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

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Abstract

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

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

Introduction

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

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

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

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

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

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

Material and methods

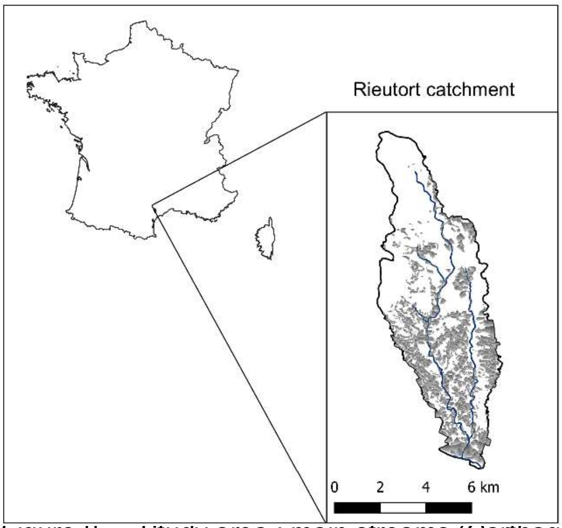


Figure 8 — Study area : main streams (Carthage BD) and vineyard plots (RPG 2017) in grey

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

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

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

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

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

Step 1: Conceptualization Phase

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

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

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

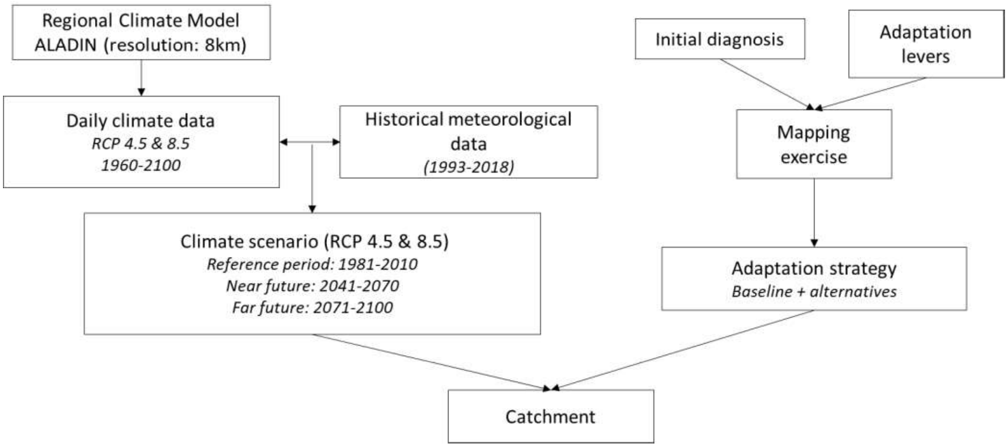
Step 2: Scenario Building

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

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

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

Figure 10—General scenarios' framework



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

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

Step 3: Quantitative Modeling

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

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

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

Preliminary results

Stakeholders identification

Table 8 — Involved stakeholders

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

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

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

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

Initial diagnosis

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

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

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

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

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

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

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

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

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

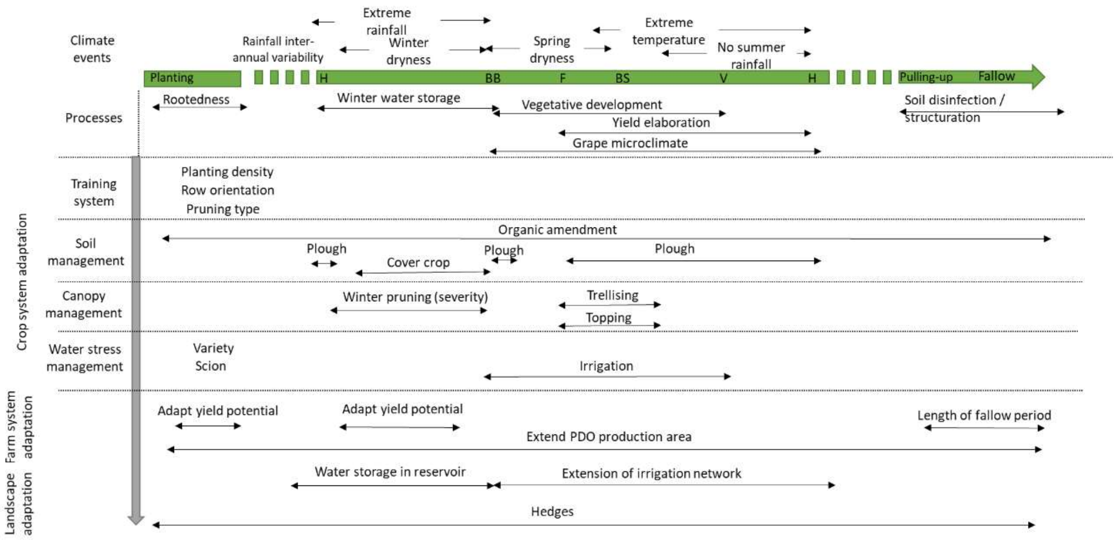


Figure 11—Adaptation options proposed by the stakeholders along grapevine cycle : BB = bud break, F = flowering, BS = berry set, V = veraison, H = harvest

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

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

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

Conceptual Model

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

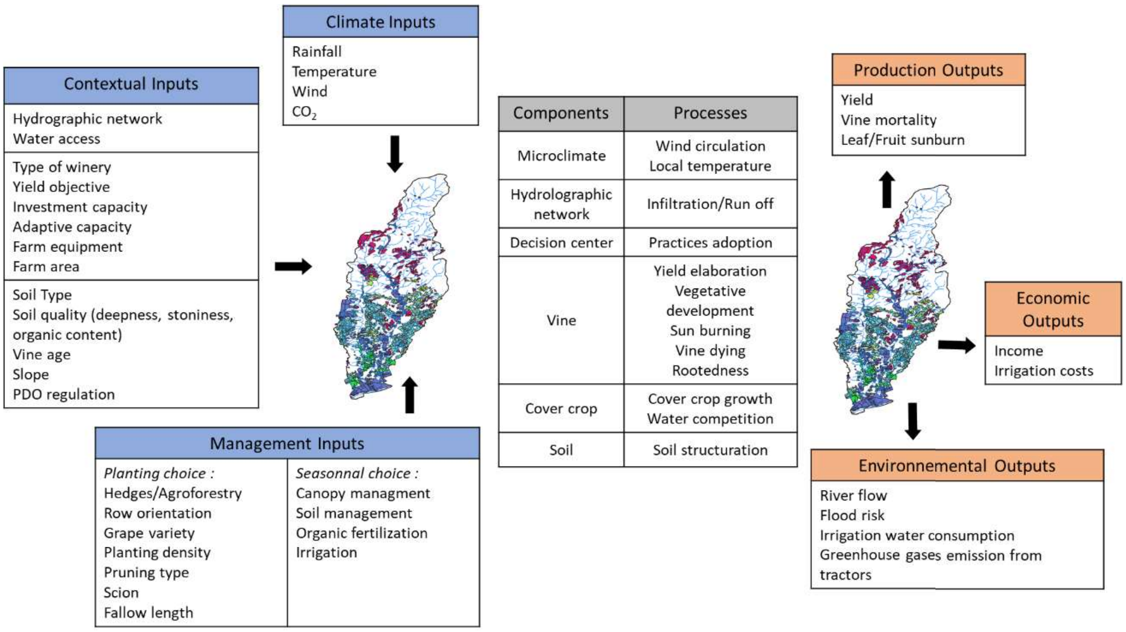


Figure 12—Conceptual model of a viticulture catchment under climate change. On the left, model inputs. In the middle, the model components with associated processes. On the right, model outputs.

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

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

Discussion

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

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

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

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

Conclusion

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

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