or relevance, the same is not true for the other innovations.

Finally, from the point of view of the ESR approach, the vote of the stakeholders does not really seem to have been influenced by the stage to which the innovation refers (E, S or R stage). Indeed, the selected innovations affect all categories, and none of them stands out in particular

[36] The list of innovations put to the vote was not exactly the same in each country and in each focus group: all the innovations were not discussed in all the focus groups.

[37] The breeders involved are either breeders, or fatteners, or breeders-fatteners. Their systems are either mainly grass-based system, or maize-based system. They also belong to conventional or organic farming. This diversity of profiles, combined with different soil and climate conditions, partly explains the variability of breeders' positions on innovations.

Table 11 - Results of the voting sequence in the focus groups with breeders and advisors: relevance of the innovations

Innovations	ESR[38]	Number of votes*	Number of focus group that select this innovation*
Genomic selection for food efficiency	E	15 (n=35)	3 (n=4)
Cattle fattening on pasture	R	13 (n=59)	4 (n=7)
Dynamic rotational grazing	E	12 (n=59)	4 (n=7)
Production of fodder through cover crops	E	10 (n=29)	4 (n=4)
Alfalfa and red clover as protein supplements in rations for young beef cattle	S	10 (n=59)	3 (n=7)
Precision Livestock Farming	E	9 (n=59)	4 (n=7)
Use of by-products coming from the agri-food industries[39]	S	8 (n=59)	5 (n=7)
Genomic selection: favouring the milk production of suckler cows	E,R	6 (n=59)	3 (n=7)
New sources of proteins: insects, algae	S	6 (n=59)	3 (n=7)
Integrated crop-livestock systems	R	5 (n=14)	2 (n=2)
Crossbreeding (continental breed x breed with early maturity) (e.g. Salers x Angus)	E,S	4 (n=59)	3 (n=7)
Terminal crossbreeding (beef breed on dairy herd)	E	2 (n=29)	2 (n=4)
Spring calving	R	2 (n=43)	2 (n=5)
Agroforestry to produce fodders	S, R	2 (n=59)	2 (n=7)
Hay dried in barn	S, R	1 (n=59)	1 (n=7)
Conservation of local pulps and by-products in a single silo	E	1 (n=29)	1 (n=4)
Limiting meat production to non-competitive feed available	R	0 (n=29)	0 (n=4)

* The list of innovations put to the vote was not exactly the same in each country and in each focus group: all the innovations were not discussed in all the focus groups. That explains the variation in the number of individuals and focus groups who participated in the vote.

[38] Characterization of the innovations based on the Eco-Efficiency – Substitution – Re-design (ESR) framework (Hill et MacRae 1995).

[39] The by-products considered differed according to their availability in the region concerned.

Table 12 - Results of the voting sequence in the focus group with value chain actors: degree of support of the innovations (n=7 individuals). Each cell corresponds to a vote. Color code: Dark green = total support; light green = support; yellow = mixed; orange = no support; red = radically opposed; white = do not know.

Innovations	ESR[40]	Degree of support (n=7)						
By-products coming from the agri-food industry: breweries dregs	S	dark green	dark green	dark green	light green	light green	light green	yellow
Alfalfa and red clover as protein supplements	S	dark green	dark green	dark green	light green	light green	light green	white
Genomic selection : favouring the milk production of suckler cows	E, R	dark green	dark green	dark green	light green	light green	light green	white
Genomic selection for feed efficiency	E	dark green	dark green	dark green	light green	light green	yellow	white
Terminal crossbreeding with beef breed on dairy breed	E	dark green	dark green	light green	light green	light green	yellow	yellow
Integrated crop-livestock systems	R	dark green	dark green	light green	light green	yellow	yellow	white
Crossbreeding (continental breed x breed with an early maturity) (e.g. Salers x Angus)	E, S	dark green	light green	light green	light green	yellow	yellow	orange
Cattle fattening on pasture	R	dark green	light green	light green	light green	yellow	yellow	white
Precision livestock farming: infra-red analysis of fodder	E	dark green	light green	light green	light green	yellow	white	white
Precision livestock farming: connected herbometer	E	dark green	light green	light green	light green	yellow	white	white
Dynamic rotational grazing	E	light green	light green	light green	light green	yellow	yellow	white
By-products coming from the agri-food industry: downgraded products (vegetable, milk powder)	S	dark green	light green	light green	yellow	yellow	yellow	yellow
Hay dried in barn	S, R	light green	light green	yellow	yellow	yellow	yellow	white
By-products coming from the agri-food industry: whey	S	light green	light green	yellow	yellow	yellow	yellow	orange
Spring calving	R	light green	light green	yellow	yellow	yellow	orange	white
Algae	S	light green	light green	yellow	yellow	white	white	white
Agroforestry	S, R	dark green	dark green	yellow	red	white	white	white
Conservation of local pulps and by-products in a single silo	E	light green	yellow	yellow	yellow	yellow	white	white
By-products coming from the agri-food industry: process waters	S	dark green	yellow	yellow	yellow	orange	orange	white
Limiting meat production to non-competitive feed	R	yellow	yellow	orange	red	red	red	red
Insects	S	orange	orange	red	red	red	red	white

[40] Characterization of the innovations based on the Eco-Efficiency – Substitution – Re-design (ESR) framework (Hill et MacRae 1995).

The barriers and levers for the innovations uptake

The focus groups also aimed to identify and characterize the barriers and levers to the implementation of the innovations at the farm, territorial and value chain scales. Figure 19 and Figure 20 give an overview of these barriers and levers from the participants' point of view (all innovations combined). The barriers refer to multiple dimensions of the socio-technical regimes for beef production, ranging from the production to the territory, by way of guidance, transformation, distribution, consumption, cattle, culture, regulations and policies. The levers refer to the innovations per se and their potential economic, social and environmental performances, but also to some components in the environment that act as many opportunities.

Figure 19 – Barriers for the innovations' uptake identified by the stakeholders of the beef sector

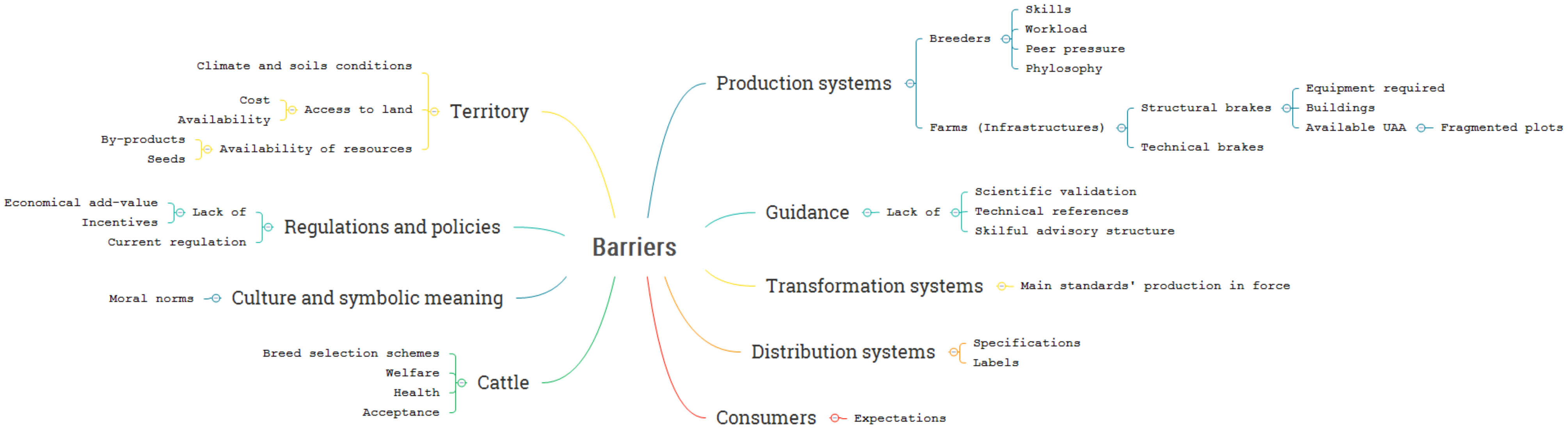
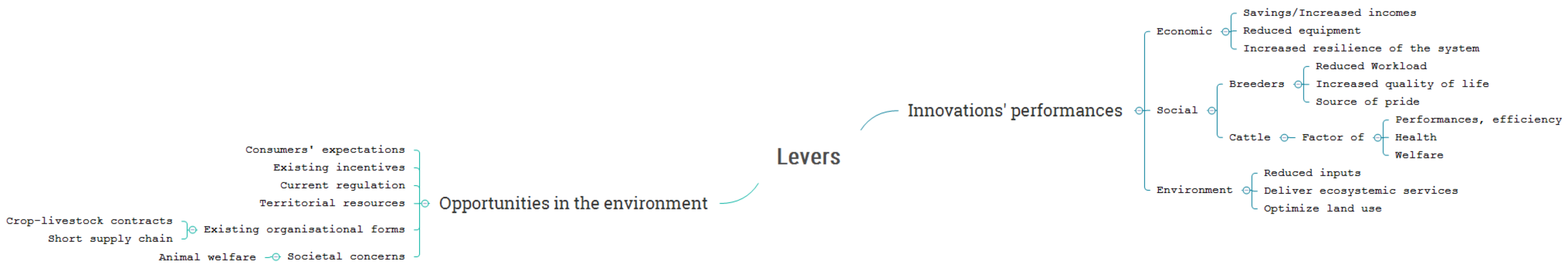


Figure 20 – Levers for the innovations' uptake identified by the stakeholders of the beef sector



Discussion

Dynamics on system innovations

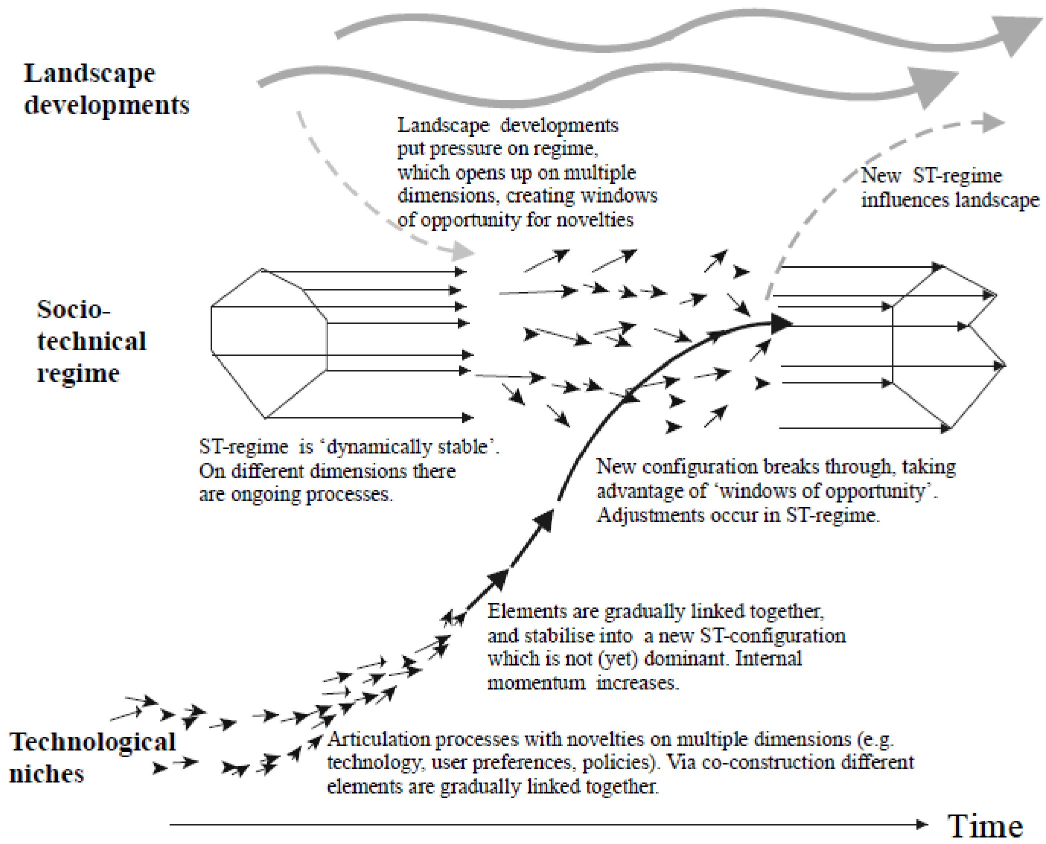
The focus groups allowed us to identify some elements that can be considered as what (Geels 2006) calls *"landscape changes that put pressure on the regime"* (see Figure 21), such as the globalization, the imports of beef meat and trade agreements, the multiple land uses (especially for energy production) that may compete with the production of food and feed, the climate change, or else the resources depletion. Note that the stakeholders also consider the criticisms of beef production systems from the perspective of feed-food competition as a pressure.

Participants also highlighted changes at the regime level, such as changes in food consumption patterns and in human-animal relationships.

These elements are what (Geels 2006) calls *"external circumstances"* that can produce *"windows of opportunity"* when they appear simultaneously, i.e. the conditions necessary for the third phase of the transition, namely the dissemination of the novelties (see above, in the methods part).

On the other hand, the focus groups helped us to identify what (Geels 2006) calls *"internal drivers that* [also] *stimulate the diffusion of innovations",* such as the potential performances of the innovations, but also the links innovations forge with elements of the environment. These links act as many opportunities for their development.

Figure 21 – A dynamic multi-level perspective on system innovations (Geels 2002b: 110) in (Geels 2006)



Conversely, the focus groups also highlighted several socio-technical locks-in, such as the standards in force in the value chain (e.g. the *"S grade ideal"* for the beef carcass conformation and "*the lean-and-tender référentiel"* in force in Belgium (Stassart et Jamar 2008) and the related breed selection schemes and bill of specifications). These locks-in prevent the change from one socio-technical system to another.

All these elements help us to better understand how the socio-technical systems for beef production can change to less feed-food competition systems.

Intersection of science and practice: a reflexive exercise

We encountered some difficulties to sort the innovations according to the ESR framework. Some innovations (e.g. "agroforestry to produce fodders", "crossbreeding", "genomic selection favouring the milk production of suckler cows") refer thus to several stages, because the boundaries between the three stages are often too fuzzy. This is one of the criticisms regularly pointed out about this conceptual framework, i.e. presenting the transition as a succession of distinctly separate stages, when they have to be seen more as overlapping (Brédart et Stassart 2017). We decided to use the ESR approach because it seemed interesting to us to distinguish the transition strategies mobilized by each innovation and to differentiate innovations that are closer to business as usual (i.e. innovations referring to the "E" or even "S" stages) and those that are more disruptive (i.e. innovations referring to the "R" stage). Indeed, the latter are potentially the ones for which support (advice, policies, research) will be the most crucial. If it is true that the barriers and levers that the stakeholders identified for the uptake of the innovations referring to the "R" stage (e.g. "integrated crop-livestock system", "cattle fattening on pasture" or else "spring calving") refer in particular to levels above the farm scale (e.g. standards' production, regulation, ...) – and in this sense need crucial support from a wide range of actors – it is also true for the implementation of innovations referring to the "E" or "S" stages (e.g. "genomic selection for food efficiency", "use of by-products coming from the agri-food industry"). As (Geels 2006) points out, this depicts that *"system innovations are not merely about changes in technical products, but also policy, user practices, infrastructure, industry structures and symbolic meanings, etc."* Therefore, system innovations have to be seen as *"changes from one socio-technical system to another"* (p.165) what implies the support of *"a wide range of actors"* (p.166). In this sense, if the characterization of the innovations thanks to the ESR framework helps us, as researchers, to differentiate between innovations that are closer to business as usual and those that are more disruptive, it seems less effective when proof against practice.

It is maybe partially due to the fact that, from a methodological point of view, the way we identified the innovations was maybe too much "science and technique oriented", i.e. limited to the technical and scientific angles and especially, in both cases, to the agronomic field (the experts met and the literature read). In particular, we should have broadened the profile of the interviewees. Indeed, the concept of innovation is too often limited to a technical sense, even though it takes many forms (organizational, social, political, etc.) (Baret et al. 2013).

The use of the term "innovation" was also probably a mistake, as innovation means "novelty" for most of the stakeholders[41], whereas several innovations identified are clearly not "novelties". This caused disappointment for some participants that consider innovation necessarily as a break.

These elements argue for a more general reflection on science-innovation relationship – and wider society-innovation relationship – and the omnipresent injunction to innovate (Ménissier 2016). This reflection will not, however, be carried out in the context of this paper.

[41] As said in the results' part, some experts met in interviews highlighted the problematic use of the term innovation. We had therefore planned a short sequence in the focus groups aiming to bring out the participants' representation of the innovation. The results of this sequence are not presented in this paper however, as the results' part is already substantial.

Characterization of the participatory design

The object of our research is not exactly the same as in the research projects Lacombe et al. analyse in their review (Lacombe, Couix, et Hazard 2018). Indeed, the authors analyse co-design projects related to the implementation of the principles of agroecology. Moreover, our aims differ, as Lacombe et al. focus on *"the link between a co-design situation and its transformational effects"* (p. 209) from the point of view of the farmers, while the paper at hands focuses on the researchers' learning. However, we can use their analytical framework to characterize the involvement of the stakeholders in our project. Thus, the process we use is clearly research-oriented, not support-oriented. The demand comes from society and research, not from farmers. The goal of the participatory process is to define relevant scenarios of change towards less competitive beef farming systems. The role played by the stakeholders is to express their opinions – about the feed-food competition, about the relevance and feasibility of the innovations we identified and about the scenarios the consortium defines – during indoor workshops. In this sense, the stakeholders are *"knowledge and feedback providers for modelling"* (Lacombe, Couix, et Hazard 2018) (p. 214). The process does not lead directly to a change of their own practices, although this could be, by a reflexive movement. The expected outcome is an assessment of the performance and sustainability of the scenarios to inform decision-makers of the innovations to be supported. The participatory approach ends with this outcome. The design is therefore neither action, nor learning oriented – although we may pursue these aspects in a later project. In this sense, the participatory design we used comes up to what the authors call "case study design".

Considerations on the methods and techniques used

The focus groups really contributed to the participatory nature of our approach. They allowed stakeholders to express themselves, without being trapped by top-down knowledge. However the recruitment of the breeders was time and energy consuming, as well as the transcript of the exchanges and the analysis. The use of this technique in the context of participatory research is therefore particularly interesting, but the resources needed to achieve it (time, skills, availability of team members, budget, ...) should not be underestimated, as it can be, when focus groups are reduced to a simple meeting of people (Barbour et Kitzinger 1998; Duchesne et Haegel 2004; Baribeau 2010).

Concerning the moving debate, this technique allowed us to go beyond components that could have "paralysed" the discussions later on by reappearing systematically throughout the debates, in an untimely manner. Furthermore, allowing the participants to express themselves on the subject of our research gave them the feeling of a "real" exchange[42] (i.e. on equal terms), where, as scientists, we did not come as "holders of knowledge", in a top-down logic.

Finally, between the two voting techniques used, our preference is for the Régnier Abacus. Indeed, while voting with coloured labels is easier and faster to implement, the Régnier Abacus' technique gives an overview of all the participants' opinion for each innovation. It also allows reducing social desirability bias.

Conclusion

In this paper, we show how a participatory approach can help researchers to better understand the dynamics of system innovations. Starting from a list of innovations likely to reduce the feed-food competition in European beef farming systems mainly focused on technical and scientific

[42] Several participants pointed out this aspect at the end of the focus groups.

aspects, the involvement of the stakeholders of the beef sector provides us an overview of the windows of opportunity as well as of the lock-in at work.

The participatory approach also allows researchers to learn through a reflective exercise. It provides a better understanding of how the methods used and the way the research is led impact the results obtained.

However, the role of the stakeholders is limited to the supply of knowledge and feedback for modelling, as the research is not action-oriented. The participatory process ends with the proposal of scenarios addressed to decision-makers.

The results presented in this paper serve as a foundation for the definition of these scenarios and their modelling by the members of the consortium. The next step of the participatory process is to discuss these scenarios and the results of their simulations (i.e. performance and sustainability assessment) with the stakeholders previously involved through restitution workshops.

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HOW TO FACE THE CHALLENGE OF ANALYSING THE RESULTS OF ON FARM EXPERIMENT TO SUPPORT PARTICIPATORY RESEARCH SCHEMES?

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INTRODUCTION

The agricultural sector faces several major drawbacks linked to its dependency toward nonrenewable resources (such as oil and phosphorus) (Van Vuuren et al. 2010), its impact on the environment (such as biodiversity loss, soil erosion, water pollution and greenhouse gas emissions) (Soule et al. 1990) and on the social system (such as land grabbing, difficult working conditions, animal wellbeing) (Altieri 2002; Rulli et al. 2013).

Several production systems, based on agroecological principles (Altieri 2018), such as organic agriculture (Seufert et al. 2012), conservation agriculture (Hobbs et al. 2007), agroforestry (Dupraz and Fabien 2008) and permaculture (Ferguson and Lovell 2014), aim to answer at least to some of those concerns. Agroecology is a holistic production system pointed out as a response to climate change and the global economic and social instability context that can be adopted by large-scale farmers historically engaged in a productionist system (Altieri 2018).

For the farmers this technical shift toward agroecology is difficult due to its knowledge-intensive nature, its relatively uncertain results and the requirement of local references (de Tourdonnet et al. 2013). For the scientist, this shift implies a new posture of agronomic research from top-down input-based research and development to bottom-up co-constructed holistic experiments with a scope not only on the production of new agronomic knowledge but also on the assistance of the farmers in their transition toward low-input agroecological systems. This requires getting closer to the realities of the field and developing participatory research schemes with groups of farmers.

This collaboration often leads to difficulties. Indeed the farmers can see formal experimental designs as impractical and too far from their ground realities (Piepho et al. 2011; de Tourdonnet et al. 2013). This highlights the need for scientists to explore new experimental schemes that can combine both of their and the farmers' needs.

In this context, we have been conducting since 2019 a participatory agronomic experiment based on the priorities and the expectations of a group of farmers in Wallonia (Belgium). The general principle is to conduct a personalized systemic experimentation in one field of each farmer of the group in order to assist them in knowledge production of locally adapted breakthrough techniques (such as direct seeding, permanent living mulch use, cash crop association and so on).

Even though this methodology enables us to assist much more efficiently the farmers in their transition toward agroecological systems, drawing general conclusions from this approach, in order to spread those innovations to a large number of farms in the Walloon area, seems much more difficult. Indeed, due to the limitations in the experimental design (Table 14) and the uniqueness of each field experiment in the different farms, common statistical tools cannot be used. However, the opportunity of developing robust and novel knowledge bases from the breakthrough techniques implemented by the farmers is not overlooked. The aim of this article is to display the methodological difficulties encountered by the scientists, especially concerning the future statistical analyses of the results and our answers to overcome those difficulties.

THE CHALLENGES OF ON FARM EXPERIMENTS

The term “on farm experiment” (OFE) refers to an agronomic experiment set up on a farm (as opposed to one set up in an experimental station). This generic term hides a lot of variability concerning stakeholders (Lightfoot and Barker 1988), objectives (Catalogna et al. 2018), experimental design (Rivière et al. 2015; Catalogna et al. 2018), time and spatial scale (Lightfoot and Barker 1988), data collection and indicators used (Toffolini et al. 2015; Catalogna et al. 2018) and results assessment (Hoffmann et al. 2007). Several examples of OFE are displayed in Table 13. This table highlights the main differences between several experimental designs that can be set up on a farm. Specifically those differences are linked to the objective, scales (spatial and time), use of indicators, results assessment and diffusion of the experiment’s results.

When both farmers and scientists are involved in an OFE, differences between the rigorousness of formal experimentation methods and the priorities of the farmer co-defining and/or hosting the experiment can lead to difficulties and unease on both sides.

On the one hand, it is not unusual for farmers to feel scientific experimental designs as an additional source of workload leading to unenforceable results. Indeed, they are usually set up with highly specific material, using multiple small plots or strips and covering modalities that are not always in line with the farmers’ expectations (Lightfoot and Barker 1988; Hoffmann et al. 2007). Furthermore, the farmers might get frustrated by the lack of flexibility of the experimental process through time if new information comes up or if the experiment shows that it is going to be a failure (Catalogna et al. 2018). Another source of frustration can come from the fact that the differences between the experimental treatments often affect only a single factor (for example fertilization type or weed management strategy) in order to highlight a causal link and does not affect the whole management system.

On the other hand, the scientists might experience difficulties analysing the results due to suboptimal experimental design that cannot allow the assessment of a phenomenon or robust statistical analyses (Perrett 2006; Lawes and Bramley 2012). Indeed, by coping with the ground reality of heavy farm motorization, it might be difficult to get a formal and complete experimental design. This led to the creation of alternate experimental designs such as strip trials (Piepho et al. 2011; Lawes and Bramley 2012) and mother-baby design (Rivière et al. 2015) or alternative statistical tools (Perrett 2006). Another common problem for the scientist is attempting to assess too many treatments and/or factors in order to answer the needs for innovation of the farmers and not being able to follow all those variating factors (Hoffmann et al. 2007).

Apart from the experimental design, other differences between the scientists and the farmers’ points of view are linked to their primary objectives and the diffusion of the results. The objective of the farmers usually being very tangible (better economic performance for example) while the primary objective of the scientists usually is to explore additional dimensions or performances, aside from the economic one (Hoffmann et al. 2007). Likewise, the results of OFE will be spread formally by the scientist through articles and conferences (usually out of reach for most of the farmers) while farmers read technical articles and/or use informal channels such as discussion with peers or social media (de Tourdonnet et al. 2013).

Nonetheless, OFE and collaboration between farmers and scientists are a cornerstone of agroecological transition (Navarrete et al. 2018; Catalogna et al. 2018). Indeed the difficulties of combining the formal scientific method and the ground-oriented approach of the farmers highlights their complementarity in agronomic research. Apart from helping the farmer in OFE design (Catalogna et al. 2018), the scientists can provide technical assistance and help famers with similar objectives to connect with each other or with rural development organisms (Navarrete et al. 2018, de Tourdonnet et al. 2013). Meanwhile, the farmers enable the design of innovations and technical itineraries with a more systemic view and a better knowledge of the realities of their systems (de Tourdonnet et al. 2013).

Table 13: Examples of on farm experiments.

	Randomized Complete Block Design (RCBD)	**Strip-trial design** (Piepho et al. 2011)	**Mother-baby design** (Rivière et al. 2015)	**Farmer's experiment** (Catalogna et al. 2018)
Experimental design	Optimal : Balanced Randomized Replicated With a control Few variable factor(s)	Sub-optimal Balanced Replicated With a control Few variable factor(s)	Sub-optimal Partially replicated With a control Few variable factor(s)	Exploratory Priority to conveniency No replication Often without control Several variating factors
Objective(s)	Technology impact on production aspect(s) (yield, workload and so on)	Technology impact on production aspect(s) (yield, workload and so on)	Usually plant breeding	Systemic innovation
Spatial scale	A few dozen square metres per treatment Experimentation in other field(s) optional	Several hundred square metres per treatment Experimentation in other field(s) optional	A few dozen square metres per treatment Usually experimentation in other farms	Several hundred square metres per treatment or more Usually only one field
Time scale	Short: one cropping season or less	Short: one cropping season or less	Long: more than one cropping season	Short and/or long
Indicators	Figures Usually only technical and/or environmental aspect(s)	Figures Usually only technical and/or environmental aspect(s)	Figures Usually only technical and/or environmental aspect(s)	Figures optional Multi criterion (social, economic)
Results assessment	Statistical analyses	Statistical analyses	Statistical analyses	Figures comparison Personal appreciation
Results diffusion	Formal Scientific journals Conferences	Formal Scientific journals Conferences	Formal Scientific journals Conferences Technical journal	Formal Technical journal Informal Discussion with peers Social media

THE FARMERS' PLOTS NETWORK SYSTEMIC EXPERIMENTATION (FPNSE)

Complaints on previous experimentation methodologies (mainly strip trials (Piepho et al. 2011; Lawes and Bramley 2012)) and the applicability of the results emerged from a Walloon (Belgium) group of farmers implementing agroecological practices on their farm. The scientists and advisors in charge of the group coordination thus developed a new experimentation process based on the farmers' priorities and expectations.

The originality of this experiment is that it puts the individual farmers and their practices at the core of the experimental process. The main objective being to get as close as possible of their individual priorities and realities to substantially help them in their transition toward low-input and low-disturbance agroecological practices.

The experiment is based on a specific crop rotation, co-developed with each farmer for at least three seasons on a given field. This is done through one or several meeting(s) between each farmer and one or several technical advisor(s). Firstly, the objectives of the farmers are discussed (for example, stop using glyphosate-based herbicides or implementing crop associations). Then the current and conceivable crops of the farm are listed. Afterward, a field is chosen based on its size (at least two hectares), the fact that it has a unique history (same crops and same management) and consistent soil texture and structure. At last, a crop rotation is co-developed with the farmer with a scope on checking his previously defined objectives. This rotation is flexible through time and can be changed in concertation between all the stakeholders. It is also discussed with other farmers during group meetings.

On one part of the field, the farmer will carry out its crops as usual with well-mastered techniques (called the *control site*) while on the other part of the field (called the *impact site*, around one hectare of surface area) the farmer will experiment new techniques. On this experimental area, except for the cultivated crop, the whole management system can potentially be impacted (fertilization, pest regulation, soil management, and so on) with a scope on reducing soil disturbance and external input use. An example is shown in Figure 22. The chosen field (with a red border) has a surface area of 10.8 hectares. The impact site, on the east, has a surface area of around 1.5 hectares (with a green border). This is the only place where a differentiated treatment will be applied. The yellow bordered rectangle is the part of the control site where measurement will be done in order to compare the usual practices with the experimented techniques.

As the only variating factors between the impact and the control sites are linked to the differentiated management strategy, all the other factors being consistent (weather conditions, field history, soil texture and initial structure, farmers, main cultivated crops), we consider that the only cause of variation between the impact and control sites are due to the differentiated management strategies over the years.

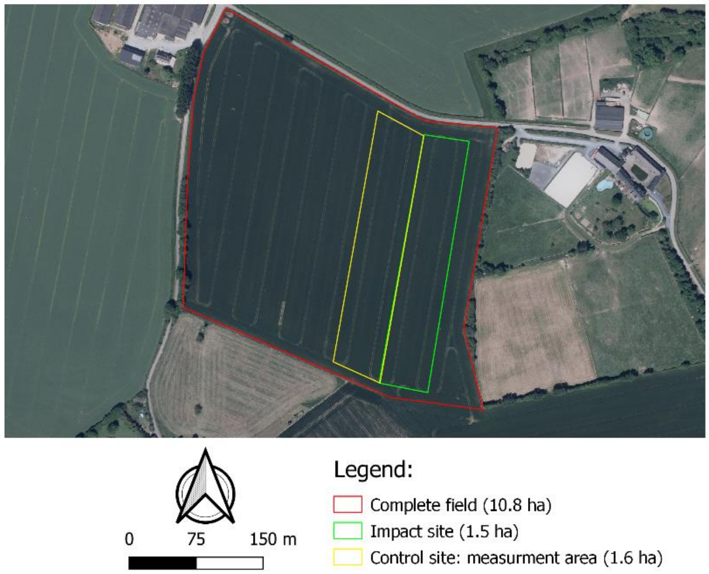

Figure 22: Example of a field part of the FPNSE. Note that the experimental design takes into account the usual tractor pathway of the farmer to limit any additional workload.

At the farm level, our experiment is unreplicated and unrandomized. This means that we cannot estimate the variance of each management strategy (through subsampling we can only estimate the variance inside a plot). Furthermore, the lack of randomization can lead to the incorporation of any potential pattern in the results (Plant 2007). However, this risk is limited by a careful choice of the impact and control sites in collaboration with the farmers.

These design limitations are quite common in the field of environmental monitoring and impact assessment (Eberhardt and Thomas 1991; Smith et al. 1993; Underwood 1994). Therefore, the methodologies used in those research fields, mainly the Before-After-Control-impact (BACI) design and its variations, have been an inspiration source for our experiment.

In its simplest form, BACI designs are composed of two sites and two time periods. The set of sites is composed of one impact site supposed to have been affected by an external source (such as a stream from which water is pumped upstream by a power plant then released downstream, warmer than before, which might have an impact on the local fauna, for example on fish laying behaviour (Smith et al. 1993)) and a control site which has not been affected. The choice of the studied sites is critical. Firstly, the impact site has to be chosen so that the impact, if existing, can be observed. Secondly, the control site must answer several powerful hypotheses. Indeed, it has to be similar to the impact site but it cannot be affected by the external source. However, all and every external factors have to be similar between the impact and control sites through time. Following the same example, the weather conditions, flow variations, fishing intensity, and so on must be similar for both sites. Another way to present the link between the two sites is that one must be able to consider them as paired, except for the assessed effect of the external source. The set of periods is simply composed of one before and one after period. Keeping on with the same example, the before period is when the power plant is not active yet while the after period begins when the plant starts electricity production (and water pumping).

The BACI design has been the subject of substantive discussions (Stewart-Oaten et al. 1986; Underwood 1991, 1992, 1994; Stewart-Oaten and Bence 2001; Stewart-oaten 2014) and has been shown to be sensitive to the methodology of analysis (Smith et al. 1993; McDonald et al. 2000; Smokorowski and Randall 2017).

Therefore, multiple variations of the initial design have been suggested (Downes 2008). Thus, one applying this kind of experimental design should be careful in the analysis and interpretation of the results.

Several major differences between BACI design (and its variations) and our experiment can be spotted. The first one is that two clear time periods (before and after) are not defined in our case where crop growth and succession are continuous processes. The second one is that the hypothesis that the impact and control sites are paired is easier to accept than in most environmental monitoring experiments because the fields share the same soil, history, weather conditions and crops. At last, in our experiment, multiple control and impact sites are monitored (one for each farm) and the experimental measures are done at the same time (at least for one set of impact and control sites). Thus our experimental design gets closer to the MBACIP design (Multiple BACI Paired) (Downes 2008) which is composed of several impact and control sites that are considered paired in time.

The cultivated crops and techniques experimented in the field will vary among farmers following their personal objectives and constraints. Thus, this experimental design has two distinct levels. Firstly, the farm or field level, with the individual co-constructed crop rotations and the comparison between the impact and control sites of each field. Secondly, the group level were farmers and scientists will be able to exchange about the individual innovations and compare the results of several similar experiments (for example the use of a strip-till for the implementation of a spring crop). The main characteristics of this experiment are summarized in Table 14.

This experimental design enables the farmers to experiment novel and uncertain agricultural techniques while limiting risks (because the experimentation is conducted on a relatively small area and the potential financial risk is shared with the scientists) and to compare those techniques to their usual management system. The scope of those techniques is quite large. It is composed of:

Low disturbance soil management techniques such as strip-till or direct seeding;

early implementation of winter crop;

crop association for multiple harvests or environmental services (nitrogen and carbon sequestration, soil fissuring, and so on);

use of a perennial living cover crop through (part of) the rotation;

crop or cover crop grazing.

Note that those techniques are usually combined on the experimental fields.

Table 14: Main characteristics of the FPNSE

Farm or field level	Group level
Long term and continuous process	
Unreplicated: one control and one impact sites.	**Unreplicated**: a different treatment is potentially applied at each location (the management techniques are decided with each farmer). However, there is some consistency in the experimented techniques.
Unrandomized: the sites are chosen with the farmer according to his usual tractor pathway in the field (Figure 22).	**Balanced**: Each experimental field has one control and one impact site
Several and simultaneous variating factor between the impact and control sites.	**Inhomogeneous blocks**. The surface area of each control and impact sites are different
Paired observations: the control and impact sites share the same history (crops and management techniques), environment (weather conditions, soil) and cultivated crops. Thus, we assume that any potential difference(s) between the impact and control area will be caused only by the new management practices over the years.	**Unpaired**: Across farms, the fields do not share a common history or a specific management system

ANALYSES OF THE EXPERIMENTAL RESULTS OF THE FPNSE

The experimental results are to be analysed in order to differentiate and communicate on innovations that show some potential from those seeming to be inefficient.

To achieve that, different analyses will be performed. Firstly, a multivariate analysis will be conducted on the different sites (impact and control) across the farms and years in order to link agricultural practices to performance indicators (environmental, social and economic). The objective of this analysis is exploratory and will allow us to highlight potential interconnections between practices and some of the performance indicators recorded. Secondly, based on these observations, the impact significance of the practices implemented across several farms will be studied. This will be done using a generalized linear mixed model (GLMM). Thirdly, in order to produce more readable results (for a public without a scientific background) and to double-check our previous conclusions, a complementary Bayesian Markov chain Monte Carlo (MCMC) (Conner et al. 2016) approach shall be used on the highlighted interconnections. Those analyses are presented in Table 15 and detailed below.

Those last two analyses (GLMM and MCMC) will use the results of the experiments at the group (or subgroup) level. They imply that the same variables and indicators will be measured through the different farms, sites and crop cycles of the study. Thus, it is essential to define those criteria beforehand to insure good recording by the farmers and appropriate measurement by the scientists.

Table 15: Synthesis of the different analyses that will be conducted in the study

	Multivariate analysis	Generalized linear mixed model (GLMM)	Bayesian Markov chain Monte Carlo (MCMC)
Aim	Exploratory	Impact assessment	Results vulgarization and validation
Expected results	Correlation structure between practices and performances indicators highlighting indicators sensitive to the practices	Significance level of the site parameter for each analysis	Distribution of the ratio between the impact and control site for each indicators
Number of analyses	One or several if needed	Several, one for each practice/indicator correlation	Several one for each GLMM
Analyses based on	Every crop cycle across the farms	Pairs highlighted by the multivariate analysis	Pairs analysed in the GLMM
Farms and years considered as random factors	No	Yes	Depending on the methodology

LINKING THE PRACTICES TO PERFORMANCE INDICATORS: MULTIVARIATE ANALYSIS

The objective of this analysis is to explore the potential relations between the agricultural practices on the impact and control sites and environmental, social and economic performance indicators. The multivariate analysis will help us to clear the view for further statistical work. It might also enable us to implement the experimented practices into a typology.

In order to optimize the ratio between the number of individuals and the number of variables while keeping consistent individuals to limit the number of NA's, we suggest that the blocking factors of the database be (1) the farm, (2) the site (impact or control), (3) the year of crop implementation, (4) the implementation order of the crop on the field for the given year (considering cover crops on equal footing as any commercial/forage crop). For example, an individual could consist of a cover crop sowed after a spring crop in 2019 on the impact site (I) of farm Y thus giving us the individual Y_I_2019_2. These blocking factors would not be active variables of the multivariate analysis.

One drawback of this approach is that some individuals will cover a longer time period than others (for example winter crops sowed in autumn) and some will cover seasons completely different than others (for example winter cover crops and spring crops). A possibility would be to conduct several separated analyses, one for each type of crop (spring, winter, frost sensible cover crop and so on). We should therefore be careful on the power of relations that will be produced by the analysis, especially for environmental indicators, which might be more sensible to a difference in the duration of a crop or its growth period.

Apart from the blocking factors, the database would also be composed of variables linked to agricultural practices and performance indicators (social, environmental and economic). Those variables are detailed below and shown in Table 16.

The variables describing the agricultural practices would cover the type of crop, the modalities of soil preparation, the use of inputs and so on. For this exploratory analysis, those variables would exclusively be factorial or binary. The variables covering the agricultural practices could potentially all be active in the multivariate analysis.

The variables used to characterize performances indicators would be continuous and linked to the workload (hours of work for soil preparation, weeding, and so on), the accounting of the plots (turnover, costs, and so on) and to environmental observations (on soil organic matter, biodiversity and so on). Note that contrary to most of the other variables, environmental observations can be done several times during the crop cycle. This means that a temporal aspect could be added for those indicators.

As shown in Table 16, the multivariate analysis would have to combine factorial (the agricultural practices) and continuous (the performance indicators) variables. From there, several options are available. On the one hand, the variables could be kept as they are, using a methodology that allows the combination of those two types of variables in the multivariate analysis. We would use either a factorial analysis of mixed data (FAMD) or a multiple factor analysis (MFA). The latter would allow splitting variables in groups in order to assess the influence of any given group (for example, combine all the variables linked to external inputs such as fertilizer, pesticides, and so on). On the other hand, the continuous variables (performance indicators) could be transformed into categorical ones using appropriate thresholds. From this derived database exclusively composed of categorical variables, a multiple correspondence analysis (MCA) could be performed. The robustness and loss of information of this transformation would have to be assessed.

The expected results are the same as for any multivariate analyses. Specifically, we hope to link breakthrough agricultural practices to performance indicators, enabling us to study these correlations in detail further on. A complementary result would be a typology of practices based on their impact on the production system.

Table 16: Illustration of the description of one crop in the database used for the multivariate analysis

	Example of variables	Main variable type	Potentially active in the analysis
Block description	Farm, site, year and order of implementation in the year	Factorial	No
Practices	Crop type, soil preparation modalities, phytosanitary product use, and so on	Factorial	Yes
Primary variables for performance indicators computation	Workload, cost and turnover, site area, environmental observations, and so on	Continuous	No
Performance indicators (derived from the primary variables)	Land and work productivity, gross margin per hectare, aggregate stability and so on	Continuous	Yes

ASSESSING THE IMPACT OF SELECTED PRACTICES: GENERALIZED LINEAR MIXED MODEL (GLMM)

Hopefully, the results of the multivariate analysis presented above will highlight correlations between agricultural practices and performance indicators. The next step will be to assess a global and somewhat consistent impact of those specific practices on performance indicators across several crops, farms and seasons during the experiment. This will be done through a Generalized Linear Mixed Model (GLMM).

As stated before, due to the design of our experiment, we suppose that the only source of variation between the impact and control sites of a field is the differentiated technical management of the crops. Note that over the crops cycles, this effect could become more and more substantial. Hence, the effect of the time period since the beginning of the experiment on selected indicators could also be assessed.

In our analysis, the studied individuals would be a subsample of the ones used in the multivariate analysis detailed above. They would share similar innovative practices, for example the use of a specific soil preparation technique. The blocking factors used to build up the database would be the same as for the multivariate analysis: the farm, the site, the year and order of implementation. If the assessed indicator can be measured more than once during the crop cycle, the time of measurement (such as before sowing or after harvest) could be a complementary blocking factor or integrated in the statistical model.

The usual analyses conducted to compare means between groups is an analysis of variance (ANOVA). This analysis has been dismissed because it cannot handle several variating random factors, which would have limited the scope of the analysis. Furthermore, we would not have been able to take any other fixed effect into account (such as the cultivated crop). This led us to consider the use of a generalized linear mixed model (GLMM) as the best approach as it would enable us to use the farms and the years of implementation as random factors and be able to add any other fixed effects if needed. This is also the methodology advised by McDonald et al. (2000) because this model does not have any normality assumption. For variables that can be measured several times during a crop cycle, this would enable us to assess the interaction parameter between the site (control or impact) and the time of measurement.

Due to the design limitations of our experiment, it is likely that we would use a method to adjust the p-value of our statistical tests as it is the case when comparing means of unreplicated experiments (Perrett 2006; Plant 2007). Several methodologies are available and further reflexion is needed to choose the most appropriate one (Smyth and Verbyla 1999; Hothorn et al. 2008; Finos et al. 2010).

COMMUNICATING THE RESULTS TO THE FARMERS THROUGH BAYESIAN MARKOV CHAIN MONTE CARLO (MCMC)

One of the main priorities of the experiment is to assist farmers in their transition toward low-input agroecological systems. One part of this task is the personal counsel and experiences acquired during the course of the study with the differentiated treatment of the impact site. This includes continuous feedback on what has been measured in the farmer's field (for example cover crop biomass or crop germination rate). The other side of this assistance is to help farmers share their experiences between them through the organization of group meetings, field trips and the synthesis of the experiments' results. The methodology of this synthesis has been largely discussed in the former sections. However, the understanding of those results requires specific statistic notions out of reach for most of the population (including farmers and policy-makers). This issue is often disregarded in OFE and can lead farmers to have scepticism toward scientific results (de Tourdonnet et al. 2013).

In order to produce results that farmers can understand themselves (as opposed to the scientific team displaying the significant effects of practices to passive individuals), we would use a Bayesian approach to present the results to the farmers and the general public. Indeed, using Bayesian Markov chain Monte Carlo (MCMC) we can provide more readable results such as the probability of a twenty percent or more increase (or decrease) in a performance indicator (Conner et al. 2016). Thus, the results are presented as a distribution of the relative change of the indicator between the impact and control site. This could be done either to estimate a distribution of the ratio between the impact and control site (Conner et al. 2016) or to estimate a distribution of the site parameter of the GLMM presented above (Gamerman 1998; Christensen et al. 2006). Furthermore, this distribution could enable us to double-check the results from the GLMM reducing the risks for types I and II errors (Conner et al. 2016).

CONCLUSION

This article presents a novel experimental design for on farm experiments based on the farmers' priorities and expectations, mainly convenience and the ability to experiment a complex and systemic crop management strategy. It aims the adoption by the farmers of new agroecological and locally suited techniques as well as robust agronomical knowledge production. It is based on a co-constructed crop rotation, specific to each farmer, of at least three years. Thus, the rotations and experimented techniques differ from farmers to farmers based on their objectives. This rotation is implemented on a part of a larger field, the rest of the field being sowed with the same crops but managed with well-mastered techniques and acts as a control. This experimental design is unreplicated and unrandomized. Those design limitations bring difficulties in the analysis of the field results and robust knowledge production.

These difficulties will be overcome using methodologies inspired from environmental monitoring studies where those design limitations are more common. However, the experiences in this field show that a careful analysis of the results is required. In our case, this analysis is foreseen as threefold. Firstly, a multivariate analysis for exploratory purposed, aimed to highlight performance indicators sensitive to the agricultural practices. Secondly, a generalized linear mixed model aimed to assess the impact significance of the former highlighted practices. Thirdly, a Bayesian Markov chain Monte Carlo would be conducted to double-check our previous results and to produce results that do not imply any statistical knowledge so that farmers can more easily get to grips with them.

This paper shows that ground oriented and locally suited agronomic knowledge can potentially be produced in close collaboration with farmers, allowing the scientists to spread innovations much more efficiently to the agricultural production sector than with conventional scientific channel such as formal publication.

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AN ASSESSMENT OF THE PRACTICAL POTENTIAL AND LEVEL OF PARTICIPATORY RESEARCH NEEDED TO MEET CATCHMENT SCALE CLIMATE CHANGE OBJECTIVES

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Abstract

We assess three approaches to climate change related catchment management for their efficacy, potential for participatory research approaches, and wider practical application in central England. Creation of clean water ponds are intended to isolate aquatic biodiversity from elevated eutrophication associated with climate change, permeable timber dams are intended to reduce downstream flood risk, and improved soil management is intended to achieve multiple benefits. These approaches vary in their potential public and private benefits, but tend to be associated with climate change adaptation, rather than mitigation. We conclude that, while traditional top-down approaches to researcher engagement with farmers might be appropriate for activities such as clean water pond creation, earlier, more active engagement is important to designing and siting permeable dams to deliver public benefits outside the study area. For soil management, where there is a complex integration of multiple public and private benefits, climate change adaptation and mitigation, and wide variation between soils, topographies and farming knowledges and cultures, early and genuine participatory approaches are essential.

Introduction

Climate change presents multiple challenges to lowland agricultural environments in the UK. Lower summer rainfall and higher temperatures may increase concentrations of phosphorus and other nutrients and pollutants in freshwaters, increasing eutrophication and ecological degradation beyond current levels. More frequent and intense winter storms are expected to increase downstream flood risk, both through higher rates of surface runoff from headwaters, and through increased soil erosion and sedimentation of drainage channels. As well as increased rates of runoff and erosion, agricultural soils can be expected to continue the current trend for increased levels of compaction, inhibiting crop performance and reducing the period in which field operations and livestock grazing can be carried out without further accelerating this trajectory.

In this paper, we explore three management approaches to meeting environmental objectives for catchment management: creation of clean water ponds for biodiversity, permeable dams for flood risk management, and soil management to meet multiple objectives. We discuss the potential wider application of these measures in the context of their role in climate change adaptation and mitigation, and their potential for public or private benefits. This context is presented conceptually in Figure 1. We anticipate that the acceptance of management approaches by farmers will increase along the continuum from public to private benefits and from mitigation to adaptation. Understanding of these relationships would help to inform future catchment management policy and support for land managers.

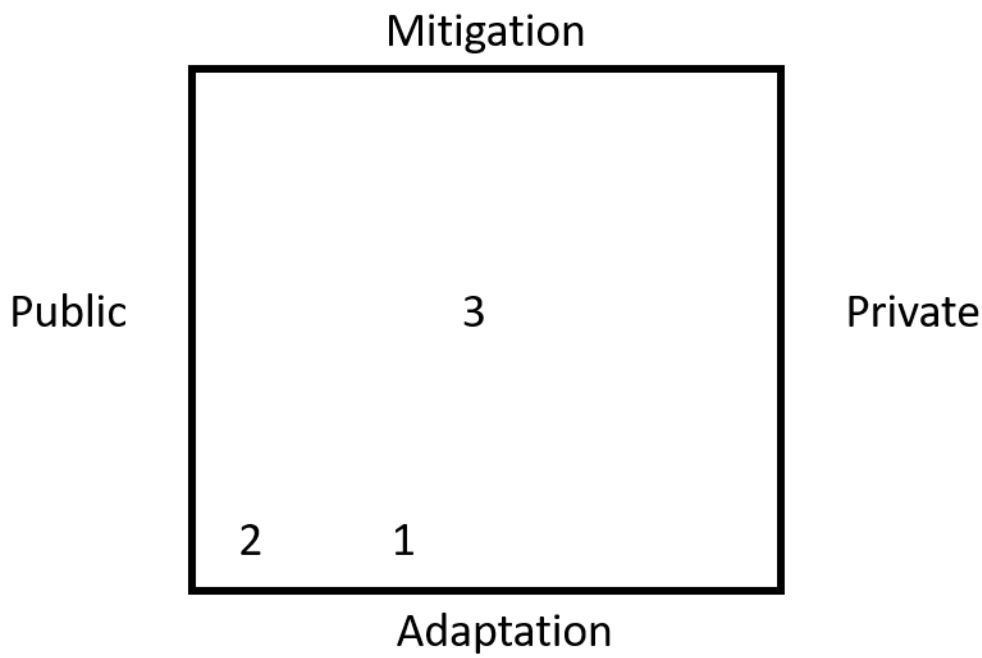

Figure 1. Climate change engagement matrix representing the continuum between mitigation and adaptation, and between public and private benefits. 1. Clean water ponds. 2. Permeable dams for managing downstream flood risk. 3. Multiple objectives for arable soils.

Traditionally, research engagement with farmers is regarded as either top-down (state or researcher led) or bottom up (citizen or farmer led), based on Arnstein's (1969) 'Ladder of participation'. More recently, Keen, Brown & Dyball (2005) have argued that some citizens prefer to stay on the lower rungs of informing and consulting, while Cook, Kesby, Fazey, & Spray (2013) have questioned whether the higher rungs necessarily lead to power-sharing by citizens. Reed et al. (2017) suggest that the choice of participatory method needs to take account of the situation, making some approaches more suitable in certain situations, and suggest a "Wheel of Participation" as an alternative metaphor that accommodates these complexities.

The research described in this paper is based on the 'Water Friendly Farming' project, a landscape scale (3,000 ha) BACI (Before, After, Control, Impact) experiment in the headwaters of the river Welland in central England. The study area is located 6km from the Allerton Project research and demonstration farm which carries out research into a wide range of agri-environmental issues on its own 333ha farm.

In conventional terms, the Water Friendly Farming project was initiated in 2010 as a 'top-down' research project, with for example, the farming community being defined by the hydrological boundaries of the three headwater catchments. Initial engagement between researchers and farmers was limited to broad discussion about the objectives of the project and obtaining agreement for involvement in principle. Different levels of more active participation have been introduced into the project and we discuss some of them here.

The objectives of the research described in this paper are therefore to:

assess the performance of physical measures for meeting climate change related catchment management objectives at the landscape scale introduce and explore a participatory research approach to involve farmers in the research and decision-making process

assess the implications of the above for future wider application of the measures being considered

We first describe the study area, then the specific objectives and activities associated with the three management approaches, and finally discuss the project in relation to the three objectives stated above.

The study area

The Water Friendly Farming project aims to test the efficacy of a range of measures to increase landscape scale aquatic biodiversity, improve water quality, and reduce downstream flood risk, while maintaining or improving agricultural productivity and profitability (Biggs et al., 2016). The soils are mainly Hanslope and Ragdale clays and the farming systems are arable, mixed arable and livestock, and grazing livestock systems (mainly sheep and beef cattle). Farm size varies considerably, as do tenure arrangements, with some areas being owner occupied, and others adopting a range of tenure arrangements including both long and short-term lets, joint ventures and contract farming agreements. The height above sea level ranges from 123m to 216m, the topography is undulating, and the annual rainfall is around 650mm. Further details for each headwater catchment are provided in Table 1.

The project started in 2010 with exploratory water quality and aquatic ecology data collection. 2012 to 2014 represented a three-year baseline period in which data were collected across the three headwaters. Almost continuous monitoring of stream depth and flow, total phosphorus, total nitrogen, and suspended sediment has been carried out at the base of each of the three catchments, with additional pesticide concentration data being collected through four autumn/winter periods (for further details of methods see Villamizar et al., 2020). Ecological survey data (aquatic macrophytes and macro-invertebrates) were collected annually from 360 ditch, stream and pond sites across the 3,000-ha study area in the baseline period, and 420 sites subsequently, to accommodate newly created features (for further details of methods see Williams et al., in press).

Table 1. *Land use details and management approaches adopted in the three headwater catchments*

Landuse	Barkby control catchment	Eye catchment	Stonton Catchment
Catchment area	9.6Km2	10.6Km2	9.4Km2
Arable	37%	45%	44%
Grass	52%	42%	41%
Woodland	7%	9%	10%
Settlements & other minor landuses	4%	4%	5%
Number of farmers	7	14	8
Management approaches discussed in this paper			
Clean water ponds	n/a		X
Permeable dams	n/a	X	
Soil management	n/a	X	X

A range of measures was introduced into the two 'treatment' headwaters (Stonton and Eye Brook) from 2014. These measures included maintaining existing riparian buffer strips, fencing livestock away from streams, installation of sediment settlement ponds at a range of scales, introduction of small woody debris dams and other site-specific measures. Here we focus on the creation of clean water ponds in the 'Stonton' catchment, the creation of permeable dams in the 'Eye Brook' catchment and a range of supporting measures to improve soil function across both catchments. The third, 'Barkby' catchment, served as a control in which no measures were introduced.

Management approaches

Clean water ponds

Elevated phosphorus concentrations in freshwater result from both agricultural runoff and domestic sources such as septic tanks and rural sewage treatment works, and even at concentrations below 100µg/L, have been shown locally to have a substantial impact on the local aquatic ecology (Jarvie et al., 2010). Sewage treatment works in the Water Friendly Farming study area are the largest single contributor to elevated phosphorus concentrations in each of the headwater catchments (Biggs et al., 2016). Climate change related concentration of these domestic sources associated, or increased frequency and intensity of runoff from agricultural sources would increase the threat to aquatic ecosystems.

In 2014, twenty clean water ponds were created in the Stonton catchment. These are off-line waterbodies (not connected to streams or ditches) located in parts of the landscape where they fill with unpolluted surface-water or groundwater. Suitable sites for locating the ponds were identified by researchers, based on the characteristics of the micro-catchments draining into them and the sites proposed were discussed with the relevant farmers. As these ponds were located in relatively unproductive areas such as open areas of woodland plantations, rough grassland and corners of relatiely low grade pasture fields, farmers were content to accommodate all the proposed ponds on their farms. Some required them to be fenced to exclude livestock while others did not.

All catchments saw a background decline in aquatic macrophyte species richness during the nine-year survey period, with a mean species loss of 1% pa, and a rare species loss of c2% pa (Williams et al., in press). The addition of clean-water ponds brought substantial catchment benefits, increasing the number of wetland plant species by 27% after five years, and the number of rare plant species by 190%. Populations of spatially-restricted species also increased.

The creation of clean-water ponds that are hydrologically isolated from the main stream network may hold considerable potential as a tool to help stem, and even reverse, ongoing declines in freshwater plant biodiversity associated with landsape scale eutrophication. Although farmers were unaware of the specific biodiversity benefits of introducing clean water ponds to their land, those involved recognised the conservation value in broad terms and were positive about having such ponds on unproductive parts of their land. Summary results of the biological surveys for each farm, and overall findings have been shared with farmers.

Permeable dams for flood risk management

As part of an increasing trend towards 'Natural Flood Management' to complement traditional engineered flood defense approaches, permeable timber dams have been introduced across several river basins but there is limited evaluation of their efficacy or the issues influencing farmers' attitudes to, or knowledge associated with their installation.

We used hydrological modelling to inform the potential distribution of dam sites within the study area. Stream water depth was monitored at the base of the headwater catchments every 15 minutes and then converted into stream flow (m^3/s) using a flow rating curve generated for the catchment. The Soil and Water Assessment Tool (SWAT; Arnold et al., 1998) was used to simulate stream flow. SWAT is a physically based hydrology and water quality model, designed to estimate impacts of land management practices on water quality in complex watersheds. SWAT divides the catchment area into sub-catchments and each of them is further divided into hydrological response units which are defined as areas of land with the same soil, land use, slope and management which are assumed to behave similarly in the model (Neitsch et al., 2005). This process formed the basis for the identification of 51 sites for permeable timber dams to manage storm water flow within the headwater and attenuate downstream flood peaks.

On the ground, locations in ditches and streams were selected carefully to optimise water storage while avoiding impeding flow from field drain outlets and waterlogging adjacent arable land. The focus was on in-channel water storage, but opportunities for temporary flooding of adjacent land were also explored. A map showing the location of these sites was used as a focus for one-to-one discussions with farmers about their acceptability or otherwise.

Following discussion with farmers, permeable dams were ultimately built at 30 sites, and many of these were not in the exact locations identified by the hydrological modelling. In some cases, it proved to be impractical to build the dams because the ground was too soft, steep or wooded to permit access for construction equipment. More often, sites were not acceptable to farmers because of conerns about waterlogging productive land or land used for vehicle access in winter. Farmers made the point that flooded land would remain waterlogged for a period after the flood event, so that it would not be possible to drive on or manage the land without causing damage to soil structure and this would have a negative impact on trafficability and grass or crop performance.

Although farmers accepted the concept of introducing permeable dams on their land to reduce downstream flood risk, there was little sense of ownership and there were concerns about maintenance and liability. Although, in this case, researchers accepted responsibility for these, this issue is of wider concern outside a research project. On the other hand, at one site, a larger area of ground was made available to receive flood water than had been assumed in the initial modelling process. This highlights the varying responses of individual farmers to proposals to install permable dams, and the need to recognize factors other than simply production forgone, in itself something that is difficult to predict because of climate change uncertainty.

A contractor based within the catchment was employed to build the dams so as to optimise engagement within the catchment community. The dams were of simple construction, and created with mainly local materials. Standard timber (mainly larch) cordwood was the main component, held in place with tanalised fence posts and steel cable. A tree trunk formed the base of each dam, spanning the full width of the channel, to ensure that winter base flow was not impeded.

Assuming optimal distribution of permable dams across the entire headwater catchment, the initial modelling estimated a peak daily flow reduction of 20%. Actual implementation of dams is currently being evaluated but is estimated to be equivalent to or in excess of this reduction, with for example a 25% reduction for one in two year storm events. The interim results therefore suggest that the dam site selection by farmers, and the reduced number adopted, has not compromised flood risk management objectives, relative to the adoption of dam sites identified by hydrological modelling.

Multiple objectives for arable soils

Poorly functioning soils result in erosion and sedimentation of watercourses, reducing biodiversity and increasing flood risk, while also increasing nutrient and pesticide transport to water. Such soils also increase grass weed populations and reduce crop rooting capacity, nutrient cycling and uptake by crops. In conversations with researchers, farmers have highlighted the negative impacts of poor soil function on both their own businesses and environmental and societal issues such as water quality, aquatic ecology and flood risk.

Farmers have been keen to address this issue in order to improve the performance and sustainability of their businesses but identified a lack of evidence-based information relating specifically to clay soils as a barrier to enabling them to do so. Following discussions with farmers, a highly respected advisor with expertise in soil management and a range of cultivation and drilling equipment was identified by the farmers and one-to-one advisory visits were arranged for each arable farmer at the end of the baseline period in 2015. Each of the farmers visited was positive about the visit and found the discussion useful.

After four years, farmers reported no improvement in soil function in terms of improved crop performance. In fact, although most of the period experienced lower than average rainfall, exceptionally heavy autumn and winter rains in 2019 completely waterlogged sols and prevented drilling of crops. Base of catchment water quality monitoring recorded no improvement in suspended sediment or associated phosphorus over the study period. Repeat visits by the same advisor as in 2015 will be carried out in 2020 to identify barriers to changes in soil management and communicate research requirements identified by farmers to researchers.

In 2017, farmers were involved in two activities which were intended to bring farmer knowledge and concerns closer to research that was relevant specifically to their circumstances. These are described more fully by Villamizar et al. (2020) and Stoate et al. (2019).

Farmers had expressed concern about the potential withdrawal or restricted use of a herbicide used to control black-grass (*Alopecurus myosuroides*), a competitive grass weed that is difficult to control. The regulatory threat to the herbicide arises from the transport to water adsorbed to soil particles eroded from arable land and regular exceedance in watercourses of the statutory 0.1µg/L limit set for drinking water supply. The herbicide is therefore linked to broader catchment management objectives and provides a common theme for discussion between farmers, researchers and catchment managers.

Farmers were invited to consider a number of approaches to soil and crop rotation management that may help them to reduce the loss of herbicide to water, and to suggest additional approaches themselves. In terms of soil management, these included a better understanding of compaction within fields, access to local soil moisture data to inform timing of management decisions, and a reduction in cultivation intensity, including a change to direct drilling. The participating farmers were already attempting to reduce cultivation intensity in at least one stage in their crop rotation.

A workshop involving a facilitator, a researcher, three catchment farmers and an agro-chemical company representative was held. The aim of the workshop was to enable discussion of the various management options. This involved farmers considering the future potential of these approaches, based in some cases on their own experience of them, and in others on evidence presented at the workshop in the form of hydrological modelling results, soil moisture data and compaction maps. The full discussion was recorded and later transcribed. Qualitative, textual data from the transcript were analysed through an inductive approach involving manual coding of the text and identification of the commonly occurring themes as these emerged across the participants (Villamizar et al., 2020).

Compaction mapping was regarded as being useful but farmers raised the question of who would pay for this to be carried out. One farmer already used a simple assessment of compaction to guide his soil management decisions. Farmers considered that the sharing of local soil moisture data could be useful but felt that this was difficult to judge without actually trying it.

Whilst the farmers were generally encouraged by their results with reduced cultivation techniques, they thought that the main barrier to a full direct drilling system on clay soils is the lengthy transition period where there is a significant drop in yield. The transition period may be a significant barrier to adopting direct drilling. There was concern that there is no considered government advice about how to proceed with conversion and one farmer drew the contrast between good husbandry of soils, and the life of a government, which is similar to the length of a normal rotation, and regretted that this prevents governments from implementing a long-term view for agriculture.

In the second initiative, interested farmers were involved, along with members of the wider local farming community, in the prioritisation of soil management research topics that would be relevant to them as part of the SoilCare project www.soilcare-project.eu . An initial meeting was held to discuss the broad issues, both positive and negative, associated with local soil management. A problem tree was used to identify problems, causes of those problems, and possible approaches to address them. A list of management practices was drawn up as potential topics for research.

At a second meeting, summaries of the management practices were provided and a critical discussion of the management practices was then held. Information was summarised on flip charts for each management practice and these provided a focus for discussion within small groups of stakeholders. Post-it notes were used to enable participants to contribute additional information individually. Based on these, a matrix was then drawn up listing the most relevant criteria for scoring the six management practices. Participants were then each given ten sticky dots to allocate to the management practices against the selected criteria.

This resulted in five management practices with similar scores, but enabled one with a lower score to be dropped from further consideration. The two highest ranking management practices (direct drilling and cover crops) were not considered further as they were already the subject of research at the Allerton Project's research and demonstration farm. Three other management practices - compaction alleviation, grass leys, and anaerobic digestate as a soil amendment - were taken forward as the topics for research within the SoilCare project. The digestate amendment could not be followed up for technical and regulatory reasons, but replicated experiments were set up to test different methods of compaction alleviation, and modern deep-rooting grass ley cultivars. The results of these experiments will be shared with farmers participating in the Water Friendly Farming project, and the wider farming community to inform future management and in order to capture feedback from particpants.

Discussion

Performance of physical measures

The introduction of clean water ponds into the agricultural landscape achieved its objective for increasing landscape scale biodiversity, as demonstrated by the data for aquatic plants.

Interim results suggest that the introduction of permeable timber dams into the stream achieved its objective of reducing downstream flood risk by reducing the base of catchment flood peak in excess of 20%.

Water quality data have not been fully analysed but the most recent results and observations indicate that there has been little or no improvement in water quality in terms of nutrients and suspended sediment since the introduction of physical measures to address this issue in 2015. Farmers continue to report crop yields that are compromised by poor soil health and function, and waterlogged soils in autumn 2019 prevented drilling of crops.

Participatory research with farmers

The level of engagement between researchers and farmers varied across the three approaches described in this paper. For the introduction of clean water ponds, the involvement of farmers in the decision-making process was minimal and could be regarded simply as consultation associated with a top-down approach on Arnstein's (1969) Ladder of Participation. This level of engagement between researchers and farmers fails to meet most of the criteria for successful outcomes defined by Reed et al. (2017). Despite this, all the proposed ponds were created in the locations that were selected by researchers and achieved the objective of improving landscape scale aquatic biodiversity, while also being acceptable to farmers. Both private and public benefits of pond creation were achieved. In fact, early engagement with farmers might have resulted in greater priority being given to private benefits such as fish ponds or duck flight ponds for shooting which would have been acceptable to farmers but would not have resulted in the biodiversity benefits achieved.

Farmer engagement for construction of permeable timber dams resulted in the rejection of several sites and the re-siting of many dams to locations that were better aligned with farmers' priorities. Although flow data are not currently fully analysed, initial indications are that this change in the siting of dams from those identified by the hydrological modelling to sites that are consistent with the flood risk management objectives, while also meeting farmers' criteria, resulted in equally effective flood risk reduction. Arguably, it might have been equally or more effective to start the process with the involvement of farmers so as to incorporate their local knowledge and values into decision making, prior to hydrological modelling. However, even taking this approach, the objectives remain driven by the delivery of public goods outside the study area, rather than the interests, concerns, knowledge or cultural values of farmers within it.

The complexity associated with soil management, combining private and public benefits, and both climate change adaptation and mitigation, requires much closer involvement of the farmers. We have adopted two structured processes for a more participatory approach. Stoate et al. (2019) evaluated these in relation to the criteria for beneficial outcomes defined by Reed et al. (2017). The criteria comprise 'Context' (challenging or conducive), Design (hierarchical and closed or systematic, transparent and structured), 'Power' (power dynamic unmanaged or managed), and 'Scalar fit' (late and poorly matched or early and well matched to spatial and temporal scale). Each criterion was awarded a score on a five-point scale. The two activities score relatively highly against these criteria, with the exception of the herbicide one for 'Context' as the participant community was defined by the hydrological boundary rather than by criteria that were formulated by the farmers themselves. Two of the five management practices identified as research priorities by farmers in the SoilCare project were already the subject of research at the Allerton project farm, suggesting good alignment of priorities between farmers and researchers.

The three activities reported in this paper therefore vary considerably in the extent to which they could be regarded as being participatory, involving genuine knowledge exchange between farmers and researchers and co-design of continuing activities.

Implications for wider application

We have reported on three approaches which address the impacts of climate change on water quality, aquatic biodiversity, flood risk and crop production in agricultural headwaters. Creation of clean water ponds has very clear biodiversity benefits. It has little impact on the productive land and can enhance the landscape and its inherent interest in a way that is acceptable to farmers. In-channel permeable dams are similarly outside the productive area but the storage of water on adjacent land has the potential to reduce agricultural production, both directly while under water, and indirectly as subsequent waterlogging reduces the period in which the land can be grazed, used for vehicle access, or worked by arable machinery. There is considerable scope for debate around the payments that might be made to farmers to deliver societal benefits in terms of flood risk management given the uncertainties associated with direct impacts on production, associated indirect impacts, and realized benefits in terms of reduced downstream damage to property. Where payments to farmers are based on expected reductions in downstream flood risk and quantifiable damage to property, that uncertainty increases further. Farmers also expressed concerns about maintenance costs, and liability for negative consequences that might arise, either on-site or downstream in the case of dam collapse.

Clean water ponds and permeable dams for flood risk management are clearly adaptation measures providing societal benefits, with clean water ponds also being accepted by farmers as inherent features of their farmland landscape (Figure 1). However, reducing intensity or frequency of cultivation is both an adaptation and a potential mitigation measure. Reduced soil disturbance can have advantages in terms of societal environmental, social and economic benefits, while also benefiting soil function from an agricultural perspective, potentially contributing to enhanced economic performance of farms, but there are clear barriers to adoption, and potential costs, at least on clay soils. Government payments to farmers, such as through agri-environment schemes, are also made more problematic where there are potential associated benefits to individual businesses alongside wider societal benefits. In addition, the relative costs and benefits will vary considerably between farms across a range of soil types, farming systems, topographies, and landscape configuration.

There are other benefits associated with reduced soil disturbance through direct drilling or incorporation of grass leys into the rotation, in that there is potential for carbon sequestration in the soil profile (Mangalassery et al., 2015). The full scale of this is not yet adequately understood, but it highlights another important consideration in terms of the measures adopted to address climate change. Each of the approaches discussed in this paper is concerned with climate change adaptation, and there is a considerable need to increase the emphasis on mitigation, and to identify synergies between adaptation and mitigation.

Catchment management practices that contribute to climate change mitigation are strongly societal rather than private benefits and consequently positioned in the top left of Figure 1. As such they require an offsetting market or government support to encourage adoption. There is also a need to identify opportunities for funding from individuals or businesses to carry out management practices that deliver private benefits alongside public ones, but public and private interests are not always complementary. To use an example from earlier in the paper, clean water ponds that are stocked with fish to obtain an income would have low biodiversity value. The lack of state support for soil carbon sequestration because of potential economic benefits to participating farm businesses is a perverse consequence of the public/private dichotomy.

Conclusions

While our findings demonstrate that some simple measures can address some objectives for delivery of societal benefits, our research in a working agricultural landscape also highlights the economic and political constraints that characterize the trade-offs between public and private goods and services. Economic pressures, potentially heightened considerably by the UK's withdrawal from the EU, increasingly threaten smaller farms, favouring large-scale contracting and short-term planning and accentuating diversity in farming cultures and socio-economic circumstances. A top-down consultation approach to researcher engagement with farmers may meet some simple objectives successfully. However, the complexity associated with interacting public and private interests, and the need to meet climate change adaptation and mitigation simultaneously, require a genuine participatory approach that is co-designed by farmers and researchers. Such an approach needs to recognise the cultural, political and socio-economic diversity of both farming and research communities.

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REDUCING PESTICIDE USE IN VINEYARDS. EVIDENCE FROM THE ANALYSIS OF THE FRENCH DEPHY-NETWORK

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Abstract: High quantities of pesticide are applied on vineyard. Transition towards low pesticide farming systems is a key issue to improve viticulture sustainability. Farmers have to gradually change their practices to engage in this transition. A large number of agroecological practices are already existing but farmers can encounter obstacles during their implementation.

This work aims at analysing the pesticide use evolution during transition towards low pesticide farming systems and identify some management options mobilized by winegrowers. To understand the diversity of pathways taken towards agroecological transition, we characterized different types of pesticide use trajectories.

We analysed the data from 244 cropping systems engaged in a network of French demonstration farms, DEPHY-Farm network, created to promote and assess the implementation of practices to reduce the pesticide use. The network provides data over a 10-year period across 12 winegrowing regions. To assess pesticide use, we used the Treatment Frequency Index (TFI) and focused on TFI trajectories. We described the TFI trajectory of each farm using six indicators: the initial TFI and final TFI, the intensity of the TFI decrease, two idicators of potential rupture and the slope. A Principal Component Analysis followed by an Ascendant Hierarchical Clustering were performed to build a typology of pesticide use trajectories. In addition, we performed a survey to identify, for each type of pesticide use trajectories, the levers implemented by winegrowers.

Our results showed that cropping systems experienced a pesticide reduction of 33% in average related to the decrease of fungicide use. Three types of pesticide use trajectories were identified : the first type represents farms with a high initial TFI and an important reduction of TFI. The second type corresponds to farms with a low TFI when entering the network and that reduced it progressively. The last type represents farms with low initial TFI and without significant pesticide use evolution.

Depending on the trajectory type, the intensity and the type of changes in fungicides applications and biocontrol used were different. From the surveys, 76 levers implemented by the winegrowers were recorded. The main levers implemented are related to the dose reduction, choice of the product, stop of herbicides and optimisation of spraying. The changes were characterized according to the ESR framework. Cluster 2 Farm mostly redesigned their cropping system while Cluster 3 Farms mostly implemented levers based on a gain on Efficiency. The context of the farm impacted changes in practices.

ASSESSMENT OF THE RESILIENCE OF FARMING SYSTEMS IN THE SAÏSS PLAIN, MOROCCO

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Abstract: The Mediterranean region is expected to become a hotspot for the impacts of climate change, with high vulnerability to global change. The major challenge is therefore making agricultural food production systems resilient to climate and market shocks (Rivington et al. 2007). Resilience can be defined as the capacity of a system to buffer shocks while maintaining its structure and function (Walker et al. 2004). Focusing on the farm scale, several studies used modelling tools to analyze the resilience of farming systems (e.g., Souissi et al. 2018), however with little involvement of stakeholders when designing scenarios and in resilience impact assessments.

Accordingly, a participatory approach was set up in the Saïs plain in Morocco with the objectives of (1) designing, with stakeholders, the possible future state of different typical farm types under major drivers of change, and (2) qualitatively assessing their resilience. This approach combined different steps: (1) characterizing the structure and performance of current farm types using literature and stakeholders' and farmers' interviews, (2) defining and selecting the main regional and specific drivers of change per farm type, (3) building cognitive maps for current and future state of each farm type according to drivers, (4) characterizing performances of future farm types, and (5) evaluating their resilience. Steps 2, 3 and 4 were achieved with a strong involvement of stakeholders via collective meetings. The indicators of the resilience assessment were defined based on literature, expert interviews and collective meetings with stakeholders. These indicators expressed different types of capitals (land, workforce, financial), public policies, market and water access.

Four representative farm types were selected: highly irrigated predominantly vegetable farms (F1), monocropping rainfed cereals farms (F2), partially irrigated cereal-legume farms (F3) and mostly irrigated fruit-tree-vegetables farms(F4). Climate change was identified as a main driver of change for F2 and F3 whereas access to irrigation water was identified for F1 and F4. According to these expected changes, stakeholders designed adaptation strategies based on the promotion of more diversified systems. Based on the resilience indicators, stakeholders identified F4 and F2 as the most and the least resilient farms, respectively. Overall, this qualitative approach provided relatively different results than previous modelling studies for the same area, thus highlighting the important role of local stakeholders in promoting adaptation strategies against global change.

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Abstract: Many sustainability problems are connected to land use and there is a high sense of urgency for socio-technological change and transformation of current land use practices. In this context, many scholars have emphasised the vital role of designing and steering efficient innovation processes (e.g. Elzen et al. 2004, Schot & Geels 2008).

However, envisaged sustainability innovations differ from other types of innovations. They serve long-term societal goals but mostly lack direct marketing or commercialisation potential. Since management of land is highly regulated in many countries of the world, land management innovations have to take regulation compliance into account. It is deeply embedded into socio-ecological systems and thus frequently contradicts with social practices, regulations and existing infrastructure.

As it is still weakly understood how transformation and socio-technological change in the specific field of sustainable land use and management can be effectively governed and supported, the aim of this talk is to contribute to this knowledge gap. We will present findings from a comparative case study on transdisciplinary innovation research projects from Germany that sought for solutions towards more sustainable land management (SLM) practices. After the introduction of a theoretical framework that supports capturing the specific nature of innovations for sustainable land management, the presentation examines i) the characterisation, leverage points and socio-technical imaginations of innovations for SLM, ii) approaches to manage the innovation processes, and iii) interactions with persisting rules, structures and networks.

Results show that innovations for SLM start with diverse problem framings, emerge from distinct action fields and reflect various socio-technical imaginaries that predetermine trajectories of transition. Furthermore, there is a broad variety of innovation types focussing on different leverage points. All projects applied multi-actor approaches to facilitate reflexive processes of learning and cognitive reframing, optimising the innovation, and interacting with persisting structures and communities.

THE CUMULATIVE TRADITION OF DECISION SUPPORT SYSTEMS RESEARCH: NEW PERSPECTIVES ON SUCCESS

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Introduction

The opportunities and challenges of agricultural Decision Support Systems (DSS)[43] in connecting science and practice are well rehearsed in the academic literature. The focus has mainly been on issues of poor uptake by practitioners. These have been problematised and theorised from different perspectives, largely in relation to the epistemological gap between the hard and soft approaches respectively of science and practice. Given the rapidly changing context in agriculture (social, technological, environmental, institutional) it seems a good time to re appraise the role of DSS and ask questions about their future development and relevance.

The history and philosophy of agricultural DSS has been well documented (Power (2003). Analysis dating back to the discipline of information systems (IS) includes the study of both the social and technical aspects of the use of information technology for decision making and problem solving (Lyytinen, 1987). This body of work supports the view that there is little evidence of uptake or sustained usage, a failure seen to be consistent across all organisations and industries (Newman *et al.*, 2000). As a result DSS have been subject to close scrutiny in a number of reviews internationally (Matthews *et al.*, 2006). Collectively scholars have addressed the question: why are the expectations for DSS usage rarely realised and how can this challenge be addressed? Over time they have built up an extensive understanding of why the optimism for DSS amongst the scientific community does not match the evidence of practitioner usage. There are a corpus of work documenting key factors to enable functioning and sustained DSSs. These date from Little (1970) who identified criteria for functioning Information Systems[44]: robustness, ease of control, simplicity, and completeness of relevant detail and have been revisited by several researchers since (e.g. Rose et al., 2018). The importance of incorporating user input through participatory DSS development has also been recognised with developers soliciting user-feedback about tool performance and ease of use (Ingram et al., 2016; Rose et al., 2018). The value of involving users in genuine co-design (Cerf et al 2012; Berthet et al., 2018; Prost et al., 2012; Volk *et al.* (2010);understanding farmers' situated knowledge (Lundström and Lindblom, 2018); and acknowledging farmers' different decision-making styles (Jørgensen et al 2007), have also been identified as important in improving the usability of DSS.

However, research still tends to focus on implementation issues, performance and uptake, with less attention being paid to questioning the assumptions underpinning DSS, the institutional context, the impact and learning achieved and how to assess it. For this reason, according to McCown (2002), DSS are in danger of being relegated to history without an adequate understanding of reasons for its market failure.

In Australia (and to some extent New Zealand) the evolutionary process of crop model based DSS in agriculture has been extensively reviewed and documented (Woodward *et al.*, 2008) with periodic questioning and reflection which has brought about considerable collective learning and reorientation in tool development. This is an evolving and dynamic domain, as agronomic understanding advances, new technologies appear, and new perspectives emerge, and farming demographics change, each prompting

[43] Decision Support Systems (DSS) and Decision Support Tools (DST) are sometimes used interchangeably. DSS are computer-aided management systems which are typically based on scientific models developed with the purpose of enhancing farmer decision-making. They are often developed into DST. DSS is used in this paper to refer to both system and tool.
[44] Information Systems preceded and preshaped the era of the agricultural DSS (McCown 2002).

further analysis and questioning the relevance of DSS. As Hayman et al (2003) noted in 2003 the "unfolding history of DSS in Australian dryland farming systems provides an interesting case study of the challenges facing agricultural scientists intervening in the world of farm management decisions". This work offers a nuanced understanding of the reasons for limitations in DSS.

This paper aims to explore these developments through a critical review of the DSS literature with particular reference to how a cumulative tradition around DSS has emerged in Australia, and aims to advance theoretical development by introducing this new lens for analysis. The paper is a 'perspective paper' drawing on the literature and personal communications with researchers in Australia as part of an OECD Research Fellowship (2019).

Agricultural Decision Support Systems

The format of decision support depends on the extent of data aggregation and analysis, ranging from simple monitoring and alerts, online calculators to sophisticated models that provide scenarios for, or assess the effects of, different management options. In this paper we refer to the latter which are called DSS[45]. Meinke *et al.* (2001), refers to all DSS as 'normative' approaches of simulation based information provision, including software products and dissemination of such information via printed or Web-based media. Agricultural DSS are however mostly computer and internet-based information systems defined as typically software applications commonly based on scientific models describing various biophysical processes in farming systems and the response to varying management practices (Jakku and Thorburn, 2010). Lynch (2003) called these systems "intelligent support systems". These DSS are usually based on an understanding derived from a statistical- and/or process-based analysis of factors affecting crop outcomes such as yield (Stone and Hochman, 2004).

Over the last 40 years, significant resources have been devoted to the development of computer-based decision support systems (DSS) derived from cropping systems models (such as APSIM). Grain production is inextricably linked to the climate in Australia, and dryland farmers in particular encounter a high level of risk and uncertainty in their agronomic decisions. DSS (with particular reference to plant available water in the soil) have aimed to support their decisions in this context (Freebairn, et al., 2018). DSS development in Australia has been funded, principally via public sector research initiatives (Federal and State Government) with external funding from the Grains Research and Development Corporation, (supported by producers via levies plus matching funds from the Federal Government).

Reflecting on DSS: what has been learned?

Extracting lessons from experience

As Woodward (2008) notes, the history of model based intervention in agriculture has been notably charted and analysed in a series of papers (Hayman, 2004; Nguyen *et al.*, 2006). Overall this literature can be characterised as reflective and formative, addressing the accumulated evidence that most DSS fail in the agricultural market place. Periodically authors suggest it is time for a reappraisal, or a reinvention, or as Cox (1996), who is highly critical, remarked, a "need to pause and think about current levels of R&D investment in information technology to support the management of agricultural production systems". Collectively this literature refers to the lessons that have been learnt through R&D (e.g. Pannell, 1996), Newman (2000) described the process of DSS development as "learning as we go", and Nelson remarks "while early expectations of computerised decision support systems (DSS) as the connecting vehicle between research and practice have gone mostly unrealised, some lessons have emerged from the attempts". Hochman et

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[45] Models (the mathematical representation of a system) are distinguished from DSS (interfaces through which users access knowledge from a model).

al. (2009) refer to the Yield Prophet DSS as being grounded in the learning from 18 years of exploring model-based decision support with Australian dryland farmers. Stone and Hochman (2004) ask "have we been asking the right questions?" and go on to say " We don't see DSS as a lost cause, provided that scientists learn hard-won lessons from their collective achievements and failures". McCown (2002) aim to improve understanding so that researchers "don't naively repeating earlier mistakes" While McCown et al. (2009) refer to "extracting learnings from experiences" and aim to interpret the rich set of experiences from the FARMSCAPE project, in ways that are meaningful for future action (or inaction). These observations follow previous earlier reflective and comprehensive accounts: EPIPRE (Zadoks, 1989) and CALEX-Cotton (Plant, 1997; Goodell et al., 1993).

Drawing on these experiences the literature also commonly refers to an 'emerging consensus' about how to tackle DSS limitations, or so called implementation challenges (Hochman and Carberry, 2011).

Of the many findings in this body of work, two key issues have been revealed that question the underlying assumptions of DSS. Firstly, users need to be involved in the tool development process to be effective. Secondly, and in connection to the first, tools are used more as learning than decision support tools.

Emerging consensus

A common failure of early DSS was that they were developed by researchers using their scientific paradigm, and so failed to take adequate account of user and other stakeholders' perspectives (Cox,1996). The importance of stakeholder involvement has long been noted, Nelson et al. (2002), for example, charts DSS research and development that has facilitated interaction between researcher and farmer back to 1980s (Hearn et al., 1981;Kingwell and Pannell, 1987;Woodruff, 1992). As experience grew the importance of involving stakeholder partnerships to improve relevance of research and analysis to decision-makers emerged as the key common theme in discussions on effective DSS. In line with this a body of work was built up describing the value of participatory DSS development from model- based intervention (Keating and McCown, 2001; Lynch, 2000 Newman, 2002).

One case of particular significance is the development in participatory design of DSS (Carberry *et al.*, 2002) in the farming systems section of CSIRO. The FARMSCAPE programme represented a new paradigm of DSS in that scientists explored, together with farmers and advisers, how simulation could be used as an aid to decisions about grain production inputs in variable climatic situations. This programme was unique in that it used qualitative evaluation and monitoring to reflect on the development process and outcomes, providing detailed longitudinal insights and socio-technical analysis of the approach (McCown *et al.*, 2009).

The development process involving stakeholders enabled an interactive approach which allowed the full extent of the model's capacity as a learning tool to be realised. This built on observations of the way the DSS were being used to support intuitive thinking or to adjust rule of thumb decisions (Long and Parton, 2012), which was contrary to scientists' expectations. A consensus grew amongst commentators that DSS have an important use that had been frequently overlooked: that they can be used heuristically, that is, as an instrument of discovery. Thus, DSS were seen to have the capability to act as a computer-aided learning device, rather than solely as a decision-making tool. In particular the use of models for simulation-aided discussion and exploration of alternatives or 'what ifs?' revealed their capacity for prompting learning (Keating and McCown, 2001). As reported "researchers were surprised to find that yield forecasting and tactical decision making, anticipated to be analyses that were both site- and season-specific forecasts, had served farmers as ''management gaming'' simulations to aid formulating action rules for such conditions, thus reducing the need for an on-going decision-aiding service" (McCown et al., 2012, p1)

Walker (2002) notes that "DSS can be designed to account for the fact that farmers prefer to rely on intuition and experience by deploying them as structured learning tools so that the decision process, embedded in the tools, can be learned, adapted and adopted by decision-makers". This is supported by a number of other commentators who agree that DSS should be designed to help users understand how things work (Stone and Hochman, 2004) or to educate farm managers' intuition (McCown et al., 2009). Scientists also saw the DSS as important for planning management strategies for a coming season to critically evaluate the full range of possible outcomes and the probability of achieving those outcomes. As such, as Hochman et al. (2009) noted, scientists aimed to put the analytical power of APSIM into the hands of growers and agronomists to produce simple "what if" scenarios rather than provide deterministic decisions.

Assessing management alternatives in this way facilitates knowledge communication between stakeholders. DSS have been observed to mediate social learning through collaboration and learning amongst stakeholders and with the development team (Jakku and Thorburn, 2010); to play a role in heuristic learning and network building around the land use policy and planning issues (Sterk et al. (2009); and capacity building when used in groups (Krueger et al., 2012; Voinov and Bousquet, 2010).

This view, that DSS were more about learning support than decisions per se, led to a reorientation or definition of DSS as broader initiatives of knowledge transfer. It also led to a realisation that, while most farmers did not routinely use DSS, many have adopted lessons learned from the information and dialogue they generated, and that their use might be more transient, with users stopping using tools once they had "learnt the principles" (Long and Parton, 2012). Understood this way, DSS became more supportive and relevant to the end-users' decision-making process (Hayman and Easdown 2002; Walker 2002), and allowed improved communication and collaborative learning (Allen et al., 2017).

Conceptualising DSS

This period of discussion and reflection has been accompanied by an evolution in thinking conceptually about DSS amongst interested scholars in Australia drawing on different bodies of international work.

Decision making

McCown (2002a,b) emphasised the need to learn from the broader history of DSS and Operation Research (OR)[46] pointing to parallels with the long recognised 'implementation problem' identified 50 years ago in OR (Ackoff and Sasieni, 1968) and from social and management theory. Drawing on this they re-examined the role of DSS in the farmers' decision space "when DSS attempt to tell managers what to do by presenting an optimal solution based on expected value or expected utility rather than help the manager satisfy their needs in a real-world situation which is uncertain, complex and unstructured. DSS should also attempt to support a continuous flow of behaviour towards a set of goals rather than a set of discrete episodes that involve choice dilemmas" (McCown, 2000a)

The challenges of dealing with the epistemological gap between science and practice, and integration of hard and soft approaches is taken up by critics of DSS. They point to the fact that tools are built on erroneous normative assumptions that science driven DSS fill the farm level 'information deficit', and some argue against the use of tools completely describing the proposed use of models in this way as a 'category mistake', that is, it conflates different categories of knowledge, and different ways of knowing (Cox, 1996). Contributions to this theorisation come from practitioners (Nicholson et al., 2015) and those interested in how digital tools fit into farmer wider learning environment (Starasts, 2015).

New ways of thinking

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[46] Operational research looks at an organization's operations and uses mathematical or computer models, or other analytical approaches, to find better ways of doing them (Operational Research Society, 2006).

Systems perspectives have informed DSS thinking from early analysis (Macadam et al.,1990). Referring to information systems development, Newman et al. (2002) identified the variance between formal methodologies and the actual subjective needs of developers as a disjuncture between rational and technical approaches of hard systems and the mostly social processes involving multiple perspectives of soft systems approaches.

Farming Systems Research perspectives heralded new ways of thinking about DSS and reoriented the focus towards epistemological and sociological reasons as a way of explaining why model- based interventions were not successful (Keating, 2001; McCown 2001, 2002), The combined experiences of previous projects, and of the Farmscape project in particular, indicated that developing a successful tool from a crop simulation model requires "a collaborative effort between farmers and scientists in which the model is used as a device to assist in organising knowledge of the participants, rather than as a source of knowledge in itself" (McCown, 2009). Thinking this way McCown (2009) claimed to have reinvented the concept of computerised support for farmers' management decisions, and that DSS could be invigorated through transdisciplinary approaches. Also drawing on systems frameworks, Hayman and Easdown (2002) used an ecological framework to explore the technical, social and management constraints on the use of the WHEATMAN tool.

This aligns with Cox's (1996) view point, that we should question the assertion that the primary benefit of this activity was the production of DSSs intended to aid routine decision-making at farm level. In this sense he asserted that the most significant contribution of early attempts at decision support were not the actual production of DSS, but rather the bringing together of researchers and farmers to improve farm management. At the time Power (2003) argued that this shift in ideology and approach of the modelling community could trigger new ways of approaching research and DTS development, indicating that DSS could be responsive to not only technological shifts, but also new ways of thinking.

This in turn inspired other work and commentary on participatory DSS (Jakku and Thorburn, 2010; Eastwood *et al.*, 2012), and has prompted calls for a wider view of decision support to encompass all forms of scientifically-informed decision support that takes away uncertainty; and to understand a decision not as a single event but as part of a whole farm management and adaptive learning. Jakku and Thorburn (2010) developed a conceptual framework for guiding the participatory development of DSS. They saw the model acting as a "boundary object", facilitating a connection between farmers and advisors, extensionists and researchers to co-create knowledge. Their vision of the model applications process was to "facilitate co-learning" rather than "produce answers" providing a "more sophisticated and humble vision of the benefits derived from modelling (Thorburn et al., 2011) compared with the used/not used framing of earlier evaluations" (McCown et al., 2002).

Evaluation and the concept of success

These theoretical developments have led some to question how DSS are evaluated. Cox (1996) for example argued that the appropriate criteria of success lie in the effectiveness of the DSS development process in bringing different points of view to bear on an issue of common concern, not in the need to run process models whenever a routine decision has to be made. Stone and Hochman (2004) using qualitative evidence, provided a more nuanced analysis of success beyond extent of adoption of DSS, and proposed a set of 'success factors' which would require a change in attitude by many DSS developers.

Building on insights from the literature more broadly (outside Australia) scholars have linked evaluating success to overall framing of DSS, their development and the way impact is assessed. For information systems research DeLone and McLean (1992) argued that the ultimate dependent variable is "success" but point out that the concept of success itself has not been adequately defined or explained in the literature. They proposed six major interdependent dimensions of system success: system quality, information quality, use, user satisfaction, individual impact, and organisational impact. These underpin assessment of DSS today, although the DSS literature in agriculture tends to have a particular concern about the former dimensions, focusing on design and performance, but paying less paid attention to the latter two. They argue that, “shopping lists of desirable features or outcomes do not constitute a coherent basis for success measurement” and that more research is needed on individual impact and organisational impact. Other scholars have identified the need to consider the wider settings that decision making operates in, and with respect to this, the absence to data on project planning or evaluation of outcomes (Matthews et al 2011). Allen et al (2017) use an outcomes-based Theory of Change approach in conjunction with DSS development to support, both wider problem-framing and outcomes-based monitoring and evaluation, and show how placing the DSS within a wider context can “contribute” to long- term outcomes. These conceptual insights can enrich our understanding of DSS success by positioning the notions of success in the contemporary evaluation literature (Berriet-Solliec et al., 2014). They also raises the question of how problems are represented and how traditions draw and re draw the boundaries around their systems of interest.

Building a Cumulative tradition

A cumulative tradition, conceptualised in the field of Information Systems, is achieved when researchers build on each other’s and their own previous work; definitions, topics and concepts are shared; there is some definition of orthodoxy, while unorthodoxy is not discouraged (Keen, 1980; Eom, 1995). Arguably a cumulative tradition has been emerging as DSS development moves towards a level of maturity on the back of increasingly rigorous empirical work, reflection and theorisation; and as a shared understanding about basic concepts and entities developed amongst a community of DSS developers and researchers. In Australia (and NZ) this has been characterised by reflection processes allowing an emerging consensus on the two phenomena discussed above, evolution in thinking in line with empirical findings and experiences, as well as questioning assumptions including how success might be conceptualised. Despite contested understandings of implementation issues persisting (Hochman and Carberry, 2011), and researchers addressing different aspects of success making comparisons difficult, the body of work suggests that a cumulative tradition has been achieved (Fig 1).

A critical question remains however and that is to what extent have the lessons learned been acted upon? Stone and Hochman (2004) suggest that the factors leading to ‘success’ or ‘failure’ of DSS are generic, and that the lessons learned from one or other DSS can be applied when considering developing or deploying another. However they point to “our [researchers] collective inability to have learned from it [the evidence that DSS fail]”, and that many scientists continue to develop and attempt to deploy DSS. A review in 2012 for GRDC might support this, finding that over the previous years at least 68 computer-based tools have been developed to support decision-making in the Australian grains industry. It concluded that many tools are still being developed without much evidence of uptake but that some tools have a long life of use and experience [47].

Hochman and Carberry (2011) suggested that lessons had been learned but not necessarily enacted. They set out to determine what lessons can be learned from the literature and from the recent experiences of champions of DSS development and delivery efforts; and then to ascertain whether these lessons are accepted and absorbed by the DSS community of practice in Australia. In a survey of these champions there

[47] In 2011, 21 tools were listed (Climate Kelpie, 2010) available for supporting farmers’ management of climate related risks and another six tools for use by researchers concerned with climate risk management in agriculture showing that tool development was still supported and an active part of R&D.

was a lack of unanimous support for any of the propositions they had derived from a literature review and they took this to indicate that, “after more than 30 years of agricultural DSS development, any statement in this domain is still contestable”. However in a workshop held with a selection of the same participants they uncovered “encouraging signs that these DSS development efforts have benefited from lessons of past experiences”. The champions reached a consensus on the key recommendations for future DSS development. In their conclusions the authors note that achieving these requires the commitment of a critical mass of appropriately skilled people involved in the development of a DSS. A shift in evaluation approaches from assessing DSS functionality and usability towards assessing how DSS facilitate learning, discussions and decision making has also become apparent and is a promising sign (Starasts, 2018).

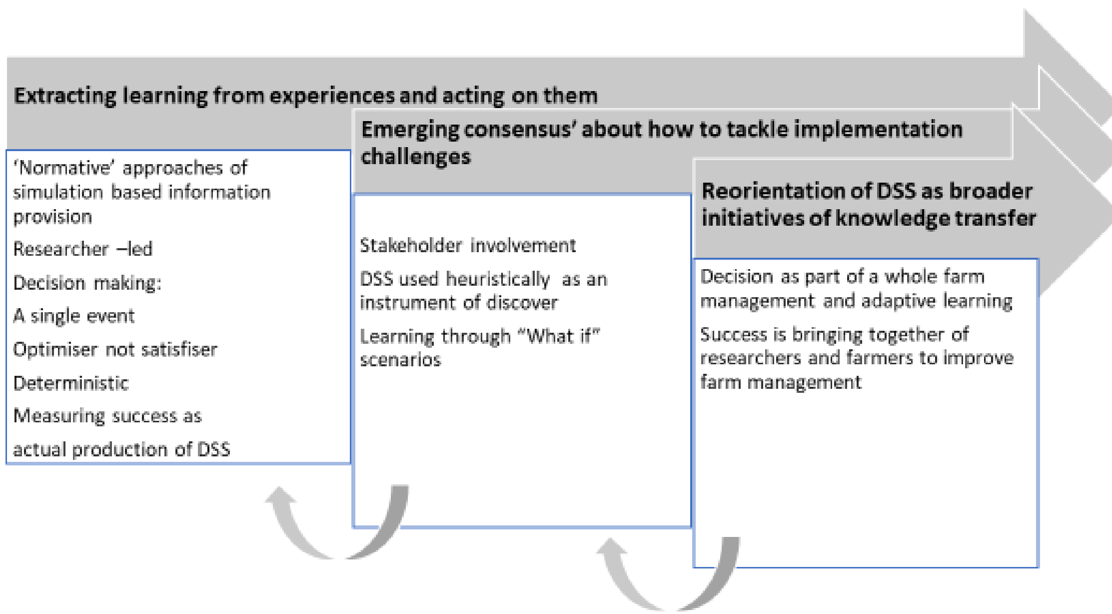

Fig 1 A Cumulative Learning Tradition in DSS

Organisational learning theory can potentially explain the difficulty in enacting lessons learned. Organisational learning is defined as a process of changing organisational actions through new knowledge and understanding, where learning involves mechanisms which link reflection and action. In R&D funding for DSS is often project based. Swan *et al.* (2010) question the value of project work in firms, which often occurs in iterations in an organisation, suggesting that even where there is significant learning generated within projects, there are often difficulties in capturing or translating this learning into new routines and practices at the level of the organisation. Their work suggests that firms generally only learn from projects, via the accumulation of experience amongst groups and individuals where the project context allows. This has some relevance to the research environment and the projectivisation of research projects arguably creating highly heterogeneous forms of learning which cannot always contribute to wider learning in organisations. It also questions to what extent the learning is embodied within the groups and individuals involved or whether it diffuses to organisations as a whole.

One way of capturing or translating learning into new routines and practices is to expand evaluation to include an explicit institutional[48] learning agenda to allow research managers to monitor and evolve new ways of addressing goals. From an Innovations Systems perspective, Hall *et al.* (2003) critiqued impact assessment research and argued that traditional assessment of 'success' needs to recognise systems of reflexive, learning interactions and their location in, and relationship with, their institutional context. Incorporating reflective approaches to assessing success and learning agendas as mechanisms to translate learning into new practices in organisations, could extend the concept of Cumulative Tradition to a Cumulative Learning Tradition.

New knowledge landscape

Australia's agricultural research, development and extension (RD&E) continues to be in a state of transition (Hunt *et al.*, 2014) and in need of reinvigoration, particularly given development in digital technologies (Ampt *et al.*, 2015; Eastwood *et al.*, 2017). Significantly the emergence of digital agriculture and big data heralds a radical change to the way growers are provided with, and access information, and make decisions. The impact of this disruption on the cumulative tradition of DSS in which researchers have built up a body of work, experience and learning deserves attention. While some see it as a threat and a loss of valuable diagnostic learning, other see opportunities for harnessing big data and the analytical powers of models to lead to a virtuous circle allowing a new generation of models and decision support (Capalbo et al., 2017).

Conclusion

We can argue that a cumulative tradition has emerged within the community of DSS developers and researchers. This has been characterised by reflection process allowing an emerging consensus as well as evolution in thinking in line with empirical findings and experiences. Enacting this learning could be enhanced with capturing or translating this learning into new routines and practices at the level of the organisation and extend this concept to a cumulative learning tradition.

[48] Institutions as distinct from organisations are existing sets of norms, rules, routines or shared expectations that govern actors' behaviour that determine how things are done.

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RESIDUAL BIOMASS MANAGEMENT IN AGRICULTURAL SYSTEMS IN THE DRÔME VALLEY. DISCUSSION OF TWO PROGRAMS OF ECOLOGIZATION: INDUSTRIAL AND EARTHBOUND

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1. Introduction

Residual biomasses, revealing the problematic nature of our interdependencies in the ecosystem

Residues are ”materials *that remain after physical or chemical operation, industrial processing, manufacturing, especially after extraction of higher value products.”* (Larousse 2018). In agricultural systems, residual biomass (RB in the rest of the text) or Residual Organic Products refers to *”any organic matter of residual origin (from an agricultural, industrial or urban activity), and spread on agricultural land to recover or recycle the nutrients and organic matter it contains”* (Paillat-Jarousseau et al. 2016). This includes manure, green waste, straw and compost (Leclerc 2001).

The circulation of RB has long nurtured close interdependencies between different systems : between urban and agricultural (Barles et al. 2011), between ecosystems and food systems (Altieri 1999), crops and livestock (Lemaire et al. 2014). Agricultural systems play a pivotal role in this metabolism : they are the site of multiple production practices (crops, livestock,.), use (spreading,.), transformation (composting, methanisation,.) of RB. During the industrial revolutions, the metabolism of RB has undergone radical changes. The discovery in 1909 of the Haber-Bosch process enabled agriculture to break the need for animall dejecta (Gu et al. 2013), forming a ”metabolic rift” (Foster 2000). ”This is a sad hoax, for industrial man no longer eats potatoes made from solar energy, now he eats potatoes partly made of oil” (Odum, quoted by Madison 1997). While they have long been resources, RB have gradually been considered as waste (Monsaingeon 2017).

This new relationship with the ecosystem has proved to be problematic : industrial and urban systems are confronted with waste that they have difficulty evacuating, generating pollution in the environment and impacting ecosystems (eutrophication, potability of water) (Bahers et al. 2019). The increase in the circulation and transformation of biomass involved in agricultural systems, both in terms of distance and volume, contributes to the depletion of resources (Fernandez-Mena et al. 2016). Soil life has declined dramatically in many cultivated soils (Díaz et al. 2006).

These reasons, which are key to the future functioning of agricultural systems, contribute to questioning the management of RB and their *transformation* in particular.

Acting on the metabolism of RB : a problem where science and politics seem inextricably linked

Debates on the management of the RB find an ambivalent place at the crossroads of science and policy. The metabolic rift is at the heart of essential political debates : as early as the 19th century, pollution and health problems have been the subject of petitions, demonstrations and public statements (Monsaingeon 2017. Today, the metabolic rift is the subject of public policies aimed at remedying it in many countries, and is considered one of the existential threats to the future of humanity, and is regularly popularized as such.

The scientific choices for representing metabolism and commitment to action are strongly intertwined (Gabriel et al., forthcoming). Representations of metabolism, as a scientific object, are themselves carrying political implications. The choices of what is represented as acting factors, the scales and functional levels chosen, are not independent of the choice to privilege certain actors (particularly economic) to the detriment of others. For example, representing metabolism in the form of biomass flows between agro-industry players contributes to considering these players as potential partners in action-research programs (Gabriel et al., forthcoming).

There is some scientific controversy about what should be a good metabolism. A variety of schools, each with a certain political agenda, exist : social metabolism, Marxist approaches to the metabolic rift, agroecology, etc. (Gabriel et al., forthcoming).

Research question and article outline

This diversity of programs and representations poses a problem for an agronomist wishing to act on waste biomass in agricultural systems. In the one hand, this poses a problem for the scientific nature of the work carried out : how can we ensure that our research is not just a mere reflection of our political opinions ? On the other hand, how do we position ourselves to act in light of this diversity of political programs, which is reflected among our scientific, institutional or agricultural partners ?

It seems essential to be able to discuss different scientific and political agendas in a concrete situation. We propose to discuss two programs : (1) Industrial ecology as a modernising and engineering program and (2) earthbound, as the ecology of pragmatic sociology. We will seek to see how farmers' RB exchange practices fit into the 2 programs, and to to identify lines of fronts and convergences.

2. Analytical framework

Among the diversity of existing ecologisation pathways, two programs are particularly significant : (1) Industrial ecology as a modernising and engineering program and (2) earthbound, as the ecology of pragmatic sociology.

Industrial ecology, a modernising and engineering program

Industrial ecology (IE) aims to break with a linear view of the economy, which requires the extraction of resources and the treatment of waste. It derives from the analogy between natural and industrial systems : Natural ecosystems are proposed as models for industry (Ayres et al. 2002). "Our industrial system would behave like an ecosystem, where waste from one species would be a resource for another species. The products of one industry [would] be the inputs of another, reducing raw material use and pollution" (Frosch et al. 1989).

The main object of study in industrial ecology is industrial metabolism, defined as **"human mediated matter change for sustaining a productive system's economic activity"** (Wassenaar 2015). It is analysed using two complementary concepts : funds and flows. This distinction is borrowed from Georgescu Roegen, who uses it in the study of economic processes (1971). A *flow* represents the change in the system : it is generally used to represent an input or output of a given process. The *funds* are durable entities, which are the "active agents of the process", while the flows are "used by the agents, or acted upon by the agents".

The purpose of these approaches is to "**close the loop**". The paradigmatic vision of sustainable industrial systems is characterized by minimized physical exchanges with the "natural" ecosystem (Wassenaar 2015), as well as sustained exchanges between different industries, operating in a symbiotic way (Ehrenfeld et al. 1997). Waste from one forms the inputs to the other, the aim being to balance production and use through material exchanges. This program has been supported by public authorities and industries since the 19th century, and is part of the program to "modernise" the productive system (Fressoz 2016). Economic agents as well as public authorities are given a central role, as they are considered to be the main bearers of technological innovations (Ayres et al. 2002).

In agricultural systems, this raises the questions of the use of RB in soil fertilisation and their origin (on the farm or otherwise), and/or their substitution by commercial fertilisers. The **carbon (C) and nitrogen (N) content** of biomass distinguishes different behaviours in its interaction with the soil. Biomasses with low C/N behave in the soil like fertilisers, playing a role in fertilising the crop of the year. In contrast, biomasses with high C/N behave like soil improvers, participating in the soil structure, releasing nitrogen over the long term. (Mustin 1987 ; Leclerc 2001). A regularly quoted limit is at a C/N ratio of 25. Below this ratio, nitrogen is in excess and will be released when plants are available. Above this ratio, nitrogen will be taken from the soil solution to meet the needs of microorganisms" (Peyraud et al. 2012). The carbon and nitrogen cycles are not independent : their coupling is considered virtuous from an ecological point of view (e.g. interaction between crops and livestock in a traditional farm) (Lemaire et al. 2014 ; Soussana et al. 2014). This model is extended to exchanges between farms (Moraine et al. 2017) and more generally at the territorial level.

2.2 Earthbound, the ecology of pragmatic sociology

In agro-food studies, pragmatic sociology brings together influential approaches that have challenged previous understandings and frameworks (Kristensen et al. 2016). It focuses attention on hybridity and the role of heterogeneous associations in complex networks (Goodman 2001).

The actor-networks theory (ANT) seeks to understand what is happening in the process of building and stabilizing networks. Both humans and non-humans participate in the action (Callon 1990). Representations describe actor-networks: a composite consisting of heterogeneous elements including humans, materials and technical devices that flexibly adjust to one another and act collectively (Çalışkan et al. 2010). The actors' discourse are "taken seriously": the researcher does not seek to reveal the hidden attentions of the actors by applying an analytical framework external to the situation he describes: he limits himself to describing the entities, themes, objects that the actors use to justify their practices (Darré et al. 2007).

Applied to biophysical or ecological interactions, the pragmatic approach **describes the diverse and multidimensional interdependencies that link all "earthbound" entities.** The goal of pragmatic sociology is not normative, but procedural : it intends to bring attention to the network of ties that binds all terrestrial life forms. These "earthbound" attachments forms the basis for a new definition of ecology (Latour et al. 2017). It seeks to pay attention to the links of interdependence between humans and non-humans and to open the door of politics to all living things in a process of hybridization. (Latour 2015 ; Conway 2016). This program is led by philosophers and sociologists, ecologists, environmental associations, but also agronomists (Barbier et al. 2013; Cohen 2017). "Earthbound"s are those who assume a belonging to the Earth in the diversity of the worlds experienced by its different beings.

World	Value	Test	Qualified objects and subjects
industrial	efficiency	competence	Technical infrastructure ; method ; plan ; Engineer ; professional ; expert
market	price	competition	market goods ; customer ; consumer ; vendors ; merchant
civic	equity	democracy	rules ; citizen ; union
domestic	tradition	reliability	local heritage ; legacy ;family ; authority

inspired	creation	passion	emotions ; body ; creative beings
opinion	reputation	popularity	signs ; media ; celebrity
green	life	sustainability	ecological ecosystems ; living beings ; natural habitats

Table 1 – Worlds according to Boltanski et al.

We wish to apprehend the **diversity of these lived worlds**, while being able to give a synthetic representation of them. One of the analytical frameworks for distinguishing this diversity of worlds is the economy of worth. (Boltanski et al. 2008). According to its authors, objects, subjects are divided into different "worlds", which are coherent discourse regimes in terms of reference values, and in which some entities, subjects, and objects are qualified, while others are rejected. This qualification rely on commonly accepted "tests".

Within the framework of the current Western society, which interests us, the diversity of these worlds is not infinite. The authors have identified 7 of them : industrial, civic, domestic, opinion, merchant, inspired and green (the green world, not present in the initial proposal, is a development proposed by other authors) (Latour 1995)). When they are brought to justify themselves, people always fit into one of these worlds. Thanks to these systems of shared equivalences, which allow each person to find the reference points that will guide his relationships in the situation, relationships between people can be established. For example, the industrial world values optimization and efficiency. Entities such as technicians and professionals are qualified in this world. The value of the entities is tested by model tests such as scientic analysis, accounting, quantification. The table 1 presents the main characterictics of each world.

2.3 The metabolic networks

In order to put into dialogue the analyses under each of the two programs, we propose to use a boundary-object, the metabolic networks (GABRIEL et al., to be published). This approach consists of being part of the paradigm of socio-ecological metabolism (SEM), while allowing multiple visions of what is a good metabolism, to be taken into account. It translates into theoretical and practical considerations, such as: relying on **a relational ontology**; propose **multiple representations**; describe **multiple entities** as agents; value **procedural rather than normative goals** and making room for collective deliberation.

3. Materials and methods

Extensive **surveys** were conducted among farmers. They focused on their RB management practices. The semi-directive framework of the interviews was designed to elicit the description and justification of the RB management practices. 32 surveys were carried out, in the form of semi-directive interviews, lasting 2.5 hours on average. In addition, 20 additional interviews were conducted, bringing the number of surveys describing exchange practices to 52. A collective composting project, was followed up, in particular through non-participant observation of meetings and assemblies. It gave rise to a privileged view of debates and controversies.

The survey was conducted in **the Drôme Valley in France**, an area known for the diversity of agricultural production systems (standard, organic, biodynamic). (Bui et al. 2015), the diversity of local actors involved in agricultural issues and divergent world views. (Sencébé 2001). This is one of the two sites of the BOAT (Organic Agricultural Biomasses in Territories) project, financed by ADEME (French Environment & Energy Management Agency).

3.1 Qualification of RB flows

For each individual surveyed, we qualified the RB flows involved in three categories of practices : (1) Production, (2) exchange and (3) transformation. In each category, we have characterized : the nature of the RB, the flows in and out per year expressed in tons of material and the origins or sources of the biomasses (e.g. neighbour, supplier, animals). RB are characterized according to their carbon and nitrogen concentrations. When information are not available, reference tables are used (Leclerc 2001). RB are divided into three categories : (1) those with a C/N ratio above 25 (e.g. plant residues), (2) those with a C/N ratio below 25 (droppings, manure) as well as (3) commercial fertilisers (industrial processed products, with C/N ratios regularly below 3, regularly produced from processed animal proteins.

Typological keys to distinguish farmers according to their degree of circularity are : (1) exchange of RB with C/N < 25 ; (2) exchange of RB with C/N≥ 25; (3) dependence on fertilizers for fertilization. Exchange takes 4 modalities : import/export/import-export/no trade.

$$I_1 = Flow(RB\frac{C}{N} \leq 25) \qquad I_2 = Flow(RB\frac{C}{N} \leq 25)$$

Fertilizer dependence in fertilization is described by I3 . It relates to the degree to which farmers substitute commercial fertilizers for RB. One way to measure it is to compare the units of nitrogen provided by RB with those provided by external fertilisers (minerals, such as ammonium nitrate, organo-minerals, commercial organic fertilisers).

$$I_3 = \frac{NitrogenUnits^{commercial\ fertilizers}}{NitrogenUnits^{total}}$$

Farmers can be divided into three categories : those who are strongly ($I \geq 66\%$), moderatly (66% I 33%) and lowly ($I \leq 33\%$) dependant on commercial fertilizers.

3.2 Qualitative description of practices

We paid attention to the discourse of the actors, as they were led to justify their practices. By following a pragmatic approach, the discourses are "taken seriously" : this means we do not seek to reveal the hidden interests of the actors. On the contrary, we consider that justification is in itself meaningful. (Darré et al. 2007). The farmers' speech was coded using RQDA.

We analyzed the **justifications**, describing the situations in which farmers are led to question their RB management practices. For each type of practice, an attempt was made to identify what constitutes good metabolism from the farmers' perspective. (1) What is a good flow, a good waste biomass ? (2) What are the active and durable entities, the funds, that contribute to good metabolic functioning ? We have tried to describe the objects, the subjects, the criteria mentioned by the farmers, as well as the way in which they recompose themselves among themselves and come into conflict with each other. (3) Finally, we show that each of these representations of a good metabolism is linked to values, within different "worlds", relying for this on Boltanski and Thévenot (2008), describing the characteristics, subjects, valued objects and tests specific to each world.

3.3 Data integration : metabolic networks

The data are integrated in a relational database (Access). Both quantitative and qualitative data have been processed in terms of funds/flows and translated into tables of nodes and links. Data is aggregated and processed using SQL requests, generating tables of nodes and links. Representations are then generated using Gephi software.

4. Results

Industrial Ecology

In our study area, high C/N waste biomass has the highest tonnages. These include green waste, industrial wastes such asfruit processing residues, wine making spent grains, fruit compotes, avender straws and distillation residues. Among the RB with low C/N, poultry droppings are particularly represented. The second source of these biomasses is goat manure. These productions are far from reflecting the needs of the territory's farmers. With 21 % of the land is devoted to organic farming, the territory's need for organic matter is much greater than its production.

Six farmers' profile are proposed in table 2.

N	Type	C/N inf 25	C/N sup 25	Dependancy on fertilizers	N (number of farms)
1	Substituent	-	-	High	8
2	Independant	No exchange	No exchange	Low to moderate	16
3	N producer-exchanger	Export	-	Low to moderate	5
4	C producer-exchanger	-	Export	Low to moderate	5
5	Hub	Import and export	Import and export	Low to moderate	7
6	Net C and N importer			Import Low to moderate	Import 10

Table 2 – Types of farmers

Substituent farmers include conventional farms that do not mobilize waste biomass. Theirproductionsystemis basedonsubstitutionbyanothersourceofnitrogThiscategory includes large cereal farms, which rely exclusively on chemical fertilizers. Some organic farms also fall within this framework : they include farmers who have decided to completely separate the issue of carbon and nitrogen management in their production system. Carbon is managed through high C/N ratio RB, such as green waste or straw, as well as conservation practices such as limited tillage or long rotations. Nitrogen is applied exclusively with commercial fertilizers. Substituent farmers maintain privileged relations with cooperatives and traders, as regards their supplies of nitrogen fertilizers. As for carbon-rich biomass, it comes from local authorities (green waste dumps) and industries (lavender distilleries, wine cellars). The fact that these farms do not use waste biomass does not mean that they do not produce it : some poultry farms prefer to export all their droppings, without mobilising them themselves, to simplify the technical itinerary or due to a lack of equipment.

- Independent farmers do not import RB for fertilizer use, and are low or medium dependent on commercial fertilizers. They are small or medium-sized mixed crop-livestock farms, often in organic farming. Some farms specializing in crops with low nitrogen demand, such as trees or vines, also fall into this category. Independant farmers are not completely self-sufficient : they import commercial fertilizers through cooperatives and traders. In reality, completely self-sufficient farmers are almost non-existent : almost all of them have to obtain fertilizer from outside, even marginally.

N-producer-exchanger farmers export low C/N ratio RB. They are typically breeders (goats, laying hens), who use and export surplus manure. They actively participate in the circulation of C and N flows : they are moderately dependent on commercial fertilizers. They potentially import RB with high C/N, especially straw for their farms.

C-producer-exchanger farmers import nitrogen, which takes the form of organic matter, for fertilization. The carbon exported concerns cereal straw, sold in bales or exported as standing crops. These are mainly small cash-crops farms, either organic or in organic conversion.

Hub farmers import and export at least one type of biomass. They group together breeders (cattle, goats), export their manure, and complete this activity by managing the manure of other farmers. This category also includes farmers who trade straw. Exchange of RB is greater than farmers' needs : they all maintain a low or medium dependence on commercial fertilizers.

Net C and N importer farmers are dependent on waste biomass for nitrogen fertilisation and soil amendments. They import both nitrogen-rich biomasses (manure, compost) and highly carbonated biomasses (green waste, etc.). The majority of them are farms, regularly engaged in organic farming, without animal husbandry, and which maintain the fertility of their soil through the input of multiple residual biomasses : for example, small market garden farms. They maintain relations with a wide variety of actors : farmers from outside the territory, directly, or by using a transporter. They prefer to use traders rather than the supply cooperative.

Figure 1 provides a representation of **interdependancies between agents**, with the flows of RB between economic actors, distinguishing between the 6 types of farmers.

Importers of C and N C and N producer-exchange farmers are interdependent with each other in exchanges within the agricultural world. These exchanges between these two types of farmers are, for example,"straw-manure exchanges", and are more generally part of the interaction between crop and livestock farming at the territorial level (Moraine et al. 2017). They are nevertheless marginal compared to other types of exchanges. In particular, some hub farmers organize around them heterogeneous networks of farmers. Their exchanges extend beyond the agricultural world : they are regularly in contact with local communities and industries, importing waste and residues.

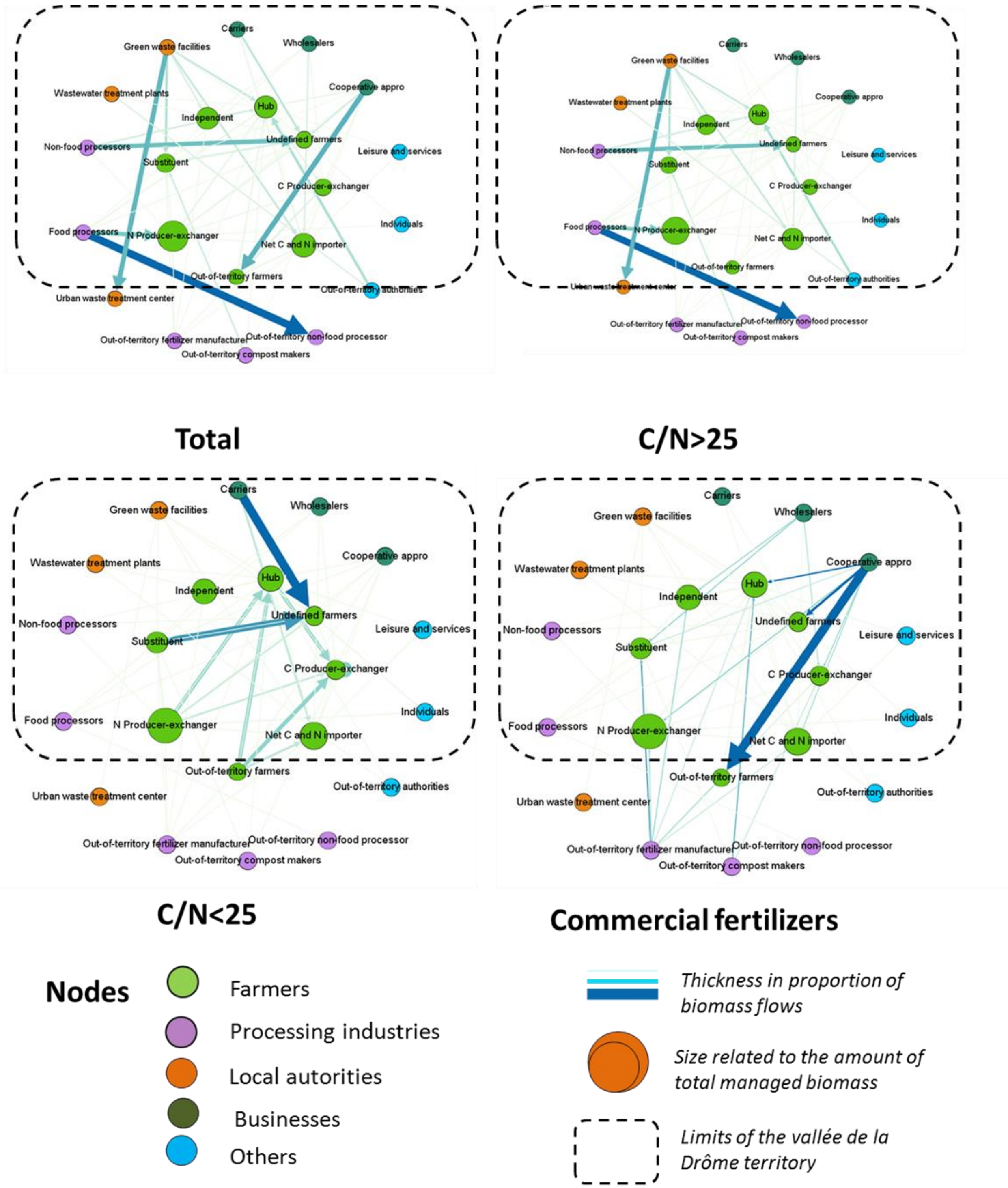


Figure 1 – Representations of metabolic networks between economic actors.

4.2 Earthbound

Among the situations in which farmers are led to question the management of the RB, the situation most often cited is the **closure of livestock farms**. This force other agents (i.e crop farmers) who were dependant on these livestocks farms for their manure to reduce fertilization or to replace certain productions by crops that require less nitrogen. Not all situations are troublesome : **opportunities** also play a key role. Since RB are rare and sought-after, farmers are easily inclined to accept RB whenever an opportunity arises.

What is a good RB for a farmer ? These events lead to a rethinking of relationships, and cause farmers to question themselves what a good RB means to them. The most widely shared criteria are technical : search for "nitrogen at the best price", for an "efficient" product. They are often opposed to other criteria : the local character of the biomass is several times associated with a notion of quality ; the organic label "without antibiotics", the "non-industrial" character, sensitive criteria such as odour and texture are also mentioned.

When a problem arises, such as repeated poor harvests, some farmers seek to test the RB on their criteria of interest. For example, a farmer decides to carry out an analysis of manure, which reveals that the nitrogen concentration is "3 points lower than what was announced", or when looking at green waste, he discovers "lots of small pieces of plastic", and calls on the community to carry out more regular physico-chemical tests.

Trade-offs between these criteria regularly occur, for example, a farmer is looking for both a reasonably priced supply of nitrogen and local resources. These tensions between different forms of values are regularly solved by the actors themselves. For example, one farmer used to obtain manure from his neighbour. The disappearance of his manure supplier led him to rethink his demands, expressed as "supply at a reasonable price", and "mobilization of the territory's resources". Unable to find new local resources under these conditions, this farmer ended up finding a compromise, changing the scale he considered "local" : "Today, it no longer makes sense to think on a small scale, to exchange neighbours. "Today, the scale is the region." "It's true, we would like it to be less than 50 km away, but well, we can't find any.

In other cases, the compromise between these different criteria is not found. For example, a farmer finds himself torn between his search for nitrogen and his refusal to accept any risk of salmonella contamination. He says he is very concerned about the sanitary measures that accompany the discovery of salmonellosis on farms, which makes him reluctant to enter into exchanges with another potentially affected farmer, even if it means missing what he considers to be an agronomically attractive opportunity : "[a colleague contaminated with salmonellosis] had called me to collect his droppings. I thought about it...then I didn't take it, I don't want it on my farm...when you get [salmonellosis] on your farm, it's like being in hell".

Recompositions and oppositions of the actors-networks What represents a "good RB" or good flow is dynamic. Changes in flows imply a recomposition of collectives of human and non-human actors. In some cases, these recompositions are marginal : Not all farmers are affected in the same way by these problematic situations. Faced with the closure of a partner farm, a farmer succeeds in entering into other contracts: a compromise is reached, and with some reorganisation, RB management practices continue.

In other cases, the changes are more profound, and strongly recompose the actor-networks: for example, the disruption in manure supply led one farmer to limit his area under organic conversion, then his sells, his choice of crops, etc. These situations of tension regularly give rise to conflicts. For example, a group of farmers decided to oppose the cooperative, which only offered Spanish compost, and stopped supplying French compost from a supplier whose quality was unanimously recognised by the farmers. This supplier is characterised as "poor" by a Diois polycultivator. Discovering that he was not alone in this case, in discussion with colleagues, he joined a collective of dissatisfied farmers, taking the initiative to write to the cooperative, urging it to reintroduce French compost.

These conflict situations sometimes lead to the expression of direct criticism from certain actors: the difficulty in finding manure, while in most cases it is attributed to a general decline in livestock farming, is denounced by one farmer as the result of unjustified privileges : "X. [a neighbour] finds manure easily, he is elected to the chamber [of agriculture], so as soon as a new livetsock farm shows up, he is the first to be there [and get the manure]. [...] We are nothing [to them]. We just watch".

These justifications and controversies help to describe what a good metabolism is, from the farmers' point of view. By relating the objects and subjects qualified in the framework of the Economy of Worth, we are able to identify what a good metabolism means in each of the worlds. Table 3 presents for each world what is considered a good practice, and how it translates into flows and funds.

World	Value	Flow (What is a good biomass?)	Fund (What is considered as valuable and active?)
industrial	efficiency; optimization	Fully valued by the plant/ without losses	Soil analyses; quantified figures; concentration of substances; NPK; mineralization rate.
market	competition; rivalry	Provides nitrogen/nutrients at the best price;	a diversity of suppliers; diversity of products; sales people; internet shopping
civic	democracy; community	Provides services to multiple local actors	the local community; meetings; grants; collective projects
domestic	tradition; hierarchy	Valued according to traditions and habits	family; inheritance; friends
inspired	creation;intuition	Gives the opportunity to follow one's inspiration or feeling	esoteric references; biodynamics; personal experience and feeling
opinion	reputation	Renowned for its quality	the opinion of neighbours; informal discussions
green	living beings interdependancy	Supports natural processes	soil life; ecosystem services

Table 3: Definition of a good metabolism in each world

4.3 Discussion of the 2 programs through metabolic networks

We propose to discuss earthbound and industrial ecology, based on a theoretical application of metabolic networks (network ontology, common grammar) (1), the other based on its practical conditions of implementation (debating irreducible representations, multiple actors, democracy and deliberation, (2).

Theoretical discussion: Farmers are part of many worlds : industrial ecology is only one of them.

Figure 2 shows the main funds mobilized in the management of RB for each type of farmer. Table 4 summarizes the share of each world in the justifications, by type of farmer. The industrial world is unquestionably the most mobilized by farmers in justifying their practices. They all refer to it, regardless of the group they belong to. Nevertheless, the place occupied by the industrial world is not uniform. By quantifying the share that the entities of each world represent, we can get an idea of the importance of each world in farmers' practices.

The farmers who contribute the most to the looping of flows (independants) attach the greatest importance to it : the industrial world dominates, and represents 81 % of the justifications. On the other hand, the least circular farmers (Net C and N importers, Substituents) include less than 50% of their justifications in the industrial world.

Type of farmer	Industrial	Market	Civic	Domestic	Opinion	Inspired	Green
Substituent	48	17	29	2	2		
N Producer-exchanger	81	6					9
Hub	51	17	20	3		1	
Net C and N importer	49	3	8			21	17
C Producer-exchanger	62	8	20	4	4		
Independant	81	1		6			17

Table 4

justifications by worlds, and by type of farmers

Practical application: a collective compost plant project

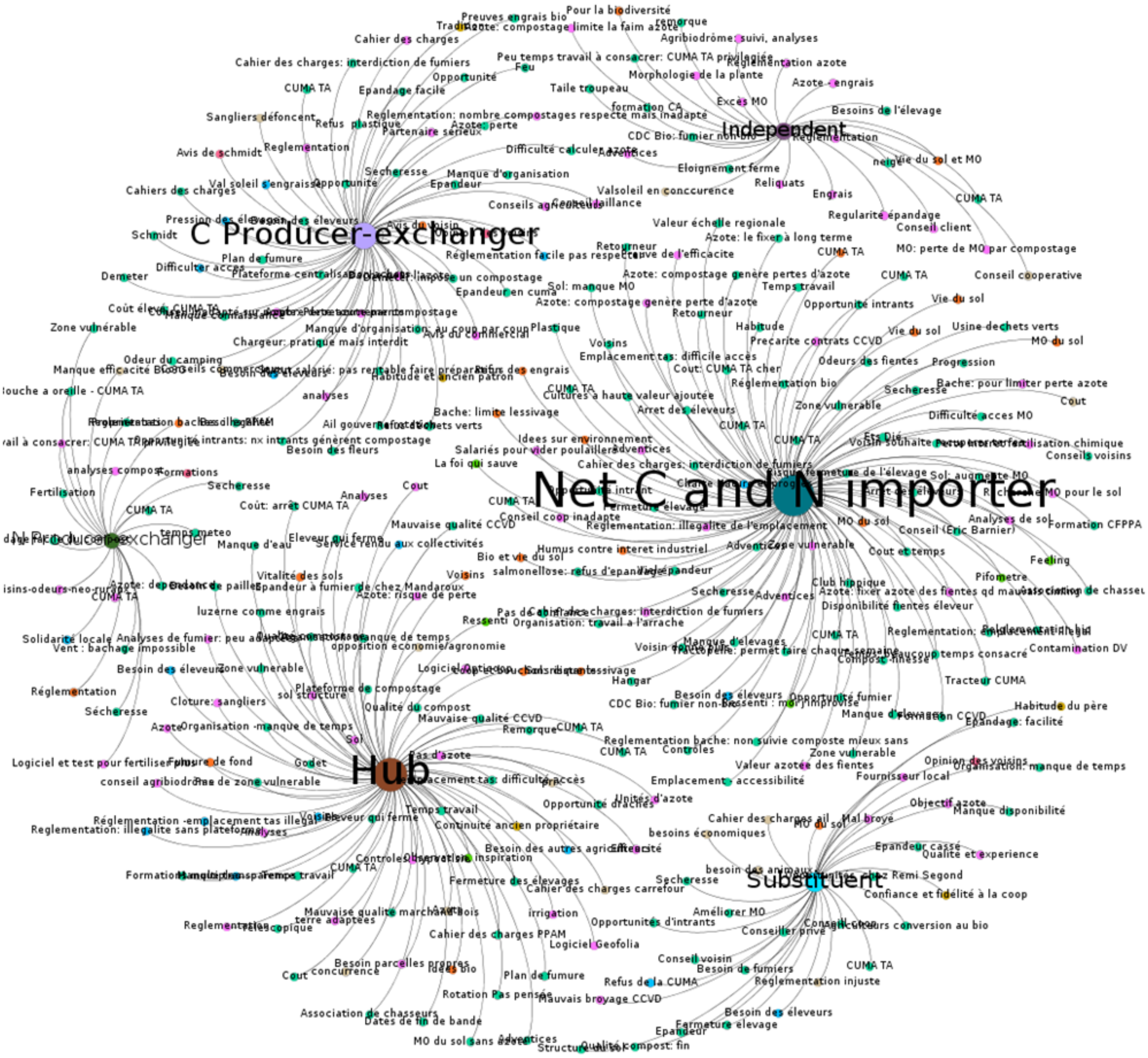
The association has its origins in the discovery of a shared interest in biomass by a cooperative of poultry farmers and a local authority. A compost plant was seen as a way for poultry farmers to find an easy outlet for their droppings, and for local authorities to guarantee local recovery of their green waste. An association was formed. The potential seems great, especially since many industries currently export waste far from the territory. The diversity of the biomasses lead the association to call upon a consultant to identify available resources and to propose technical solutions for discussion.

The study proposes an inventory of potential inputs and outputs. It confirms the importance of poultry droppings, which represent more than 50 % of the total 4800 tons of potential agricultural effluents. Concerning industrial waste, only a tiny part (2700 tons) is available for the project : many companies are bound by contracts, preventing them from freely redirecting their waste to the composter. Concening outputs, or market opportunities, the data is highly indeterminate : only the areas of organic land for each crop are known, but the willingness to pay is unknown. The regulatory risks, linked to the existence of different product qualities, are also highlighted.

Different technical options are proposed : one or several composting sites ; production of bulk or granulated fertilizers; treatment of salmonella-infected manure; integration of sludge from wastewater treatment plants ? The debates bring out a point of agreement on the centrality of profitability : the project must be economically viable, and the final product must be competitive. Two scenarios emerge : a single platform, on a single site, with a storage building and granulation. The second scenario integrates sludge from wastewater treatment plants, but maintain two separate sub-plants, one of these being kept sludge-free.

The technical arbitrations are debated by an extended panel of farmers. Workshops are organized for three different themes : the choice of options, the cost of treatment (for local authorities and industries), as well as the final cost of the product. These discussions lead farmers to question their own RB management practices, and to describe what a good collective composter would be for them. Some farmers argue that today, they have access to a diversity of biomasses (manure, droppings, green waste), each one being adapted to a specific use. The disappearance of these diverse biomasses and their replacement by a single, standardized product is seen as a risk factor for their own production. Moreover, some biomasses are integrated into informal exchanges between farmers, which involve exchanges of labour or services.

The project of industrial symbiosis is progressively amended, taking into account the multiple attachments of the actors. It appears from the discussions that the expectations of the farmers go beyond the initial logic (economic viability with a competitive product). The study of the multiple technical constraints reveals that the product is unlikely to be the cheapest on the market, nor the most efficient in terms of nitrogen. The fact that despite this, the various stakeholders have taken the decision to continue reveals the importance of these multiple other attachments. The moderators of the debates summarized it under the term 'offer of service' : the goal of the compost plant is to provide services to farmers. For example, to help the poultry farmers with the management of salmonellosis, while ensuring their participation.



Worlds	Values	Example of funds
Industrial	Efficiency, optimisation	Scientific analysis, a technician
Civic	Democracy, community	Local authorities, associations
Domestic	Tradition, hierarchy	Family, olders knowledge
Inspired	Creation, intuition	Emotions, personal inspiration
Market	Competition, rivalry	Businessmen, marketable goods
Opinion	Reputation	Others people opinion
Green	Human non-human interdependancy	Natural environment, living entities
Unrelated		

Figure 2 – Representations of the actor-networks made up of the funds mentioned in the justifications, by type of farmer

5. Discussion

Frontlines and meeting points between the two ecologies

The two programs, although theoretically far apart, have many points in common in the concrete situation of waste biomass management in the Drôme valley. The foundations of industrial ecology are already widely taken into account by farmers, and they demonstrate a strong attachment to the values (efficiency, optimisation) and objects of the industrial world, as well as to the same attributes of the biomasses (carbon and nitrogen content), and the same qualification of the actors (technicians, analyses) in the choice of their practices.

Nevertheless, the study of farmers' attachments reveals broader attachments that go beyond the industrial world (domestic, inspired, etc.). These attachments may prove to be compatible, even synergistic, with the objective of closing the flow loop. In other cases, these attachments may come under tension : circularization results in the breakdown of certain attachments, i.e. a break in interdependence between cereal farmers and livestock farmers.

These meeting points and fronts contribute to questioning what a ”good” metabolism is, as far as the management of residual biomasses is concerned. They ask us about the ends : do we want to loop the flows at any cost, even if it means destroying other forms of attachment? On the contrary, do we want to valorise other forms of attachment, even if it means helping to maintain sub-optimal systems? But also on the means : couldn't the looping of flows be based on attachments other than those specific to the industry, by relying on the diversity of the actors' attachments ?

5.2 Perspectives for action

The path we are proposing to think about ends and means together. Metabolic networks can help us in this task. The adoption of a common network ontology, as well as a common grammar, makes it possible to place industrial ecology among the multiple earthbound attachments of farmers. The industrial world provides a very good framework for industrial ecology : the criteria specific to industrial ecology are completely in line with its grammar (Plumecocq et al. 2018). This puts us in the position of being able to discuss different visions of what a good metabolism is, rather than imposing a normative vision.

In the composting project, this was translated into participatory workshops, giving each member the opportunity to express what was important to them. The objectives were defined collectively : the farmers took part in defining what they expected from the composter, and thus in the choice of the technical and organizational system. This requires to accept multiple mutually irreducible representations, and to renegotiate what are considered to be relevant attributes for qualifying biomass flows, or qualified funds.

The main difficulty lies in opening the discussion to the widest possible range of actors, especially those who do not have a direct interest in the project. The ”network-metabolic” crossovers also make it possible to highlight anything that is not taken care of in a given collective. For example, the question of the interdependence between the issue of tourism and that of composting.

Limits and weaknesses

However, this study shows strong limitations to this method. Each of the frameworks is not developed in all its complexity, which may contribute to caricature. Iin industrial ecology, networks were represented with incomplete information : not all farmers in the territory were surveyed. This gives an important limitation to the interpretation of the graphs, which should be seen mainly as representative of a certain diversity, and not of exhaustiveness. With regard to earthbound : the framework of the study did not allow the full development of a pragmatic approach, which presupposes a detailed description of all the processes involved. More broadly, following our methodology means adding a layer of complexity to the approach to metabolism, and seeking to describe several mutually irreducible facets of it. Whether in theory or in practice, it therefore implies time, and thus a questioning of the imperative of efficiency specific to many engineering projects.

6. Conclusion

This study proposes to gain a level of reflexivity on the management of RB in agricultural systems. By adopting a certain common grammar, made up of backgrounds, flows, nodes and links, it enables a dialogue to take place between academic traditions that are sometimes quite distant. It raises questions about our own position as researchers. Putting oneself in a position to act, to develop certain attachments (to ecosystems, flow closures, territories, etc.) necessarily involves questioning other attachments (traditions, institutions, etc.). These values are incommensurable (Giampietro 2005), and the diversity of attachments (as rich as human experience is) can only be described in an extremely partial and incomplete way by an investigator. Thus, it would seem that, like our respondents, we are not exempt, as researchers, from questioning our own attachments. Wouldn't that be ecologization: questioning oneself about one's own attachments, and therefore assuming to take a political stand accordingly.

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