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Analysis

# A hydro-economic model for the assessment of climate change impacts and adaptation in irrigated agriculture

Paloma Esteve [a,*], Consuelo Varela-Ortega [a], Irene Blanco-Gutiérrez [a], Thomas E. Downing [b]

[a] Department of Agricultural Economics, Statistics and Management, Universidad Politécnica de Madrid, Av. Complutense s/n, 28040 Madrid, Spain
[b] The Global Climate Adaptation Partnership, Oxford Centre for Innovation, New Road, Oxford OX1 1BY, UK

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ABSTRACT

Recent research has demonstrated the multidimensional and multi-scalar nature of climate change, evidencing the need to develop integrated tools for the analysis of impacts and adaptation. This research presents a hydro-economic model of the Middle-Guadiana basin, Spain, to assess potential effects of climate change on irrigated agriculture and options for adaptation. It combines a farm-based economic optimisation model with the hydrologic model WEAP, and represents the socio-economic, agronomic and hydrologic systems in a spatially-explicit manner covering all dimensions and scales relevant to climate change. Simulated scenarios include a severe A2 climate change scenario up to 2070, two policy-based adaptation scenarios, and autonomous adaptation. Results show that climate change may impact severely irrigation systems reducing water availability and crop yields, and increasing irrigation water requirements. The risk faced by farmers is determined by technology and water use efficiency but also by spatial location and decisions made in neighbouring irrigation areas. The analysis of adaptation strategies underscores the role of current EU water policy in facilitating adaptation. Overall, the applied framework proved to be a useful tool for supporting water and climate change policy-making. It contributes to improve understanding about potential impacts of climate change, multi-scale vulnerability and the scope for adaptation.


## 1. Context and Objectives

The Mediterranean region is considered a climate change "hot-spot" (Giorgi, 2006; Iglesias et al., 2011), where water resources are likely to be seriously affected by climate change in the form of increased water scarcity and more frequent droughts (Arnell, 2004; Bates et al., 2008). In Spain, semi-arid Mediterranean regions that are vulnerable to water scarcity will have to deal with the additional challenges of climate change that will require the adaptation of economic activities dependent on water resources, such as irrigation agriculture, to new climatic conditions. Dealing with climate change will require a shift in water management and farming decisions towards more sustainable agricultural production and more efficient water allocation, distribution and use.

Along the last decades, the production of knowledge on climate change has been highly fragmented. Recent research on climate change has approached the assessment of impacts, vulnerability and adaptation under biophysical or social perspectives (Downing, 2012; Füssel, 2007). In the field of agriculture and water resources, most assessments have been based on biophysical modelling focusing on one specific dimension of climate change, such as the agronomic dimension (Moriondo et al., 2010; Ventrella et al., 2012), or the hydrological dimension (Joyce et al., 2011; Rochdane et al., 2012). However, the recognition of water management and climate change as multidimensional and multi-scalar concerns (Downing, 2012; Meinke et al., 2009) evidence the need to integrate biophysical and social aspects looking at environmental and human contexts. In line with this, varied types of integrated modelling frameworks have been developed to address the different scales (from the crop to the river basin) and the different dimensions of climate change, water and agriculture (hydrological, agronomic, socio-economic). However, these frameworks have not always represented the socio-economic dimension of water use in sufficient detail and in some cases they have undervalued the role of human response to climate impacts.

Trying to better represent socio-economic issues, hydro-economic modelling has been extensively used along the last decades as a prominent tool for guiding and implementing water policy decisions (Blanco-Gutiérrez et al., 2013; Brouwer and Hofkes, 2008; Heinz et al., 2007). These models are capable to consider the economic behaviour of water users and the economic principles that govern water allocation

* Corresponding author.
*E-mail addresses:* paloma.esteve@upm.es (P. Esteve), consuelo.varela@upm.es (C. Varela-Ortega), irene.blanco@upm.es (I. Blanco-Gutiérrez), TDowning@ClimateAdaptation.cc (T.E. Downing).

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and use among different sectors. This modelling approach has been applied at different scales and has been used for the analysis of varied agricultural concerns (Peña-Haro et al., 2009, and Volk et al., 2008, for agriculture-driven pollution; Blanco-Gutiérrez et al., 2013, and Rosegrant et al., 2000, for water allocation policies; Harou and Lund, 2008; Varela-Ortega et al., 2011, for groundwater overexploitation). Only in recent years, hydro-economic modelling has been applied for the assessment of impacts and adaptation to climate change, and the associated uncertainties (D'Agostino et al., 2014; Hurd and Coonrod, 2012; Jeuland, 2010; Medellín-Azuara et al., 2011). These models are able to represent people's response to climatic stimuli and climate change impacts on water resources and agricultural production guided by economic principles. However, the consideration in these models of crop growth processes has been uneven.

Along this line, this paper presents a novel application of a hydro-economic modelling framework that is used to assess climate change impacts and adaptation in the Middle Guadiana Basin, taking into account the agricultural, socio-economic and hydrology systems. The novelty of the approach presented here lies in the capability of this integrated framework to take into consideration agronomic, economic and hydrologic processes that take place at different scales. This way, this research takes a step forward in hydro-economic modelling to advance in the analysis of climate change implications on irrigation agriculture systems from the crop to the farm and the water system levels. The applied modelling framework includes the development of a farm-based economic mathematical programming model (MPM) of constrained optimisation that illustrates farm-level decision-making, and an application of the hydrology model WEAP (Water Evaluation and Planning System) (Yates et al., 2005) with its agronomic module (the MABIA Method, Jabloun and Sahli, 2012) that represents hydrological, agronomic and water management processes. This model combination permits to make socio-economic and agronomic processes spatially-explicit. Using this integrated approach, this paper evaluates the impacts of a severe climate change scenario (A2) on the water system, on farms and on crops, looking at farmers' capacity to adapt. It also explores the potential of selected water policies in facilitating adaptation, considering the various entities relevant to water management decision-making, including the farm, irrigation community (IC) and river basin levels.

## 2. Water, Agriculture and Climate Change in the Middle Guadiana Basin

The Middle Guadiana Basin, in the South-Western Spanish central plateau, illustrates the complexities and challenges of climate change adaptation in irrigated agriculture areas where water is scarce. The basin (Fig. 1) covers an area of about 34,000 km$^2$ and it is characterised by a continental Mediterranean climate with a marked dry season, an average annual precipitation of 500 mm, and a semi-arid humidity regime (CHG (Confederación Hidrográfica del Guadiana), 2008). Rural development policies during the 50's and 60's and recent National Irrigation Plans fostered the development of irrigation districts, primarily based on the development of hydraulic infrastructures. These infrastructures have provided a water storage capacity of 8000 Mm$^3$ to the basin, which has been crucial for irrigation development and rural socio-economic progress, and for mitigating the effects of the region's recurrent droughts.

Irrigation covers an area of around 130,000 ha where the main crops include maize, rice and horticulture, fruit trees, olive trees and vineyards (INE, 2009). Farmers are organised in irrigation communities that are in charge of managing water distribution to all farms, collecting water fees and controlling water use and irrigation. Management at the community level plays an important role with respect to the adoption of technologies and, in turn, to the efficiency of water use in the farms. There are 12 main Irrigation Communities in the Middle Guadiana from which in this research we will focus on three that show different water

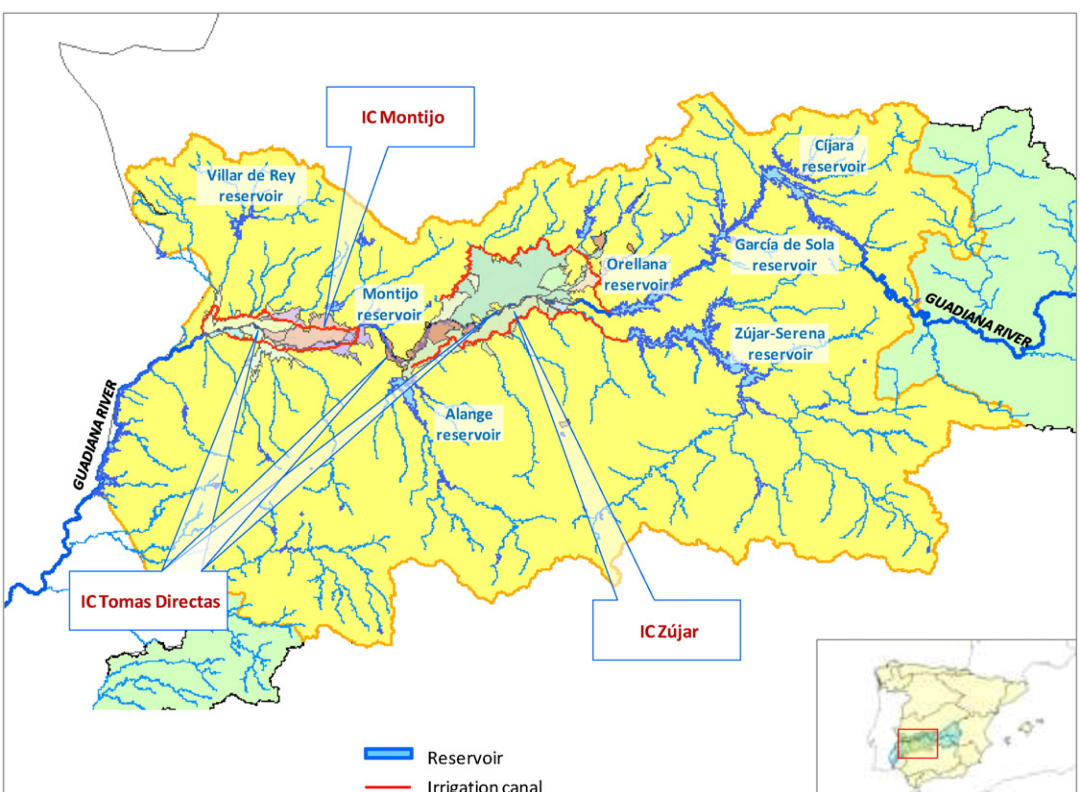


Fig. 1. The Middle Guadiana basin. Source: based on Blanco-Gutiérrez et al. (2013) and MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente) (2013).