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

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13   **Abstract**

14   European farmers are facing challenges that call for important transformations on their
15   agricultural production systems, including an increasing number of regulations aimed at
16   reducing environmental impacts from farming practices. Climate change is also expected to
17   affect agricultural production in most European regions, and in Southern Europe this effect is
18   expected to negatively impact yields. In this study, we present the application of an innovative
19   participatory approach to assess the potential of innovative agricultural systems to reconcile
20   environmental sustainability with economic viability while contributing to local and global
21   food security. Our approach consisted of combining (1) the participation of local stakeholders
22   in the design of narrative scenarios, and (2) an integrated assessment of scenarios through the
23   calculation of indicators at different scale with a bio-economic model. We tested our approach
24   with a case study situated in the Camargue region of Southern France. Rice is currently the
25   main crop in this region, but farmers there face adverse economic conditions linked to the
26   recent reform of European Common Agriculture Policy. After identifying the main drivers of
27   change, local stakeholders developed narrative scenarios and described how farmers would
28   adapt within the context of those changes. These elements were then translated into model
29   inputs. At the regional level, the four scenarios led to variations in farmland acreage (28,000-
30   33,000 ha), as well as the proportion of rice crops (19-75%) and areas cultivated under
31   organic farming standards (8-43%). The four scenarios also led to different values for
32   indicators of agricultural economic welfare, food production, and environmental impacts.
33   Trade-offs between these indicators and the associated objectives assigned to agriculture were
34   identified and discussed with the stakeholders. We end with a discussion of the limitations

35 and advantages of our approach to the participatory development and assessment of locally

36 developed narrative scenarios.

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38 **Keywords**

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43 **Highlights**

44 • Participatory development of narrative scenarios and bio-economic models are used.

45 • Main drivers of change are economic conditions for rice and climate change.

46 • Simulated rice acreages range between 6,000 and 23,000 ha, depending on scenario.

47 • Gross margin and food production are the most impacted socio-economic indicators.

48 • GHG emissions and water consumption are the most impacted environmental indicators.

49

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).

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84 Projections have been made for impacts at regional, national and global levels, but in most

85 cases these studies concern large areas, and few studies have simultaneously analyzed the

86 impacts of CC and the evolution of local dynamics and constraints. These latter factors have

87 considerable impact on viable adaptation and mitigation strategies for agricultural systems in

88 a given region. This deficiency has led a number of authors to call for more studies involving

89 smaller regions (such as ecoregions) that evaluate the potential impact of CC on agricultural

90 systems (Abildtrup *et al.*, 2006; Sleeter *et al.*, 2012), and include the assessment and design of

91 adaptation and mitigation strategies at the scale of farms (Reidsma *et al.*, 2015).

92 Since the magnitude of CC and its consequences on crop physiology and resources (such as

93 water) remain uncertain, relevant studies must be conducted using different CC scenarios.

94 IPCC climatic scenarios project how CC impacts future weather conditions on a large scale,

95 and modeling approaches attempt to down-scale these projections to regional and local levels

96 (Abildtrup *et al.*, 2006; Sleeter *et al.*, 2012). However, the use of these results by local

97 stakeholders of a given area often remains limited, and requires integration with the parallel

98 evolution in local drivers of change that effect these same stakeholders.

99 **1.2 Scenario studies**

100 Therefore the development of regional scenarios that focus on potential agricultural systems

101 in locally defined contexts should include both local and global drivers (including CC) (Ebi *et*

102 *al.*, 2014). This requires appropriate methods for scenario development. Narrative scenarios

103 and Representative Agricultural Pathways (RAPs) are considered as a logical framework for

104 studying the evolution of agricultural systems at different scales (Rosenzweig *et al.*, 2013).

105 Narrative scenarios can include both local and global changes: local dynamics such as urban

106 development or specific environmental constraints, and global variables such as the evolution

107 of the crop and energy markets, and climate change (e.g., Kok *et al.*, 2006, Hossard *et al.*,

108 2013; Kok *et al.*, 2007, Reed *et al.*, 2013). Narrative scenarios have been used to encourage

109 stakeholders to think creatively about the evolution of land use and the possible consequences

110 on indicators that are often related to socio-economic aspects (see, for example, Fohles *et al.*,

111 2015) or ecological services (see, for example, Petersen *et al.*, 2003; Bohensky *et al.*, 2006;

112 Plieninger *et al.*, 2013). Such scenarios are often written as a short, coherent story, which is

113 seen as a format suitable for being communicated to stakeholders (Rasmussen, 2005). A

114 common practice includes the use of four different scenarios simultaneously delineated on the

115 basis of two drivers that could evolve in two opposite directions (van 't Klooster and van

116 Asselt, 2006). This enables stakeholders to quickly understand the explorative nature of the

117 scenarios. Such scenarios usually include four elements: (1) a representation of the initial

118 situation (reference), (2) a description of the drivers of change, (3) a description of the

119 evolution of the system, and (4) a description of the future state of the system (Alcamo and

120 Henrichs, 2008).

121 Scenarios can then be assessed in term of their capabilities to create good conditions for

122 agricultural sustainability (Delmotte *et al.*, 2013). The process of integrated assessment and

123 modelling has proven to be capable of producing useful information about the possible future

124 states of agricultural systems, and about the consequences of changes in agricultural systems

125 on a wide range of sustainability issues (van Ittersum *et al.*, 2008; Castoldi and Bechini, 2010;

126 Bezlepkina *et al.*, 2011; Reidsma *et al.*, 2015). In this study, we present a method to (1)

127 develop narrative scenarios related to the evolution of the agricultural systems by combining

128 drivers of changes related to global changes and local constraints and opportunities, and (2)

129 perform an integrated assessment of these scenarios. This method is aimed at foreseeing the

130 possible future states of agricultural systems from the perspective of stakeholders, and

131 assessing the consequences of these states with a model. We applied the method in

132 collaboration with stakeholders in the Camargue, a wetland region in southern France. After

133 presenting the case study and methods used for scenario development and analysis, we

134 present an assessment of these scenarios. We then discuss the implications of these results for

135 the case study, the methodological lessons learned, and the further improvements needed.

136

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

138 This study was conducted during 2014 and 2015 in the Camargue, a deltaic region in the

139 South of France. Following a brief introduction of the region's characteristics and an outline

140 of the method for scenario development and integrated assessment, we present the four steps

141 used in the methodology for scenario assessment, and the bio-economic model used to assess

142 the scenarios.

2.1. The Camargue region

144 The Camargue is home to large tracts of protected wetlands which are recognized for their

145 importance to biodiversity. These wetlands are in close proximity to agricultural land

146 primarily used for livestock (extensive systems raising local landrace), and for intensive

147 cultivation (c.a. 55% in rice crops, 30% in durum wheat). The Camargue is the only place in

148 France where rice is grown on a large scale, and all industries associated with the supply

149 chain are located in this region. The salinity of the region's groundwater tables is

150 compounded by evapotranspiration that is on average twice as important as annual rainfall

151 (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

219 two axes, creating four spaces of possible futures that define the basis of four scenarios

220 (Figure 2).

221 **2.2.2. Step 2. Development of the narratives**

222 Starting from each corner of the matrix, the stakeholders developed the scenarios

223 progressively, during the second and third meetings (Figure 1). Each story includes most of

224 the initial 13 drivers of changes and their possible evolution.

225 During this step, four rules guided the arrangement of the drivers' in each scenario, adapting

226 recommendations by Alcamo (2001):

227 • Realism: Each scenario must represent a possible future, avoiding ideal or worse case

228   situations that would have limited interest *per se,* and when being compared to the others.

229 • Consistency: The choice of the additional drivers' directions must be logical within each

230   scenario; for example, if the farming systems are facing economic constraints, the

231   investment in new machineries would be limited.

232 • Contrast: In order to compare and discuss different adaptations and innovations for farming

233   systems, the scenarios must be as contrasted as possible, in both their drivers and

234   subsequent adaptations.

235 • Creativity: The objective is to go beyond common thinking, to imagine innovative and

236   surprising scenarios.

237 Among the four criteria, "creativity" and "realism" were two objectives that were ensured

238 through the facilitation of the participatory exercise. "Contrast" and "consistency" were also

239 addressed in the lab, when the research team worked to reframe the different scenarios (see

240 appendix 1). The balance between these four criteria was obtained ex-post, when the final

241 narratives were written and presented to the stakeholders. The resulting four narrative

242 scenarios are presented in Box 1.

243 **2.2.3. Step 3. Adaptation strategies for narrative scenarios**

244 The third step in developing scenarios was the identification of adaptation strategies within

245 each scenario's context. Taking into account the diversity of the current farming systems, we

246 classified them into six types adapted from the typology presented in Delmotte *et al.* (2016).

247 These types are based on farm size, relative share of livestock production, and surface area

248 exploited with OF methods. This classification enabled consideration of the specificities and

249 constraints that the different farming systems would face in the context of the different

250 scenarios (e.g., the differential in effects from changes in economic conditions of rice for a

251 livestock farmer or for a diversified crop farmer).

252   Different adaptation strategies were discussed with the stakeholders during the third workshop

253   (Figure 1). These strategies included the following:

254   - Changes in the farm activities, such as the development of new livestock activities (scenario

255   A).

256   - Development of innovative cropping systems, including new crops (e.g., soft wheat and

257   intercropping systems in scenario C), new crop rotations (in scenarios B and C for example),

258   or new cropping practices for a given crop (e.g., dry sowing of rice, low pesticides systems).

259   - Changes in land availability, such as abandonment of lowlands (in scenario C), or on the

260   contrary, cultivation of currently abandoned land (in scenario B).

261   **2.2.4. Step 4. Bio-economic modelling and scenario assessment**

262   For each narrative scenario, we formalized the information in terms of (1) the changes that

263   define conditions for future agricultural systems, and (2) the adaptation strategies designed by

264   stakeholders. The scenarios were then translated into a quantitative assessment of the

265   agricultural systems via the use of a bio-economic model (BEM). We used the BEM to

266   generate a set of optimal land uses for each scenario and selected one of these land use

267   combination that was in agreement with the scenario. These land uses were presented to the

268   stakeholders during the fourth meeting (Figure 1), where they were given an opportunity to

269   suggest modifications if some model outputs were found uncoherent. Based on this feedback,

270   we modified the constraints in the BEM, and obtained the final land uses presented in this

271   paper. Based on these land uses, an integrated assessment of the scenarios was realized by

272   comparing the evolution of multiple indicators at the farm and regional scale.

273   **2.3 Parametrization of the bio-economic model**

274   **2.3.1 Presentation of the bio-economic model**

275   We used a bio-economic model previously developed in the Camargue (Delmotte *et al.*,

276   2016), based on a multiple goal linear programing model. This BEM optimizes the allocation

277   of land uses, taking into account multiple variables, one being the objective function (to be

278   maximized or minimized), and the others being used as constraints. Both the objective and the

279   constraints can be set at the farm and/or regional levels (see Delmotte *et al.* (2016) for a

280   detailed description of the model and its equations). The possible land uses are defined as

281   agricultural activities following Hengsdijk and van Ittersum (2003), and are described in

282   terms of agricultural inputs (e.g., fertilizer, pesticide, energy and water use, costs of

283   production, labour) and outputs (e.g., yield of the crops, GHG and particulate emissions,

284   energy and protein contents). This quantified information came from multiple sources of data:

285   farmers' interviews, databases, crop modelling and expert knowledge (Delmotte *et al.*, 2016).

286 Agricultural activities are used as the building blocks of farming systems. The specificities of

287 the different types of farming systems are represented as constraints on available land and on

288 land use (e.g., livestock farmers need to cultivate a minimum acreage of forage crops). We

289 used the typology presented in Delmotte *et al.* (2016) as a reference for current conditions and

290 added specific constraints for each scenario and adaptation strategy as detailed in the

291 following section.

292 After the identification of an optimal combination of agricultural activities, indicators are

293 computed by multiplying the surface area of each agricultural activity by their relevant inputs

294 and outputs. The aggregation of the farm scale to a regional scale is based on the area of each

295 farm type at the regional level. Model outputs are therefore indicator values at the farm and

296 regional scale (Table 2). Compared to the model used in Delmotte *et al.* (2016), new

297 indicators were introduced (see Appendix 2 for details). First, indicators related to GHG

298 emissions as well as energy consumption and particulate emissions (PM10) were included.

299 Then, indicators related to the nutritional potential of the crop production in terms of energy

300 (calories) and protein content (in % of mass) were added for the integrated assessment of

301 agricultural systems, in order to represent the objective of food security. Finally, based on

302 both the nutritional potential and the energy consumption, we computed an indicator of

303 energy efficiency, defined as the ratio of the nutritional potential in terms of energy

304 production over the total energy consumption. For the purpose of this paper, only indicators at

305 the regional level are presented.

306 **2.3.2 Parametrization of the bio-economic model for each scenario**

307 For each scenario, we defined a specific set of values for the parameters of the BEM. These

308 parameters are related to the content of each scenario, and the information to set their values

309 was obtained all along the study, through the interactions with the stakeholders (see appendix

310 1 for details). As introduced in section 2.2, the main drivers of the scenarios were economic

311 conditions for rice production, and climate change. The first driver prompted the

312 implementation of different levels and types of subsidies in the model, according to the

313 perceptions of stakeholders. It also led to different price levels for crops, including differences

314 between conventional and organic productions, as well as changes in the price of inputs such

315 as water and energy (Table 3). Climate change was implemented in the model through three

316 different modalities: (1) changes in availability of land for agricultural production, because

317 climate change is expected to increase the evapotranspiration and therefore the salt

318 concentration in soil composition, making cultivation of non-irrigated crops in lowland soils

319 difficult or impossible; (2) constraints on crops, notably the need for more frequent rice

320 cultivation in the crop rotation cycle in order to limit the salt concentration in soils that remain

321 viable for cultivation (thus requiring larger quantities of irrigation water) in scenario C and D;

322 and finally (3) the direct impact of climate change on crop yield (in scenario D only since

323 these consequences were considered too uncertain) for which rough hypotheses were made

324 (see Table 3).

325 The other drivers were incorporated in the model according to their relevance to (1) the

326 maximizing or minimizing of the various objectives, in the scenarios, and (2) the constraints

327 on environmental indicators, such as pesticide use in scenario B, nitrogen application in

328 scenario C and D, and the burning of rice straw in scenario C. The rate of conversion to OF

329 also had to be specified, as in most cases activities in OF are more profitable than in

330 conventional systems, leading the model to select only these activities.

331 The model was also parameterized to generate a reference scenario (Figure 3 and appendix 3)

332 that was used for comparison with the future scenarios. This reference scenario reproduced an

333 approximation of land use in 2014 (based on local land use maps created by the Regional

334 Nature Park), and the subsidy and price conditions found in the same year (obtained from

335 interviews with farmers and grain millers). This reference scenario and its assessment in term

336 of indicators were discussed and confirmed with the local stakeholders during the fourth

337 meeting.

338 **3. Results of the integrated assessment of the scenarios**

339 **3.1 Impact of the scenarios on land uses**

340 The four scenarios led first to different acreage of farmland cultivated at the regional scale,

341 due to either the cultivation of abandoned lands in scenario B (33,000 ha, due to farmers

342 willingness to increase the cultivated area), or on the contrary the abandonment of lands in

343 scenarios A (31,300 ha, mostly due to unfavourable conditions for crop cultivation) and C

344 (28,000 ha, land abandonment being due to climate change effects on salt concentration in

345 soil of lowlands) (see table 3). They also led to different land uses at the regional level. In

346 particular, the surface area of rice cultivation varied from approximately 6,000 ha (in scenario

347 A, the worst in terms of economic conditions for rice) to 23,000 ha (in scenario D, the most

348 economically favourable for rice cultivation), thus ranging from a reduction of 66% to an

349 increase of 31% when compared to the surface are of rice cultivation in the reference scenario

350 (17,770 ha). As in scenarios A and C, the surface area of rice cultivation in the Camargue

351 would be reduced if the economic conditions were not suitable for the crop (i.e., low prices

352 and low level of policy support). In scenario A, with CAP subsidies redirected to livestock,

353 cropping systems in the Camargue would primarily evolve towards the cultivation of forages,

354 and notably alfalfa, to feed the animals. The stakeholders felt that under these conditions,

355 forage, and particularly alfalfa, would become the main crop in the Camargue. It would lead

356 to 68% of the arable land in the region being cultivated in alfalfa, and only 19% in rice

357 (Figure 3). In scenario C, farmers adapt their practices to climate change and to a drop of the

358 rice prices. Two possible pathways of adaptation were suggested depending on the type of

359 farm: conversion to organic farming or intensification of conventional production (see table

360 3). In conventional farming systems, rice would remain the main crop, but it would be

361 cultivated in rotation with durum wheat and soya (also in intercropping systems) as well as

362 with maize. This scenario suggests that the cultivation rice would fall to 31% of arable land

363 (figure 3 – scenario C), which represents a strong reduction when compared to the reference

364 scenario (52%, see figure 3 – reference). However, in both scenarios (A and C), the local

365 stakeholders never considered the possibility of a total disappearance of the rice crop, because

366 of its role in desalinating the soil through the irrigation system.

367 By contrast, in scenarios B (low climate change impacts) and D (high climate change

368 impacts), which are both economically favourable to rice production, rice cultivation

369 represents a large area (45% of arable land in scenario B and 75% in scenario D, figure 3).

370 Scenario B would, however, lead to the introduction of leguminous crops in rotation with the

371 main cereals while the remaining land primarily allocated to alfalfa (15% of the region's

372 farmland) and soya (15% of the region's farmland) (Figure 3 – scenario B). Durum wheat

373 would be cultivated under both conventional (5% of the arable area) and organic (7% of the

374 arable area) systems, but also intercropped with soya and alfalfa (4% and 6% of the arable

375 land, respectively). In scenario D, the increase of subsidies for rice and the increase of rice

376 yield due to climate change, lead to rice being the main crop in the region. This implies that

377 salt concentration in the soil would remain low and allow the cultivation of dry crops in most

378 area soils. The crops cultivated in rotation to rice would be sunflower (9% in conventional

379 and 2% in organic), pea (10% of the arable land) and wheat intercropped with soya in OF

380 (4%).

381 The four scenarios also projected different amounts of surface areas cultivated with organic

382 farming methods, ranging from 2,500 ha in scenario D to 12,300 ha in scenario C. Although a

383 larger percentage of surface area under organic farming would improve environmental

384 performances, it would decrease the area dedicated to rice cultivation, because the delay

385 between two successive crops is longer under organic systems than under conventional

386 systems, due to increased pressure from weeds (Delmotte *et al.*, 2011; Mailly *et al.*, 2013).

387 Scenario C would be the most favourable to organic production, since one of the adaptation

388 strategies was to convert to OF. That strategy led to a future with more than 40% of the

389 region's farmland being cultivated under organic standards. In all scenarios, the OF systems

390 would be based on rotations, primarily with rice, durum wheat and alfalfa, and possibly other

391 crops in smaller proportions (see for example Figure 3 – scenario C).

392 **3.2 Consequences of the scenarios on socio-economic indicators**

393 As a consequence of the changes in economic conditions and land use in the four scenarios,

394 the socio-economic indicators changed markedly in comparison with the reference (Figure 4).

395 At the farm level, the average gross margin increases in scenario A and B. It shows a slight

396 decrease in scenario C and a large decrease in scenario D. The increase in scenario A was due

397 to the high profitability of alfalfa in a situation that would be realistic should a market for

398 alfalfa develop. In scenario B, the gross margin would increase primarily as a result of high

399 prices for rice. In scenario C, the decrease in the average gross margin of the farms comes

400 mostly from reduced subsidies but also from a decrease in the market price of rice. Since the

401 prices of organic products in this scenario are only 20% greater than those of conventional

402 ones (Table 3), they would be unlikely to compensate for the losses in yield (previously

403 mentioned) occurring in a conversion to OF. In scenario D, the gross margin would drop due

404 to fewer subsidies and to the increase of production costs (e.g., water and energy costs). In the

405 four scenarios, the amount of subsidies available would decrease, from -25% in scenario D to

406 more than -50% in scenario C (Table 3). As a consequence, the dependency on subsidies

407 would decrease in all scenarios but D (In scenario D, the dependency to subsidies increase as

408 the share of revenue coming from the sale of the crop compared to the subsidies is lower in

409 proportion), and suggest an increase in farm financial autonomy. The cost benefit ratio, an

410 indicator of the dependency on external inputs, followed the same trend as the gross margin.

411 For example, in scenarios B and C, the cost benefit ratio would increase with the introduction

412 of leguminous crops, the diversification of the rotations and the conversion to organic

413 farming, requiring fewer inputs.

414 At the regional level, none of the scenarios would lead to a reduction of the total value of

415 production, which is an indicator of the economic well-being of the value chain. This

416 indicator remained stable in scenario C and increased approximately 50% in scenario A and B

417 due to the increased price of crops, and also in scenario D, from the increase in cultivated

418 surface area. The employment generated by agriculture would generally vary less than the

419 other indicators. In scenario A, it would remain stable, as the cultivation of alfalfa is as labour

420 intensive as rice. In scenario B and C, it would slightly decrease as a consequence of the

421 adoption of cropping systems with lower demand in terms of labour when compared to rice.

422 However, in scenario D, as rice cultivation increases, the employment would increase by
423 11%. Finally, indicators related to food production, both in terms of calories and proteins,
424 would greatly change between the scenarios. In scenario A and B, even if the total volume of
425 production would remain quite stable, these indicators would drop due to the fact that the
426 leguminous crops cultivated would be directed towards animal feed, which is less efficient in
427 terms of food production than cultivation for direct human consumption. In scenario C, the
428 same trend could be observed due to the lower yield of OF production impacting the total
429 volume of production, and leading to fewer crops to store and manipulate in the supply chain.
430 Scenario D is the only scenario where the potential food production would increase as well as
431 the total volume of production, due to the high yield of rice relative to the other crops.

432 **3.3 Environmental indicators**

433 Environmental indicators were also affected by the changes of cropping systems (figure 5). In
434 the case of scenarios A, B and C, there would generally be fewer environmental impacts, but
435 in the case of scenario D, the impacts would be higher than those in the reference situation. In
436 scenarios A and C, water consumption would be strongly reduced as a result of the decrease
437 in rice cultivation, which is the only irrigated cultivation in the Camargue. This reduction of
438 water consumption would also lead to important savings in terms of energy consumption from
439 water pumping. In scenario A, the other inputs would be considerably reduced, particularly
440 fertilizers (mineral nitrogen) and pesticides, which were both reduced by almost 75%. The use
441 of these two inputs would also be reduced by 50% in scenario B, and by 60% for mineral
442 nitrogen and 25% for pesticide use in scenario C. These reductions of inputs were attributable
443 to the diversification in crop rotation and particularly to the introduction of leguminous crops.
444 The energy consumption would also decrease in these three scenarios, from 30% in scenario
445 C to more than 50% in scenario A, due to the decrease of the energy consumption for water
446 pumping and nitrogen fertilizer synthesis. However, in these three scenarios the energy
447 efficiency evolves negatively, and would decrease from 10% to 15% as compared to the
448 reference scenario because the potential of food production in term of energy (calories) would
449 decrease more than the energy consumption. Finally, the atmospheric emissions of the
450 cropping systems would be lower in these three scenarios (A, B and C) as compared to the
451 reference situation, both in terms of GHG and particulate matter emissions. This is mostly due
452 to the lower use of inputs, but also to the reduction of flooded rice fields, which are associated
453 with high levels of GHG emissions through the burning of the straw in scenarios A and C. In
454 scenario C, the GHG and particulate matter emissions would be reduced by about 75% and
455 85%, respectively, as compared to the reference situation, suggesting that there is a large

14

456   room to manoeuvre the reduction of these environmental impacts. Finally, the scenario D was

457   the only one that would imply greater impacts on the environment from agricultural

458   production. Due to the increase in surface area of rice cultivation, the water consumption

459   would increase (approximately 35%), as would the pesticide use (+30%) and the energy

460   consumption (+14%). The mineral nitrogen use would be reduced by 12%, mostly due to the

461   lower consumption of nitrogen fertilizers by rice as compared to other cereals (particularly

462   durum wheat). The energy efficiency would increase, because the increase in energy content

463   of the production would be greater than the increase in energy consumption. However, as a

464   consequence of the increase in rice cultivation, the GHG and particulate matter emissions

465   would increase 32% and 39%, respectively.

466   **3.4 Synthesis**

467   The two scenarios that assume a low impact from climate change (scenarios A and B) lead to

468   different adaptations in land use, but presented similar assessment profiles. They both

469   suggested favourable economic and environmental situations, but with lower food production

470   potential (in terms of proteins and calories). The two scenarios that assume a high impact

471   from climate change (scenarios C and D) presented a strong contrast to scenarios A and B.

472   The scenario with high climate change impact and unfavourable economic conditions for rice

473   production (scenario C) favoured the environmental aspect at the expense of economic aspect

474   and food production potential. The scenario D with high climate change impact and

475   favourable economic conditions for rice production was the only scenario leading to an

476   increase of the regional potential for food production, however, at the expense of

477   environmental and economic aspects when compared to the reference and the three other

478   scenarios. Finally, none of the scenarios led to the improvement of all indicators, suggesting

479   the necessity of trade-offs between the different aspects of sustainability, as highlighted in

480   previous integrated assessments of agricultural scenarios (e.g., Gutzler *et al.*, 2015 ; Reidsma

481   *et al.*, 2015).

482   **4. Discussion**

483   We will focus the discussion on two main aspects: (1) the strong and weak points of our

484   approach as seen by the local stakeholders and (2) the use of bio-economic models for the

485   integrated assessment of narrative scenarios.

486   **4.1. Stakeholders' assessment of the method and results**

487   During the last workshop, the stakeholders provided feedback about the approach and results

488   of this study. They expressed that the four narrative scenarios were sufficiently contrasted to

489   highlight a range of possible strategies for adapting to various future contexts. The scenarios

490 were also seen as realistic representations of the possible evolutions in the Camargue's

491 agricultural systems. The analyses of scenarios led to further discussions about possible

492 adaptation strategies that the stakeholders considered logical at both farm and regional levels.

493 The stakeholders raised two main concerns with regards to the indicators used in assessing the

494 scenarios. Firstly, the indicators calculated to assess consequences on the economic welfare of

495 the agricultural sector, and particularly for the rice supply-chain, were simple proxies (e.g.,

496 the total value of production and the total volume of production). But the economic

497 performance of a sector may not be linearly linked to the field or farm-based outputs,

498 therefore more complex analyses of the impacts on the supply chain in each scenario could be

499 beneficial. Secondly, although the indicators related to the potential for food production were

500 seen as positively highlighting the contribution of regional agriculture to global issues of food

501 security, they lacked attention to the qualitative aspect of human food systems (i.e., food

502 safety). Indeed, food safety in Europe is likely to be affected by climate change, suggesting

503 the need for more inclusive approaches, from the farm to the table, in which the different

504 aspects of food quality are taken into account (Miraglia *et al.*, 2009).

505 The stakeholders particularly emphasized two positive aspects of the methods used in this

506 study. The first one is related to the relevance of the scenario development method itself.

507 Collectively developed scenarios was seen as an effective way to support the contemplation

508 and sharing of perspectives among stakeholders, considering what *could* happen, rather than

509 what *will* happen. Local stakeholders therefore acknowledged the explorative nature of the

510 methods and results of this study. The second aspect concerned the use of the quantitative

511 results to anticipate future changes of context in order to better adapt. They mentioned the

512 possibility of using these results in negotiations about public subsidies at the national level.

513 This was particularly the case with "Subsidizing local constraints" in scenario D, where

514 stakeholders explored the consequences of the Camargue being classified as a *less favoured*

515 *area* leading to subsidies equal to the payment they received for rice before the 2012 CAP

516 reform. This scenario led to higher rice production, which could contribute to food security,

517 but at the expense of the farms' gross margins. One of the local stakeholders was considering

518 using these results to highlight the "absolute need" of both re-establishing a specific subsidy

519 for rice (he considered elimination of the previous subsidy to be a "wrong decision made by

520 the French government"), and obtaining new subsidies related to the specific (salt) constraints

521 in the Camargue.

522 Scenario development and evaluation has often been used to inform decision-making in the

523 development of public policies and objectives (normative scenarios, Wilkinson and Eidinow,

524 2008) or to explore the impact of policy choices (e.g., Therond *et al.*, 2009). Such studies,

525 however, are usually performed in a top-down approach where governmental actors, either at

526 the local or the national levels, examine the consequences of policy options previously

527 developed (e.g., Therond *et al.*, 2009 ; Gutzler *et al.*, 2015). One of the strong points

528 identified by the stakeholders in the development and application of the methods presented

529 here was the bottom-up approach for scenario development. They felt that this approach gave

530 them a clear view and understanding of the content and scope of the scenarios, and helped

531 them imagine the potential use of these scenarios in their future decision-making and

532 negotiating. This approach could be further completed by backcasting exercises consisting in

533 fixing first the situation the stakeholders want to reach in the future ("desirable future") and

534 then the necessary steps (i.e., changes) to attain such future (Holmberg and Robèrt, 2000).

535 In this study, we chose to work with a relatively small group of stakeholders that was already

536 known from past studies in this area (Delmotte *et al.*, 2016). We chose to put the emphasis on

537 building a small group of people to ensure that the group would remain stable all over the

538 process, in order to promote a more systemic view (Petersen et al., 2004). Our choice also

539 helped to run the process in a continuous manner in a relatively short period of time. We

540 nevertheless consider that the stakeholders who participated were representative of the

541 diversity of the local farming community and of the issues of rural development (e.g., two

542 participants were also farmers). Working with a larger group of stakeholders could have been

543 beneficial to ensure that the whole diversity of point of views would be considered. However,

544 it would probably have been more difficult to manage in terms of organizing the meeting and

545 ensuring the group stability at each step of the process.

546

547 **4.2. Model-based assessment advantages and limitations**

548 The integrated assessment of the narrative scenarios in this study was conducted with a bio-

549 economic model. Bio-economic models have been widely used in agricultural sciences to

550 assess scenarios and support decision-making (see Janssen and van Ittersum (2007); Delmotte

551 *et al.*(2013)). The usefulness of bio-economic models for such studies is based primarily on

552 their capacity to account for the variability in performance (e.g., yield) with respect to area

553 and time period (e.g., soils characteristics of an area, and climate during a time period)

554 (Flichman, 2002).

555 Their use, however, is governed and limited by currently available data. In our study, the

556 alternative agricultural activities relied strictly on known practices and the available data on

557 inputs and outputs (e.g., organic production techniques, intercropping systems). Other

558 innovations were not included in the bio-economic model due to the lack of available data on

559 their performance (e.g., cultivation of new crops like sweet potato or lettuce). Similarly, our

560 bio-economic model did not explicitly include the livestock rearing activities. Livestock

561 requirements in forage were translated into model objectives or constraints, in order to

562 account for the influence of these activities on the surface area devoted to local cultivation.

563 This implicit representation did not, however, allow the representation of an evolution in

564 livestock activities in the indicators even though they are a central element in scenario A.

565 Although crop and livestock activities are not tightly interlinked in Camargue, further work is

566 needed to formalize the performance of livestock activities and include them in the bio-

567 economic model to enable the exploration of future scenarios that include related adaptation

568 strategies.

569 We used multiple goal linear programing in our bio-economic model to develop an optimal

570 solution for each scenario. The resulting land uses and performances were determined by

571 choosing the objective function (to be minimized or maximized) depending on the narratives

572 built by the stakeholders. Different functions were used for each scenario, including the

573 maximization of gross margin, forage production, or food production, and the minimization of

574 greenhouse gas emissions. This innovative approach was driven by the intensive participation

575 of stakeholders in the study, notably for the translation of the scenarios in the model

576 (Mallampalli *et al.*, 2016). In most studies using bio-economic modelling for agriculture, the

577 objectives are linked to the maximization of farm profitability (e.g., van Calker *et al.*, 2004;

578 Gutzler *et al.*, 2015), or to a compromise between profitability and another performance (e.g.,

579 minimizing a negative environmental output) through multi-objective linear programming

580 (e.g., Groot *et al.*, 2012).

581 Linear programming models are often accused of being a "black-box" for stakeholders,

582 making direct interactions with stakeholders difficult (Sterk *et al.*, 2007). This issue was not

583 emphasized by the stakeholders in our study, which on the contrary acknowledge the

584 usefulness of the approach to stimulate a shared vision of the future. This may be due to (1)

585 the initial legitimacy of the research team, and its history of long-term research in the

586 Camargue (as highlighted in e.g., Sterk *et al.*, (2006)), (2) previous experience with the bio-

587 economic model among most of the stakeholders who participated in this study (Delmotte *et*

588 *al.*, 2016) and (3) the time taken with stakeholders to contextualize the results in terms of

589 indicators, farm types, etc. (e.g., Blazy *et al.*, 2009). Their participation into the translation of

590 the narrative scenarios to the quantitative assessment was probably key to ensure their

591 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° 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

626   in the Camargue region of southern France. The scenario narratives designed by local
627   stakeholders were then translated in inputs for a bio-economic model, allowing the integrated
628   assessment of the consequences of these scenarios on agricultural systems. The two main
629   drivers of change of the scenarios were related to climate change and economic conditions for
630   rice production. At the regional level, the four scenarios showed significant differences in the
631   acreage of farmland cultivated (28,000-33,000 ha), the proportion of area under rice (19-75%)
632   and the areas cultivated under organic farming (8-43%). These changes implied large
633   contrasts between the scenarios assessed on the basis of 16 socio-economic and
634   environmental indicators. The four scenarios showed trade-offs between these indicators. The
635   method used and the information generated were found relevant by the stakeholders, who
636   acknowledged the interest of the approach for anticipating possible futures, and assisting on-
637   going and future negotiations with policy-makers.
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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.
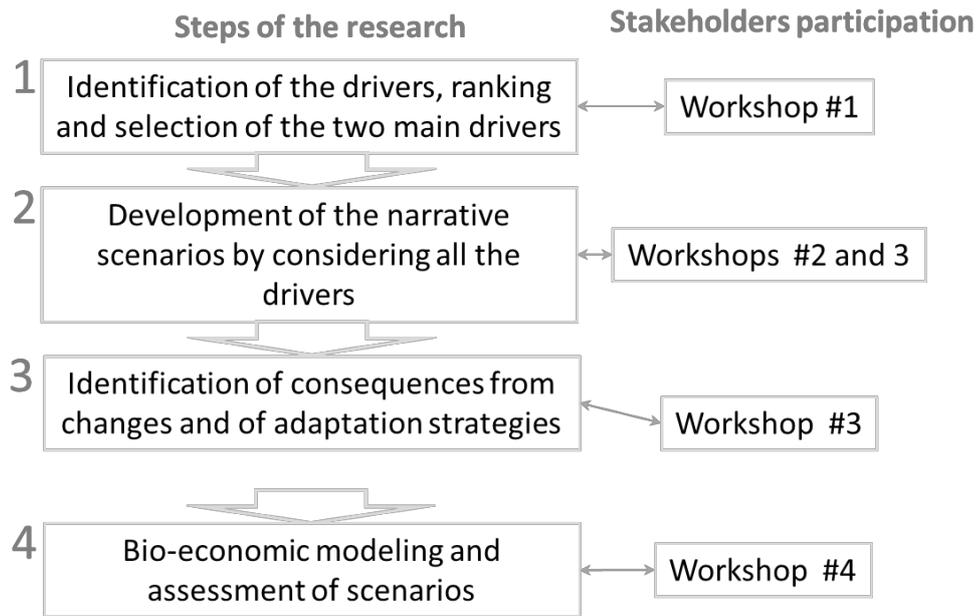
Scenario C. Coexistence of opposites: Differentiating farming systems to intensive or organic

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
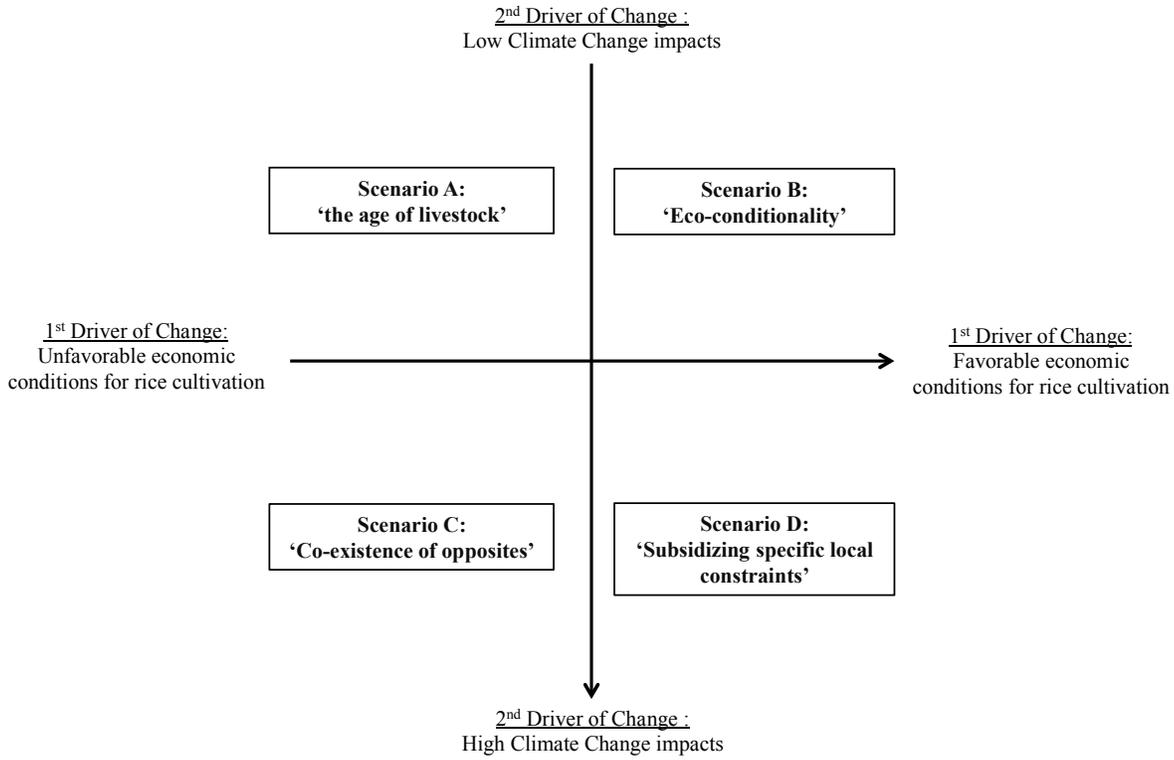
receive are single farm payments, uniformly distributed between farms. Because of the development of organic farming, new species are introduced in the rotation: soft wheat, maize, sorghum, lentils, old varieties of durum wheat. Additionally, a local tomato processing industry increases its capacity 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.

Steps of the research

Stakeholders participation

1 | Identification of the drivers, ranking and selection of the two main drivers → Workshop #1

2 | Development of the narrative scenarios by considering all the drivers → Workshops #2 and 3

3 | Identification of consequences from changes and of adaptation strategies → Workshop #3

4 | Bio-economic modeling and assessment of scenarios → Workshop #4

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

2nd Driver of Change :
Low Climate Change impacts

Scenario A: **'the age of livestock'**	**Scenario B:** **'Eco-conditionality'**

1st Driver of Change:
Unfavorable economic
conditions for rice cultivation

1st Driver of Change:
Favorable economic
conditions for rice cultivation

Scenario C: **'Co-existence of opposites'**	**Scenario D:** **'Subsidizing specific local constraints'**

2nd Driver of Change :
High Climate Change impacts

Figure 2. Scenario orientation for the two main drivers of change : (1) Economic conditions for rice cultivation, and (2) Climate change impacts.
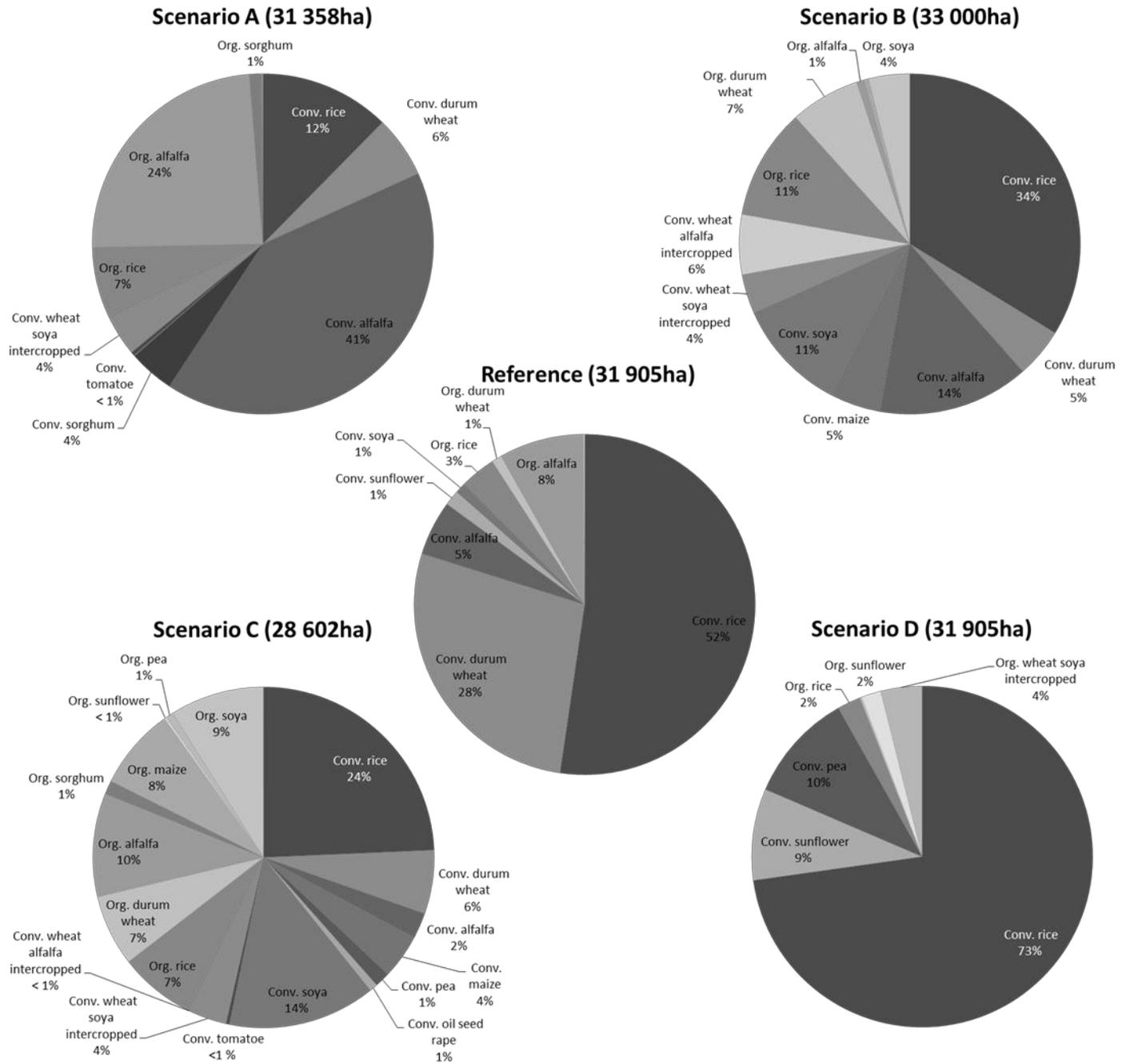
Figure 3. Land use at the regional level for the reference situation and for the four scenarios. The numbers between brackets indicate the total cultivated area at the regional level. The proportion of land use is indicated for each crop.
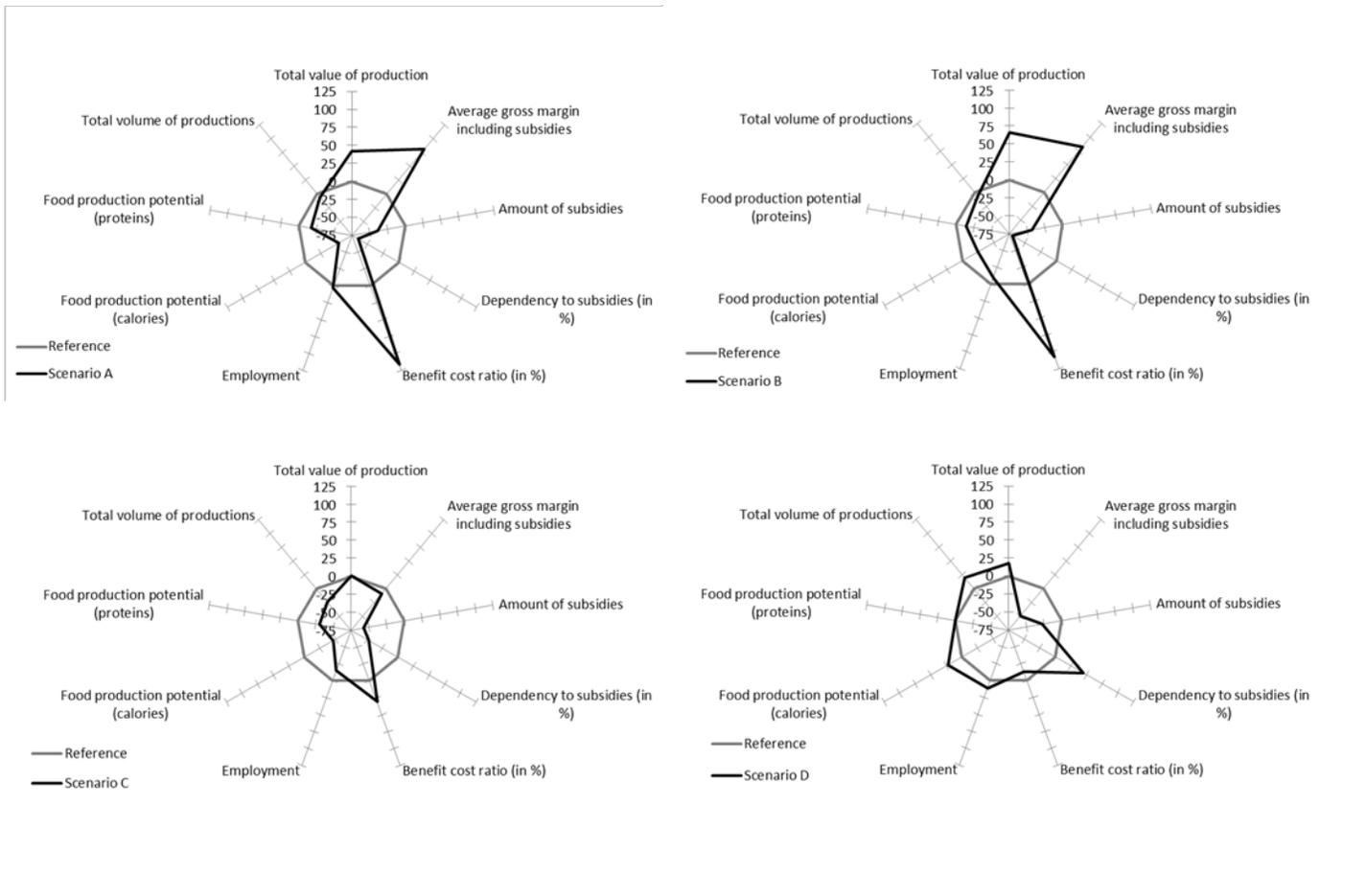
Figure 4. Radar diagram comparing the socio-economic indicators values for the reference situation (values at 0, in grey) and for each of the four scenarios.
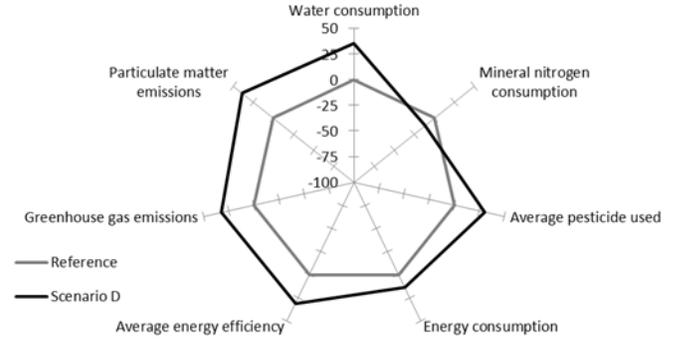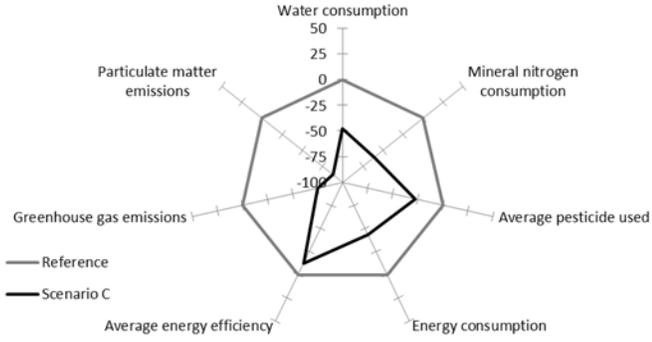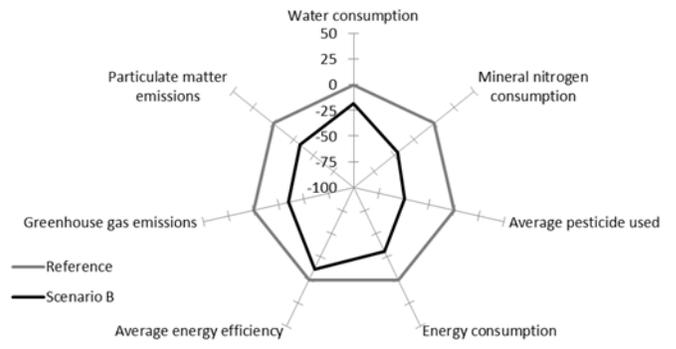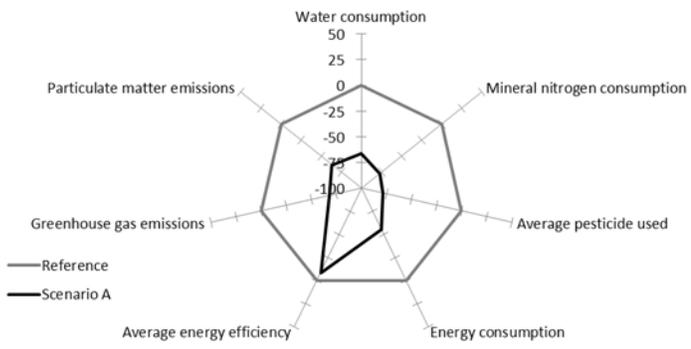
Figure 5. Radar diagram comparing the environmental indicators values for the reference situation (values at 0, in grey) and for each of the four scenarios.

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.

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

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).

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[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.

References cited in the appendix 1:

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.

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

Reference situation	
Objective function	Maximize gross margin
Subsidies	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.
Prices of production	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.
Difference of prices between organic and conventional productions	60%
Maximum area in organic farming	Crop producer (small: 0%, medium : 0%, large: 6%) : , organic crop producer: 100%, livestock farmer (conventional : 10%; organic: 100%)

Constraints on crops

Farm types	Minimum proportion of... (in % of farmland surface area)			
	Rice	Alfalfa	Durum wheat	Oil seed rape and soya
Organic crop producer	25	9	46	7
Large size crop producer	60	0	28	1
Medium size crop producer	54	0	32	3
Small size crop producer	34	0	25	3
Livestock farmer	35	12	29	0
Organic livestock farmer	10	42	17	0