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Cross sectoral impacts on water availability at +2 °C and +3 °C for east Mediterranean island states: The case of Crete

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SUMMARY

Ensemble pan-European projections under a 2 °C global warming relative to the preindustrial period reveal a more intense warming in south Eastern Europe by up to +3 °C, thus indicating that impacts of climate change will be disproportionately high for certain regions. The Mediterranean is projected as one of the most vulnerable areas to climatic and anthropogenic changes with decreasing rainfall trends and a continuous gradual warming causing a progressive decline of average stream flow. Many Mediterranean regions are currently experiencing high to severe water stress induced by human and climate drivers. Changes in average climate conditions will increase this stress notably because of a 10–30% decline in freshwater resources. For small island states, where accessibility to freshwater resources is limited the impact will be more pronounced. Here we use a generalized cross-sectoral framework to assess the impact of climatic and socioeconomic futures on the water resources of an Eastern Mediterranean island. A set of representative regional climate models simulations from the EURO-CORDEX initiative driven by different RCP2.6, RCP4.5, and RCP8.5 GCMs are used to form a comparable set of results and a useful basis for the assessment of uncertainties related to impacts of 2° warming and above. A generalized framework of a cross-sectoral water resources analysis was developed in collaboration with the local water authority exploring and costing adaptation measures associated with a set of socioeconomic pathways (SSPs). Transient hydrological modeling was performed to describe the projected hydro-climatological regime and water availability for each warming level. The robust signal of less precipitation and higher temperatures that is projected by climate simulations results to a severe decrease of local water resources which can be mitigated by a number of actions. Awareness of the practical implications of plausible hydro-climatic and socio-economic scenarios in the not so distant future may be the key to shift perception and preference towards a more sustainable direction.

1. Introduction

The target of 2 °C global warming above preindustrial levels has been recognized as a threshold above which consequences would be disastrous (Vautard et al., 2014). However, the prospects of global warming to be limited to this target have weakened (Sanford et al., 2014), while it is believed that we are currently heading to the 4 °C by the end of the century (Betts et al., 2011). The adaptation of the strictest emissions policies, that yield a 50% chance of succeeding in maintaining climate below a 2 °C target, could reduce climate change induced impacts by 20–65% relative to a 'business-as-usual' pathway reaching the 4 °C until 2100 (Arnell et al., 2013). Apart from the increase in temperature, the projected climate changes may also impose changes in the water availability through regional changes in other parameters of the hydrological budget. Projections indicate a robust signal of reduction for renewable surface water and groundwater across Representative Concentration Pathways (RCPs), especially for the dry subtropical regions, that may lead to increased water competition among sectors (Field et al., 2014).

The concept of RCPs (Moss et al., 2010) is based on overall additional radiative forcing in 2100 from human activities, and is expressed as a set of greenhouse gas concentration trajectories adopted by the climate and impact modeling community for near and long-term modeling (Vuuren et al., 2011). Four pathways of 2.6, 4.5, 6.0, and 8.5 W/m^2 additional energy taken up by the earth system cover a wide range of possible anthropogenic changes in

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the future. The projected global mean temperature will likely increase by 0.3–4.8 °C by the end of the 21st century compared to the recent past, across all RCPs (Alexander et al., 2013). RCP4.5 is a stabilization pathway leading to 4.5 W m^{-2} in the year 2100 (Thomson et al., 2011) with a most likely increase of 1.8 °C (1.1–2.6) by that time. The higher end RCP8.5 (Riahi et al., 2011) assumes high population and modest technological and energy improvements resulting to high greenhouse gas emissions and a mean global temperature increase by 3.7 °C (2.6–4.8), as a consequence.

While RCPs are designed to serve the climate modelling community, the integrated assessment modeling community and the vulnerability, impacts, and adaptation community can be served by the Shared Socio-economic Pathway (SSPs). Shared Socio-economic Pathway (SSPs) identify a range of different technological, socioeconomic, and policy futures that could lead to particular concentration pathways and magnitude of climate change (van Vuuren et al., 2012). The outcomes of the SSPs can be envisioned as society's response to the combination of adaptation and mitigation challenges posed by climate change (O'Neill et al., 2015). Depending on the preference towards mitigation or adaptation, five SSPs span the mitigation and adaptation challenges space, starting from the low challenges – sustainability oriented SSP1 to the intermediate challenges – close to business as usual SSP2 and high challenges – "regional rivalry" SSP3 of limited cooperation regarding environmental issues (O'Neill et al., 2013).

The global water scarcity assessment by Hanasaki et al. (2013a) foresees that, according to the socio-economic futures with no climate policies adaptation, during the last 30-year period of the 21st century the global population living under severe water stress will range from 39% to 50%. Even under the scenario of rapid technological change and high environmental awareness (SSP1), the water shortage is still projected to be significant (affecting 39–42% of global population), nevertheless, more due to population increase and characteristics of socio-economic activities rather than climate induced hydrological changes. For the medium "water efficiency" SSP2 scenario, the number of people living under absolute water scarcity (less than 500 m^3/yr/capita) is foreseen to increase by 40% as a result from a warmer world by +2 °C above present (or +2.7 °C from preindustrial) (Schewe et al., 2014). Future water demand assessments indicates that many regions will rely on non-renewable groundwater, water reuse, and desalinated water as global demand may increase by 67–134% up to 2050 and 31–242% by the end of the century (Hejazi et al., 2014).

At the spatial level of the Mediterranean climate change hot spot (Diffenbaugh and Giorgi, 2012; Diffenbaugh et al., 2007; Giorgi, 2006), temperature increase is expected to be one degree higher that the global average (Vautard et al., 2014). Specifically, by the time that global warming reaches the +2 °C relatively to the preindustrial baseline period (1881–1910), it is estimated that the region will experience approximately 0.2 °C higher temperatures on average, implying hotter Mediterranean summers. Higher temperatures will intensify evaporation rates from surface reservoirs and the potential evapotranspiration over land (Bates et al., 2008). Additionally, climate change is projected to pose changes in the precipitation regime (Hagemann et al., 2013), with climate models to depict that precipitation on average is likely to be less frequent but more intense, while drought events are likely to become more frequent and severe in some regions (Koutroulis et al., 2013; Tsanis et al., 2011). The progressive decline of water availability foreseen in future scenarios for the Mediterranean will most likely cause short-term unsustainability of many water infrastructures in the Mediterranean basin (García-Ruiz et al., 2011), posing additional pressures to water availability in addition to human induced changes (Grouillet et al., 2015).

Groundwater resources play an important role in freshwater availability for the majority of the Mediterranean coastal and island water system, especially during dry summer periods (García-Ruiz et al., 2011; Ranjan et al., 2006). Degradation of the groundwater quantity and quality is a common problem in the Mediterranean region due to a range of anthropogenic pressures on the aquifers (e.g. over-pumping in relation to average natural recharge, agrochemical leaching, urban waste and waste-water inflows, mining activity). On top of those, changes in climatic variables can significantly alter groundwater recharge rates and thus affect the availability of fresh groundwater (Iglesias et al., 2007). Despite their significance and risk exposure, the Intergovernmental Panel on Climate Change (Parry, 2007) and FAO (Schneider et al., 2013) recently highlighted the paucity of research into groundwater resources and climate change. As relevant processes are seldom linear, the estimation of groundwater availability is not always straightforward and introduces and additional layer of uncertainty. Thus, in the Mediterranean regions there are also cases where the increased rainfall variability may increase the recharge rate even with lower mean rainfall values (Pulido-Velazquez et al., 2015).

Several studies have assessed cross-sectoral climate change impacts at global and continental scale (Arnell et al., 2013; Harrison et al., 2012; Metzger et al., 2005; Piontek et al., 2014; Schewe et al., 2014; Warszawski et al., 2014) but few have done so at local or even regional scale. Other local climate change impact studies (Cleridou et al., 2014; Fabre et al., 2015; Garrote et al., 2015; Vargas-Amelin and Pindado, 2013) are framed on socioeconomic prospective scenarios and management choices without considering water demand in the form of qualitative/narrative scenarios according to the SSPs. After our recent studies on water availability and stress (Koutroulis et al., 2013, 2015; Tsanis et al., 2011) for the island of Crete, Greece, the issue of future water resources availability is revisited under the latest generation of climate scenarios (RCPs) combined with tailored information on the most relevant socio-economic futures according to the SSPs. We integrate the major impacts of climate change on the water resources of a Mediterranean insular socioeconomic system by downscaling socio-economic drivers such as population and economic development and climate information relevant to the local information. Therefore, the present study is one of the few to date that is considering water use in the context of qualitative/narrative scenarios of SSPs at local level, following a plausible combination of SSP-RCPs scenarios to examine future water availability under a cross-sectoral climate change impacts framework.

2. Methods

The present study is built around the scenario-based impact assessment approach (Christensen et al., 2011; Ciscar et al., 2014) focusing on the risks of future climate change. The methodology described in the present study is developed based on ground knowledge of local experts and stakeholders interacting with impact modelers aiming to assess the impact of future climate change on water availability, and considering adaptation measures, from a cross-sectoral perspective. In the context of water resources research, the basic information provided by the SSPs are population and economic growth trends while RCPs provide climate information. Two different climatic pathways, namely RCP4.5 and RCP8.5, are considered for assessing the future climate relative to a baseline (near past to current) period. Projection periods are defined by the level of global warming (+2 °C and +3 °C) as simulated by the driving GCMs (described in detail in the dataset section). In correspondence to the climate scenarios, three potential associated socio-economic pathways are considered, SSP1, SSP2