ANALYZING CLIMATE CHANGE ADAPTATION IN THE AGRICULTURE AND THE WATER SECTORS: SCREENING FOR RISKS AND OPPORTUNITIES

CONSUELO VARELA-ORTEGA[1], *IRENE BLANCO-GUTIÉRREZ*[1], *PALOMA ESTEVE*[1]
Universidad Politécnica de Madrid

SUKAINA BHARWANI[2]
Stockholm Environment Institute

THOMAS E. DOWNING[3]
Global Climate Adaptation Partnership

STEFAN FRONZEK[4]
Finnish Environment Institute

ABSTRACT

As part of the Mediterranean area, the Guadiana basin in Spain is particularly exposed to increasing water stress due to climate change. Future warmer and drier climate will have negative implications for the sustainability of water resources and irrigation agriculture, the main socio-economic sector in the region. This paper illustrates a systematic analysis of climate change impacts and adaptation in the Guadiana basin based on a two-stage modeling approach. First, an integrated hydro-economic modeling framework was used to simulate the potential effects of regional climate change scenarios for the period 2000-2069. Second, a participatory multi-criteria technique, namely the Analytic Hierarchy Process (AHP), was applied to rank potential adaptation measures based on agreed criteria. Results show that, in the middle-long run and under severe climate change, reduced water availability, lower crop yields and increased irrigation demands might lead to water shortages, crop failure, and up to ten percent of income losses to irrigators. AHP results show how private farming adaptation measures, including improving irrigation efficiency and adjusting crop varieties, are preferred to public adaptation measures, such as building new dams. The integrated quantitative and qualitative methodology used in this research can be considered a socially-based valuable tool to support adaptation decision-making.

KEYWORDS

Climate change, water resources, agriculture, downscaled climate projections, integrated hydrologic-economic modeling, Analytic Hierarchy Process.

[1] *Departamento de Economía y Ciencias Sociales Agrarias, Universidad Politécnica de Madrid. Avda. Complutense s/n – 28040 Madrid, consuelo.varela@upm.es, irene.blanco@upm.es, paloma.esteve@upm.es*

2 Stockholm Environment Institute (SEI), Oxford Office, Florence House, 29 Grove Street, Summertown, Oxford, OX2 7JT, UK, sukainabharwani.sei@gmail.com

3 The Global Climate Adaptation Partnership (GCAP), Oxford Centre for Innovation, New Road, Oxford, OX1 1BY, UK, tdowning.cc@gmail.com

4 Finnish Environment Institute (SYKE), Box 140, 00251 Helsinki, Finland, Stefan.Fronzek@ymparisto.fi

1. Introduction

Adaptation to climate change impacts has become a major source of concern for human development and for ecosystem conservation. Whatever the warming scenarios and regardless of the success of mitigation measures, climate change will increase in the coming decades due to past greenhouse gas emissions and the inertia of the climate system (EC 2013; IPCC 2001). Thus, increase focus has been placed on how adapt to the inevitable impacts of climate change in order to avoid the economic, environmental and social damage they can cause. In this changing natural and social environment it becomes crucial to know how decisions are taken, how they may evolve over time and how different actors are involved in such decisions. Within the scientific community, considerable efforts are devoted to addressing various aspects of climate change, including studies on how to best adapt to future climatic conditions given the uncertainty associated with climate prediction (Pielke et al., 2007; Reidsma et al., 2010; Swart et al., 2009, among many others).

The process of adaptation is generally framed in a four-stage iterative learning cycle as described in the PROVIA guidance (UNEP, 2013): 1) appraising climate change vulnerability and impacts; 2) selecting and appraising adaptation options; 3) implementing adaptation options, and; 4) monitoring and evaluation adaptation action and learning. However, this general frame has to be adjusted to a particular adaptation situation as it effectiveness will depend on the local specificities of every region, country and social group.

This paper presents a systematic analysis of the process of adaptation to climate change structured along the first two general stages of the adaptation learning cycle. The research identifies the key risks and opportunities associated to long-term climate change by exploring the future impacts of climate change and evaluating stakeholder preferences on alternative adaptation options. The assessment of climate change impacts was carried out by the use of regionalized climate change scenarios and the development of an integrated modeling framework that includes an on-farm economic model and a basin-wide hydrologic model. In particular, the application of integrated hydro-economic models and the incorporation of economic principles, concepts and instruments into environmental management are steadily gaining attention (Harou et al., 2009). The combination of economic insights with hydrology and engineering processes in water modeling provides a more realistic and coherent framework to analyze the economic and environmental consequences of climate and policy changes for households, farms, and business firms and for aquatic ecosystems (Brouwer and Hofkes, 2008). Hydro-economic models can better inform policy-makers regarding to the more efficient use of water resources and the optimization of water allocation among competing uses and users (Medellín-Azuara et al., 2009), which will undoubtedly lead to more rational decisions on water planning, investment and financial operations, policy design and implementation (Ward and Pulido-Velázquez, 2008).

Hydro-economic models have been successfully applied as a research tool to study and simulate climate change impacts (see Medellín-Azuara et al., 2008; Connell-Buck et al. 2011; Hurd and Coonrod, 2012; Jiang and Grafton, 2012; Qureshi et al., 2013). This study follows a modular approach which implies that the hydrology and economic models are independent and that only the input/output data are exchanged between them. Among others, Ahrends et al. (2008) and Bharati et al. (2008) coupled the hydrology model WaSIM with a non-linear economic model in the Volta Basin (West Africa); Quinn et al. (2004) integrated the hydrology model CALSIM II with the economic model APSIDE in the San Joaquin basin (California); Maneta et al. (2009) coupled the hydrology model MODHMS with a positive mathematical programming model in the São Francisco River in Brazil; Qureshi et al. (2008) integrated the hydrology model MODFLOW with a liner mathematical programming model in the Burdekin delta in Australia; Volk et al. (2008) coupled the hydrology model SWAT with a linear economic model, BEMO, in the Upper Ems River Basin in Germany.

evaluating the usefulness and potential for success of adaptation options.

As a next step and in view of the projected impacts of climate change, the Analytic Hierarchy Process (AHP), a multicriteria technique, was used to select and rank alternative policy planned adaptation options related to the water and the agricultural sectors. The AHP method was developed in the early 1980s (Saaty, 1980) to help decision-makers find the option that best suits their goal and understanding of the 'problem'. While it has been used in a wide variety of fields (e.g. engineering, business strategic management, education, quality assessment) it also has benefits for the analysis of climate adaptation related decisions since it is most useful where a range of stakeholders are dealing with problems with a high degree of complexity, uncertainty and risk, involving human perceptions and judgments, whose resolutions have long-term repercussions. It has advantages when important elements of the decision are difficult to quantify or compare, or where communication among stakeholders is impeded by their different agendas, terminologies, or perspectives. When applied to climate adaptation the method can be used to compare a set of adaptation options against a set of criteria using participants' experience and judgment about the issue at of concern. It allows the comparison of diverse elements that are often difficult to measure in a structured and systematic way (AHP measures intangibles in relative terms) and permit to evaluate the usefulness and potential for success of adaptation options.

Though its first applications in field of climate change were in the context of the global negotiations (Ramanathan, 1998) and mitigation policy instruments (Konidari and Mavrakis, 2007), AHP has been used increasingly in the field of climate adaptation. For example, it has been applied using a participatory approach for the integration of indigenous knowledge for adaptation strategies in the Tabasco Plains of Mexico (Ponce-Hernandez and Patel, 2011), or in the evaluation of adaptation options for human settlements in South East Queensland (Choy et al., 2012), the integration with GIS modeling to look at crop impacts in Australia (Sposito, 2006), or for storm surge and sea level rise in Canada and Caribbean (Lane and Watson, 2010). Yin et al (2008) apply AHP to evaluate adaptation options for the water sector, in the Heihe River Basin in north-western China, resulting in institutional options for managing water demand (imposing constraints on large consumers, water conservation initiatives through water user associations and transferrable water allocation permits) ranking higher than engineering options to increase water supply.

This paper offers an integrated quantitative and qualitative methodology to study different aspects of the adaptation cycle that can be considered a socially-based valuable tool for supporting decision making in climate change adaptation. The different stages of the adaptation cycle are usually studied separately, while they are in fact the two sides of the same coin. In this paper, the range of impacts and implications of climate change are analyzed together with the appraising of several adaptation options within a local specific situation, the Middle Guadiana basin. Although the study is site-specific and reflects a particular adaptation situation, the methodology here developed can be easily replicated and applied in other areas.

2. Study site

As part of the Mediterranean area, the Guadiana basin, in south-central Spain (Fig. 1), is experiencing increasing water stress which is expected to further increase under climate change scenarios (CEDEX, 2011).

The Guadiana Basin is expected to be one of the basins most negatively affected by climate change in the country. Future climate projections suggest a decrease in precipitation, an increase in evaporation and more frequent and more intense droughts. As a consequence, the annual Guadiana river inflow could be reduced by 9-12% until the period 2011-2040 relative to 1961-1990 conditions (CEDEX, 2011). This will have dramatic implications for the sustainability of water resources and for agriculture, which mainly depends on irrigation and represents the main socio-economic sector in the region. Temperature increase will affect crop yields but whether it will be a positive impact or negative remains unclear as it will depend on several factors such as fertilization produced by increased CO_2 concentrations in the atmosphere, extreme temperatures and water availability, among others. Moreover, the decrease in water availability will make agricultural systems even more dependent on irrigation. Projected climate changes will affect the extension and productivity of irrigated agriculture, which is the most important water-withdrawing sector. Climate change will also exacerbate the ongoing environmental degradation linked to the overexploitation of water resources.

In particular, the study focuses on the Middle Guadiana basin, an area of approximately 27000 km^2 located in the Autonomous region of Extremadura (see Fig. 1), The middle Guadiana irrigation agriculture is based on surface water, and it is characterized by the existence of a large number of reservoirs with a total storage capacity of 9000 Mm^3. In spite of this buffering capability, climate change predictions are foreseen to have the largest impacts on the agricultural sector, due to the expected reduction on water availability, increased evapotranspiration and reduction in crop yields.

Policy makers at national and regional levels face the challenge to design adequate climate change adaptation strategies to cope with these impacts. Local circumstances are of key importance when developing regional adaptation plans (Krysanova et al., 2010). Adaptation options provide a way to cushion the adverse effects of climate change. Thus, increasing attention has been paid to the need to integrate climate change adaption into decision-making.

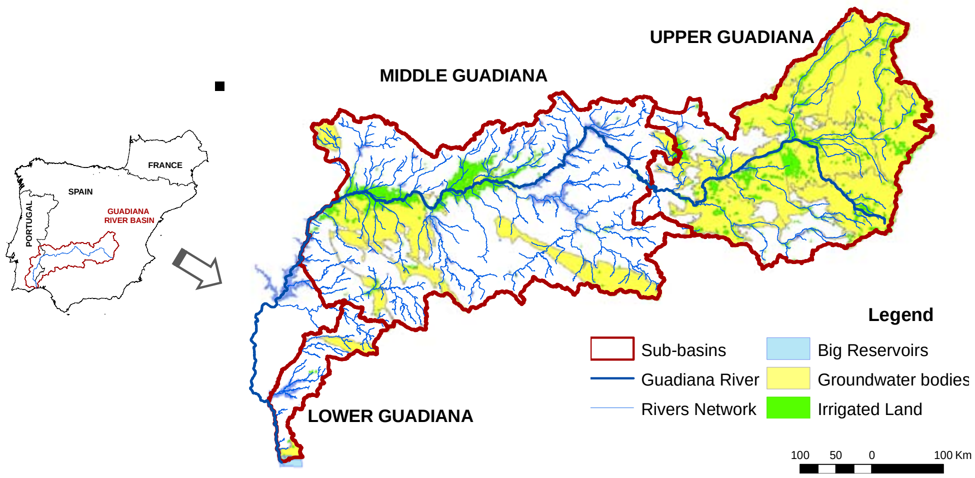

Fig. 1. Location and physical characterization of the Guadiana basin.
Source: Blanco (2010)

3. Data and methods

The modeling approach, summarized in figure 2, follows the diagnostic framework for problem-oriented adaptation research developed in the Mediation Project[4] (Hinkel and Bisaro, 2013). It involves a two-stage process:

a) In the first stage, an integrated modeling framework that includes an economic and a

[4] MEDIATION (Methodology for Effective Decision-making on Impacts and AdaptaTION). Small of medium scale focussed research project. FP7, European Commission. DG Research. Contract nº 244012 (http://mediation-project.eu/).

hydrologic model is proposed to analyze the potential impact of climate change on water and agriculture. As Global Climate Models (GCMs) used to simulate present and future climate are generally not designed for local or regional climate change impacts studies, downscaling techniques were applied to capture sub-grid scale phenomenon (such as precipitation and temperature) from 1971 to 2069 at the local scale.

b) In the second stage, a participatory multi-criteria decision-making process is followed to select potential options for adaptation, identify criteria for the selection of the best options and establish a priority ranking of adaptation options, using the Analytic Hierarchy Process (AHP) technique. Through this participatory decision-making process, we ensure that selected strategies are relevant and socially acceptable for stakeholders.

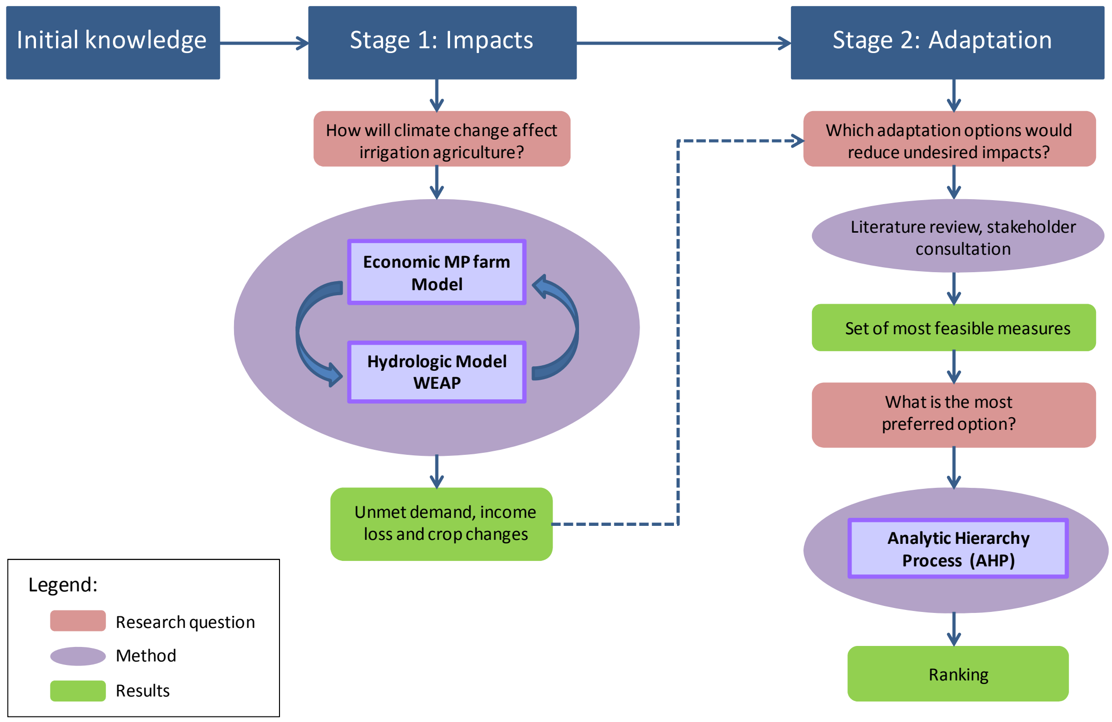

Fig. 2. Methodological scheme

Downscaling climate change scenarios

Agriculture and water resources sustainability in Guadiana basin are threaten by projected climate change effects. Climate projections for the 21st century have been obtained from the Third Coupled Model Intercomparison Project (CMIP3, Meehl et al. 2007) for simulations of two General Circulation Models (GCMs), BCCR-BCM2.0 from the Bjerknes Centre for Climate Research, Norway, with SRES B1 forcing and CNRM-CM3 from Météo France with SRES A2 forcing and with historic forcing for the 20th century. These have been selected to represent the range of changes in the study region as simulated by a larger ensemble of

GCMs, showed in Fig. 3. BCCR-BCM2.0/B1 lies at the lower end of long-term changes in temperature and precipitation, whereas CNRM-CM3/A2 is warm and dry end of the range of changes. Long-term mean changes in the study area between 1971-2000 and two future periods, 2010-2039 and 2040-2069, were calculated as absolute changes for monthly mean temperature, wind speed and vapor pressure and as relative changes for precipitation and global radiation. Changes were applied to the observed time-series of the period 1971-2000, thus replicating the observed variability, to create 30-year time-series for the two future periods.

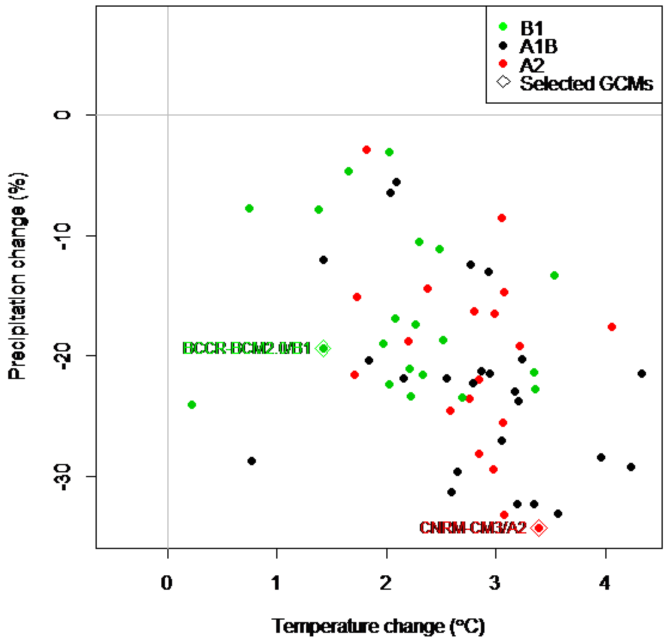

Fig. 3. Annual changes in air temperature and precipitation for the Guadiana basin, Spain, between the periods 2040-2069 and 1971-2000 with an ensemble of GCMs.

Integrated modeling for assessing climate change impacts

To examine how different climate change scenarios will affect natural as well as socio-economic conditions, we used an integrated modeling framework that includes the hydrologic model WEAP and a non-linear mathematical programming economic model of constrained optimization.

- Hydrologic model

The WEAP model (Yates et al. 2005 a, b) simulates water balance components (transpiration, evaporation, runoff, infiltration, percolation) and the performance of engineered systems (irrigation canals, reservoirs), and therefore, it is well-suited to analyze agricultural water demands.

Within WEAP, different catchment calculation methods can be used. In this research we use the MABIA crop module (Sahli and Jabloun, 2005) that simulates irrigation catchment performance. The WEAP-MABIA method permits not only to look at the effects of climate change on water resources but also to assess the impacts on crop physiology. It specifically simulates daily evaporation and transpiration, crop growth, yields and irrigation requirements. The MABIA Method uses the 'dual' crop coefficient Kc method, as described in Allen et al. (1998), whereby the Kc value is divided into a 'basal' crop coefficient, Kcb, and a separate component, Ke, representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration. In this way, MABIA is an improvement over CROPWAT, which use a single Kc method, and hence, does not separate evaporation and transpiration.

The WEAP-MABIA method computes daily water mass balances within each catchment considering two buckets or soil compartments. The top bucket is defined by the rooting zone, and includes the surface layer (the layer that is subject to drying by evaporation). The bottom bucket is the remainder of the soil below the rooting depth down to the total soil thickness and represents the slower hydrologic response in a basin. Transpiration, evaporation, runoff, and infiltration, takes place at the top bucket only, baseflow is generated from the bottom bucket only. Flow from bucket one to bucket two only occurs if the bucket's field capacity is exceeded.

- Economic model

The economic optimization model of farm-decision making developed for this research built upon previous studies (Blanco-Gutiérrez et al., 2011; Blanco-Gutiérrez et al., 2013; Esteve, 2009; Varela-Ortega et al., 2011), but it has been modified, adjusted and recalibrated to simulate climate change scenarios. It is used in combination with the WEAP model to analyze crop pattern changes and to examine the socio-economic effects of climate change. The model simulates farmers' behavior. Based on Von Neuman and Morgenstern's theory (1944), we assume that farmers are rational, self-interested individuals who try to maximize their 'expected' utility subject to one or more constraints. In the present study, the objective function corresponds to the farm income minus a variation of that income due to fluctuations in price and production output.

$$MaxU = \sum_f Z_f - \phi_f \sigma_f$$

; where U is the regional expected utility (at the IC level), Zf is the average net income by farm type, ϕ_f is the risk aversion coefficient, σ_f is the standard deviation of income.

The objective function is subjected to land, labor, water and policy constraints: $g(x) \in S_1$; $x \in S_2$; where x is the set of production activities defined by a combination of crop types, production techniques, soil quality, and farm types.

Without risk of failure, farmers would maximize their expected utility as if they relied only on farm revenue. However, risk situations (changes in crop yields and crop prices due to climatic and market fluctuations) often occur forcing farmers to adopt less risky cropping patterns which may imply sacrificing part of the farmers' potential income.

- Integration

Model integration permits to upscale climate and policy impacts at the farm and irrigation community level to the basin and look at how changes in different agricultural systems affect the total agricultural water demand and the hydrological system. Reversely, it also allows for downscaling the effects of bio-physical processes that occur at the basin and sub-basin levels, such as the impact of climate change on water resources, to the irrigation community and farm levels. This way, model integration addresses the multi-scale nature of climate change risks and opportunities.

The integration of models is based on the use of one model's outputs as inputs for the other model and vice versa. Here, the economic model runs first, providing farmers' crop choice under specific current or future environmental and policy constraints. Then, using cropping patterns, WEAP simulates the hydrology system function, water supplies, crop growth, evapotranspiration and irrigation requirements and the overall demand satisfaction. In a second iteration, the economic model uses WEAP results on water availability at the irrigation community level, crop yields and irrigation requirements for simulating farmers' optimization of cropping patterns. Finally WEAP runs again for simulating the effects of those optimized crop choices on the water system.

Multicriteria analysis for appraising adaptation options

To select and appraise different adaptation options we have developed a participatory multi-criteria decision-making process, using the Analytical Hierarchy Process (AHP) technique, which is a structured method of pair-wise comparison that helps decision-makers facing a complex problem with multiple conflicting and subjective criteria (Iszhaca & Labib, 2011).

The process began by specifying the adaptation strategies that are being considered by policy-makers in the adaptation to climate change. This step provided the starting point for stakeholder-driven evaluation and prioritization of potential adaptation strategies. The analysis explored the different options considered in the climate change adaptation plans at the national and regional to increase the resilience of the water and agriculture sectors in view of the projected impacts of climate change. In this context, and given the importance of agriculture for the local economy and the vulnerability of the sector against climatic variations, the Government of Extremadura initiated its Strategy against Climate Change in 2009, which resulted into the Climate Change Adaptation Plan for the Agricultural Sector (Junta de Extremadura 2011). The Plan aimed to identify the main impacts on the sector and define adaptation measures to guarantee its viability, minimizing the negative consequences of climate change as well as maximizing the new opportunities brought about this process. The Plan contains a number of programs of measures aimed to adapt agricultural production in Extremadura to the new climate reality, including: (i) increasing water availability; (ii) management and planning of new crops; (iii) reduction of vulnerability against extreme climate conditions; (iv) plant health; (v) research and development; (vi) training and Information for farmers; (vii) leveraging positive impacts.

Drawing from these programs and their specific measures, the research team started the design of an AHP exercise aimed to prioritize different adaptation options for the agricultural sector in the Guadiana River Basin. In order to develop this exercise, we defined the problem under analysis, this is "Adaptation of the agricultural sector to climate change in the Guadiana River Basin", set the list of options under evaluation and choose the criteria that will inform our decision. Four OPTIONS were identified according to their feasibility and their relevance for the area under study based on the authors' extended research expertise in the area (Blanco-Gutiérrez et al., 2011; Carmona et al., 2011; Krysanova et al, 2010; Varela-Ortega et al, 2008, 2011) and following advice from relevant experts and stakeholders with knowledge and previous experience in the region:

Option 1: Improving technical efficiency in the use of water

Option 2: Increasing reservoir storage capacity

Option 3: Choosing species and crop varieties best suited to the new climate conditions

Option 4: Creation of agricultural insurance systems

The criteria were chosen based again on expert opinion and literature reviews on adaptation to climate change following multi-criteria decision de Bruin et al., 2009; Mesaa et al., 2008; Miller and Belton, 2011; Parra-Lopez et al., 2008). As a result, the following criteria were identified:

Criterion 1: Legal and political implementation feasibility

Criterion 2: Capacity to generate employment

Criterion 3: Financial feasibility

Criterion 4: Increase in farm income

Criterion 5: Speed of implementation

Criterion 6: Protection of environmental resources

Second, we constructed the Decision Hierarchy with the elements defined in the previous step (Fig. 4).

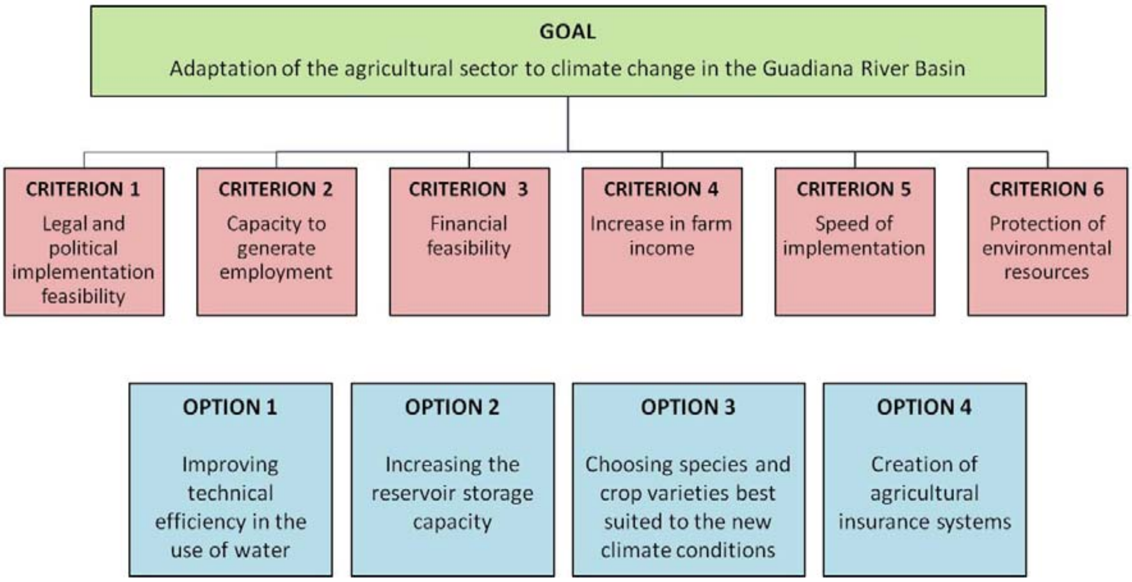

Fig. 4. Hierarchical decision tree.

The next step in the development of the AHP exercise was to carry out a pairwise comparison, comparing elements to one another, two at a time, with respect to their impact or importance on an element above them in the hierarchy. That is, we first compare the relative preference for each of the measures based on every criterion. For example, for the first criterion, feasibility of its legal and political implementation, which refers to the applicability of the chosen measure in relation to the existing legal framework, interviewees have to compare one option against another in relation to their ability to be designed, supported and implemented from the political standpoint. This exercise will be repeated with the rest of the criteria: capacity to generate employment; financial feasibility; increase in farm income; speed of implementation; and protection of environmental resources. Second, we assess the relative importance of the criteria with regard to the achievement of the goal. That is, they will need to compare the relative importance of each of the above criteria undertaking a pairwise comparison with respect to their importance in the adaptation of the agricultural sector to climate change in the Guadiana River Basin.

In order to fulfill this step and keep a record of the interviews, the research team designed a questionnaire divided in two sections that were filled out by relevant stakeholders in the

Guadiana Basin following personal interviews with the research team. A total of 20 interviews were undertaken. Respondents fitted into four different roles: policymakers, farmers, environmental NGOs and academics, and were chosen by the research team following previous stakeholder mappings in the area undertaken for several EU projects with UPM participation (NEWATER[5] and SCENES[6]). The participants' answers were processed using the decision-making software Expert Choice (Expert Choice Inc., 2013) in order to calculate their relative priorities.

3. Results and discussion

Assessing the impacts and risks of climate change

In this section, we present the results of climate change scenario simulation and the impacts on the water system and on the irrigation communities. Fig. 5 shows the impacts of climate change (CNRM-CM3/A2 scenario) on crop yields and irrigation water requirements. Figure 6 illustrates the predicted unmet irrigation water demand due to climate change. Figure 7 shows the expected effects of changes in crop yields, crop water requirements and water availability on farm income and crop choice.

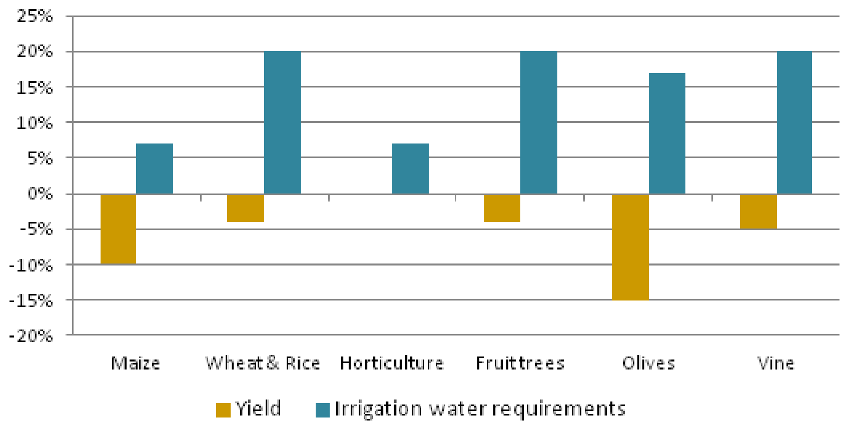

Fig. 5. Changes in crop yields and irrigation water requirements under the CNRM-CM3/A2 scenario for the 2041-2070 period.
Source: Esteve (forthcoming)

The results show that crop water needs are very sensitive to climate variations. Irrigation

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[5] NEWATER (New Approaches to Adaptive Water Management under Uncertainty) (2005-2009). Integrated Project. FP6, European Commission. DG Research. Contract nº 511179-2. (www.newater.everyone)

[6] SCENES (Water Scenarios for Europe and for the Neighbouring States) (2006-2011). Integrated Project. FP6, European Commission. DG Research. Contract nº 036822 (www.environment.fi/syke/scenes)

water requirements under the CNRM-CM3/A2 scenario increase around 20% for wheat and rice and permanent crops. Maize and horticultural crops show moderate increases in irrigation water needs. At the same time, crop yields decrease for all crops except for horticulture. Most negatively affected crops are olives, with 15% reduction of yields, followed by maize that would face 10% yield reduction.. Other crops are less negatively affected with yield reductions equal to or below 5%. These estimates do not consider the potentially fertilizing effect of increased CO_2 concentrations on crop yields. The combination of increased CO_2 concentrations and increased temperatures could lead to more moderate yield reduction or even increased crop yields as shown by several authors such as in Carmona (2011) or Giannakopoulos et al. (2005), among others. However, most studies showing the beneficial effects of increased CO_2 concentrations are based on controlled field experiments and model simulations under optimal conditions that do not account for the likely restrictions on other resources driven by climate change, such as water shortage or soil degradation. Here we present the results of a model simulation that accounts for actual climate and water system conditions. Not considering the potential effect of CO_2, the results presented here can be regarded as a pessimistic future climate change driven scenario.

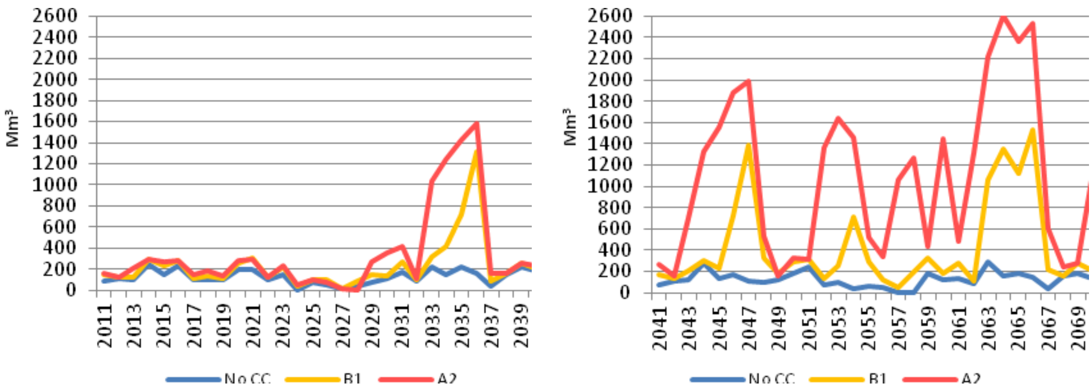


Fig. 6. Annually accumulated unmet irrigation water demand for present and future climate conditions (BCCR-BCM2.0/B1 and CNRM-CM3/A2).
Source: Esteve (forthcoming)

Fig. 6, shows the results of climate scenario simulation on water demand satisfaction. The results show that in the period 2011-2040 unmet demand is small. Water storage can to a great extent mitigate the reduction of natural water availability during dry climate periods as demand satisfaction is to a great extent similar to the "No climate change" (No CC) scenario. For that period, there is only one big drought, in which demand satisfaction is almost zero. However, for the period 2041-2070 water storage fails to mitigate the impacts of drought because of increased and generalized water scarcity. Specially, for the CNRM-CM3/A2 scenario average water supply in the period falls around 20% for the Middle Guadiana with some differences across irrigation communities. In addition, there are many severe drought periods, which drive crop failure and subsequent large economic losses. This evidences the need for implementing adaptation measures.

Following the hydrology model results, when severe climate change occurs (A2 scenario) water availability decreases with different impacts at the irrigation community level. Using the average decrease on water supply for the period 2040-2069 under the A2 scenario for each irrigation community and the potential impacts on crop yields and water requirements (provided by WEAP), we simulated farmers' crop choice and impacts on farm income (Fig. 7). In this case, both ICs experience income losses as they switch to lower water demanding cropping patterns with reduced crop yields. The traditional irrigation community of Montijo faces a slightly greater income loss (12% compared to 10% in the modern irrigation community of Zújar). The reason for this is the lack of modern pressurized irrigation systems that makes farms in this community less flexible and less capable to adapt by switching to more water efficient crop production systems. Under the A2 scenario, both irrigation communities expand rain fed land. However, while farms in Zújar expand horticulture, farms in Montijo IC cannot grow that type of modern and efficient crops. Highly water demanding crops, such as rice, would disappear under severe climate change. This could have important social implications as this is a relevant crop in some areas of the basin where soil quality and technology adoption are low.

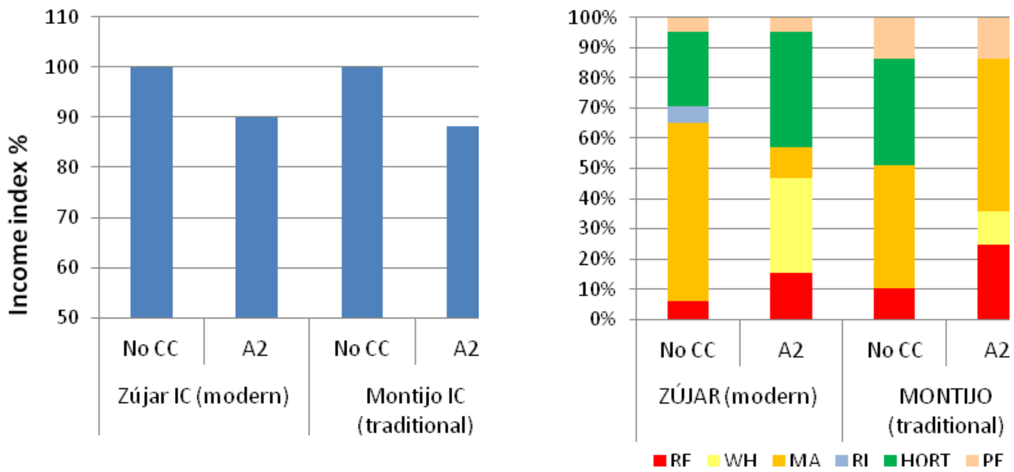


Fig. 7. Climate change impacts on farm income and crop choices in two different irrigation communities in the Middle Guadiana.

Source: Esteve (forthcoming)

Having an average 20% decrease of water availability, crop yields reductions between 4 and 15%, and irrigation requirements increases between 7 and 20%, income reduction reaches

10-12% of farms gross margin. This evidences the capacity of farmers to mitigate impacts and adapt to changing condition through adaptation of crop mixes (Reidsma et al., 2010).

Appraising and ranking potential adaptation options

In this section, we present the results of the multi-criteria analysis carried out to obtain a priority ranking of potential adaptation options based on different stakeholder preferences. Fig. 8 shows the AHP aggregate results. Fig. 9 illustrates the full results by group of stakeholders (policy makers, farmers, environmental NGO's, academics).

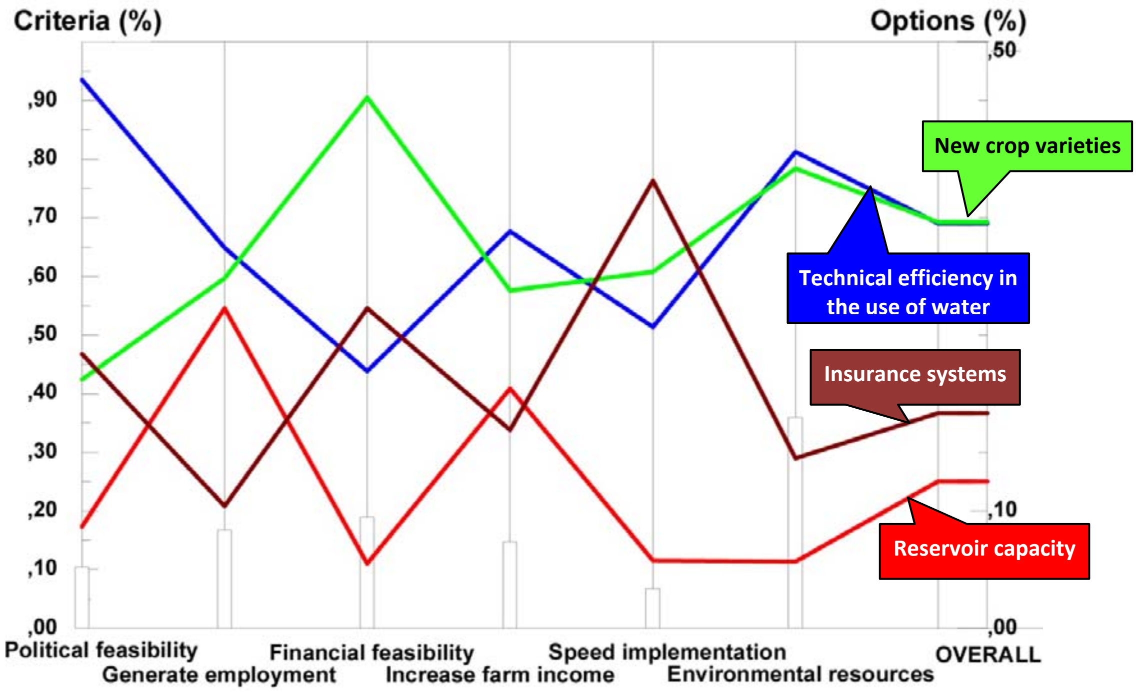
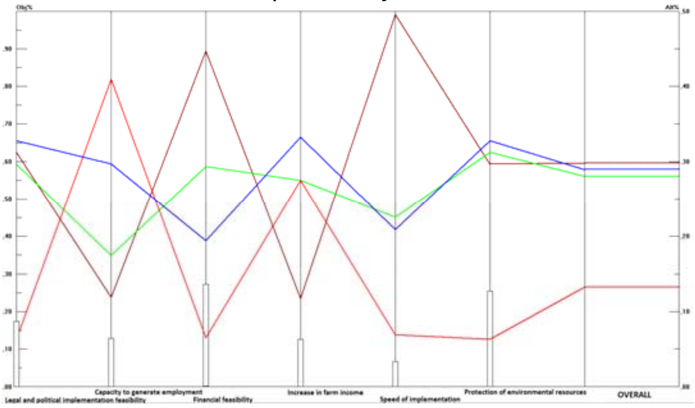
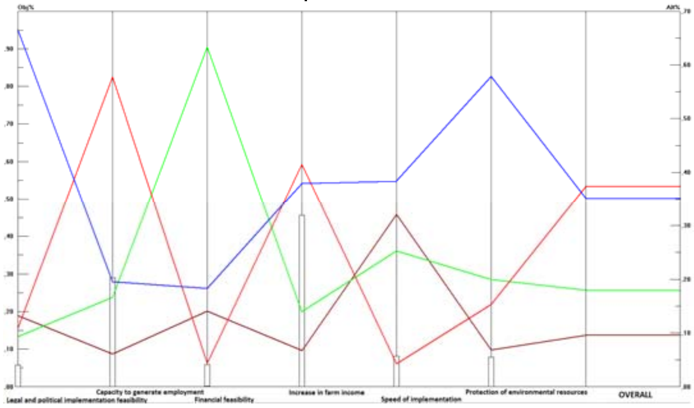


Fig. 8. Aggregate results

Group 1: Policymakers



Group 2: Farmers



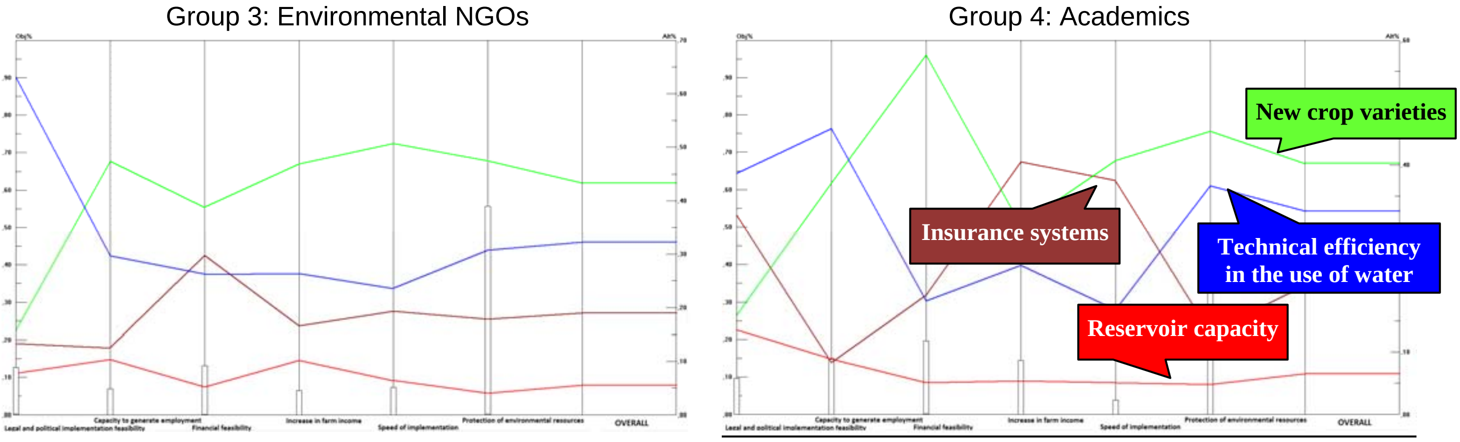


Fig. 9. Graphs showing the full results by group of stakeholders.

The results as a whole (see Fig. 8) shows that the options 3 (choice of new crop varieties best suited to the new climate conditions) and 1 (improving technical efficiency in the use of water) virtually tie in the first position of the ranking, weighing 34.6% and 34.5% respectively. Option 4 (creation of agricultural insurance systems) ranks third with 18.3% and finally option 2 (increase reservoir storage capacity) ranks fourth with 12.5%. Option 3 (choice of new crop varieties best suited to the new climate conditions) and 2 (improving technical efficiency in the use of water) perform very well under all selected criteria, ranking first except for financial feasibility and speed of implementation, where option 4 (creation of agricultural insurance systems) ranks first due to its lower cost and relative easiness. We should mention here the low performance of the option 1 (increase reservoir storage capacity) in aggregate terms. This option was highly controversial during our interviews and criticized by most respondents, who made reference to the high cost and large environmental impact of this option, even though it was envisaged as an option able to generate employment. All groups except farmers ranked this option at the bottom. This choice derives from the fact that farmers seemed to create a strong link between the abundance of water and the fight against climate change.

Taking the discussion to the criteria, we see how the protection of environmental resources is clearly the most influential criterion for respondents at the aggregate level with an aggregate weight of 35.4%, followed by financial feasibility and capacity to generate employment, (18.3% and 16.1% respectively) two topics of relevance in the region given the current economic situation in Spain at the moment. The protection of environmental resources is the dominant overall criterion given the support provided by all respondent groups. Even farmers, that are normally thought to perceive the preservation of environmental resources as a drawback, do not completely neglect this criterion. The reason behind this is lies not only in the formality behind their answer but also may be explained by the role farmers had in the elaboration of the Hydrology Plan for the Guadiana Basin following the Water Framework Directive, which helped to raise environmental awareness among farmers. Similarly financial feasibility is highly ranked by most groups, especially policymakers. Given the important budget constraints that the Spanish economy is facing at the moment, this criterion was seen as an important obstacle in the definition.

An analysis of the choices made by respondents divided by their role (policymakers, farmers, environmental NGOs and academics) (see Fig. 9) follows:

- Policy makers

The results show a very tight result on the top of the ranking, with option 4 (creation of agricultural insurance systems) ranking first (29.8%), followed by option 1 (improving technical efficiency in the use of water) (29%) and option 3 (choice of new crop varieties) (28%). Policymakers were the only group to rank the option 4 (creation of agricultural insurance systems) in the first place, an option that the rest of the groups did not seem to value. This is explained by its easiness and lower cost when compared to the other three. Unsurprisingly, and given the current economic situation, financial feasibility is the criterion that policymakers value the most in the design and implementation of adaptation plans (26.9%), followed closely by protection of environmental resources (25.1%) and legal and political implementation feasibility (17%).

- Farmers

Option 1 (increase in the reservoir storage capacity) (37.3%) ranks first, slightly above option 2 (improving technical efficiency in the use of water) (35.1%) while the option 4 (creation of agricultural insurance systems) remains at the bottom (9.6%). Farmers are the only group that chooses reservoirs as the best option (which is actually considered the least attractive for the rest of the groups). As it was explained before, this result derives from the strong link farmers create between water and adaptation to climate change. The other groups seemed to have a wider perception of the difficulties brought in by this phenomenon and therefore provide more nuanced answers that lead to somewhat opposite conclusions. On the other hand, the option 4 (creation of agricultural insurance systems) was regarded with mistrust by farmers, who did not seem to benefit from currently existing insurance systems and therefore see this option as less beneficial for their interests.

- Environmental NGO’s

Option 3 (choice of new crop varieties best suited to the new climate conditions) stands as the most valuable option (43.3%), followed by option 2 (improving technical efficiency in the use of water) (32.2%) and the option 4 (creation of agricultural insurance systems) (18.9%), with option 1 (increase reservoir storage capacity) in the last position (5.5%). This results are similar the ones obtained at the aggregate level. However, we see how this solution is more stable than the first one we observed, with the different options performing similarly in al selected criteria. Unsurprisingly, the criterion protection of environmental resources is by far the most important one for this group (55,3%), clearly outperforming the other five criteria.

- Academics

Academics provided a similar ranking to that of environmental organizations ranking option 3 (choice of new crop varieties best suited to the new climate conditions) as the most valuable option (40.2%), followed by option 2 (improving technical efficiency in the use of water) (32.6%) and the option 4 (creation of agricultural insurance systems) (20.7%). In this case we observe how the results are less stable than with environmental organizations, and the first three options (leaving aside the Option 1 (increase reservoir storage capacity), which always ranks last with 6.5%) perform differently according to the different criteria. The reason behind this similarity may lie on the fact that both groups (academics and NGO members) approach the climate change phenomenon in a similar way, establishing strong links and information flows among them. In terms of criteria, again the protection of environmental resources is the most important (39.2%), followed by financial feasibility (19.3%) and capacity to generate employment (14.7%).

4. Conclusions

Climate change adaptation is a relevant concern for sustainable development and a prominent issue in the EU political agenda. This research evidenced the need for adaptation in semi-arid irrigated basins, such as the Middle Guadiana in Spain, and provided systematic analytical framework for assessing climate change impacts and appraising adaptation options.

Through the use of an integrated hydrologic-economic modeling framework, this paper demonstrates the large impact that climate change may produce on water resources and subsequently in the irrigation agriculture sector. The integrated hydrologic-economic model provides a useful tool for assessing climate change risk at multiple scales, linking the bio-physical dimension of water resources with the relevant decision-making context. Results show that in the middle-long run agricultural water demands are at a great risk of not being satisfied. Average decrease in water availability of around 20% and changes in crop yields and irrigation requirements may translate in 10% reduction of farm income. However, irrigation technology will play a key role in facilitating adaptation at the farm level, being the most traditional irrigation communities more negatively affected than the modern ones. In addition, the sustainability of some specific water demanding crops, such as rice, will be compromised in the future if the most pessimistic scenarios are realized. Then, adapting cropping activities and water management principles and systems seems a crucial issue in the region. Involving stakeholders in such an important process supports the acceptance and up-taking of selected potential measures.

In this research, different adaptation options were selected and identified and discussed by stakeholders on the basis of a multi-criteria process. Using the AHP technique, different adaptation options were ranked according to a set of criteria relevant to stakeholders and decision makers. The AHP results show that, in the aggregate, options related to private farming (new crops and irrigation efficiency) are ranked highest, stressing the large adaptation potential at the farm and irrigation community levels, which was also highlighted by the economic model results. On the other hand, public-funded hard measures (reservoirs) are lowest, public soft measures (insurance) are ranked middle. Environmental criteria are preferred to socio-economic criteria and to technical criteria as all stakeholders relate climate change to the environment and to a lesser extent to human action. However, these visions vary, once again, across groups of stakeholders. While environmental groups and academics seem to have a balanced vision and rank climate change options similarly to the average aggregate, policy makers prefer soft measures (insurance) and discard large irrigation infrastructures. This is due to the severe financial, political and environmental constraints they will need to face in the latter options. On the contrary, farmers' priorities are technically oriented ranking first the construction of water storage infrastructures as their main concern in relation to climate change is the reduction of water availability and climate change is perceived as a threat to farming and crop failure.

Further research should explore the barriers to adopt climate change adaptation options, such as lack of common understanding, financial resources, integration of policies and coordination across different administration levels, which seems key for the successful implementation of climate change adaptation policies. In an overall perspective, the integrated quantitative and qualitative methodology used in this research can be considered a valuable tool for guiding and supporting decision-making in climate change adaptation in intensively irrigated semiarid areas, such as the Guadiana basin or similar.

Acknowledgements

The authors wish to greatly acknowledge the EU project Mediation (project number: 244012) for funding this research. They are also indebted to the numerous stakeholders that have taken part in this study

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