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From stakeholders narratives to modelling plausible future agricultural systems. Integrated assessment of scenarios for Camargue, Southern France.

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Abstract

European farmers are facing challenges that call for important transformations on their agricultural production systems, including an increasing number of regulations aimed at reducing environmental impacts from farming practices. Climate change is also expected to affect agricultural production in most European regions, and in Southern Europe this effect is expected to negatively impact yields. In this study, we present the application of an innovative participatory approach to assess the potential of innovative agricultural systems to reconcile environmental sustainability with economic viability while contributing to local and global food security. Our approach consisted of combining (1) the participation of local stakeholders in the design of narrative scenarios, and (2) an integrated assessment of scenarios through the calculation of indicators at different scale with a bio-economic model. We tested our approach with a case study situated in the Camargue region of Southern France. Rice is currently the main crop in this region, but farmers there face adverse economic conditions linked to the recent reform of European Common Agriculture Policy. After identifying the main drivers of change, local stakeholders developed narrative scenarios and described how farmers would adapt within the context of those changes. These elements were then translated into model inputs. At the regional level, the four scenarios led to variations in farmland acreage (28,000-33,000 ha), as well as the proportion of rice crops (19-75%) and areas cultivated under organic farming standards (8-43%). The four scenarios also led to different values for indicators of agricultural economic welfare, food production, and environmental impacts. Trade-offs between these indicators and the associated objectives assigned to agriculture were identified and discussed with the stakeholders. We end with a discussion of the limitations

and advantages of our approach to the participatory development and assessment of locally developed narrative scenarios.

Keywords

Participatory approach, Multi-criteria assessment, Bio-economic model, Climate change, Greenhouse gas emissions

Highlights

- Participatory development of narrative scenarios and bio-economic models are used.
- Main drivers of change are economic conditions for rice and climate change.
- Simulated rice acreages range between 6,000 and 23,000 ha, depending on scenario.
- Gross margin and food production are the most impacted socio-economic indicators.
- GHG emissions and water consumption are the most impacted environmental indicators.

1. Introduction

1.1 Challenges for agricultural systems

European farmers are facing challenges that call for important transformations on their agricultural production systems, such as new regulations that constrain their management practices, especially in terms of their environmental impacts (e.g., pollution from leaching of nitrates and pesticides). The new rules pressure farmers to use practices that favour the reduction of pesticides use (European Commission, 2009, 2013). The emission of greenhouse gases (GHG) and the energy consumption of agriculture are also increasingly monitored to assess their contribution to, and potential for mitigation of, CC in Europe (see, for example, Smith, 2012; Bell *et al.*, 2014). In the meantime, numerous studies (e.g., Olesen and Bindi, 2002; Maracchi *et al.*, 2005; Miraglia *et al.*, 2009; Olesen *et al.*, 2007) contend that climate change (CC) is expected to affect agricultural production in most European regions, but differently between Northern and Southern Europe. While climate change may have positive effects on crop production in the North, southern areas could face water shortage and extreme events leading to lower yields, especially in Mediterranean areas (Olesen and Bindi, 2002; Maracchi *et al.*, 2005; Miraglia *et al.*, 2009). In these regions, climate change may threaten the achievement of food security objectives. New agricultural systems need to be developed with the objective of balancing environmental sustainability, economic viability, social acceptability and contribution to local and global food security.

Low input and organic farming (OF) systems have been suggested as potential ways to reconcile these issues (see, for example, International Assessment of Agricultural Knowledge, 2009; Loyce *et al.*, 2012). Both of these farming systems use less chemical inputs and/or energy (Matson *et al.*, 2007; Hossard *et al.*, 2016), however, recent studies have highlighted yield losses of 19 to 25% for organic crops when compared to yields from conventional farming methods (Badgley *et al.*, 2007, de Ponti *et al.* 2012, Seufert *et al.* 2012, Ponisio *et al.*, 2015). Relative yield loss under low-input systems has been shown to range from zero to 12% for maize and soft wheat crops, respectively (Hossard *et al.*, 2014; 2016). What's more, the profitability of these low-input systems is still variable. When cereal prices are high, even low yield losses may not be compensated by the reduction of input costs (Hossard *et al.*, 2014). Examining the potential of these systems to simultaneously meet environmental, economic, and food security objectives in a future undergoing climate change requires integrated studies that combine research on these objectives and their potential trade-offs.

There is a large body of recent research analysing climate change scenarios and their impacts on crop production (see, for example, Berg *et al.* (2013) and Donatelli *et al.* (2015).

Projections have been made for impacts at regional, national and global levels, but in most cases these studies concern large areas, and few studies have simultaneously analyzed the impacts of CC and the evolution of local dynamics and constraints. These latter factors have considerable impact on viable adaptation and mitigation strategies for agricultural systems in a given region. This deficiency has led a number of authors to call for more studies involving smaller regions (such as ecoregions) that evaluate the potential impact of CC on agricultural systems (Abildtrup *et al.*, 2006; Sleeter *et al.*, 2012), and include the assessment and design of adaptation and mitigation strategies at the scale of farms (Reidsma *et al.*, 2015).

Since the magnitude of CC and its consequences on crop physiology and resources (such as water) remain uncertain, relevant studies must be conducted using different CC scenarios. IPCC climatic scenarios project how CC impacts future weather conditions on a large scale, and modeling approaches attempt to down-scale these projections to regional and local levels (Abildtrup *et al.*, 2006; Sleeter *et al.*, 2012). However, the use of these results by local stakeholders of a given area often remains limited, and requires integration with the parallel evolution in local drivers of change that effect these same stakeholders.

1.2 Scenario studies

Therefore the development of regional scenarios that focus on potential agricultural systems in locally defined contexts should include both local and global drivers (including CC) (Ebi *et al.*, 2014). This requires appropriate methods for scenario development. Narrative scenarios and Representative Agricultural Pathways (RAPs) are considered as a logical framework for studying the evolution of agricultural systems at different scales (Rosenzweig *et al.*, 2013). Narrative scenarios can include both local and global changes: local dynamics such as urban development or specific environmental constraints, and global variables such as the evolution of the crop and energy markets, and climate change (e.g., Kok *et al.*, 2006, Hossard *et al.*, 2013; Kok *et al.*, 2007, Reed *et al.*, 2013). Narrative scenarios have been used to encourage stakeholders to think creatively about the evolution of land use and the possible consequences on indicators that are often related to socio-economic aspects (see, for example, Fohles *et al.*, 2015) or ecological services (see, for example, Petersen *et al.*, 2003; Bohensky *et al.*, 2006; Plieninger *et al.*, 2013). Such scenarios are often written as a short, coherent story, which is seen as a format suitable for being communicated to stakeholders (Rasmussen, 2005). A common practice includes the use of four different scenarios simultaneously delineated on the basis of two drivers that could evolve in two opposite directions (van 't Klooster and van Asselt, 2006). This enables stakeholders to quickly understand the explorative nature of the scenarios. Such scenarios usually include four elements: (1) a representation of the initial situation (reference), (2) a description of the drivers of change, (3) a description of the evolution of the system, and (4) a description of the future state of the system (Alcamo and Henrichs, 2008).

Scenarios can then be assessed in term of their capabilities to create good conditions for agricultural sustainability (Delmotte *et al.*, 2013). The process of integrated assessment and modelling has proven to be capable of producing useful information about the possible future states of agricultural systems, and about the consequences of changes in agricultural systems on a wide range of sustainability issues (van Ittersum *et al.*, 2008; Castoldi and Bechini, 2010; Bezlepkina *et al.*, 2011; Reidsma *et al.*, 2015). In this study, we present a method to (1) develop narrative scenarios related to the evolution of the agricultural systems by combining drivers of changes related to global changes and local constraints and opportunities, and (2) perform an integrated assessment of these scenarios. This method is aimed at foreseeing the possible future states of agricultural systems from the perspective of stakeholders, and assessing the consequences of these states with a model. We applied the method in collaboration with stakeholders in the Camargue, a wetland region in southern France. After presenting the case study and methods used for scenario development and analysis, we present an assessment of these scenarios. We then discuss the implications of these results for the case study, the methodological lessons learned, and the further improvements needed.

2. Methodology for narrative development and the modelling of plausible futures

This study was conducted during 2014 and 2015 in the Camargue, a deltaic region in the South of France. Following a brief introduction of the region's characteristics and an outline of the method for scenario development and integrated assessment, we present the four steps used in the methodology for scenario assessment, and the bio-economic model used to assess the scenarios.

2.1. The Camargue region

The Camargue is home to large tracts of protected wetlands which are recognized for their importance to biodiversity. These wetlands are in close proximity to agricultural land primarily used for livestock (extensive systems raising local landrace), and for intensive cultivation (c.a. 55% in rice crops, 30% in durum wheat). The Camargue is the only place in France where rice is grown on a large scale, and all industries associated with the supply chain are located in this region. The salinity of the region's groundwater tables is compounded by evapotranspiration that is on average twice as important as annual rainfall (Heurteaux, 1994). An irrigation and drainage system used for rice cultivation plays a crucial role in providing fresh water to the natural wetlands and controlling soil salinity in flooded fields. However, these rice fields represent a potential loss to the environment ofpesticides (Comoretto *et al.*, 2008) and greenhouse gases (GHG) (Linquist *et al.*, 2012). Alternative farming systems, such as Organic Farming (OF) or low input systems, are expected to improve the sustainability of agriculture in the region (Lopez Ridaura *et al.*, 2014). Since 2012, rice cultivation also faces challenges from the reform of the European Common Agricultural Policy (CAP), and a reduction in the number of different herbicides allowed for weed management. This context has lead farmers to diversify crop rotation, reducing rice cultivation (from 21,000 ha in 2011 to 14,000 ha in 2015), potentially threatening soil fertility with higher salt concentration.

2.2. Method for scenario development and integrated assessment

This study was conducted in collaboration with a group of stakeholders facing these on-going and future challenges. The group consisted of two representatives from local public institutions (the Regional Nature Park of the Camargue, and a group of municipalities called the *Pays d'Arles*), two representatives of local farmers' unions (the president of the union of local rice farmers and the president of the association of livestock breeders, both farmers themselves) and one researcher specialist on rice-based systems in the Camargue. These stakeholders were selected based on their knowledge of the regions but also on the basis of their expertise about the drivers of changes at larger scales. Stakeholder participation was needed to improve the credibility, coherence and relevance of scenarios, and ensure their usefulness to the stakeholders themselves as they manage future evolutions in local agricultural systems.

Along with the stakeholders, we developed four narrative scenarios related to the evolution of agriculture in the Camargue, and performed an integrated assessment of these scenarios using a bio-economic model. The design of these narrative scenarios is not intended to be predictive. They are explorative and depend on the multiple choices of the group of stakeholders and researchers who developed them. A scenario is composed of drivers of change (e.g., climate change or food demand), their local consequences (e.g., the creation of a new supply chain) and farmers' adaptation strategies (e.g., conversion to organic farming - OF). The time horizon was set to 15 years from 2014. Local stakeholders considered this to be a relevant time span for the principal changes they might expect to experience

The research was developed in four successive steps presented in figure 1 and in the following sections. The participatory process is detailed in appendix 1.

2.2.1. Step 1. Identification and selection of drivers of change

The development of the scenarios began with the identification of the main drivers of change in the Camargue. In this case, drivers are phenomena that can influence the evolution of the resources used by the farming systems and can be either internal or external. Internal drivers are those influenced by local stakeholders through their decisions or behaviours (e.g., available labour force, local market for commodities, infrastructure development). External drivers originate outside of the regional system and require adaptation by stakeholders (e.g., the international exchange price of commodities, national and international policies, climate change) (Zurek *et al.*, 2007).

The main drivers of farming systems in the Camargue were selected during the first meeting held with the stakeholders (Figure 1). The research team first compiled a list of drivers that influenced the evolution of regional farming systems over the last 30 years (Mouret *et al.*, 2004, Delmotte *et al.*, 2011, Delmotte *et al.*, 2016). This list was further completed with drivers identified by the stakeholders as potentially influential in the mid-term future. The final list contains 13 drivers (Table 1) separated into four different categories: technical, social, economic and environmental. These drivers were defined at different spatial levels, ranging from local (e.g., new supply chains) to global level (e.g., climate change). The drivers were ranked according to the number of times each driver was cited by the participants. The participants were incited to think about (1) the potential impacts of the driver on the farming systems, and about (2) the level of uncertainty associated with its evolution (e.g., magnitude of climate change).

We then identified the two main drivers and placed them in a two-dimensional matrix (Figure 2) in order to define four different combinations (van 't Klooster and van Asselt, 2006). The first main driver is a combination of two economic drivers, “prices of commodities” and “public subsidies”, that we used to designate a single, more inclusive driver, entitled ‘economic conditions for rice cultivation’. The discussion with the stakeholders highlighted that the economic conditions seems to evolve in cyclic manner, depending on the prices and programs of subsidies. As this driver remains one of the most important factor influencing farmers’ decisions for land use, we chose to represent it this way, not focusing on the prices only but in a more general term, on the economic conditions. The second main driver is climate change, which impacts fresh water availability and yields. Each driver is oriented in two directions: economic conditions can be either favourable or unfavourable for rice cultivation, and climate change impacts can be either low or high in accordance with IPCC scenarios (Jouzel *et al.*, 2014). The opposing directions of the two drivers are positioned on two axes, creating four spaces of possible futures that define the basis of four scenarios (Figure 2).

2.2.2. Step 2. Development of the narratives

Starting from each corner of the matrix, the stakeholders developed the scenarios progressively, during the second and third meetings (Figure 1). Each story includes most of the initial 13 drivers of changes and their possible evolution.

During this step, four rules guided the arrangement of the drivers' in each scenario, adapting recommendations by Alcamo (2001):

- Realism: Each scenario must represent a possible future, avoiding ideal or worse case situations that would have limited interest *per se,* and when being compared to the others.
- Consistency: The choice of the additional drivers' directions must be logical within each scenario; for example, if the farming systems are facing economic constraints, the investment in new machineries would be limited.
- Contrast: In order to compare and discuss different adaptations and innovations for farming systems, the scenarios must be as contrasted as possible, in both their drivers and subsequent adaptations.
- Creativity: The objective is to go beyond common thinking, to imagine innovative and surprising scenarios.

Among the four criteria, "creativity" and "realism" were two objectives that were ensured through the facilitation of the participatory exercise. "Contrast" and "consistency" were also addressed in the lab, when the research team worked to reframe the different scenarios (see appendix 1). The balance between these four criteria was obtained ex-post, when the final narratives were written and presented to the stakeholders. The resulting four narrative scenarios are presented in Box 1.

2.2.3. Step 3. Adaptation strategies for narrative scenarios

The third step in developing scenarios was the identification of adaptation strategies within each scenario's context. Taking into account the diversity of the current farming systems, we classified them into six types adapted from the typology presented in Delmotte *et al.* (2016). These types are based on farm size, relative share of livestock production, and surface area exploited with OF methods. This classification enabled consideration of the specificities and constraints that the different farming systems would face in the context of the different scenarios (e.g., the differential in effects from changes in economic conditions of rice for a livestock farmer or for a diversified crop farmer).

Different adaptation strategies were discussed with the stakeholders during the third workshop (Figure 1). These strategies included the following:

- Changes in the farm activities, such as the development of new livestock activities (scenario A).
- Development of innovative cropping systems, including new crops (e.g., soft wheat and intercropping systems in scenario C), new crop rotations (in scenarios B and C for example), or new cropping practices for a given crop (e.g., dry sowing of rice, low pesticides systems).
- Changes in land availability, such as abandonment of lowlands (in scenario C), or on the contrary, cultivation of currently abandoned land (in scenario B).

2.2.4. Step 4. Bio-economic modelling and scenario assessment

For each narrative scenario, we formalized the information in terms of (1) the changes that define conditions for future agricultural systems, and (2) the adaptation strategies designed by stakeholders. The scenarios were then translated into a quantitative assessment of the agricultural systems via the use of a bio-economic model (BEM). We used the BEM to generate a set of optimal land uses for each scenario and selected one of these land use combination that was in agreement with the scenario. These land uses were presented to the stakeholders during the fourth meeting (Figure 1), where they were given an opportunity to suggest modifications if some model outputs were found uncoherent. Based on this feedback, we modified the constraints in the BEM, and obtained the final land uses presented in this paper. Based on these land uses, an integrated assessment of the scenarios was realized by comparing the evolution of multiple indicators at the farm and regional scale.

2.3 Parametrization of the bio-economic model

2.3.1 Presentation of the bio-economic model

We used a bio-economic model previously developed in the Camargue (Delmotte *et al.*, 2016), based on a multiple goal linear programing model. This BEM optimizes the allocation of land uses, taking into account multiple variables, one being the objective function (to be maximized or minimized), and the others being used as constraints. Both the objective and the constraints can be set at the farm and/or regional levels (see Delmotte *et al.* (2016) for a detailed description of the model and its equations). The possible land uses are defined as agricultural activities following Hengsdijk and van Ittersum (2003), and are described in terms of agricultural inputs (e.g., fertilizer, pesticide, energy and water use, costs of production, labour) and outputs (e.g., yield of the crops, GHG and particulate emissions, energy and protein contents). This quantified information came from multiple sources of data: farmers' interviews, databases, crop modelling and expert knowledge (Delmotte *et al.*, 2016).

Agricultural activities are used as the building blocks of farming systems. The specificities of the different types of farming systems are represented as constraints on available land and on land use (e.g., livestock farmers need to cultivate a minimum acreage of forage crops). We used the typology presented in Delmotte *et al.* (2016) as a reference for current conditions and added specific constraints for each scenario and adaptation strategy as detailed in the following section.

After the identification of an optimal combination of agricultural activities, indicators are computed by multiplying the surface area of each agricultural activity by their relevant inputs and outputs. The aggregation of the farm scale to a regional scale is based on the area of each farm type at the regional level. Model outputs are therefore indicator values at the farm and regional scale (Table 2). Compared to the model used in Delmotte *et al.* (2016), new indicators were introduced (see Appendix 2 for details). First, indicators related to GHG emissions as well as energy consumption and particulate emissions (PM10) were included. Then, indicators related to the nutritional potential of the crop production in terms of energy (calories) and protein content (in % of mass) were added for the integrated assessment of agricultural systems, in order to represent the objective of food security. Finally, based on both the nutritional potential and the energy consumption, we computed an indicator of energy efficiency, defined as the ratio of the nutritional potential in terms of energy production over the total energy consumption. For the purpose of this paper, only indicators at the regional level are presented.

2.3.2 Parametrization of the bio-economic model for each scenario

For each scenario, we defined a specific set of values for the parameters of the BEM. These parameters are related to the content of each scenario, and the information to set their values was obtained all along the study, through the interactions with the stakeholders (see appendix 1 for details). As introduced in section 2.2, the main drivers of the scenarios were economic conditions for rice production, and climate change. The first driver prompted the implementation of different levels and types of subsidies in the model, according to the perceptions of stakeholders. It also led to different price levels for crops, including differences between conventional and organic productions, as well as changes in the price of inputs such as water and energy (Table 3). Climate change was implemented in the model through three different modalities: (1) changes in availability of land for agricultural production, because climate change is expected to increase the evapotranspiration and therefore the salt concentration in soil composition, making cultivation of non-irrigated crops in lowland soils difficult or impossible; (2) constraints on crops, notably the need for more frequent rice cultivation in the crop rotation cycle in order to limit the salt concentration in soils that remain viable for cultivation (thus requiring larger quantities of irrigation water) in scenario C and D; and finally (3) the direct impact of climate change on crop yield (in scenario D only since these consequences were considered too uncertain) for which rough hypotheses were made (see Table 3).

The other drivers were incorporated in the model according to their relevance to (1) the maximizing or minimizing of the various objectives, in the scenarios, and (2) the constraints on environmental indicators, such as pesticide use in scenario B, nitrogen application in scenario C and D, and the burning of rice straw in scenario C. The rate of conversion to OF also had to be specified, as in most cases activities in OF are more profitable than in conventional systems, leading the model to select only these activities.

The model was also parameterized to generate a reference scenario (Figure 3 and appendix 3) that was used for comparison with the future scenarios. This reference scenario reproduced an approximation of land use in 2014 (based on local land use maps created by the Regional Nature Park), and the subsidy and price conditions found in the same year (obtained from interviews with farmers and grain millers). This reference scenario and its assessment in term of indicators were discussed and confirmed with the local stakeholders during the fourth meeting.

3. Results of the integrated assessment of the scenarios

3.1 Impact of the scenarios on land uses

The four scenarios led first to different acreage of farmland cultivated at the regional scale, due to either the cultivation of abandoned lands in scenario B (33,000 ha, due to farmers willingness to increase the cultivated area), or on the contrary the abandonment of lands in scenarios A (31,300 ha, mostly due to unfavourable conditions for crop cultivation) and C (28,000 ha, land abandonment being due to climate change effects on salt concentration in soil of lowlands) (see table 3). They also led to different land uses at the regional level. In particular, the surface area of rice cultivation varied from approximately 6,000 ha (in scenario A, the worst in terms of economic conditions for rice) to 23,000 ha (in scenario D, the most economically favourable for rice cultivation), thus ranging from a reduction of 66% to an increase of 31% when compared to the surface are of rice cultivation in the reference scenario (17,770 ha). As in scenarios A and C, the surface area of rice cultivation in the Camargue would be reduced if the economic conditions were not suitable for the crop (i.e., low prices and low level of policy support). In scenario A, with CAP subsidies redirected to livestock, cropping systems in the Camargue would primarily evolve towards the cultivation of forages, and notably alfalfa, to feed the animals. The stakeholders felt that under these conditions, forage, and particularly alfalfa, would become the main crop in the Camargue. It would lead to 68% of the arable land in the region being cultivated in alfalfa, and only 19% in rice (Figure 3). In scenario C, farmers adapt their practices to climate change and to a drop of the rice prices. Two possible pathways of adaptation were suggested depending on the type of farm: conversion to organic farming or intensification of conventional production (see table 3). In conventional farming systems, rice would remain the main crop, but it would be cultivated in rotation with durum wheat and soya (also in intercropping systems) as well as with maize. This scenario suggests that the cultivation rice would fall to 31% of arable land (figure 3 – scenario C), which represents a strong reduction when compared to the reference scenario (52%, see figure 3 – reference). However, in both scenarios (A and C), the local stakeholders never considered the possibility of a total disappearance of the rice crop, because of its role in desalinating the soil through the irrigation system.

By contrast, in scenarios B (low climate change impacts) and D (high climate change impacts), which are both economically favourable to rice production, rice cultivation represents a large area (45% of arable land in scenario B and 75% in scenario D, figure 3). Scenario B would, however, lead to the introduction of leguminous crops in rotation with the main cereals while the remaining land primarily allocated to alfalfa (15% of the region's farmland) and soya (15% of the region's farmland) (Figure 3 – scenario B). Durum wheat would be cultivated under both conventional (5% of the arable area) and organic (7% of the arable area) systems, but also intercropped with soya and alfalfa (4% and 6% of the arable land, respectively). In scenario D, the increase of subsidies for rice and the increase of rice yield due to climate change, lead to rice being the main crop in the region. This implies that salt concentration in the soil would remain low and allow the cultivation of dry crops in most area soils. The crops cultivated in rotation to rice would be sunflower (9% in conventional and 2% in organic), pea (10% of the arable land) and wheat intercropped with soya in OF (4%).

The four scenarios also projected different amounts of surface areas cultivated with organic farming methods, ranging from 2,500 ha in scenario D to 12,300 ha in scenario C. Although a larger percentage of surface area under organic farming would improve environmental performances, it would decrease the area dedicated to rice cultivation, because the delay between two successive crops is longer under organic systems than under conventional systems, due to increased pressure from weeds (Delmotte *et al.*, 2011; Mailly *et al.*, 2013). Scenario C would be the most favourable to organic production, since one of the adaptation strategies was to convert to OF. That strategy led to a future with more than 40% of the region's farmland being cultivated under organic standards. In all scenarios, the OF systems would be based on rotations, primarily with rice, durum wheat and alfalfa, and possibly other crops in smaller proportions (see for example Figure 3 – scenario C).

3.2 Consequences of the scenarios on socio-economic indicators

As a consequence of the changes in economic conditions and land use in the four scenarios, the socio-economic indicators changed markedly in comparison with the reference (Figure 4). At the farm level, the average gross margin increases in scenario A and B. It shows a slight decrease in scenario C and a large decrease in scenario D. The increase in scenario A was due to the high profitability of alfalfa in a situation that would be realistic should a market for alfalfa develop. In scenario B, the gross margin would increase primarily as a result of high prices for rice. In scenario C, the decrease in the average gross margin of the farms comes mostly from reduced subsidies but also from a decrease in the market price of rice. Since the prices of organic products in this scenario are only 20% greater than those of conventional ones (Table 3), they would be unlikely to compensate for the losses in yield (previously mentioned) occurring in a conversion to OF. In scenario D, the gross margin would drop due to fewer subsidies and to the increase of production costs (e.g., water and energy costs). In the four scenarios, the amount of subsidies available would decrease, from -25% in scenario D to more than -50% in scenario C (Table 3). As a consequence, the dependency on subsidies would decrease in all scenarios but D (In scenario D, the dependency to subsidies increase as the share of revenue coming from the sale of the crop compared to the subsidies is lower in proportion), and suggest an increase in farm financial autonomy. The cost benefit ratio, an indicator of the dependency on external inputs, followed the same trend as the gross margin. For example, in scenarios B and C, the cost benefit ratio would increase with the introduction of leguminous crops, the diversification of the rotations and the conversion to organic farming, requiring fewer inputs.

At the regional level, none of the scenarios would lead to a reduction of the total value of production, which is an indicator of the economic well-being of the value chain. This indicator remained stable in scenario C and increased approximately 50% in scenario A and B due to the increased price of crops, and also in scenario D, from the increase in cultivated surface area. The employment generated by agriculture would generally vary less than the other indicators. In scenario A, it would remain stable, as the cultivation of alfalfa is as labour intensive as rice. In scenario B and C, it would slightly decrease as a consequence of the adoption of cropping systems with lower demand in terms of labour when compared to rice.

However, in scenario D, as rice cultivation increases, the employment would increase by 11%. Finally, indicators related to food production, both in terms of calories and proteins, would greatly change between the scenarios. In scenario A and B, even if the total volume of production would remain quite stable, these indicators would drop due to the fact that the leguminous crops cultivated would be directed towards animal feed, which is less efficient in terms of food production than cultivation for direct human consumption. In scenario C, the same trend could be observed due to the lower yield of OF production impacting the total volume of production, and leading to fewer crops to store and manipulate in the supply chain. Scenario D is the only scenario where the potential food production would increase as well as the total volume of production, due to the high yield of rice relative to the other crops.

3.3 Environmental indicators

Environmental indicators were also affected by the changes of cropping systems (figure 5). In the case of scenarios A, B and C, there would generally be fewer environmental impacts, but in the case of scenario D, the impacts would be higher than those in the reference situation. In scenarios A and C, water consumption would be strongly reduced as a result of the decrease in rice cultivation, which is the only irrigated cultivation in the Camargue. This reduction of water consumption would also lead to important savings in terms of energy consumption from water pumping. In scenario A, the other inputs would be considerably reduced, particularly fertilizers (mineral nitrogen) and pesticides, which were both reduced by almost 75%. The use of these two inputs would also be reduced by 50% in scenario B, and by 60% for mineral nitrogen and 25% for pesticide use in scenario C. These reductions of inputs were attributable to the diversification in crop rotation and particularly to the introduction of leguminous crops. The energy consumption would also decrease in these three scenarios, from 30% in scenario C to more than 50% in scenario A, due to the decrease of the energy consumption for water pumping and nitrogen fertilizer synthesis. However, in these three scenarios the energy efficiency evolves negatively, and would decrease from 10% to 15% as compared to the reference scenario because the potential of food production in term of energy (calories) would decrease more than the energy consumption. Finally, the atmospheric emissions of the cropping systems would be lower in these three scenarios (A, B and C) as compared to the reference situation, both in terms of GHG and particulate matter emissions. This is mostly due to the lower use of inputs, but also to the reduction of flooded rice fields, which are associated with high levels of GHG emissions through the burning of the straw in scenarios A and C. In scenario C, the GHG and particulate matter emissions would be reduced by about 75% and 85%, respectively, as compared to the reference situation, suggesting that there is a large room to manoeuvre the reduction of these environmental impacts. Finally, the scenario D was the only one that would imply greater impacts on the environment from agricultural production. Due to the increase in surface area of rice cultivation, the water consumption would increase (approximately 35%), as would the pesticide use (+30%) and the energy consumption (+14%). The mineral nitrogen use would be reduced by 12%, mostly due to the lower consumption of nitrogen fertilizers by rice as compared to other cereals (particularly durum wheat). The energy efficiency would increase, because the increase in energy content of the production would be greater than the increase in energy consumption. However, as a consequence of the increase in rice cultivation, the GHG and particulate matter emissions would increase 32% and 39%, respectively.

3.4 Synthesis

The two scenarios that assume a low impact from climate change (scenarios A and B) lead to different adaptations in land use, but presented similar assessment profiles. They both suggested favourable economic and environmental situations, but with lower food production potential (in terms of proteins and calories). The two scenarios that assume a high impact from climate change (scenarios C and D) presented a strong contrast to scenarios A and B. The scenario with high climate change impact and unfavourable economic conditions for rice production (scenario C) favoured the environmental aspect at the expense of economic aspect and food production potential. The scenario D with high climate change impact and favourable economic conditions for rice production was the only scenario leading to an increase of the regional potential for food production, however, at the expense of environmental and economic aspects when compared to the reference and the three other scenarios. Finally, none of the scenarios led to the improvement of all indicators, suggesting the necessity of trade-offs between the different aspects of sustainability, as highlighted in previous integrated assessments of agricultural scenarios (e.g., Gutzler *et al.*, 2015 ; Reidsma *et al.*, 2015).

4. Discussion

We will focus the discussion on two main aspects: (1) the strong and weak points of our approach as seen by the local stakeholders and (2) the use of bio-economic models for the integrated assessment of narrative scenarios.

4.1. Stakeholders' assessment of the method and results

During the last workshop, the stakeholders provided feedback about the approach and results of this study. They expressed that the four narrative scenarios were sufficiently contrasted to highlight a range of possible strategies for adapting to various future contexts. The scenarios were also seen as realistic representations of the possible evolutions in the Camargue's agricultural systems. The analyses of scenarios led to further discussions about possible adaptation strategies that the stakeholders considered logical at both farm and regional levels.

The stakeholders raised two main concerns with regards to the indicators used in assessing the scenarios. Firstly, the indicators calculated to assess consequences on the economic welfare of the agricultural sector, and particularly for the rice supply-chain, were simple proxies (e.g., the total value of production and the total volume of production). But the economic performance of a sector may not be linearly linked to the field or farm-based outputs, therefore more complex analyses of the impacts on the supply chain in each scenario could be beneficial. Secondly, although the indicators related to the potential for food production were seen as positively highlighting the contribution of regional agriculture to global issues of food security, they lacked attention to the qualitative aspect of human food systems (i.e., food safety). Indeed, food safety in Europe is likely to be affected by climate change, suggesting the need for more inclusive approaches, from the farm to the table, in which the different aspects of food quality are taken into account (Miraglia *et al.*, 2009).

The stakeholders particularly emphasized two positive aspects of the methods used in this study. The first one is related to the relevance of the scenario development method itself. Collectively developed scenarios was seen as an effective way to support the contemplation and sharing of perspectives among stakeholders, considering what *could* happen, rather than what *will* happen. Local stakeholders therefore acknowledged the explorative nature of the methods and results of this study. The second aspect concerned the use of the quantitative results to anticipate future changes of context in order to better adapt. They mentioned the possibility of using these results in negotiations about public subsidies at the national level. This was particularly the case with "Subsidizing local constraints" in scenario D, where stakeholders explored the consequences of the Camargue being classified as a *less favoured area* leading to subsidies equal to the payment they received for rice before the 2012 CAP reform. This scenario led to higher rice production, which could contribute to food security, but at the expense of the farms' gross margins. One of the local stakeholders was considering using these results to highlight the "absolute need" of both re-establishing a specific subsidy for rice (he considered elimination of the previous subsidy to be a "wrong decision made by the French government"), and obtaining new subsidies related to the specific (salt) constraints in the Camargue.

Scenario development and evaluation has often been used to inform decision-making in the development of public policies and objectives (normative scenarios, Wilkinson and Eidinow,

2008) or to explore the impact of policy choices (e.g., Therond *et al.*, 2009). Such studies, however, are usually performed in a top-down approach where governmental actors, either at the local or the national levels, examine the consequences of policy options previously developed (e.g., Therond *et al.*, 2009 ; Gutzler *et al.*, 2015). One of the strong points identified by the stakeholders in the development and application of the methods presented here was the bottom-up approach for scenario development. They felt that this approach gave them a clear view and understanding of the content and scope of the scenarios, and helped them imagine the potential use of these scenarios in their future decision-making and negotiating. This approach could be further completed by backcasting exercises consisting in fixing first the situation the stakeholders want to reach in the future ("desirable future") and then the necessary steps (i.e., changes) to attain such future (Holmberg and Robèrt, 2000).

In this study, we chose to work with a relatively small group of stakeholders that was already known from past studies in this area (Delmotte *et al.*, 2016). We chose to put the emphasis on building a small group of people to ensure that the group would remain stable all over the process, in order to promote a more systemic view (Petersen et al., 2004). Our choice also helped to run the process in a continuous manner in a relatively short period of time. We nevertheless consider that the stakeholders who participated were representative of the diversity of the local farming community and of the issues of rural development (e.g., two participants were also farmers). Working with a larger group of stakeholders could have been beneficial to ensure that the whole diversity of point of views would be considered. However, it would probably have been more difficult to manage in terms of organizing the meeting and ensuring the group stability at each step of the process.

4.2. Model-based assessment advantages and limitations

The integrated assessment of the narrative scenarios in this study was conducted with a bio-economic model. Bio-economic models have been widely used in agricultural sciences to assess scenarios and support decision-making (see Janssen and van Ittersum (2007); Delmotte *et al.*(2013)). The usefulness of bio-economic models for such studies is based primarily on their capacity to account for the variability in performance (e.g., yield) with respect to area and time period (e.g., soils characteristics of an area, and climate during a time period) (Flichman, 2002).

Their use, however, is governed and limited by currently available data. In our study, the alternative agricultural activities relied strictly on known practices and the available data on inputs and outputs (e.g., organic production techniques, intercropping systems). Other innovations were not included in the bio-economic model due to the lack of available data on their performance (e.g., cultivation of new crops like sweet potato or lettuce). Similarly, our bio-economic model did not explicitly include the livestock rearing activities. Livestock requirements in forage were translated into model objectives or constraints, in order to account for the influence of these activities on the surface area devoted to local cultivation. This implicit representation did not, however, allow the representation of an evolution in livestock activities in the indicators even though they are a central element in scenario A. Although crop and livestock activities are not tightly interlinked in Camargue, further work is needed to formalize the performance of livestock activities and include them in the bio-economic model to enable the exploration of future scenarios that include related adaptation strategies.

We used multiple goal linear programing in our bio-economic model to develop an optimal solution for each scenario. The resulting land uses and performances were determined by choosing the objective function (to be minimized or maximized) depending on the narratives built by the stakeholders. Different functions were used for each scenario, including the maximization of gross margin, forage production, or food production, and the minimization of greenhouse gas emissions. This innovative approach was driven by the intensive participation of stakeholders in the study, notably for the translation of the scenarios in the model (Mallampalli *et al.*, 2016). In most studies using bio-economic modelling for agriculture, the objectives are linked to the maximization of farm profitability (e.g., van Calker *et al.*, 2004; Gutzler *et al.*, 2015), or to a compromise between profitability and another performance (e.g., minimizing a negative environmental output) through multi-objective linear programming (e.g., Groot *et al.*, 2012).

Linear programming models are often accused of being a “black-box” for stakeholders, making direct interactions with stakeholders difficult (Sterk *et al.*, 2007). This issue was not emphasized by the stakeholders in our study, which on the contrary acknowledge the usefulness of the approach to stimulate a shared vision of the future. This may be due to (1) the initial legitimacy of the research team, and its history of long-term research in the Camargue (as highlighted in e.g., Sterk *et al.*, (2006)), (2) previous experience with the bio-economic model among most of the stakeholders who participated in this study (Delmotte *et al.*, 2016) and (3) the time taken with stakeholders to contextualize the results in terms of indicators, farm types, etc. (e.g., Blazy *et al.*, 2009). Their participation into the translation of the narrative scenarios to the quantitative assessment was probably key to ensure their understanding (Mallampalli *et al.*, 2016). Working with a group of stakeholders without experience with bio-economic modeling would have required either a more participatory development of the model, as proposed in Delmotte *et al.* (2016), either specific meetings for reaching a consensus on model functioning (as proposed by Hossard et al. (2013) for simulation models).

Finally, hypotheses on the impact of climate change on performance (e.g., yield) were made with knowledge and reasoning of the involved stakeholders and researchers. Rice yields were expected to increase and durum wheat yields were expected to decrease. The rice yield increase was linked to the longer crop season (due to the rise in temperature), which was expected to enhance biomass accumulation since lower temperatures are considered a limiting factor for rice production in the Camargue, especially during sowing (Delmotte *et al.*, 2011). This hypothesis is in line with current local knowledge, but may not be consistent with knowledge about climate change impacts on rice yields at other latitudes. For instance, in the Philippines, Peng *et al.* (2004) found a 10% decline in rice yield when the growing-season's minimum temperature increased by 1^{o} C. For durum wheat, the most important climate variables in the Mediterranean basin are related to drought and temperature extremes (Nachit and Elouafi, 2004). Climate change is thus expected to decrease the yields of durum wheat (Ferrise *et al.*, 2011), depending on the range of temperature increase (Ventrella *et al.*, 2012). Some studies (e.g., Ventrella *et al.*, 2012) have suggested that the negative impact of climate change could be decreased or counterbalanced by changes in crop management, such as irrigation or nitrogen fertilization strategies, and innovations in cultivar characteristics, such as drought resistance (Habash *et al.*, 2009). Given these insights, our analysis could be updated using simulations with crop models, in order to better assess the effects of climate change on performances of different crops. Broadening the type of performances analysed could also help by including other indicators such as grain quality. For example, durum wheat quality varies with climate (Dalla Marta *et al.*, 2010). We could also decrease uncertainty by adding variability to performances such as the work on yield variability with climate by Olesen and Bindi, (2002).

5. Conclusion

Linking changes at the regional and global levels in studies focusing on the future of agricultural systems currently remains challenging, especially when including climate change issues. In this paper, we used narrative scenarios as a method to explicitly link local and global changes, and the integrated assessment of scenarios as a way to foresee their consequences at the farm and regional levels. We developed scenarios with local stakeholders in the Camargue region of southern France. The scenario narratives designed by local stakeholders were then translated in inputs for a bio-economic model, allowing the integrated assessment of the consequences of these scenarios on agricultural systems. The two main drivers of change of the scenarios were related to climate change and economic conditions for rice production. At the regional level, the four scenarios showed significant differences in the acreage of farmland cultivated (28,000-33,000 ha), the proportion of area under rice (19-75%) and the areas cultivated under organic farming (8-43%). These changes implied large contrasts between the scenarios assessed on the basis of 16 socio-economic and environmental indicators. The four scenarios showed trade-offs between these indicators. The method used and the information generated were found relevant by the stakeholders, who acknowledged the interest of the approach for anticipating possible futures, and assisting on-going and future negotiations with policy-makers.

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7. References

Abildtrup, J., Audsley, E., Fekete-Farkas, M., Giupponi, C., Gylling, M., Rosato, P., Rounsevell, M., 2006. Socio-economic scenario development for the assessment of climate change impacts on agricultural land use: a pairwise comparison approach. Environmental Science & Policy 9, 101-115.

Alcamo, J., 2001. Scenarios as tools for international environmental assessment. European Environment Agency, p. 31p.

Alcamo, J., Henrichs, T., 2008. Toward guidelines for environmental scenario analysis, in: Alcamo, J. (ed.), Environmental Futures. The Practice of Environmental Scenario Analysis. Elsevier, Amsterdam, The Netherlands, pp. 13-35.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Aviles-Vazquez, K., Samulon, A., Perfecto, I., 2007. Organic agriculture and the global food supply. Renewable Agriculture and Food Systems 22, 86-108.

Bell, M.J., Cloy, J.M., Rees, R.M., 2014. The true extent of agriculture's contribution to national greenhouse gas emissions. Environmental Science & Policy 39, 1-12.

Berg, A., de Noblet-Ducoudré, N., Sultan, B., Lengaigne, M., Guimberteau, M., 2013. Projections of climate change impacts on potential C4 crop productivity over tropical regions. Agricultural and Forest Meteorology 170, 89-102.

Bezlepkina, I., Reidsma, P., Sieber, S., Helming, K., 2011. Integrated assessment of sustainability of agricultural systems and land use: Methods, tools and applications. Agricultural Systems 104, 105-109.

Blazy, J.M., Dorel, M., Salmon, F., Ozier-Lafontaine, H., Wery, J., Tixier, P., 2009. Model-based assessment of technological innovation in banana cropping systems contextualized by farm types in Guadeloupe. European Journal of Agronomy 31, 10-19.

Bohensky, E.L., Reyers, B., Van Jaarsveld, A.S., 2006. Future ecosystem services in a Southern African river basin: a scenario planning approach to uncertainty. Conservation Biology 20, 1051-1061.

Castoldi, N., Bechini, L., 2010. Integrated sustainability assessment of cropping systems with agro-ecological and economic indicators in northern Italy. European Journal of Agronomy 32, 59-72.

Comoretto, L., Arfib, B., Talva, R., Chauvelon, P., Pichaud, M., Chiron, S., Höhener, P., 2008. Runoff of pesticides from rice fields in the Ile de Camargue (Rhône river delta, France): Field study and modeling. Environmental Pollution 151, 486-493.

Dalla Marta, A., Grifoni, D., Mancini, M., Zipoli, G., Orlandini, S., 2011. The influence of climate on durum wheat quality in Tuscany, Central Italy. International Journal of Biometeorology 55, 87-96.

de Ponti, T., Rijk, B., van Ittersum, M.K., 2012. The crop yield gap between organic and conventional agriculture. Agricultural Systems 108, 1-9.

Delmotte, S., Barbier, J.-M., Mouret, J.-C., Le Page, C., Wery, J., Chauvelon, P., Sandoz, A., Lopez Ridaura, S., 2016. Participatory integrated assessment of scenarios for organic farming at different scales in Camargue, France. Agricultural Systems 143, 147-158.

Delmotte, S., Lopez-Ridaura, S., Barbier, J.-M., Wery, J., 2013. Prospective and participatory integrated assessment of agricultural systems from farm to regional scales: Comparison of three modeling approaches. Journal of Environmental Management 129, 493-502.

Delmotte, S., Tittonell, P., Mouret, J.C., Hammond, R., Lopez-Ridaura, S., 2011. On farm assessment of rice yield variability and productivity gaps between organic and conventional cropping systems under Mediterranean climate. European Journal of Agronomy 35, 223-236.

Donatelli, M., Srivastava, A.K., Duveiller, G., Niemeyer, S., Fumagalli, D., 2015. Climate change impact and potential adaptation strategies under alternate realizations of climate scenarios for three major crops in Europe. Environmental Research Letters 10, 075005.

Ebi, K.L., Hallegatte, S., Kram, T., Arnell, N.W., Carter, T.R., Edmonds, J., Kriegler, E., Mathur, R., O'Neill, B.C., Riahi, K., Winkler, H., Van Vuuren, D.P., Zwickel, T., 2014. A new scenario framework for climate change research: background, process, and future directions. Climatic Change 122, 363-372.

European Commision. 2009. Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides. Official Journal of the European Union, 24.11.2009. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:309:0071:0086:en:PDF (Accessed, January 2016)

European Commision. 2013. Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy. Official Journal of the European Union, L226/1. 2013. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:226:0001:0017:EN:PDF (Accessed, January 2016)

Ferrise, R., Moriondo, M., Bindi, M., 2011. Probabilistic assessments of climate change impacts on durum wheat in the Mediterranean region. Natural Hazards and Earth System Sciences 11, 1293-1302.

Flichman, G., 2002. Building Agro-Environmental Indicators by the Integration of Biophysical and Economic Models for Assessing Sustainability of Agricultural Trade Liberalisation., Paper presented at the Workshop Methodological Tools for Assessing the Sustainability Impact of EU's Economic Policies, with applications to Trade Liberalisation Policies, Brussels 7-8 November 2002. Organised by CEPII - European Commission, November 2002.

Folhes, R.T., de Aguiar, A.P.D., Stoll, E., Dalla-Nora, E.L., Araujo, R., Coelho, A., do Canto, O., 2015. Multi-scale participatory scenario methods and territorial planning in the Brazilian Amazon. Futures 73, 86-99.

Groot, J.C.J., Oomen, G.J.M., Rossing, W.A.H., 2012. Multi-objective optimization and design of farming systems. Agricultural Systems 110, 63-77.

Gutzler, C., Helming, K., Balla, D., Dannowski, R., Deumlich, D., Glemnitz, M., Knierim, A., Mirschel, W., Nendel, C., Paul, C., Sieber, S., Stachow, U., Starick, A., Wieland, R., Wurbs, A., Zander, P., 2015. Agricultural land use changes - a scenario-based sustainability impact assessment for Brandenburg, Germany. Ecological Indicators 48, 505-517.

Habash, D.Z., Kehel, Z., Nachit, M., 2010. Genomic approaches for designing durum wheat ready for climate change with a focus on drought(vol 60, pg 2805, 2009). Journal of Experimental Botany 61, 1249-1249.

Hengsdijk, H., van Ittersum, M.K., 2003. Formalizing agro-ecological engineering for future-oriented land use studies. European Journal of Agronomy 19, 549-562.

Heurteaux, P., 1994. Essai de quantification des termes du bilan hydrique des étangs du système Vaccarès (Camargue, France). Ann. Limnol. - Int. J. Lim. 30, 131-144

Holmberg, J., Robèrt, K.H., 2000. Backcasting from non-overlapping sustainability principles: a framework for strategic planning. International Journal of Sustainable Development and World Ecology 74, 291-308.

Hossard, L., Jeuffroy, M.H., Pelzer, E., Pinochet, X., Souchere, V., 2013. Participatory approach to design spatial scenarios of cropping systems and assess their effects on phoma stem canker management at a regional scale. Environmental Modelling & Software 48, 17-26.

Hossard, L., Philibert, A., Bertrand, M., Colnenne-David, C., Debaeke, P., Munier-Jolain, N., Jeuffroy, M.H., Richard, G., Makowski, D., 2014. Effects of halving pesticide use on wheat production. Scientific Reports 4, 4405.

Hossard, L., Archer, D. W., Bertrand, M., Colnenne-David, C., Debaeke, P., Ernfors, M., Jeuffroy, M.H., Munier-Jolain, N., Nilsson, C., Sanford, G.R., Snapp, S.S., Jensen, E.S., Makowski, D., 2016. A meta-analysis of maize and wheat yields in low-input vs. conventional and organic systems. Agronomy Journal, 108(3), 1-13.

International Assessment of Agricultural Knowledge. 2009. Agriculture at a crossroads, synthesis report (Island Press). IAASTD.

http://www.unep.org/dewa/agassessment/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Synthesis%20Report%20%28English%29.pdf (accessed 16 Apr. 2016).

Janssen, S., van Ittersum, M.K., 2007. Assessing farm innovations and responses to policies: A review of bio-economic farm models. Agricultural Systems 94, 622-636

Jouzel, J., Ouzeau, G., Déqué, M., Jouini, M., Planton, S., Vautard, R., 2014. Le climat de la France au XXIe siècle. Volume 4. Scénarios régionalisés : édition 2014 pour la métropole et les régions d'outre-mer., Direction générale de l'Energie et du Climat, Ministère de l'Ecologie, du Développement durable et de l'Energie, p. 64p.

Kok, K., Patel, M., Rothman, D.S., Quaranta, G., 2006. Multi-scale narratives from an IA perspective: Part II. Participatory local scenario development. Futures 38, 285-311.

Kok, K., Biggs, R., Zurek, M., 2007. Methods for developing multiscale participatory scenarios: insights from southern Africa and Europe. Ecology and Society 12, 8.

Linquist, B., van Groenigen, K.J., Adviento-Borbe, M.A., Pittelkow, C., van Kessel, C., 2012. An agronomic assessment of greenhouse gas emissions from major cereal crops. Global Change Biology 18, 194-209.

Lopez Ridaura, S., Delmotte, S., Le Page, C., Le Quéré, L., Goulevant, G., Chauvelon, P., Sandoz, A., Mouret, J.-C., 2014. Multi-critera and multi-scales evaluation of different organic farming extension scenario. In: Bellon, S., Penvern, S. (Eds.), Organic Farming, prototype for sustainable agricultures, Dordrecht, NLD : Springer. , pp. 453-478.

Loyce, C., Meynard, J.M., Bouchard, C., Rolland, B., Lonnet, P., Bataillon, P., Bernicot, M.H., Bonnefoy, M., Charrier, X., Debote, B., Demarquet, T., Duperrier, B., Felix, I., Heddadj, D., Leblanc, O., Leleu, M., Mangin, P., Meausoone, M., Doussinault, G., 2012. Growing winter wheat cultivars under different management intensities in France: A multicriteria assessment based on economic, energetic and environmental indicators. Field Crops Research 125, 167-178.

Mailly, F., Delmotte, S., Schaller, N., Mouret, J.C., Ridaura, S., Barbier, J.M., 2013. Un modèle de décision d'assolement en riziculture conventionnelle et biologique pour prédire les usages des sols sous différents scénarios : cas de la Camargue (Sud de la France). Cahier Agriculture 22, 424-431.

Mallampalli, V.R., Mavrommati, G., Thompson, J., Duveneck, M., Meyer, S., Ligmann-Zielinska, A., Druschke, C.G., Hychka, K., Kenney, M.A., Kok, K., Borsuk, M.E., 2016. Methods for translating narrative scenarios into quantitative assessments of land use change. Environmental Modelling & Software 82, 7-20.

Maracchi, G., Sirotenko, O., Bindi, M., 2005. Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Climatic Change 70, 117-135.

Matson, P.A., Parton, W.J., Power, A.G., Swift, M.J., 1997. Agricultural intensification and ecosystem properties. Science 277, 504-509.

Miraglia, M., Marvin, H.J.P., Kleter, G.A., Battilani, P., Brera, C., Coni, E., Cubadda, F., Croci, L., De Santis, B., Dekkers, S., Filippi, L., Hutjes, R.W.A., Noordam, M.Y., Pisante, M., Piva, G., Prandini, A., Toti, L., van den Born, G.J., Vespermann, A., 2009. Climate change and food safety: An emerging issue with special focus on Europe. Food and Chemical Toxicology 47, 1009-1021.

Mouret, J.-C., Hammond, R., Dreyfus, F., Desclaux, D., Marnotte, P., Mesleard, F., 2004. An integrated study of the development of organic rice cultivation in the Camargue (France). In: Ferrero, A., Vidotto, F. (Eds.), Challenges and Opportunities for Sustainable Rice-Based production systems. Edizioni Mercurio, Torino, Italy, 13-15 September. 13p.

Nachit, M.M., Elouafi, I. ,2004. Durum wheat adaptation in the Mediterranean dryland: Breeding, stress physiology, and molecular markers. Challenges and Strategies of Dryland Agriculture, 203-218.

Olesen, J.E., Bindi, M., 2002. Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy 16, 239-262.

Olesen, J.E., Carter, T.R., Diaz-Ambrona, C.H., Fronzek, S., Heidmann, T., Hickler, T., Holt, T., Minguez, M.I., Morales, P., Palutikof, J.P., Quemada, M., Ruiz-Ramos, M., Rubaek, G.H., Sau, F., Smith, B., Sykes, M.T., 2007. Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems based on scenarios from regional climate models. Climatic Change 81, 123-143.

Peng, S.B., Huang, J.L., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X.H., Centeno, G.S., Khush, G.S., Cassman, K.G., 2004. Rice yields decline with higher night temperature from global warming. Proceedings of the National Academy of Sciences of the United States of America 101, 9971-9975.

Peterson, G. D., T. D. Beard Jr., B. E. Beisner, E. M. Bennett, S. R. Carpenter, G. S. Cumming, C. L. Dent, and T. D. Havlicek. 2003. Assessing future ecosystem services: a case study of the Northern Highlands Lake District, Wisconsin. Conservation Ecology 7(3): 1. [online] URL: http://www.consecol.org/vol7/iss3/art1/

Peterson, T.R., Kenimer, A., Grant, W.E., 2004. Using mediated modeling to facilitate collaborative learning among residents of the San Antonio Watershed, Texas, U.S.A. In:

van den Belt, M. (Ed.), Mediated Modeling: a System Dynamics Approach to Environmental Consensus Building. Island Press, Washington D.C., U.S.A., pp. 136-163.

Plieninger, T., Bieling, C., Ohnesorge, B., Schaich, H., Schleyer, C., Wolff, F., 2013. Exploring Futures of Ecosystem Services in Cultural Landscapes through Participatory Scenario Development in the Swabian Alb, Germany. Ecology and Society 18.

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C., 2015. Diversification practices reduce organic to conventional yield gap. Proceedings of the Royal Society B-Biological Sciences 282.

Rasmussen, L.B., 2005. The narrative aspect of scenario building - How story telling may give people a memory of the future. AI & SOCIETY 19, 229-249.

Reed, M.S., Kenter, J., Bonn, A., Broad, K., Burt, T.P., Fazey, I.R., Fraser, E.D.G., Hubacek, K., Nainggolan, D., Quinn, C.H., Stringer, L.C., Ravera, F., 2013. Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK uplands. Journal of Environmental Management 128, 345-362.

Reidsma, P., Wolf, J., Kanellopoulos, A., Schaap, B.F., Mandryk, M., Verhagen, J., van Ittersum, M.K., 2015. Climate change impact and adaptation research requires integrated assessment and farming systems analysis: a case study in the Netherlands. Environmental Research Letters 10, 045004.

Rosenzweig, C., Jones, J.W., Hatfield, J.L., Ruane, A.C., Boote, K.J., Thorburn, P., Antle, J.M., Nelson, G.C., Porter, C., Janssen, S., Asseng, S., Basso, B., Ewert, F., Wallach, D., Baigorria, G., Winter, J.M., 2013. The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. Agricultural and Forest Meteorology 170, 166-182.

Seufert, V., Ramankutty, N., Foley, J.A., 2012. Comparing the yields of organic and conventional agriculture. Nature 485, 229-U113.

Sleeter, B.M., Sohl, T.L., Bouchard, M.A., Reker, R.R., Soulard, C.E., Acevedo, W., Griffith, G.E., Sleeter, R.R., Auch, R.F., Sayler, K.L., Prisley, S., Zhu, Z., 2012. Scenarios of land use and land cover change in the conterminous United States: Utilizing the special report on emission scenarios at ecoregional scales. Global Environmental Change 22, 896-914.

Smith, P., 2012. Agricultural greenhouse gas mitigation potential globally, in Europe and in the UK: what have we learnt in the last 20 years? Global Change Biology 18, 35-43.

Sterk, B., van Ittersum, M.K., Leeuwis, C., Rossing, W.A.H., van Keulen, H., van de Ven, G.W.J., 2006. Finding niches for whole-farm design models - contradictio in terminis? Agricultural Systems 87, 211-228.
Sterk, B., van Ittersum, M.K., Leeuwis, C., Wijnands, F.G., 2007. Prototyping and farm system modelling--Partners on the road towards more sustainable farm systems? European Journal of Agronomy 26, 401-409.
Therond, O., Belhouchette, H., Janssen, S., Louhichi, K., Ewert, F., Bergez, J.E., Wery, J., Heckelei, T., Olsson, J.A., Leenhardt, D., Ittersum, M.v., 2009. Methodology to translate policy assessment problems into scenarios: the example of the SEAMLESS integrated framework. Environmental Science & Policy 12, 619-630.
van Calker, K.J., Berentsen, P.B.M., de Boer, I.M.J., Giesen, G.W.J., Huirne, R.B.M., 2004. An LP-model to analyse economic and ecological sustainability on Dutch dairy farms: model presentation and application for experimental farm "de Marke". Agricultural Systems 82, 139-160.
van 't Klooster, S.A., van Asselt, M.B.A., 2006. Practising the scenario-axes technique. Futures 38, 15-30.
van Ittersum, M.K., Ewert, F., Heckelei, T., Wery, J., Alkan Olsson, J., Andersen, E., Bezlepkina, I., Brouwer, F., Donatelli, M., Flichman, G., Olsson, L., Rizzoli, A.E., van der Wal, T., Wien, J.E., Wolf, J., 2008. Integrated assessment of agricultural systems - A component-based framework for the European Union (SEAMLESS). Agricultural Systems 96, 150-165.
Ventrella, D., Charfeddine, M., Moriondo, M., Rinaldi, M., Bindi, M., 2012. Agronomic adaptation strategies under climate change for winter durum wheat and tomato in southern Italy: irrigation and nitrogen fertilization. Regional Environmental Change 12, 407-419.
Wilkinson, A., Eidinow, E., 2008. Evolving practices in environmental scenarios: a new scenario typology. Environmental Research Letters 3.
Zurek, M.B., Henrichs, T., 2007. Linking scenarios across geographical scales in international environmental assessments. Technological Forecasting and Social Change 74, 1282-1295.

Table 1: Main drivers for scenario development, their level and degree of influence and final rank in importance for scenario development. Some drivers are ranked equally.

Domain	Driver	Level	Influence	Level of uncertainty	Ranking
Agronomic	New technical innovations such as no-till systems, direct seedling or organic farming systems	Local	High	Low	3
	New water management	Local	Medium	Low	2
Environmental	Climate change impacts on water availability, salt pressure and crop yield	Global	High	High	1
	Pressure of environmental concerns on agriculture (NGO's, social expectations)	Regional and national	Medium	Low	2
	Environmental regulations	National and European	Medium	Low	2
Economic	Public subsidies	National and European	High	High	1
	Price of commodities	European and global	High	High	1
	Price of energy and inputs	Global	Medium	High	2
	New supply-chain(s) for local/specific productions	Local and national	Medium	Medium	3
Social	Diversification through agro-tourism or pluri-activity	Local	Medium	Low	4
	Changes in diet	National to global	Medium	High	3
	Land ownership and farm transfer	Local	Medium	High	4
	Traceability and labeling of production	Local and national	Medium	Low	4

Table 2: Indicators calculated at the different levels (F: farm; R: Region) by the BEM to assess the scenarios. (see Delmotte et al. (2016) for details on computation methods)

Sustainability domain	Indicator	Level	Unit	Calculation method
Socio-economic	Production costs	F	€	Sum of production costs for each activity
	Production of each crop under organic and conventional management	F, R	ton	Yield multiplied by the area of each crop
	Total volume of production	R	ton	Sum of the production of each crop
	Gross margin	F	€	Yield multiplied by the price minus cost of production
	Amount of subsidies	F, R	millions €	Sum of subsidies of each activity
	Gross margin including subsidies	F	€	Gross margin plus amount of subsidies
	Average gross margin including subsidies	F	€.ha^{-1}	Gross margin including subsidies divided by the farm area
	Total value of production	F, R	millions €	Sum for each activity of the yield multiplied by the price
	Cost benefit ratio	F	-	Total value of production divided by costs of production
	Total labor	F	hours / year	Sum of labor for each activity
	Employment	R	full time equivalent	Sum of labor divided by 1683 (number of hours worked per year)
	Food production potential (in terms of energy (calories) and protein)	R	Kcal and g	Yield of each activity multiplied by the calorie content (or protein content)
Environmental	Water used for irrigation	F, R	m^3	Area in rice multiplied by 25000 (average volume per ha)
	Pesticides Treatment Frequency Index (TFI)	F, R	-	Average number of pesticide applications relative to recommended doses

	Energy consumption	R	MJ/ha	Sum of direct and indirect consumption
	Particulate emissions	R	kgPM10	Sum of the particulate emissions of each activity
	Mineral nitrogen consumption	R	kgN	Sum of the mineral nitrogen applied
	Green-house gas emissions	R	tCO2 eq	Sum of the greenhouse gas emissions
	Energy efficiency	R	-	Ratio of food production potential in term of calories over energy consumption

Table 3: Changes of parameters values in the model used to run simulations for the four scenarios.
The values used for the reference situation are presented in appendix 2.

	Scenario A	Scenario B	Scenario C	Scenario D
Objective function	Maximize forage production	Maximize gross margin	Minimize GHG emissions	Maximize food production (calories)
Subsidies	Direct payment subsidy, and agro-environmental measures: 100€/ha for organic farming, 100€/ha for intercropping with winter grazing	Direct payment subsidy, a specific payment for rice of 150€/ha, agro-environmental measures: 100€/ha for OF, 74€/ha for incorporating the rice straw, 66€/ha for the dry seedling of rice, 60€/ha for leguminous crops	Direct payment subsidy only	Direct payment subsidy, 150€/ha for handicaped zone, agro-environmental measures: 100€/ha for OF, 74€/ha for incorporating the rice straw, 66€/ha for the dry seedling of rice, 60€/ha for leguminous crops
Prices of production (compared to reference prices)	Rice: +15%, Durum wheat: +30%, Sorghum +5%, Maize and Sunflower: + 10%, Other: same.	Rice: +80%, Other similar to the reference.	Rice: -10%, Other similar to the reference.	Same as in the reference, see appendix A
Difference of prices between organic and conventional productions	60%	60%	20%	60%
Changes in prices of inputs	--	--	Increase in the price of water	Increase in the price of water. Increase in the price of energy
Change on land availability	Hydromorphic and salty soil not cultivated in OF livestock breeding farms	Abandoned land are cultivated: + 3.4% of regional area	Hydromorphic and salty soils not cultivated.	Similar to the reference.
Maximum area in organic farming	All livestock breeders are 100% organic, maximum of 20% for other farm types	Organic livestock breeders and organic crop producers are 100% organic, maximum of 20% for other farm types	OF livestock farmer and OF crop producers: 100%. Small crop producers: 100%. Livestock and large crop producers: 45%. Medium crop producer: 0%.	OF livestock breeders and OF crop producers are 100% organic, maximum of 20% for other farm types
Environmental constraints	--	Pesticide use divided by 2 compared to reference	Decrease nitrogen application by 20% compared to the reference - no straw burning for rice	Decrease nitrogen application by 20% compared to the reference.
Constraints on crops	Dry seedling rice is maximum 33% of rice area. No maize cultivation.	Maximum of 15% of area of alfalfa at the regional level. Dry seedling rice is maximum 33% of rice total area. Durum wheat and soya as intercrop is maximum of 33% of durum wheat total area.	Shorter crop return time of rice. Durum wheat and soya as intercrop is maximum of 33% of durum wheat total area. Alfalfa is limited to 10% of the land use in the large and small crop producers, and not cultivated in the medium size crop producer.	Shorter crop return time of rice to desalinate the soil.
Crop yield	--	--	--	Wheat yield decrease of 10%. Rice yield increase by 10%.

Box 1: The four narratives of scenarios developed with the stakeholders of Camargue.

Scenario A. "The age of Livestock": Redirecting public subsidies from cereal based farming systems to livestock based farming systems.

In 2030, at the national and European levels, public subsidies to farming are redirected to support livestock rearing activities. In the Camargue, this is justified in part by the benefits of maintaining open landscapes where farms raise herds of local landrace in natural environments. Agro-environmental measures are therefore directed at systems integrating both livestock and crops, such as cropping systems with winter vegetation grazed by cattle. Farmers also have access to subsidies related to the extensive grazing of natural areas and the support of threatened local landraces. In order to maintain the low-profit activity of Camargue landrace bull rearing, breeders introduce a second herd of more common and productive livestock races (e.g., Angus, Aubrac and Salers). They are supported by consumer habits trending towards quality and local foods. Therefore herds in the Camargue increase approximately 25% as compared to 2014, and some cereal-based farming systems integrate new activities related to livestock rearing. More forage is needed to feed the increase in herds, therefore locally increasing both the demand for forage and its market price. With the redirection towards livestock activities, rice cultivation receives less support. The effects of climate change are still low in the Camargue, and do not prompt changes in the farming systems. Due to the high prices for forage and low subsidies for rice, farms that were cultivating cereals also begin to grow forage. With lower subsidies, production costs are reduced (particularly in terms of fertilizers) by introducing other systems to the rotation, such as relay cropping with wheat and alfalfa, and leguminous crops.

Scenario B: "Eco-conditionality": Enforcing the eco-conditionality of the EU subsidies.

In 2030, governmental supports for agriculture strongly encourage the protection of the environment in the process of crop production. The system of subsidies is regionalized for better management of local specificities and possible local crises, such as low yields due to climate events or pest damage, even if the effects of climate change are still not clearly visible. Single farm payments are reduced compared to 2014 levels, and contingent on a 50% reduction in pesticide use as compared to 2008. In addition to this eco-conditionality, agro-environmental measures are regionally aimed at supporting (1) the development of leguminous crops in order to reduce the use of mineral fertilizers, (2) an end to the practice of rice straw burning after harvest, and (3) the protection of biodiversity, by planting hedgerows and trees, and protecting the reproduction of endangered bird species by keeping some specific areas flooded in winter. To decrease the use of pesticides and fertilizers, farmers tend to diversify and lengthen their crop rotations by incorporating leguminous crops. The price of rice has followed an increasing trend due to a higher demand for rice in the international market. With the highly profitability of rice, and the need to diversify crop rotations in order to comply with environmental constraints, farmers seek to increase rice cultivation by adding land that had been lying fallow or used for livestock in 2014.

Scenario C. Coexistence of opposites: Differentiating farming systems to intensive or organic

In 2030, the price of rice is kept low in the international market to avoid hungers and political instability. In Europe, consumers are increasingly demanding local and organic food, leading to high prices for organic crops and organic meat from local landrace. The organic supply chain has become more developed and its actors consider the market to be mature. As a consequence, subsidies designed to maintain organic farming have been suppressed to reduce the cost of government. The only subsidies that livestock and crop farmers receive are single farm payments, uniformly distributed between farms. Because of the development of organic farming, new species are introduced in the rotation: soft wheat, maize, sorghum, lentils, old varieties of durum wheat. Additionally, a local tomato processing industry increases its capacity and develops new contracts with farmers in the Camargue. Climate change is increasingly becoming a factor in local agriculture: salt is reaching the surface soil more rapidly in the lowlands due to increased springtime evapotranspiration. Cultivating in the region is increasingly difficult, and in 2030 most of the low lands becomes fallow, grazed by the cattle and used for hunting in winter. Episodes of heavy rain become more frequent in the fall, while the springs suffer from periods of drought. Debates and citizen awareness of climate change effects have led to new regulations for the reduction of greenhouse gas (GHG) emissions, leading to the interdiction of rice straw burning and incentives for the reduction of mineral fertilizer use and production, which is energy intensive and produces large amounts of GHG. Water consumption is also more carefully monitored, and the cost of irrigation water is based on volume rather than irrigated acreage, leading to an increase of irrigation costs in most cases. As a reaction to these changes, the farming systems of 2014 have adapted differently. Numerous smaller farms, and farms with livestock convert to organic farming, while other farms, primarily the large farms, remain conventional, only making slight changes in their practices to reduce their environmental impact.

Scenario D. "Subsidizing specific local constraints": The Camargue classified as a less favoured area

In 2030, climate change impacts are affecting the level and flows of the Rhône River due to less snow in the mountains. The Camargue suffers extreme weather events more frequently: heavy rains in fall and drought in spring. Salinity increases in the water of the Rhône River due to seawater intrusions. Consequently irrigation infrastructures have to be modernized to reduce the threat of salt in the irrigation of rice production. New rules are structured to limit the volume of water used, and the cost of water increases. Because of these issues, the government grants a new (local) subsidy in addition to the single farm payment. This subsidy helps to ensure the economic viability of the farms, but also to ensure an important rice production in Camargue. Rice production is also supported by high prices as the international market responds to increased concerns about feeding a growing world population. Due to climate change, higher yields of rice are observed. The increasing need to reduce salt concentration in the soil leads to more frequent rice cultivation in the rotation schedule. The increase in rice production is also supported by high prices. On the contrary, durum wheat is negatively affected by the excessive rain in the fall and drought in spring. Mitigation strategies are put in place to reduce the use of mineral fertilizers, and agro-environmental measures are introduced to proscribe burning rice straw, encourage sowing rice in dry conditions, and favour the incorporation of legumes in crop rotations, as well as the grazing of intercrops in winter. Farmers also tend to reduce their input use due to an increased price of energy.

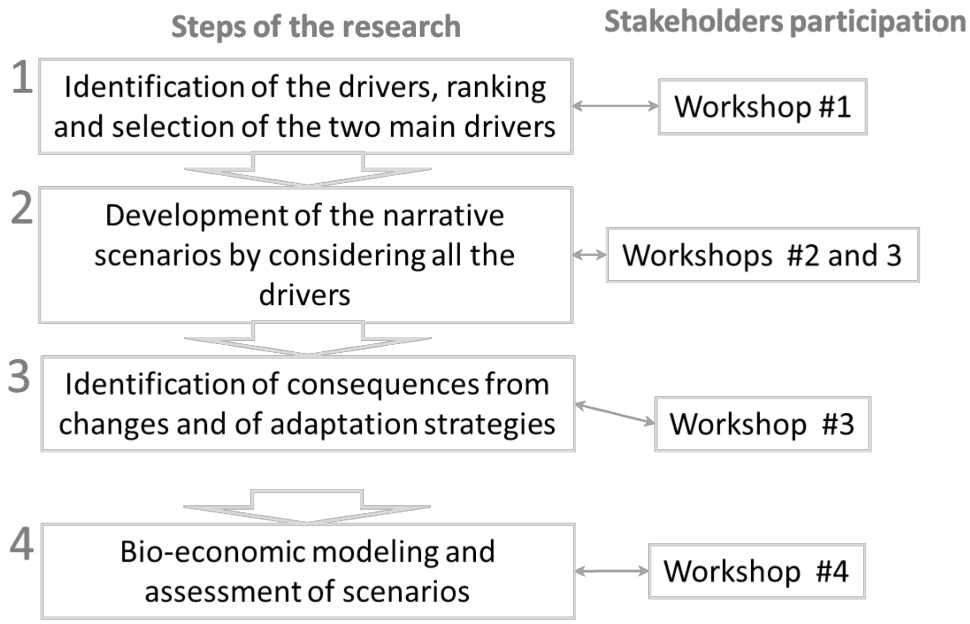

Figure 1: The four steps of the research, mobilizing the stakeholder participation.

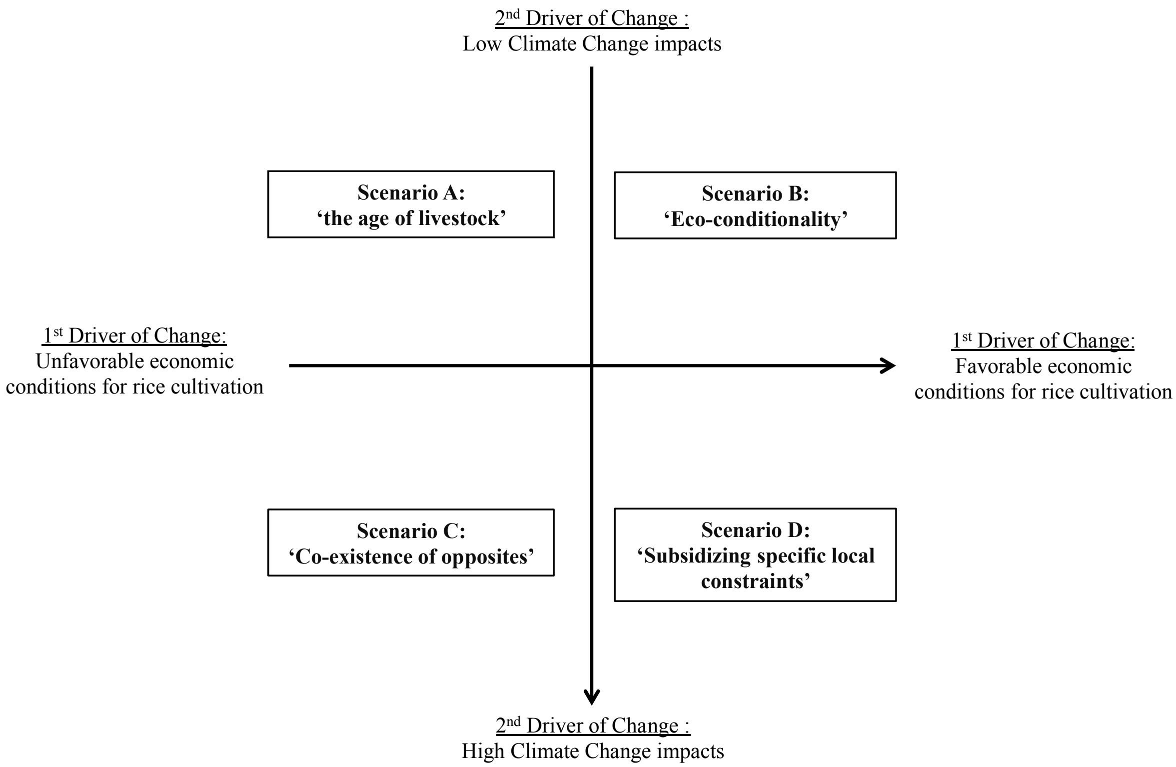

Figure 2. Scenario orientation for the two main drivers of change : (1) Economic conditions for rice cultivation, and (2) Climate change impacts.

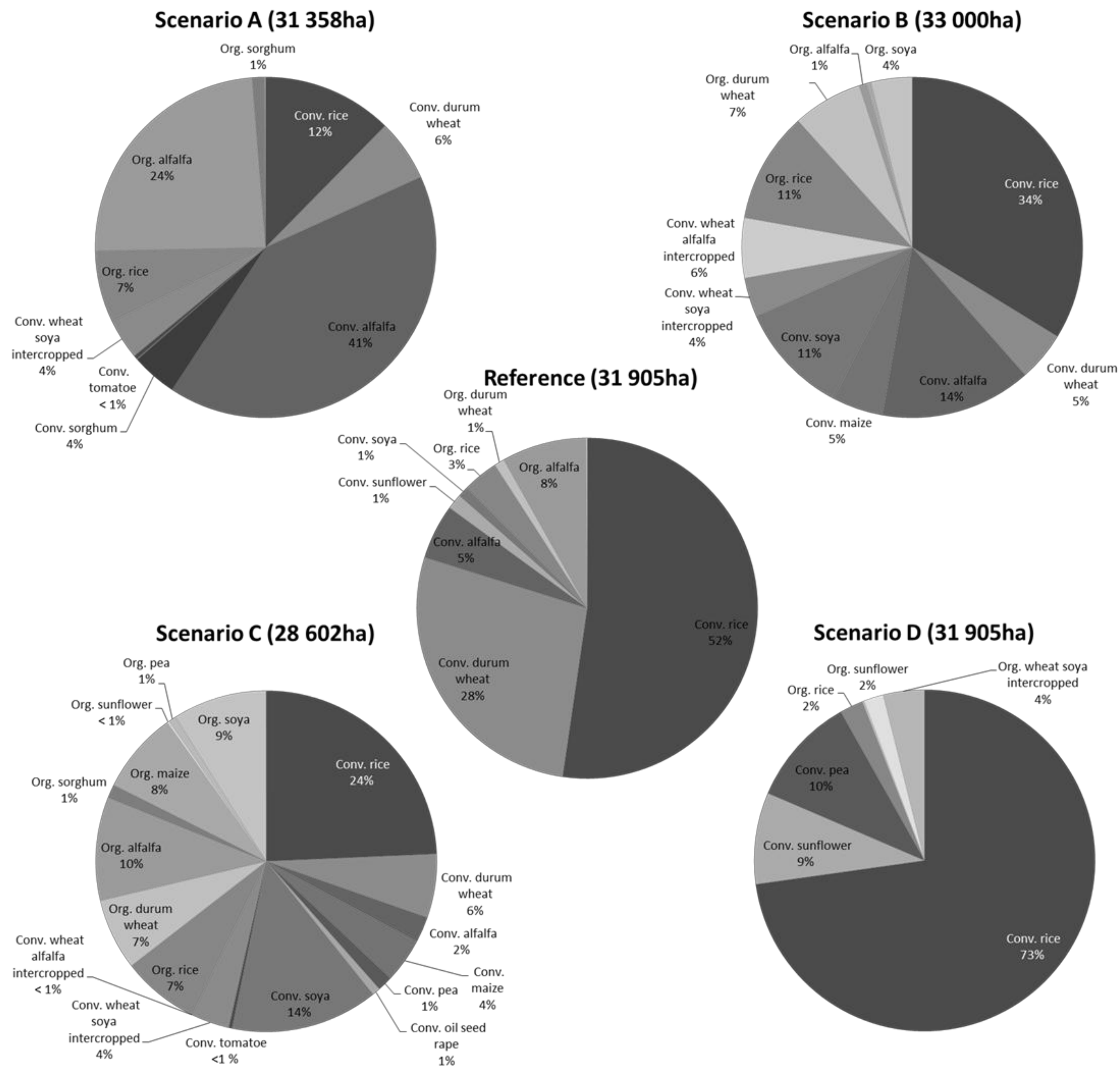

Figure 3. Land use at the regional level for the reference situation and for the four scenarios. The numbers between brackets indicate the total cultivated area at the regional level. The proportion of land use is indicated for each crop.

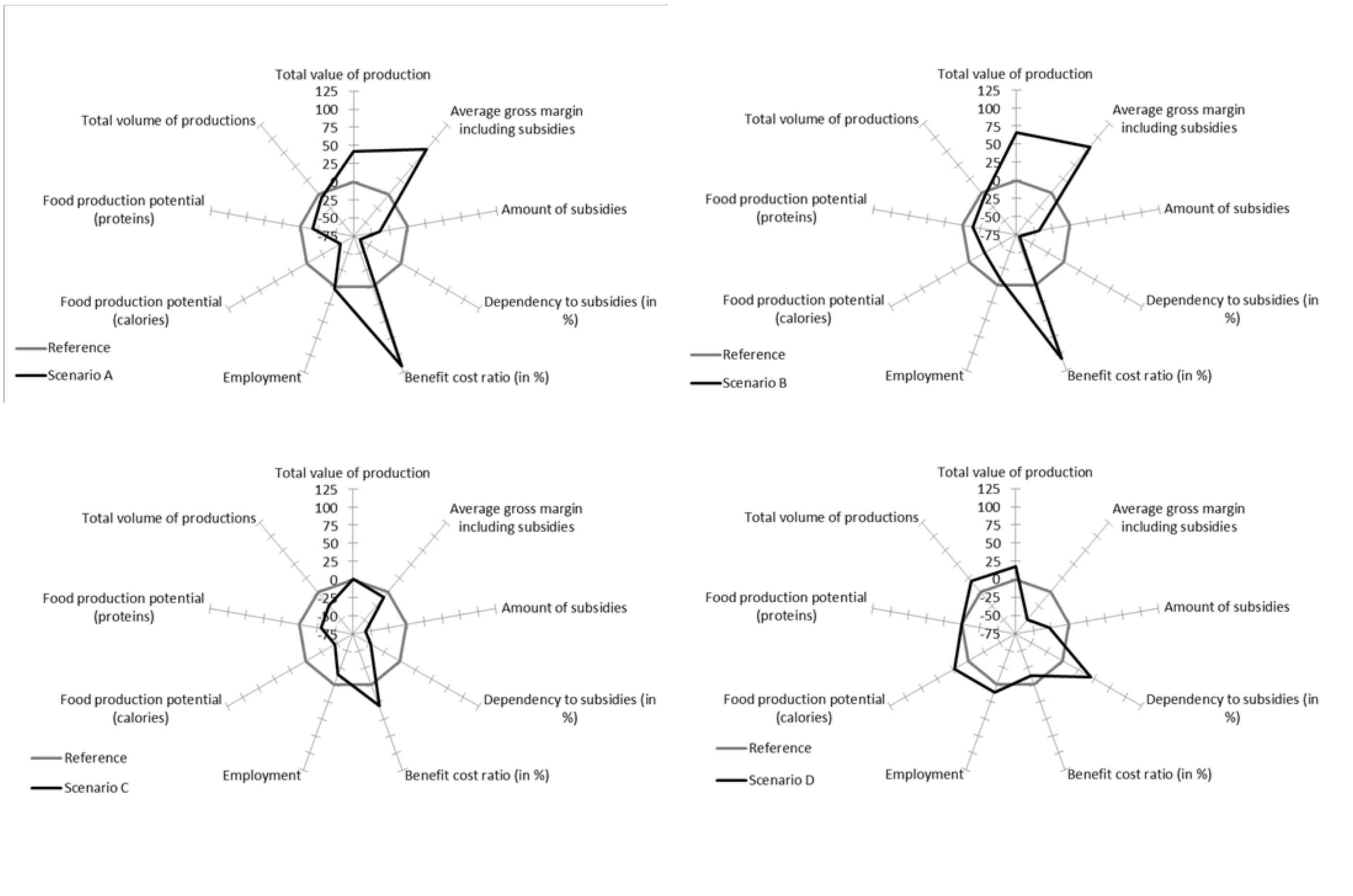

Figure 4. Radar diagram comparing the socio-economic indicators values for the reference situation (values at 0, in grey) and for each of the four scenarios.

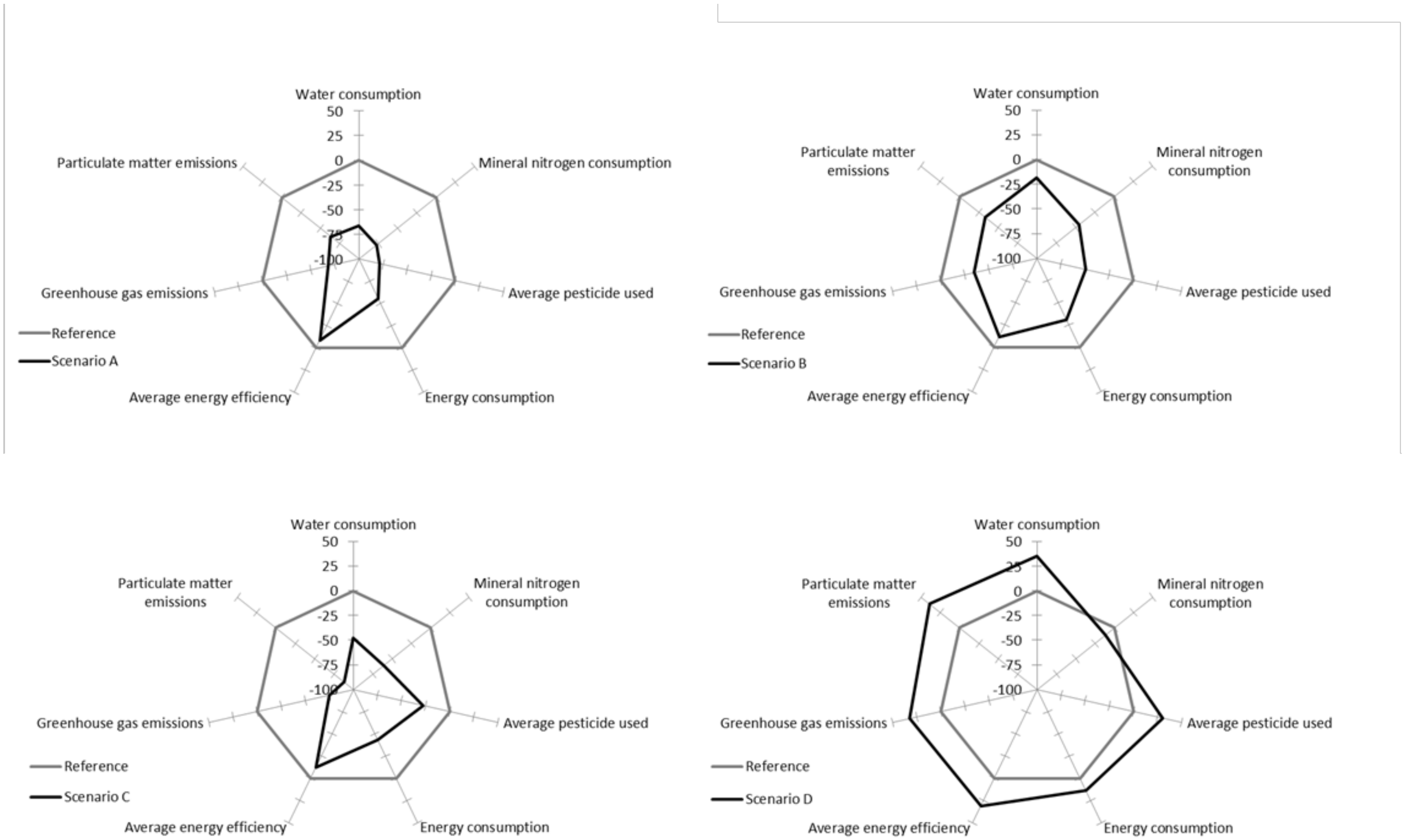

Figure 5. Radar diagram comparing the environmental indicators values for the reference situation (values at 0, in grey) and for each of the four scenarios.

Appendix 1. Description of the participatory process for scenario development and model parameterization

The participatory process was facilitated by two researchers (co-authors of this article). Overall, the facilitation aimed at balancing the speaking time between the participants, regardless of their local responsibilities and power. The specific methods for facilitation depended on the objective of the meetings (go around the table, brainstorming); these methods are detailed below.

1. Drivers

Identification (1st meeting)

During the first meeting with the stakeholders, one facilitator presented a first list containing five drivers that were previously identified by the research team. The facilitator then asked each participant, by going around the table, to identify the most important driver for him/her. The driver could be picked from the initial list or not, and the reason of its prime importance was explained. The participant could cite drivers that were already chosen by another participant, in case they agree with their importance for the future of the agricultural sector of Camargue. This activity was stopped when no new driver was proposed. During this exercise, the second facilitator was writing the drivers on post-it, and counting the number of participants citing it.

Ranking (1st and 2nd meetings)

The ranking of the drivers was performed by counting the number of times a specific driver was cited by the participants. At this step, four main drivers were identified, which included local drivers (water management), national/European drivers (French policies and Common Agricultural Policy), and global drivers (climate change; price of the commodities). The identification of global drivers may however have been biased by (1) the presence of such drivers in the list pre-identified by the research team, and (2) the context of the study (i.e., a research project on local strategies for adaptation and mitigation of climate change).

2. Scenario narratives

Participatory design (2nd meeting)

During this step, the facilitation consisted in two main actions: (1) ensuring that all the stakeholders would express themselves, as some were not spontaneously giving their opinion, and (2) highlighting possible inconsistencies in the scenarios, by recording the drivers identified for each scenario and their direction of change on a paper board.

At the beginning of the scenario exercise, the facilitator picked two of the four most important drivers (listed above) to give an example of the starting point of a scenario. The development of the scenario specifications was performed as a brainstorming, each participant giving its view of what could happen, and reacting to others' participant points of view. This allowed (1) an in-depth explanation of the choice of each driver and its direction, in link with the other drivers constituting the scenarios, and (2) the confrontation between the points of views of the different participants facilitating the consensus for each scenario. In the rare cases where the consensus was not emerging from the discussion between the stakeholders based on their arguments, the facilitator was orientating it by either (1) highlighting the potential greatest consistency of one driver's direction with the rest of the scenario, or (2) suggesting to include the driver in another scenario (either already built if consistent, or a new one).

At this stage, five scenarios were built by the participants, who all agreed with their specifications. One of these scenarios could be considered as the 'worth-case scenario'. In agreement with the stakeholders, the research team proposed to exclude it, as it led to the end of the agricultural activities in Camargue and was thus considered as unrealistic.

Research team work

Based on the audio recording and on the synthesis of the scenarios written during the second meeting on the paper boards, the research team wrote the first complete versions of the scenario narratives. At this stage, it appeared that the four main drivers constituting the basis of the scenarios could be merged two by two (climate change + water management; price + subsidies) to form the two-dimensional matrix.

These narratives included quantitative information provided by the stakeholders during the second meeting (e.g., price of the subsidies). When the quantitative information required for simulating the scenario with the bio-economic model had not been specified, the research team proposed plausible quantifications, based on the previous meetings, literature and their knowledge on the Camargue case study.

Validation/updating of the scenario narratives (3rd meeting)

The four scenario narratives were sent to the participants before the third meeting. In this working paper the proposition of the research team for the two axes of the matrix was explained.

At the beginning of the 3rd meeting, the facilitator first presented and explained the two-dimensional matrix and the two more general drivers forming it. This aimed to gather the reactions of the stakeholders on this choice, which was important regarding the synthesis of the scenarios. Once the stakeholders had discussed and agreed on this matrix, the facilitator read the scenarios one by one, asking the participants if they agreed and which elements should be modified/specified according to their points of view. The updating and validation of the scenarios was realized as a brainstorming, with the facilitator asking for agreement in case one stakeholder did not spontaneously react. For each scenario, the quantifications that were suggested by the research team were highlighted to get feedbacks from the stakeholders. At this stage, the narratives were thus modified according to the stakeholders' opinions, to form the final storylines included in this paper.

3. Adaptation strategies (3rd meeting)

After the updating and validation of each scenario, the facilitator asked the participants their opinion on the impacts of such scenarios on the local farming systems, and their subsequent adaptations. The focus was put on the land use (fallow conversion into arable land; land abandonment) and the technical adaptations (rotations, crop management) that could happen in the context of each scenario. These adaptations were distinguished according to the farm types (breeders, rice growers, farm size) when the stakeholders thought their adaptations would differ. These adaptation strategies were designed by the stakeholders in a brainstorming.

4. Model parameterization

The model parameterization was realized in six steps, which occurred throughout the study.

(1) The first step consisted in using the quantifications that were provided by the stakeholders during the second meeting.

(2) The second step consisted, while writing the complete narratives, in identifying the missing parameters of the narratives, and searching a way to make a first assessment (based on the information gathered during the first meeting, as well as based on previous studies in the research area (see for example Delmotte et al., 2016), and on expert knowledge and literature. For instance, the 50% reduction of pesticides in scenario B came from the French environmental plan 'Ecophyto 2025' (French Ministry of Agriculture, Food Industry and Forest, 2015). The amounts of subsidies were based on a previous study realized to set up the payment for agri-environmental measures of the new CAP (Cavalier, 2013). For the commodity prices and the differences between organic and conventional, we used values provided by grain millers. For the specification of the cropped area, the numbers were based on land use information provided by the Natural Regional Park of Camargue (NRPC). For the maximum proportion of organic farming per farm type, it was based on expert opinions and previous studies (Delmotte *et al.*, 2016). The reduction of nitrogen applications came from discussions with the NRPC, while the yield changes resulting from climate change were based on experts' opinions.

(3) The third step consisted in presenting these estimates to the study participants for agreement or updating.

(4) During the fourth step, the objective function to be maximized or minimized was selected. For each scenario, this selection was performed based on three aspects: the general context of the scenario, the adaptation strategies suggested by the stakeholders (3rd meeting), and the differentiation between the scenarios:

- Scenario A: the maximization of the forage production was selected as this scenario favors livestock rearing at the expense of the cereal sectors, so the stakeholders suggested that forage production would be more profitable and thus increased by local farmers.

- Scenario B: the maximization of the gross margin was chosen as the change in EU subsidies could, according to the stakeholders, largely threaten farm economics. The idea was then to test whether (and how) the farms could maintain their profitability.

- Scenario C: the minimization of the greenhouse gas emissions was chosen as this scenario considers new regulations and subsidies concerning this issue. The objective was here to test how much could the GES be decreased, while respecting the adaptation strategies designed by the stakeholders.

- Scenario D: the maximization of food production was selected as the international context show a raising concern for feeding a growing world population, this argument being used by the rice farmer union to negotiate subsidies with the French government.

(5) For each scenario, several simulations were performed, by changing step by step the constraints on crops (Table 3). Their range was determined based on technical possibilities (e.g., dry seeding of rice impossible on some soil types; possibility of investment regarding new machineries required). For each scenario, one final simulation was chosen by the research team, which was the closest to stakeholders' expectations regarding farm adaptations under such changes of context.

(6) In the fourth meeting, the scenario parameters and objective functions (Table 3) were presented to the stakeholders, together with the resulting land uses and performances. Their reactions to both the parameters and results (e.g., on the proportion of organic farming) were used to update the model and perform the final simulations that are presented in this paper.

Reference cited:

Cavalier, S., 2013. Recueil et analyse de bonnes pratiques agronomiques et environnementales dans les systèmes de production agricole camarguais. Master Agro-écologie, AgroParisTech. 89p.

Delmotte, S., Barbier, J.-M., Mouret, J.-C., Le Page, C., Wery, J., Chauvelon, P., Sandoz, A., Lopez Ridaura, S., 2016. Participatory integrated assessment of scenarios for organic farming at different scales in Camargue, France. Agricultural Systems 143, 147-158.

French Ministry of Agriculture, Food Industry and Forest. Plan Ecophyto 2. 2015.

Appendix 2: Method for the calculation of indicators related to GHG and particulates emissions and energy consumption.

As compared to the model used in Delmotte *et al.* (2016), new indicators were introduced. First of all, indicators related to GHG emissions as well as energy consumption and particulates emissions (PM10) were included. We considered both direct and indirect emissions of CO2, CH4 and N2O. We considered the global warming potential of CH4 and N2O emissions into CO2 equivalent used by the IPCC for 100 years' time horizon, i.e., 25 and 298 for CH4 and N2O, respectively (IPCC/TEAP, 2005). Indirect GHG emissions are related to the production, transport and storage of pesticides, fertilizers and seeds (Indirect GHG from seeds were calculated using an estimation of GHG from the activities and considering that a part of the production is reseeded the next year). Indirect GHG emissions were computed for each agricultural activity using the EcoInvent® database (Nemecek and Kagi, 2007; Nemecek and Schnetzer, 2012). Direct field emissions take into account GHG emitted during field operations (i.e., rice straw burning and fuel burning for e.g., sowing, tillage, mineral products applications, water pumping, etc.) and emitted by the soils. GHG emissions due to fuel burning during field operations were computed using data on agricultural activities defined in Camargue by Goulevant and Delmotte (2011), and emission coefficient retrieved from the ClimAgri®[1] (2012). For the N2O emitted by the soils, we used the Tier 1 method developed by the IPCC (2007), and the default values of the emission factors (IPCC 2007). The CH4 emissions by the soils were calculated using the method developed by USDA (Ogle e*t al.*, 2014). Emissions of CO2, CH4 and N2O from rice straw burning were also calculated using the method of IPCC (2007).

The direct and indirect energy consumptions were also defined for each agricultural activity. As for GHG emissions, indirect energy consumption included production, transport and storage of pesticides, fertilizers and seeds; it was assessed using the EcoInvent database. Direct energy consumption included fuel and water pumping for irrigation and drainage; data were retrieved from Goulevant and Delmotte (2011), ASA (personal communication, 2014) and Climagri® (2012). We also included an indicator regarding the emissions of particulate matter, considering those whose diameter is lower than 10 µm (PM10), for which daily thresholds are applied in Europe since 2005 (UE Directive 2008/50/CE). Both direct and indirect emissions were quantified for each agricultural activity, for the same aspects than GHG emissions and energy consumption. Calculations were performed using the methodology prescribe by the French Minister in charge of environment (Citepa 2014).

[1] http://www.ademe.fr/expertises/produire-autrement/production-agricole/passer-a-laction/dossier/levaluation-environnementale-agriculture/loutil-climagri

Secondly, indicators related to the nutritional potential of the crop production were also added for the integrated assessment of agricultural systems, representing the objective that agriculture should feed the human population. The estimation of this nutritional potential in terms of energy (calories) and protein content was made with the ADEME calculation method (ADEME and CEREOPA, 2011) and using data from Climagri® (2012).

Finally, based on both the nutritional potential and the energy consumption, we computed an indicator for energy efficiency, defined as the ratio of the food production potential in term of energy over the total energy consumption. This indicator is defined at the regional scale, as a sum of the ratio computed for each activity, weighted by its areas.

<u>References cited in the appendix 1:</u>

Delmotte, S., Barbier, J.-M., Mouret, J.-C., Le Page, C., Wery, J., Chauvelon, P., Sandoz, A., Lopez Ridaura, S., 2016. Participatory integrated assessment of scenarios for organic farming at different scales in Camargue, France. Agricultural Systems 143, 147-158.

Goulevant, G. and S. Delmotte (2011). "Proposition of a typology for the farms producing rice in the Camargue." Internal report: 12p.

IPCC/TEAP (2005). Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons. Bert Metz, Lambert Kuijpers, Susan Solomon, Stephen O. Andersen, Ogunlade Davidson, José Pons, David de Jager, Tahl Kestin, Martin Manning, and Leo Meyer (Eds) Cambridge University Press, UK. pp 478.

IPCC (2007) Climate Change Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L. A. Meyer (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 862pp.

Nemecek, Thomas, and Thomas Kägi. 2007. Life Cycle Inventories of Agricultural Production Systems - Ecoinvent V2.0 Final Report. Dübendorf.

Nemecek, Thomas, and Julian Schnetzer. 2012. “Methods of Assessment of Direct Field Emissions for LCIs of Agricultural Production Systems.” 0(15): 34.

Ogle, S.M., P.R. Adler, F.J. Breidt, S. Del Grosso, J. Derner, A. Franzluebbers, M. Liebig, B. Linquist, G.P. Robertson, M. Schoeneberger, J. Six, C. van Kessel, R. Venterea, T. West, 2014. Chapter 3: Quantifying

Greenhouse Gas Sources and Sinks in Cropland and Grazing Land Systems. In Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity - Scale Inventory. Technical Bulletin Number 1939. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC. 606 pages. July 2014. Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley- Gilbert, and S. Biggar, Eds.

Appendix 3: Parameters used for the simulation of the reference situation.

<table>
<tr><th></th><th>Reference situation</th></tr>
<tr><td>Objective function</td><td>Maximize gross margin</td></tr>
<tr><td>Subsidies</td><td>A direct payment varying between 574€/ha and 689€/ha depending on the farm type. A couple payment for durum wheat of 25€/ha, a coupled payment for soya of 150€/ha, a coupled payment of 1066€ for tomatoes. An agro-environmental measure of 56€/ha for rice. A payment of 100€/ha for organic farming.</td></tr>
<tr><td>Prices of production</td><td>Rice: 225€/t, Durum wheat: 210€/t, Alfalfa: 150€/t, Sorghum 145€/t, Maize: 152€/t, Sunflower: 305€/t, Pea : 200€/t, Oil seed rape : 360€/t, Soya: 450€/t, wheat soya intercropped: 290€/t , wheat alfalfa intercropped: 190€/t.</td></tr>
<tr><td>Difference of prices between organic and conventional productions</td><td>60%</td></tr>
<tr><td>Maximum area in organic farming</td><td>Crop producer (small: 0%, medium : 0%, large: 6%) : , organic crop producer: 100%, livestock farmer (conventional : 10%; organic: 100%)</td></tr>
<tr><td>Constraints on crops</td><td>
<table>
<tr><th></th><th colspan="4">Minimum proportion of… (in % of farmland surface area)</th></tr>
<tr><th>Farm types</th><th>Rice</th><th>Alfalfa</th><th>Durum wheat</th><th>Oil seed rape and soya</th></tr>
<tr><td>Organic crop producer</td><td>25</td><td>9</td><td>46</td><td>7</td></tr>
<tr><td>Large size crop producer</td><td>60</td><td>0</td><td>28</td><td>1</td></tr>
<tr><td>Medium size crop producer</td><td>54</td><td>0</td><td>32</td><td>3</td></tr>
<tr><td>Small size crop producer</td><td>34</td><td>0</td><td>25</td><td>3</td></tr>
<tr><td>Livestock farmer</td><td>35</td><td>12</td><td>29</td><td>0</td></tr>
<tr><td>Organic livestock farmer</td><td>10</td><td>42</td><td>17</td><td>0</td></tr>
</table>
</td></tr>
</table>