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ORIGINAL ARTICLE

# How can irrigated agriculture adapt to climate change? Insights from the Guadiana Basin in Spain

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**Abstract** Climate change is already affecting many natural systems and human environments worldwide, like the semiarid Guadiana Basin in Spain. This paper illustrates a systematic analysis of climate change adaptation in the Guadiana irrigation farming region. The study applies a solution-oriented diagnostic framework structured along a series of sequential analytical steps. An initial stage integrates economic and hydrologic modeling to evaluate the effects of climate change on the agriculture and water sectors. Next, adaptation measures are identified and prioritized through a stakeholder-based multi-criteria analysis. Finally, a social network analysis identifies key actors and their relationships in climate change adaptation. The study shows that under a severe climate change scenario, water availability could be substantially decreased and drought occurrence will augment. In consequence, farmers will adapt their crops to a lesser amount of water and income gains will diminish, particularly for smallholder farms. Among the various adaptation measures considered, those related to private farming (new crop varieties and modern irrigation technologies) are ranked highest, whereas public-funded hard measures (reservoirs) are lowest and public soft measures (insurance) are ranked middle. In addition, stakeholders highlighted that the most relevant criteria for selecting adaptation plans are environmental protection, financial feasibility and employment creation. Nonetheless, the social network analysis evidenced the need to strengthen the links among the different stakeholder groups to facilitate the implementation of adaptation processes. In sum, the diagnostic framework applied in this research can be considered a valuable tool for guiding and supporting decision making in climate change adaptation and communicating scientific results.

**Keywords** Climate change adaptation · Decision making · Hydro-economic modeling · Multi-criteria analysis · Social network mapping · Spain's agriculture

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## Introduction

Over the course of history, societies and individuals have adapted to changing climate conditions by a mixture of practices. In agriculture, an intrinsically climate-sensitive sector, these practices include cropping changes, new water technologies and innovative modes for resource

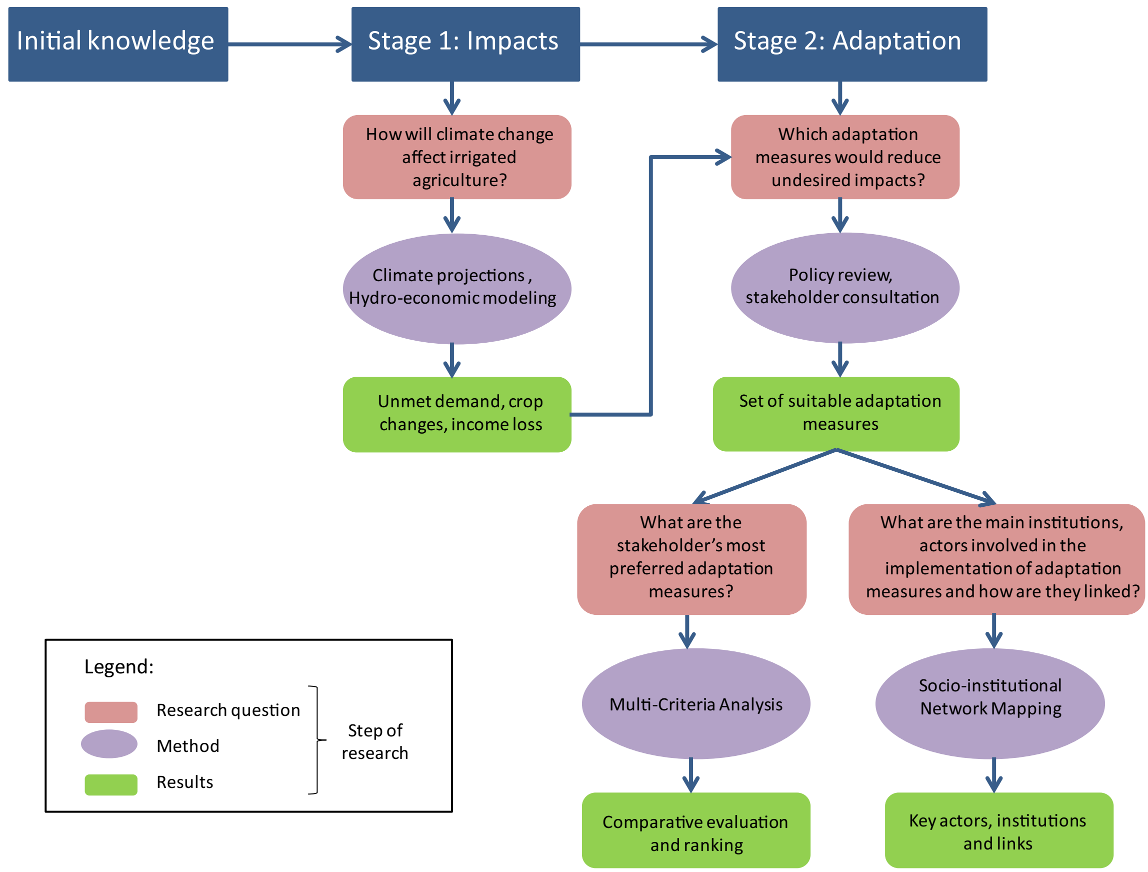


**Fig. 1** Application of the diagnostic framework to analyze climate change adaptation for water and agriculture in the Guadiana Basin

management (Dolan et al. 2001; Howden et al. 2007; Reidsma et al. 2010). However, while the effects of climate change are increasingly perceived worldwide, the design and implementation of climate change adaptation measures have been translated into effective action at a slower pace (Adger et al. 2007; EEA 2012). Yet, during recent years, adaptation has evolved rapidly. It has shifted from actions taken upon historical knowledge, experience and common perception (Meinke et al. 2009) to a scientifically structured vision that integrates economic, social and environmental aspects (EEA 2012; Downing 2012). In this context, considerable efforts are devoted to addressing on how best to adapt to future climatic conditions given the uncertainty associated with climate projections (Dessai et al. 2009; Swart et al. 2009). In general, planned adaption initiatives are not undertaken in isolation and are part of more ample sector-wide policy programs, such as agricultural and environmental policies. Hence, climate change adaptation affects multilevel decisions, varied spatial locations, diverse economic sectors, a diverse suite of actors and human relations within distinct ecological, social and institutional settings (Dovers and Hezri 2010; Downing 2012; Smith et al. 2009; van Buuren et al. 2013).

In a changing natural and social environment, it is crucial to know how decisions are taken, how they may evolve over time and how different actors are involved in such decisions. In this context, the need for a scientifically based conceptual framework seems critical to analyze climate change adaptation across national, regional and local scales with the aim of developing proactive planned adaptation initiatives and support policy-making (Meinke et al. 2009). In line with this, the European Union (EU) strategy on adapting to climate change (CEC 2013) builds on national initiatives developed by the member states and supports the implementation of regional actions to achieve climate-proofing economic and social sectors across the EU. Among those, agriculture and water are key sectors in the EU where climate change adaptation has been integrated into the correspondent policies (the Common Agricultural Policy, CAP) and legislation (inland waters) to better inform decision making. In fact, policies can play an essential role in enhancing the ability of agriculture to adapt to present and future climate variability and change, while protecting and preserving the environment (Berry et al. 2006; Varela-Ortega et al. 2011).

Adaptation to climate change within the agricultural and water sectors of a semiarid region of south-western Spain is the basis of the analysis carried out in this study. However, adaptation to climate change in these sectors requires a revision of the region's current governance structures. Local circumstances and the involvement of key stakeholders are of major importance when developing regional adaptation plans (Downing 2012; Krysanova et al. 2010). To address these issues, it has been pointed out the necessity to develop appropriate frameworks, models and tools to support decision making and to bridge the gap between science, policy and action (Meinke et al. 2009; CEC 2013).

In this perspective, this paper illustrates a systematic analysis of the climate change adaptation context in the Guadiana Basin in Spain, a semiarid Basin particularly vulnerable to climate change. The study applies a solution-oriented diagnostic framework structured along a series of sequential analytical steps (illustrated in Fig. 1). The framework supports the assessment of climate change impacts and the selection and implementation of planned climate change adaptation measures in the region of study. To date, climate change adaptation strategies in Spain are developed for the national level but are still at an incipient phase regionally, still pending full definition and implementation. Therefore, coordination between the national and the sub-national administrations as well as the involvement of stakeholders is key for the efficient and coherent development of adaptation actions in Spain. This study will help policy-makers in the region of the Guadiana Basin face the challenge to design and select adequate climate change adaptation strategies to cope with the adverse effects of climate change in the agriculture and water sectors.

## Case study: the adaptation challenge in the Guadiana Basin

This research focuses on the Middle Guadiana Basin, which is located in the south-western central plateau of the Iberian Peninsula. The Basin occupies an area of 27,000 $km^2$ (about 50 % of the total drainage area) mostly within the Extremadura region in Spain.

The Guadiana Basin is expected to be one of the Basins most negatively affected by climate change in Spain. Future climate projections suggest a decrease in precipitation, an increase in evaporation and more frequent and intense droughts (see Table 1). As a consequence, the annual Guadiana river inflow may be severely reduced, which could have dramatic implications for the sustainability of water resources and for irrigated agriculture, the major source of water demand and a cornerstone of socio-economic development in the region. Climate change is expected to affect the extension and productivity of irrigated agriculture and will likely make agricultural systems even more dependent on irrigation.

As seen in Table 1, the potential effects of future warming on weather patterns have been thoroughly explored in the Guadiana Basin. However, regionalized climate change impacts on water and agriculture remain vague and poorly understood. Current adaptation efforts in the region are hampered by the lack of reliable information on climate change impacts, and adaptation measures, and by a lack of coordination across institutions and actors. This study tries to shed light on these issues following a solution-oriented approach.

**Table 1** Recent and future climate change trends and their potential effects on water and agriculture in the Guadiana Basin

| CC impacts | What is already happening | What may happen in the future (data relative to 1961–1990 conditions) |
|---|---|---|
| Temperatures | Mean annual temperature is about 16 °C<br>Slight increase, notably in summer | General increase: +1 °C in 2030 and between +2.5 °C and +4 °C in 2060 |
| Precipitations | Mean annual precipitation is 521 mm<br>Slight decrease, notably in summer | Severe decrease: −5 % in 2030 and between −8 and −15 % in 2060. Increase in variability |
| Extreme events | Recurrent drought episodes (5 years duration)<br>Occasional heavy rains in spring and autumn | Increased risk of heat waves<br>More intense, more frequent and longer-lasting droughts. Lower rainfall intensity |
| Water resources | Low river flows during summer<br>Recurrent river flow droughts<br>Very occasional flood events | Severe decrease in river inflow: −11 % in 2030 and −17 and −22 % in 2060. More intense and frequent hydrological droughts<br>Increased water stress. Water shortages (unclear) |
| Agriculture | Slight increase in irrigation water requirements<br>Falls in crop production due to rainfall variability and droughts | Increased irrigation water requirements. Lower suitability for rain-fed agriculture<br>Increased crop damage. Effects on plan growth, crop yields and crop distribution not conclusive |

*Source*: Own elaboration based on JE (2013), and MMA (2005)

## Building a diagnostic framework for climate change adaptation

This paper presents an application of the *diagnostic framework for solution-oriented adaptation research* developed within the MEDIATION project (Hinkel and Bisaro 2014) and included in the UNEP guidelines for the assessment of impacts, vulnerability and adaptation (PROVIA 2012). The diagnostic framework consists of a sequence of decision trees that map potential ways to address different kinds of adaptation challenges. Instead of focusing on methods alone, the diagnostic framework places special attention on the adaptation problem being studied and to the steps of research taken to address it (Juhola and Kruse 2013; Roman et al. 2011). Each step is characterized by a research question, a method (or a combination of methods) applied to answer the question raised, and finally, the results achieved which can lead to new research questions and thus, trigger subsequent steps. The steps of research are conducted until a clear understanding of the adaptation problem is attained when practice can start (Hinkel and Bisaro 2014).

Figure 1 shows the diagnostic framework for climate change adaptation. The research questions for the Guadiana were developed through active interaction between scientists and stakeholders. Starting from existing knowledge of climate change, a number of analytical steps structured along two general stages that rationally follow the sequence of the adaptation learning cycle were identified: (1) appraising climate change impacts and (2) selecting and implementing climate change adaptation measures.

The following sections explain in detail the two stages of the diagnostic framework in which we describe the question raised, the methods used and the results obtained within each method. The framework highlights the interlinkages between stages and steps (see Fig. 1). The first stage comprises an analysis of the impacts of climate change, for which a hydro-economic model was used. The results of this model, validated by relevant stakeholders in the area, are subsequently used in the following stage. This second stage focuses on the selection and implementation of adaptation measures and is based upon a participatory stakeholder initiative. Firstly, we use a multi-criteria analysis to rank adaption options and, in parallel, a socio-institutional network mapping, that enables the analysis of the institutions and actors engaged in the decision-making process related to adaptation.

## Assessing climate change impacts

Reliable information concerning climate change and its potential effects is essential for designing good adaptation policies. Thus, the research starts by addressing the following question: *How will climate change affect irrigated agriculture in the study region?* (see Stage 1 in Fig. 1). To answer this question, regional climate projections for the Guadiana Basin were obtained and applied to a hydro-economic model.

Climate projections for the twenty-first century were taken from the Third Coupled Model Intercomparison Project (CMIP3, Meehl et al. 2007) for simulations of two general circulation models (GCMs), BCCR-BCM2.0 (Furevik et al. 2003) with SRES B1 forcing and CNRM-CM3 (Salas-Mélia et al. 2005) with SRES A2 forcing and with historic forcing for the twentieth century. These were selected to represent the range of changes in the study region as simulated by a larger ensemble of GCMs, showed in Fig. 2. BCCR-BCM2.0/B1 lies at the lower end of long-term changes in temperature and precipitation, whereas CNRM-CM3/A2 is at the warm and dry end of the range of changes. Long-term mean changes in the study area between 1971 and 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 past time series of the period 1971–2000 obtained from the CRU-TS 3.10 climate database (Jones and Harris 2011), thus replicating the observed variability, to create 30-year time series for the two future periods.

Future climate data were used as inputs in a compartmental hydro-economic model developed and applied to

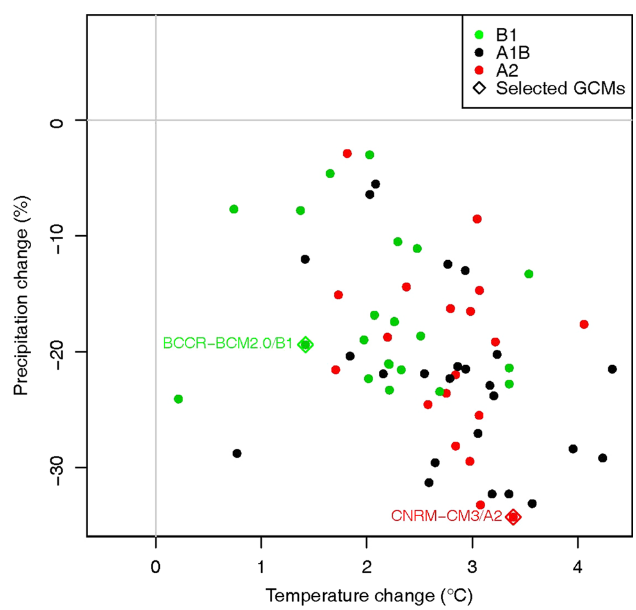


**Fig. 2** Annual changes in air temperature and precipitation for the Guadiana Basin between the periods 2040–2069 and 1971–2000 with an ensemble of GCMs. *Source*: Derived from Meehl et al. (2007)

the Guadiana Basin to analyze the potential impacts of projected climate change on water and agriculture. The hydro-economic model here presented is based on the integration of two models: a hydrologic simulation model, Water Evaluation And Planning system (WEAP) (Yates et al. 2005) and an economic optimization model (Hazell and Norton 1986). Both the hydrologic and economic models run in stand-alone mode, but the output of one model is used as input in the other. The hydrologic model WEAP simulates rainfall–runoff processes following the basic principle of water balance accounting. It incorporates the agronomic module MABIA (Jabloun and Sahli 2012) that allows for the simulation of crop growth processes, including crop irrigation requirements and yields. The economic model is a farm-based nonlinear mathematical programming model (MPM) of constrained optimization that maximizes a utility function (defined by farm annual gross margin and utility losses driven by market and natural risks) subject to technical, economic and policy constraints. The WEAP results on the potential effects of climate change on water availability and crops are entered into the MPM economic model, which in turn provides insights into farmers' crop choices and farmers' income. For further details on the characterization and functioning of this hydro-economic model, see Blanco-Gutiérrez et al. (2013), and Esteve (2013).

Both the hydrologic and the economic models were dully calibrated and validated. The calibration of the WEAP model was done for the period 1971–1990 by adjusting soil and agronomic parameters. The accuracy of the model at predicting stream flows was assessed through Nash and Sutcliff (1970) efficiency coefficient and a standardized bias score (Weglarczyk 1998). Both coefficients showed a good level of accuracy with a Nash–Sutcliff coefficient above 0.7 and a bias of less than 20 %. In the case of the MPM economic model, calibration was done for the base year 2009 through the risk aversion coefficient that defines farmers' risk tolerance and utility losses derived from risk. The percentage absolute deviation parameter (Hazell and Norton 1986) was calculated to assess model accuracy and was used to validate the model comparing observed and simulated land allocation and resource use for 2012 (capturing the CAP reform of 2010). This parameter showed a good level of accuracy with values below 20 for all farms represented. Finally, modeling results were presented in a stakeholders' validation workshop where stakeholders were asked to evaluate the model results according to their usefulness, credibility and consistency. Participants particularly stressed the coherence of the model results and the value of the modeling exercise as a knowledge generating process. The involvement of stakeholders in the validation process is considered crucial to increase trust in the model (Varela-Ortega 2011; Voinov and Bousquet 2010).

The results achieved regarding climate change impacts on unmet irrigation demand, cropping patterns and farm income are shown in Figs. 3 and 4. Results on crop yields are not displayed in this paper, but they can be found in Esteve (2013). Figure 3 illustrates the Basin's annually accumulated unmet irrigation demand for the period 2010–2070 assuming different future climates. Unmet irrigation demand refers to the total amount of water needed to meet crop irrigation requirements that is not fulfilled by the available water supply. It has been obtained from the hydrologic model WEAP.

Modeling results suggest that the Guadiana Basin could start experiencing situations of significant unmet demand as early as 2030, with water supply largely surpassed by water demands. On the one hand, rising temperatures will likely translate into increased water requirements for farming activities. On the other hand, multiyear droughts

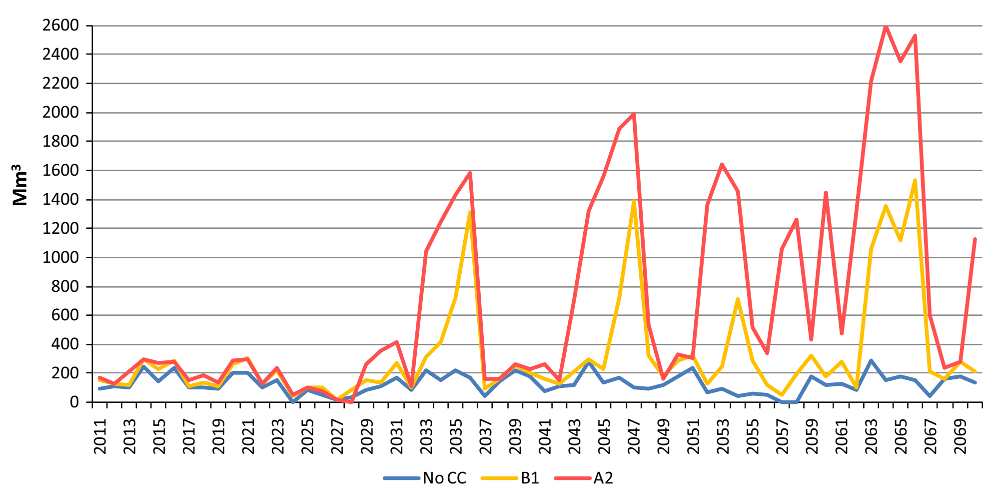


**Fig. 3** Annually accumulated unmet irrigation water demand in the Guadiana Basin under no climate change, BCCR-BCM2.0/B1 and CNRM-CM3/A2 scenarios for the period 2010–2070. *Source*: Derived from Esteve (2013)

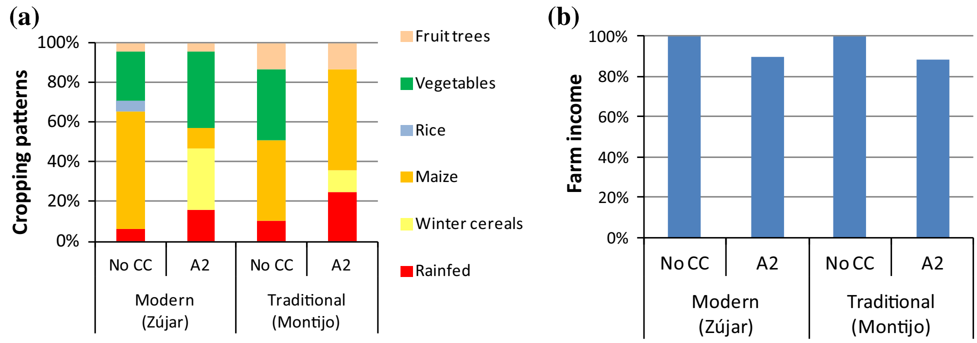


**Fig. 4** Climate change impacts on **a** crop choices and **b** farm income in two irrigation communities of the Guadiana Basin under the CNRM-CM3/A2 scenario (average values for the period 2040–2069) *Source*: Derived from Esteve (2013)

are expected to become more frequent and intense resulting in a reduced availability of water for crops. As shown in Fig. 3, under severe climate change (CNRM-CM3/A2 scenario), water storage fails to mitigate the effects of combined lower water availability and higher water demands, and inter-annual variability is translated into high peaks of unmet demand, showing a cyclic fashion of droughts of different intensity. By the end of the simulated period, unmet irrigation demand could reach about 2,600 $Mm^3$ in the worst case scenario (CNRM-CM3/A2).

Figure 4 illustrates the potential effects of severe climate change (CNRM-CM3/A2 scenario) on (a) crop choices and (b) farm income in two different irrigation communities of the Guadiana Basin categorized by their irrigation technologies (traditional and modern irrigation). These results were obtained from the economic model simulation of annual water supply reductions of 20 %, along with irrigation water requirement increases of 17 %. These values represent averages for the period 2040–2069, as calculated by WEAP.

As seen in Fig. 4, climate-induced impacts may vary at the farm level. Similarly to other studies (Reidsma et al. 2010; Varela-Ortega et al. 2011), we observe that farmers adopt different adaptation strategies to cope with climate change depending on their technological (crop diversification and irrigation technologies) and structural (farm size, labor intensity and access to credit) potential. Farmers belonging to the traditional irrigation community (Montijo) grow crops in small-size holdings that lack pressurized irrigation systems, and therefore, they are less capable to adapt to water stress situations than farmers that belong to the modern irrigation community (Zújar).

Figure 4a shows that while farms in the modern irrigation community (Zújar) respond to climate change by expanding high-value low-water-consuming crops such as vegetables and fruit trees, farms in the traditional irrigation community (Montijo) are forced to replace profitable crops (notably vegetables) by low-value cereals (wheat, maize). In both cases, climate change is expected to increase rainfed production and to decrease farm income, as shown in Fig. 4b. Again, farmers belonging to the traditional irrigation community (Montijo) seem more vulnerable to climate change. They will face greater income losses than farmers located in the modern irrigation community (Zújar) (12 % compared to 10 %). In line with previous findings (Jiang and Grafton 2012; Qureshi et al. 2013), the obtained results indicate that farm income decreases proportionally less compared with the decline in water availability, which means that in all cases crop adaptation helps to mitigate income losses to farmers. These estimates only consider private economic losses and certainly underestimate the total potential economic losses and socio-ecological disruption that are likely to result from severe changes in climate (Hurd and Coonrod 2012).

## Selecting and implementing climate change adaptation measures

Once climate change impacts are appraised, it is important to analyze what measures should be taken to adapt to the potential consequences of climate change (PROVIA 2012). This section focuses on the selection, evaluation and implementation of appropriate adaptation measures for the region of study. It summarizes the analytical steps underlying the second stage of the diagnostic framework presented in Fig. 1.

### Policy screening and identification of adaptation measures

The first question formulated in stage 2 asks about *the adaptation measures that would reduce the potential undesirable impacts of climate change in the region of study*. To answer this question, several policy documents were reviewed and discussed with selected stakeholders.

Firstly, we began by examining the existing climate change adaptation plans at the national (OECC 2009) and regional level (JE 2013), and in particular, the adaptation programs for water and agriculture sectors. This review allowed us to make an inventory of planned adaptation measures that turned out to be fairly undefined because of the incipient stage of climate change adaptation policies in Spain. In view of this, key stakeholders (local climate change experts and decision makers) were consulted to better define and describe adaptation actions. They were asked to decide on a reduced set of planned adaptation measures according to their suitability and effectiveness to increase resilience in the Guadiana Basin in light of the adverse impacts of climate change illustrated by the modeling results.

Following stakeholders' advice and based on previous studies (Blanco-Gutiérrez et al. 2013; Krysanova et al. 2010), four adaptation measures were selected as the most appropriate to deal with climate change impacts in the region of study: (1) improving technical efficiency in the use of water ($M_1$); (2) increasing reservoir storage capacity ($M_2$); (3) choosing new crop varieties best suited to the new climate conditions ($M_3$); and (4) creation of agricultural insurance systems ($M_4$). These measures are commonly presented in other adaptation studies as key strategic actions to increase the resilience of the agriculture sector to climate change (e.g., Dolan et al. 2001; Howden et al. 2007). In the Guadiana Basin, these measures are already available and are regularly employed to deal with climate variability and droughts. As reported by Schmidt-Thomé et al. (2013), climate change adaptation measures are often built upon existing protection measures designed to cope with current hazard patterns, with the prospect of enhancing these measures along with ongoing climate change.

## Comparative evaluation and ranking of adaptation measures

Identifying preferred measures can facilitate social acceptance and the implementation of adaptation plans and strategies (Dolan et al. 2001). Thus, after identifying suitable adaptation measures, we asked about: *What are the stakeholders' most preferred adaptation measures?* To answer this question, we applied the Analytic Hierarchy Process (AHP), a multi-criteria decision-making approach that allowed us to compare and rank potential adaptation measures.

Analytic Hierarchy Process is a structured method of pairwise comparison introduced by Saaty (1980) that helps solve complex decision problems by involving multiple conflicting and subjective criteria. Though its first applications in the 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 (Sposito 2006; Yin et al. 2008). In the present study, pairwise comparison was implemented in two stages. First, stakeholders were required to provide judgments on the relative importance of each potential adaptation measure in relation to a number of criteria, namely (1) legal and political implementation feasibility, (2) capacity to generate employment, (3) financial feasibility, (4) increase in farm income, (5) speed of implementation and (6) protection of environmental resources. Second, stakeholders were asked to specify their views about the relative importance of each criterion with regard to the achievement of the overall goal, that is, to reduce the adverse effects of climate change. These comparisons were used to obtain the relative importance, or weight, of each criterion and adaptation measure. The criteria were chosen based on expert opinions and reviews of the multi-criteria literature on evaluation of adaptation strategies related to water and agriculture (de Bruin et al. 2009; Parra-López et al. 2008). In total, 20 in-depth interviews were undertaken among various stakeholders (policy-makers, farmers, environmental organizations and academics) selected following previous stakeholder mappings in the area (Varela-Ortega 2011). Stakeholders' responses were processed using the decision-making software expert choice (http://expertchoice.com/).

The results of the AHP analysis, illustrated in Fig. 5, show stakeholders' prioritization of the criteria and adaptation measures. Electronic supplement 1 displays the results for each stakeholder group.

Figure 5 shows that the *Protection of environmental resources* is clearly the most influential criterion with an aggregate weight of 35 %, followed by *Financial feasibility* and *Capacity to generate employment* (18 and 16 %, respectively). In terms of adaptation measures, *Choice of new crop varieties* (*$M_3$*) and *Improving technical efficiency* (*$M_1$*) in the use of water related to private farming virtually tie in the first position of the ranking, weighing 35 and 34 %, respectively. The public soft adaptation measure *Creation of agricultural insurance systems* (*$M_4$*) ranks third with 18 %, and finally, the public-funded hard measure *Increasing reservoir storage capacity* (*$M_2$*) ranks fourth with 12 %. Results show that none of the adaptation measures considered in the study has a clear advantage to achieve the overall goal. The most preferred adaptation measure, *Choice of new crop varieties* (*$M_3$*) performs very well under the *Financial feasibility* and *Protection of environmental resources* criteria, but it gets a relatively low score in *Political feasibility*. In line with other studies (see, e.g., Yin et al. 2008), the hard adaptation measure *Increasing reservoir storage capacity* (*$M_2$*) was very controversial and highly criticized by most respondents because of its high cost and associated environmental impacts. Nevertheless, Hallegate (2009) and Sovacool (2011) argue that adaptation measures are not always mutually exclusive and that combining hard and soft

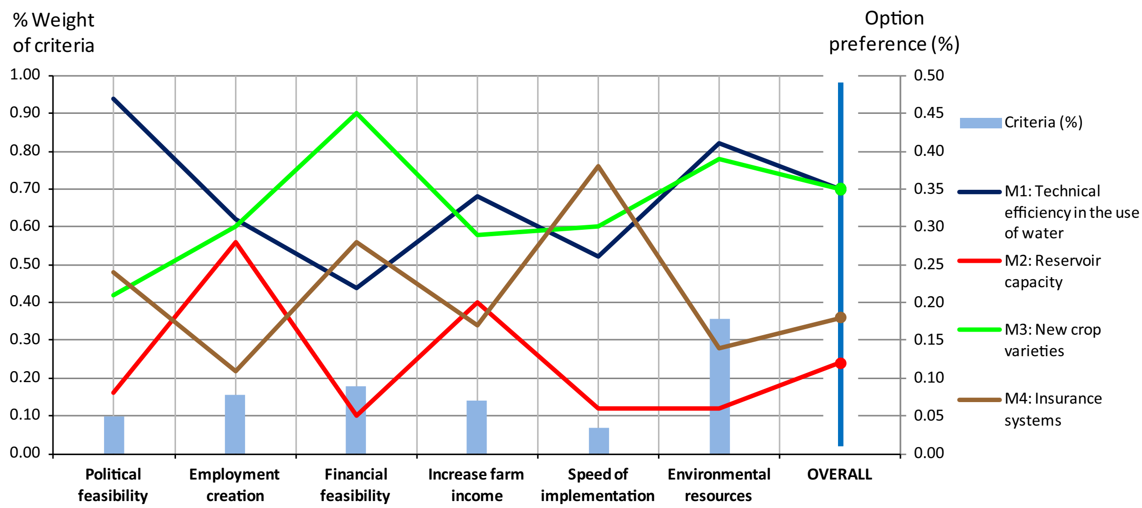


**Fig. 5** Performance of the different criteria (*vertical bars*) and adaptation measures (*horizontal lines*), the latter with respect to each criterion and the overall goal

interventions are often required to efficiently reduce the impacts of climate change.

Attending to the choices made by the different stakeholder groups (see electronic supplement 1), we can observe that policymakers are the only group that ranks first the adaptation measure *Creation of agricultural insurance systems* ($M_4$) due to its lower cost and the relative easiness of its implementation. Contrarily, and given the strong link farmers perceive between water availability and climate change, farmers prioritize more technical-oriented solutions, predominantly the adaptation measure *Increasing reservoir storage capacity* ($M_2$). Environmental organizations and academics go in line with the balanced average, being *Choice of new crop varieties* ($M_3$) the top-ranked measure among these stakeholder groups. These results are in line with those obtained by Dolan et al. (2001) for adaptation to climate change in the Canadian agricultural sector, where crop diversification is ranked highest among farmers while for public agents (government) crop insurance programs are the top preferred option. Niang-Diop and Bosch (2004) stress the importance of involving a wide variety of stakeholders in the identification and prioritization of adaptation options; however, they alert to the difficulty of reaching a consensus.

## Implementing adaptation measures: actors, institutions and inter-linkages

The successful implementation of adaptation policies, programs and measures depend on the institutional arrangements used to pursue adaptation (Dovers and Hezri 2010; Smith et al. 2009). In consequence, we finally addressed the following question: *What are the main institutions and actors involved in the implementation of adaptation measures and how are they linked?* To answer this question, we performed a socio-institutional network analysis for climate change adaptation.

A socio-institutional network mapping (SNM) exercise was conducted using NetMap, a participatory mapping tool developed by Schiffer and Hauck (2010), which allows for visualization of complex formal and informal social networks, identifying the goals and influence of different types of actors, and describing the linkages among them. SNM has been extensively used in natural resource management (Bodin and Crona 2009; Stein et al. 2011) and is being progressively applied in climate change adaptation (Aberman et al. 2011).

For this, a stakeholder workshop was held participated by 15 stakeholders, who were divided into homogeneous groups according to the type of institution they belonged to: water administration, farmers and environmental organizations (including climate change offices). Group discussions took place through guided questionnaires (see electronic supplement 2) about main actors in adaptation decision making, about how information, capacity building and funding flowed among them, and about what barriers may arise when implementing adaptation processes according to actor relations and flows among them.

Figure 6 shows the socio-institutional networks produced by the water administration authorities in the workshop. SNMs produced by the other two groups are shown in electronic supplement 3. The networks show the different actors involved in climate change adaptation in the water and agricultural sectors and the relations among them in terms of information (red arrows), financing (green arrows) and implementation capacity (blue arrows) flows,

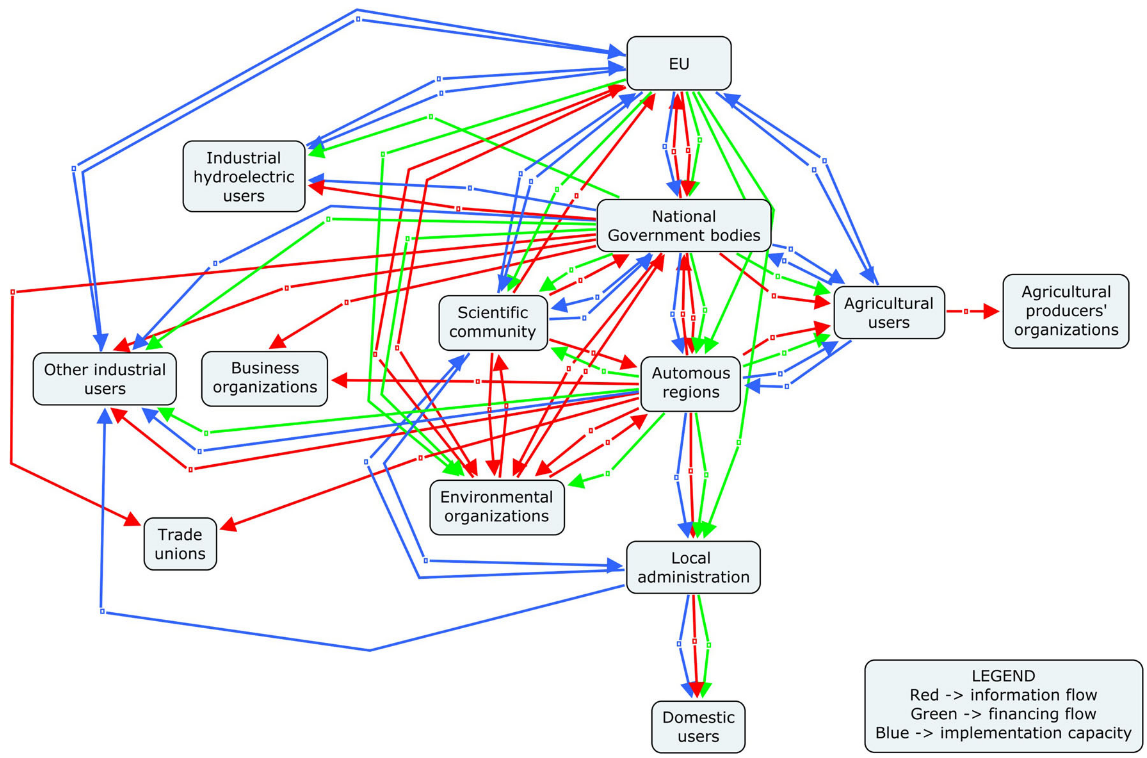


**Fig. 6** Socio-institutional network developed by water administration authorities

as perceived by the participants. The network structure provides insights into what are the central actors, how knowledge and capacities are transferred across institutions and individuals, and what actions may be taken to reinforce climate change adaptation processes.

As shown in Fig. 6, the water administration group built a hierarchical type of network where administrations are placed in the middle of the network and work as bridges among water users and other stakeholders. Flows mainly go from the EU to other administrations and to users, showing reciprocal interdependences. The group also identified the weak links between central administration and other users as the main barrier in adaptation to climate change and therefore proposed the improvement of opportunities for public participation, the reform of the legal framework, and the elimination of overlaps in the different government offices' competences as a way to overcome this barrier.

The group made up by farmers designed a more fragmented network (see figure. 1 in electronic supplement 3) where individual action predominates and irrigators are strongly linked to other organizations, but they do not act as bridges among them. Most of the depicted links correspond to information flows. Implementation capacity flows emanate only from governmental bodies which emphasizes the important role of government initiatives and leadership in climate change adaptation processes. This group highlighted the need to empower irrigation communities in decision-making processes, placing a stronger emphasis on private adaptation initiatives as opposed to the current predominance of adaptation actions triggered by public institutions.

The group composed by environmental representatives designed a more ample, homogeneous and detailed network (see figure. 2 in electronic supplement 3) in which the different actors are highly connected. The EU is the main source of flows of information and funds, while irrigators and the organizations of agricultural producers are the main focus of implementation capacity. This group underlined the need to empower the regional government with the support of local organizations as a key actor in the implementation of adaptation processes, and also the need to place more attention on the role of the media to raise awareness about climate change.

The three networks represented by the stakeholder groups show two main common features: (1) the preeminent role of the EU and central governmental bodies and (2) the scarce links among different water users and between water users and other stakeholder groups such as the environmental groups. Relating to the first feature, the numerous links between different governmental levels indicate a well-established hierarchy that may facilitate adaptation practice. This also underlines the relevance of coordination and integration at different institutional levels in building adaptive capacity, as shown in climate change adaptation and adaptive governance research (Engle 2011; Ivey et al. 2004). Referring to the second feature, the lack of connections between water users and environmental groups may be related to low levels of awareness, which may prevent the development of a common understanding by the different users and may reduce the likelihood of joint actions in the Basin (Bodin and Crona 2009).

## Concluding reflections

Responding to the multifaceted challenge of climate change, this research was developed with the aim of identifying solution-oriented adaptation research questions and methods in the irrigation-dependent Guadiana Basin in Spain. In line with recent literature (Adger et al. 2007; Downing 2012; Juhola and Kruse 2013), this research contributes to the vision of adaptation as a socio-institutional pathway where various modeling initiatives are integrated as well as the participation of relevant actors. The diagnostic framework undertaken in this research has permitted addressing climate adaption from various angles and not only from the perspective of a single model. This allows to match science-driven research questions to the needs of policy-makers and stakeholders for better informed decision making on adaptation.

The diagnostic framework was applied to a context-specific adaptation challenge. This framework may be applied beyond the specific case of the Guadiana Basin to other climate adaptation challenges worldwide. However, the specific methods within the diagnostic framework and their related assumptions should be carefully selected to reflect specific local contexts. In some cases, the methods selected might influence the research outcomes. For instance, in the hydro-economic modeling, permitting more flexible water allocations (such as prioritizing water diversions to permanent crops during drought periods) may lead to less negative impacts of climate change as those shown in the results. Yet, the research highlights that, in spite of its limitations, hydro-economic modeling is a valuable tool for assessing climate impacts on the agriculture and water sectors.

Engaging key stakeholders at various decision units (national, regional and local) for evaluating adaptation measures can be illustrative to understand planned adaptation programs. Stakeholder-based approaches, such as the ones applied in this research, provide outcomes that are dependent on the stakeholders involved in the participatory exercise. Therefore, having a balanced representation of stakeholder groups can be crucial in achieving more legitimate results.

The stakeholder-based multi-criteria analysis demonstrates that stakeholders relate climate change to the environment and to a lesser extent to human action. It reveals that, in the Guadiana Basin, human action in climate change adaptation is still a learning process.

Mapping actors' networks in relation to climate change adaptation processes can help to understand the potential uptake of the programs. The study reveals that, in spite of some revealed differences among stakeholders, scale is an important issue for all groups. Actors' visions on hierarchies coincide that there is a downward trend in the scale of influence, the EU administration being the most influential followed by the central and local administrations down to the least influential individual farmers.

Further research should take into account a more elaborated vision of barriers to implementing climate change options, such as access to financial resources and integration of policies. In particular, increasing attention should be paid to integrating climate change adaptation into sectoral policies and develop sector-specific plans. This will require supporting changes in the current institutional structures to enhance their flexibility and adaptability. From an overall perspective, the diagnostic framework developed in this research could be a valuable method for decision making in climate change adaptation.

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