Koutroulis, A.G.; Grillakis, M.G.; Daliakopoulos, I.N.; Tsanis, I.K.; Jacob, D.:

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

In: Journal of Hydrology (2012) Elsevier

DOI: 10.1016/j.jhydrol.2015.11.015

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

A. G. Koutroulis[a],

M. G. Grillakis[a],

I. N. Daliakopoulos[a],

I. K. Tsanis[b,a],

D. Jacob[c]

[a] *Technical University of Crete, School of Environmental Engineering, Chania, Greece*

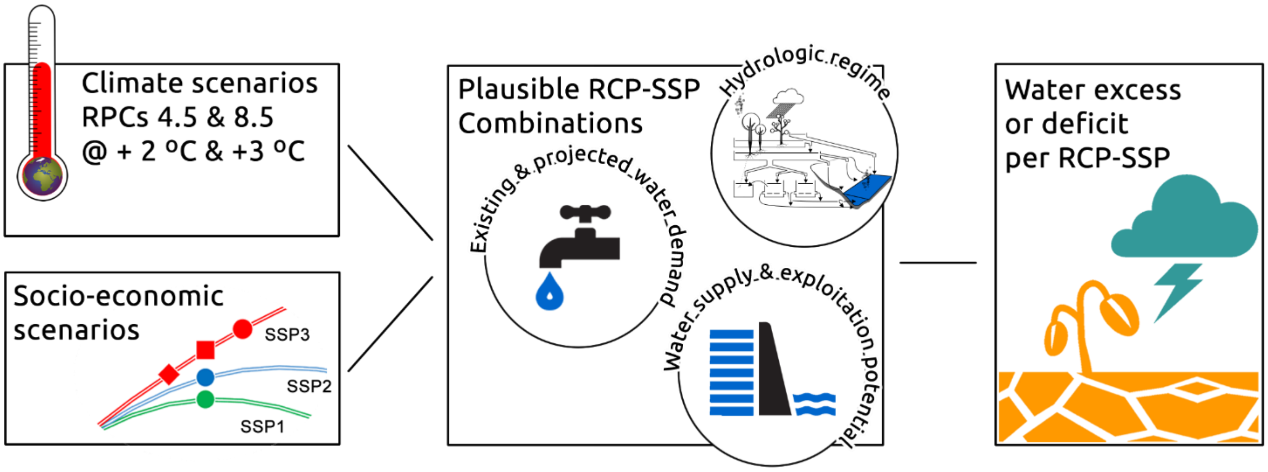
[b] *McMaster University, Department of Civil Engineering, Hamilton, Canada*

[c] *Climate Service Center Germany (GERICS), Helmholtz-Zentrum Geesthacht, Hamburg, Germany*

Research highlights

- Generalized framework of cross sectoral impacts on water resources
- Simulations project robust signal of less precipitation and higher temperatures
- Severe decrease of local water resources at +2°C and +3°C
- Development of a set of plausible hydro-climatic and socio-economic scenarios
- Practical implications of water scenarios point towards more sustainable direction

Graphical abstract



Abstract

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, RCP 4.5, 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 degrees 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.

Keywords: climate change; climate impacts; water resources; hydrological modeling; Mediterranean; Crete Island

---

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 the future. The projected global mean temperature will likely increase by 0.3 to 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 to 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 to 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 Socioeconomic 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., 2015, 2013; 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 RCP 4.5 and RCP 8.5, 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 and SSP3. Figure 1 includes the socio-economic information derived from the SSPs supporting the present study. Global population (Figure 1, top) information at the specific timings of warming level is assessed to food demand and therefore trends of crop and livestock demand and tourism activity. National population projections (Figure 1, middle) can be used for the estimation of energy demand and domestic water demand. The evolution of national GDP in the future (Figure 1, bottom) is useful for assessing the cost of adaptation.

The changes in freshwater supply and demand are assessed at the global warming levels of +2 °C and +3 °C. Three 30 years periods are considered, a reference period between 1971 and 2000 and the future time-slices around +2 °C according to RCP4.5 and around +2 °C and +3 °C under the RCP8.5. The +2 °C and +3 °C periods were explicitly defined for each model as the period in which each driving GCM reaches this specific level of global warming comparing to the preindustrial baseline period 1881-1910 (Vautard et al., 2014). The 30-year time slice around which the +2 °C and +3 °C periods are defined for each GCM driving model, are shown in Figure 1.

2.1 Water demand

Regarding global population, SSP trajectories are very coherent until around 2030s, while by 2050 a clear differentiation occurs, with the highest (SSP3) and the lowest (SSP1) trajectories diverging by 1.5 billion inhabitants (Figure 1, top). This difference expands further until 2100 with world population reaching 12.6 billion in SSP3 and dropping to 6.9 billion, lower than at present, in SSP1 (KC and Lutz, 2014). According to the World Bank, Greece belongs to the "rich" OCED membership countries, with low fertility (average offspring per woman ≤ 2.9). SSP1, which assumes a future moving toward a more sustainable path, predicts that Greek population will increase marginally, while from 2060 and forth, there will be a decline in the total population. Figure 1 (middle) shows the trajectory of Greece's population for each RCP – SSP scenario relative to that of the global population in Figure 1 (top). Close to SSP1, the middle road scenario SSP2, assumes medium fertility and medium mortality for all countries, which translates as a faster stabilization of the Greek population, and a subsequent decline at 2040. The SSP3 scenario refers to a fragmented world with an emphasis on security at the expense of international development. Global population growth is higher comparing to the previous scenarios, driven by the growth in the developing countries. Nonetheless, fertility is assumed to be low in the rich OECD countries, thus projecting severe reduction of the Greek population as early as 2020.

A critical limitation of SSP scenarios is that they do not provide any qualitative or narrative information on the future water use (Naota Hanasaki et al., 2013) that would be downscaled and adjusted to the needs of a local or regional study. Hence, water use scenarios compatible with the SSPs have to be developed in taking into account global and national trends, various assumptions as well as expert opinion from policy makers such as the local water authorities. The effect of increased temperature on domestic water consumption is introduced as a factor of 7% increase (or 15 L/day/capita) per degree of warming (Chang et al., 2014). A slight increase of 7% in domestic water use could be expected for the approaching 2026 – 2055 +2 °C period of the RCP8.5 – SSP3 pathway, mainly due to the increase of temperature. At the highest warming level of +3 °C, despite the intense temperature increase, a decrease of -3% is projected, mainly driven by the population decrease of 18% depicted in SSP3. For the warmer projection periods, the effect of increased temperature on tourism water consumption, similarly to domestic use, is also taken into consideration. Here, the projection of overnight stays is derived as a combination of the information of projected climate comfort related to tourism activities through the Tourism Climatic Index (TCI) approach (Grillakis et al., 2015a; Mieczkowski, 1985), and projections of global population that drives the tourism demand.

Realistic future scenarios of irrigation demand are based on local development plans and proposed strategies for expansion of irrigation networks, along with the corresponding information of each SSP for irrigated area and crop intensity presented by several studies (N. Hanasaki et al., 2013; O'Neill et al., 2013). According to the SSP3 of low water efficiency and high growth in crop intensity, crop water demand is assumed to follow global population trends based as a food demand driven approach (Ignaciuk and Mason-D'Croz, 2014). Total demand is based on the demand of SSP2 on top of which the proportional increase of the global population (Figure 1, top) of SSP3 is added. Regarding livestock, the projections of the corresponding RCP-SSP combinations are based on global population trends for each SSP (Figure 1, top) as a demand driver along with a climatic index of potential evapotranspiration change (increase) according to the livestock watering method. For specific species (mainly caprinae), a decreasing trend is assumed due to decreased production trends affected by low price competitive imports and changes of the European Common Agricultural Policy (CAP) aiming towards higher productivity rather that high production capital (Hansen and Herrmann, 2012).

Projections of industrial water needs are adjusted according to industrial water withdrawal scenarios presented by Hanasaki et al. (2013a). Future projections of water consumption of olive mills, that constitute a crucial part of the industrial water use (Table 6), are estimated proportionally to irrigation needs. Projections of future water needs for energy are derived proportionally from the total projected water needs of other sector needs (domestic, tourism, industry, olive mills) based on the rationale that they constitute the key energy intensive sectors. Finally, for SSP1 the potential introduction of additional renewable energy sources and the connection of the island to the national grid are considered.

2.2 Water availability

In order to derive water availability, RCM data are initially downscaled to basin level. The difference in mean and standard deviation of the downscaled time series are then adjusted using measured basin scale precipitation (P) and temperature (T) time series. The methodology used for this adjustment is presented in (Haerter et al., 2011) and is performed at a monthly time step. Regional climate model data from five Euro CORDEX RCMs at 0.11 degrees resolution provided the climate projections according to RCP 4.5 and RCP 8.5 (Table 1). The climatic information is only analyzed for the climate model and RCP combinations that reached the respective target global average temperatures (+2 °C or +3 °C) at some point of the investigated time frame (i.e. until 2100).

Hydrological simulations are performed at basin scale using the calibrated SAC-SMA continuous rainfall–runoff model (Tsanis et al., 2011). The SAC-SMA Sacramento model is a lumped continuous rainfall-runoff model that estimates stream runoff (Q) from P and potential evapotranspiration (PET) records, based on soil moisture accounting (Podger, 2004). Here, PET is derived from values of T using the Blaney-Criddle formulation (Allen and Pruitt, 1986). SAC-SMA is based on the assumption that soil moisture storage is increased by P and reduced by actual evapotranspiration (AET) and total runoff Q ($Q_{\text{direct}} + Q_{\text{surface}} + Q_{\text{baseflow}}$) and infiltration I between the upper and lower zone that discharges at a slower rate (Q_{slow}). The size and relative wetness of the storage determines the depth of P absorbed, the amount of water that evaporates or transpires from vegetation, and that moving vertically or laterally out of the store. These processes are described by 16 model parameters that are determined using a scheme based on an application of Genetic Algorithms (Wang, 1997).

Here we assume that given suitable infrastructure, various parts of the hydrological budget can be transformed to some degree of efficiency in water availability. Thus, P can be converted to surface water storage with the construction of surface reservoirs, Q has the potential of reclaimed as surface water with the construction of dams, and I can recharge aquifers for the benefit of groundwater availability. At the same time surface water resources can be depleted via evaporation and networks suffer loses when operated to cover demand. Details regarding existing and future water resources infrastructure are case specific and need to be provided by the local authority, including capacity, and costs of construction and maintenance, as well as a ranking in terms of feasibility and priority associated with the set of socioeconomic pathways.

2.3 Cross sectoral framework

The three SSPs are suitably combined to the hydro-climate projections to incorporate scenarios of alternative futures of water supply and demand under future economic and societal development. More specifically, the climate scenarios provide the climatic information for the assessment of the hydrological impacts at specific warming levels by modeling the changes in the local terrestrial water cycle. Information of existing and planned water resources infrastructures and management practices are used for the development of realistic local water demand and supply scenarios compatible to each respective SSP. Scenarios of future changes in irrigation, tourism, energy, domestic, livestock and industrial water demand were also composed according to the potential socio-economic futures, within a framework of a cross-sectoral water resources analysis. Finally, hydro-climatic and socio-economic scenarios were associated in the context of plausible RCP-SSP combinations. Five future situations under different local hydro-climatic and socioeconomic conditions are considered to examine the range of potential impacts on water availability at +2°C and +3°C of global warming. This methodological framework is illustrated in Figure 2.

3 Area of study

Crete is the fifth largest island of the Mediterranean and the first and most populated island of Greece. The climate on the island is characterized as Mediterranean – Semiarid featuring long and dry summers, and relatively wet and cold winters (Kottek et al., 2006). The Water District of Crete (GR13) is the southernmost Water District of the country (Figure 3) and includes the entire area of the Region of Crete (RoC). The RoC consists of four territorial units according to NUTS3 classification: Chania (GR434), Heraklion (GR431), Rethimno (GR433) and Lasithi (GR432). The intense tectonic activity has formed the complex topography of the island with the elevation ranging from sea level to 2,450 m, shaping small catchments with ephemeral streams and karst geology (Tsanis et al., 2011).

During an average hydrological year, Crete receives about 7.7 billion m^3 of precipitating water, of which 68-76% evaporates or transpires, 14-17% infiltrates and 10-15% is lost to the seas as surface runoff (Koutroulis et al., 2013). Total annual surface runoff is about 1,080 Mm^3 and half of it discharges through the major streams of the island. Total subsurface recharge is estimated to 780 Mm^3 per year. It is estimated that the total water consumption corresponds to the 7% of the total precipitation (Tsagarakis et al., 2004). However, there are often water imbalance issues that are attributed to the temporal and spatial variations in the precipitation over the island, the increase in water demand during the dry months due to tourism, and the difficulty of transporting water due to the mountainous terrain of the island (Tsagarakis et al., 2004). The main water consuming sectors in Crete are agriculture that share the 84.5% of the total consumption, while domestic and industrial sectors use the 12% and 3.5% of the water respectively (Chartzoulakis, 2001). Agricultural water is mainly used to grow of vegetable crops, fruit trees and vines. More than 91% of vegetable crops are irrigated, 34.0% for row crops, 36.3% for fruits and 45.1% for vineyards (Chartzoulakis, 2001).

The highly rugged terrain of Crete is crucial in terms of the spatial organization, the urban structure, the drivers of development of the productive sectors, the transport system and generally all to date, and future parameters related to human activities on the natural environment. The population of Crete corresponds to 5.4% of the national population, with an increasing trend, since between the censuses of 2001 and 2011 the population increased by 3.65% reaching 623,065 inhabitants (Figure 4, left). The RoC contributes about 5% (12.854 billion € in 2008) to the Gross Domestic Product (GDP) of the country. Regarding the three major sectors of the economy of Crete, during 2008 the primary sector participated with 5.51%, the secondary (Industry and Construction) contributed 13.84%, while the tertiary sector had the highest share with 80.65%. Before the 2008 crisis and during the period 2000-2008, the most important contribution to the added value of products of Crete was the "Trade and Tourism" sector, as part of the tertiary sector with 4.59 billion €, growing by 85% from 2000 to 2008. The primary sector, in absolute terms, remained stagnant, with a significantly reducing rate of contribution to the regional added value from 10.04% in 2000 to 5.51% in 2008. On the other hand, the "Industry and Energy" sector increased its contribution from 4.96% in 2000 to 7.48% in 2008. Since 2008, the island is facing a prolonged crisis, on par with that of the rest of the country (Figure 4, right), leading to little overall investments and financial contraction. Nevertheless, tourism is the most dynamically growing sector and the demand has given incentives for significant investment in hotel facilities, resulting in a quantitative and qualitative improvement of the accommodation infrastructure. Overnight stays in Crete in 2010 amounted to 16,449,065, representing 24.6% of all overnight stays in Greece. The intensification of tourism activity has increased the environmental stress (Andriotis, 2003), including the water demand stress.

3.1 Present water demand

Current average annual domestic water consumption is estimated based on the historical average consumption of 288 L/day/capita and the latest population census data (623,065 in 2011), resulting to a total of 65.49 Mm3 for the Water District of Crete. This constitutes almost 13% of the 525.62 Mm3 of total water demand (Figure 6, Table 6). Based on this estimation and (Chang et al., 2014), the effect of increased temperature on water consumption is 15 L/day/capita per degree of warming. The highly developed tourism sector in Crete has relatively large water requirements especially during the summer season. For the estimation of the average water demand associated to tourism activities, a consumption rate of 400 L per overnight stay is assumed (Papagrigoriou et al., 2001). Information regarding current local population and overnight tourism stays has been retrieved from the Hellenic Statistic Authority.

Total cultivated land in the Region of Crete is 255,359 ha, of which 107,909 ha (42%) are irrigated (Papagrigoriou et al., 2001). A fraction of 70% (178,401 ha) corresponds to olive groves and only 68,949 ha (39%) are irrigated, producing on average 150,000 tons of olive oil annually. Vineyards cover an area of 27,665 ha (11%), arable land 27,236 ha (11%), orchards 7,748 ha (3%), horticulture 10,032 ha (4%), greenhouses 2,286 ha (1%), and the rest of the area is covered by other cultivations. Crop water requirements per cultivation type have been defined by the local authority in consultation with the research team of Papagrigoriou et al., (2001) that estimated the irrigation demand based on theoretical methods of optimum crop yield. Table A2 of the appendix summarizes water demand, land extend and irrigated area per cultivation type. It should be noted that the adopted crop water needs which have arisen from the local-scale research and expert judgment of the local Authority, are typically greater than the total annual consumption reported by the Local Organizations of Land Reclamation (LORL) that are the major irrigation organizations (in many cases fields are not irrigated to full extent, or irrigation restrictions are applied for some resilient cultivations like olive trees during dry seasons). Moreover, actual water needs are further estimated at local (municipal level) taking into account the losses of individual irrigation networks. Thus, a loss factor of 15% is assumed for organized irrigation networks of irrigation organizations and 25% for municipal networks. Total irrigation needs including systems losses are estimated to 439.62 Mm^3 (Table 6), making up the largest share (84%) of total water demand (Figure 6). Current water needs for livestock are estimated at 8.7 Mm^3 annually, based on animal watering requirements (Papagrigoriou et al., 2001) and the number of animals as listed in the national census, described in the appendix (Table A1).

The secondary sector of Crete is less developed compared to the primary. The majority of industries – manufacturing (more than 60%) are concentrated in the regional unit of Heraklion, at the central part of the island. Main industrial – manufacturing activities include production of plastics, marble processing and concrete production, clothing and textile, milk products, citrus and vegetable packaging, canneries and metal constructions. Total industrial water consumption is estimated to 4.1 Mm^3 (Table 6). As olive tree cultivation is the primary agricultural activity in the region, occupying 70% of the total agricultural land, water used by olive mills is an important part of this sector. Olive oil is currently produced by 620 olive mill facilities spread over the island, operating annually from November to February. The average water requirement is estimated at 1,500 m^3/year for each olive mill (Papagrigoriou et al., 2001) resulting to a total 0.93 Mm^3 annually. Energy needs of the island are covered by three thermal power stations of total power 950 MW. Average annual water needs for steam production are estimated at 0.2 Mm^3. Information regarding the industry and energy sector has been retrieved from the Hellenic Statistic Authority.

3.2 Present water availability

Regarding historical climate, observed precipitation data from 53 rain gauges (Figure 3) and 15 temperature stations were used to estimate the basin scale precipitation and temperature time-series for the 130 distinct watersheds of Crete. The SAC-SMA model was calibrated with a Genetic Algorithm optimization scheme yielding a satisfactory fit (R^2 between 0.590 and 0.917) for 15 gauged basins. Resulting calibration parameters were generalized over all 130 major watersheds of the island.

The Integrated Water Resources Management study of Crete (Papagrigoriou et al., 2001) includes all existing water infrastructure (dams, reservoirs, abstractions) until 2001. The infrastructure that developed since 2001 in order to support the water supply of the Water District of Crete is described in the recent draft of water resources management (Special Secretariat for Water, 2014). Existing infrastructure (dams, reservoirs, groundwater abstractions) shapes the current supply potential to 421.40 Mm^3/yr. Total water supply in Crete is estimated at 421.40 Mm^3/yr and distributed 335.40 Mm^3/yr for irrigation (80%), 8.70 Mm^3/yr for livestock and 77.3 Mm^3/yr for water supply, tourism, energy and industry (18%). It is important to emphasize the heavy reliance to the system to groundwater, as water resources originating from surface bodies account only 8% of the total availability.

The localized scenarios are developed in collaboration with the Directorate of Water, the general water managing authority for the Region of Crete, exploring the feasibility and the costing of adaptation measures, in terms of additional water infrastructures, associated with the set of socioeconomic pathways. Future plans focus on the exploitation of surface water due to the overexploitation of groundwater resources (Daliakopoulos et al., 2005; Varouchakis et al., 2015) in several aquifers of the island and the consequent salt intrusion (Dokou and Karatzas, 2012; Kourgialas and Karatzas, 2015). Future exploitation plans include the construction of small – local scale dams and reservoirs, large embankment dams of wider operation range, improvement of existing boreholes, construction of new irrigation networks and other complex water engineering structures. A total number of 68 water engineering projects were defined with a total capacity of 166.8 Mm^3 (about 40% additional supply compared to existing, at present climate conditions) and a cumulative construction cost of 893 M€ (current prices). The feasibility and the implementation maturity of these projects are evaluated in collaboration with the local authority in the context of the SSPs.

4 Results

4.1 Hydro-meteorologic projections

Transient temperature response at local level reveals an increasing temperature trend that is more pronounced in the case of the high-end RCP8.5 scenario (Figure 5). A global temperature increase by 2 °C is projected to be milder at local level (Crete), reaching the +1.69°C above the annual average of 16.92 °C (median 18.61 °C) according to RCP4.5 (2037-2066 on average) and +1.80 °C under RCP8.5 (2026-2055 on average). Similarly local temperature is projected to increase by 2.86 °C around 2060 on average, at the global warming level of +3 °C. Detailed projected changes of the range of the multi-model projections are included in Table 2. Average annual precipitation (903 mm) is projected to decrease by 6% at the global warming level of +2 °C, regardless of the concentration pathway (around 2050s for RCP4.5 or around 2040s for RCP8.5). This is underlines the robust response of precipitation to climate change to the cumulative CO_2 concentration (about 70 PgC from 2000 to 2050 for RCP4.5 or until 2040 for RCP8.5), regardless of the exact timing. In a +2°C warmer world, dry years (5th percentile) are also expected to be dryer by 7.3% and 11.9% under RCP4.5 and RCP8.5, respectively (Table 2). Drought is projected even more pronounced (-17.9% of the 5th percentile of annual precipitation) at the higher warming level of +3 °C.

Potential evapotranspiration is expected to increase by roughly 5% at +2 °C and by 8% at +3 °C (Table 2) attributed to temperature increase. The combined effect of increasing temperatures and decreasing precipitation drives a decrease of average annual availability, defined as the sum of runoff and infiltration (Koutroulis et al., 2013; Tsanis et al., 2011). The availability decrease is more pronounced compared to that of precipitation. At a +2 °C warmer world, according to RCP8.5 the water availability is simulated to decrease roughly by a factor of two (-12.1%) compared to precipitation (-6%). The corresponding availability under RCP4.5 and compared to precipitation change is foreseen to decline by a factor of three (-18%) probably due to the further slow discharge of groundwater aquifers to the sea (RCP4.5 crosses the level of +2 °C warming by 10 years later compared to RCP8.5). Dry years (in terms of availability) are expected to be drier by 20% – 25% in the case of +2 °C and by over 35% at +3 °C. The availability of wet years is projected to slightly decrease for RCP4.5 at +2 °C and for RCP8.5 at +3oC and on the other hand, increase by almost 15% under RCP8.5 at +2 °C (Table 2).

4.2 Water supply and exploitation potential

Table 4 includes the number of future water resources infrastructure per RCP – SSP combination, the total capacity and the construction cost, projected to the corresponding period according to the projections of the national GDP (Figure 1, bottom). This classification was established after consultation with the Directorate of Water of the Decentralized Administration of Crete that serves as an end user for the project. The impact of climate change on water supply for open structures (dams, reservoirs) is associated to the changes in potential evaporation and for groundwater abstractions the output of hydrological modeling regarding changes in subsurface availability are considered (Table 3). Capacity and surface extend from 5 dams and 8 open reservoirs over Crete are examined to estimate the average water storage area per Mm^3 of stored water for the island of Crete.

For the period 2037 – 2066 and the RCP4.5 – SSP1 high efficiency scenario, a total of 39 infrastructure projects are considered feasible (Table 4), 24 of them further exploiting or optimizing groundwater and 15 harvesting surface runoff. The total capacity of surface projects (64.36 Mm^3) is almost four times the groundwater abstractions (16.52 Mm^3) and the implementation cost is more than 8 times compared to groundwater exploitation (Table 4). The increased costs compared to SSP2 scenario, despite the lower capacity, reflects the cost of investing on water saving technologies. The *business as usual* RCP4.5-SSP2 scenario foresees additional infrastructure (4 groundwater and 8 surface) providing a total of 117.69 Mm^3, thus increasing current availability by 28% with a total approximate construction cost of 1.289 billion €. According to the low water efficiency and high growth SSP3 scenario an approximate of 160 Mm^3 (ranging from 158.8 Mm^3 to 162.5 Mm^3 depending on the warming level – reference period of each RCP) could be added to the available water resources. The cost of this "upgrade" is estimated at around 1.3 billion € which is mainly attributed to the construction of surface water resources infrastructure such as dams and reservoirs.

4.3 Projected water demand

Regarding domestic water consumption, future projections for the RCP-SSP combinations are based on national level projections according to the examined SSP and the corresponding +2 °C or +3 °C warming level period. Domestic consumption is projected to increase up to 77.5 Mm^3 (+18%) for the +2 °C period (2037-2066) according to the RCP4.5 - SSP1 combination (Table 6). Similarly, a 14% increase is foreseen for the RCP4.5 – SSP2 combination and for the same period, while a decrease of -1% is projected following the RCP4.5 – SSP3 scenario mainly due to the projected population decrease for Greece expected under SSP3 (Figure 1, middle). Regarding tourism, Table 5 contains information on multi-model projections of overnight stays (median, interquartile and 5-95 percentile estimates) for every analyzed period and corresponding RCP-SSP combination, as derived by (Grillakis et al., 2015b). The combined effect of increased consumption of 12% due to +2 °C (downscaled to a local

+1.7 °C), of 42% due to climate comfort improvement under RCP4.5 for the 2037-2066 period and due to global population under SSP1 (Table 5) results to an overall increase of 59% (from 6.6 to 10.5 Mm^3) in water demand for tourism activities (Table 6). Similar increasing trends are projected for all RCP-SSP storylines, driven by global population increase (from +39% to +74%), increase due to improved climate comfort (from +7.1% to 7.9%) and increase from higher temperature consumption (from +12% to +20%) resulting to higher consumption (Table 6) ranging from +59% (3.9 Mm^3) to +116% (7.6 Mm^3).

Regarding the primary sector, for the sustainability scenario (SSP1) of low growth in irrigated area and crop intensity combined with high water use efficiency, the demand could be shaped to 543.76 Mm^3 annually for the period 2037-2066. This increase by 24% is attributed to the extension of irrigation networks along with the application of water saving technologies. For the medium crop intensity growth scenario (SSP2) and medium water use efficiency (which is considered as the *business as usual* scenario), irrigation water demand is expected to increase by 30% to a total 571.94 Mm^3 per year on average for the period 2037-2066. The estimated irrigation demand of the *business as usual* scenario RCP4.5-SSP2 is estimated at 675.91 Mm^3 that is close to the 670.80 Mm^3 estimated by Papagrigoriou et al., (2001). For the same level of warming (and period) of RCP4.5 and SSP3, an increase of 37% is estimated. According to SSP3 projections, resulting annual crop water demand is shaped to 623.47 Mm^3 during 2037 – 2066 and RCP4.5, 576.08 Mm^3 during 2026 – 2055 and RCP8.5 and 661.42 Mm^3 for the period 2047 – 2076. Regarding livestock, projected water demand ranges from 11.4 to 11.7 Mm^3 (increase from +31% to +34%), depending on scenario (Table A1 of Appendix).

According to SSP1, industrial water consumption is expected to remain at current levels (4.1 Mm^3) for the period 2037 – 2066 at +2 °C of global warming, mainly due to advances in water saving technologies. For the same period and following SSP2 of medium water saving efficiency, the increase is estimated at +21% (+0.9 Mm^3), while for low efficiency and high growth (SSP3), the increase ranges from +14% to +67% (Table 6). Projections of future water needs for energy (Table 6) are derived proportionally from the total projected water needs of other sector needs (domestic, tourism, industry, olive mills) based on the rationale that they constitute the key energy intensive sectors. The slight increase in SSP1 is associated to the potential introduction of additional renewable energy sources or the connection to the national grid (Table 6).

A robust signal of increase is projected for all future scenarios mainly attributed to the increase of irrigation demand. The total demand of the +2 °C warmer 2037 – 2066 period according to SSP1 – RCP4.5 combination is shaped to 648.69 Mm^3, increased by 29% compared to present situation. Respectively, for the higher end scenario of RCP8.5 the same level of warming is reached approximately 10 years sooner (2026 – 2055) and combined with SSP3 results to a total demand of 675.25 Mm^3 (increase by 28%). For the higher levels of warming (+3 °C) of RCP8.5 that are reached during the period 2047 – 2076 and for the fragmentation – high growth and low efficiency scenario, total demand is shaped at 758.87 Mm^3. This increase (44%) is attributed to high population change which in turn generates higher food demand and thus increased irrigation needs (87% of the total needs).

4.4 Water resources availability and cost

The impact of climate change on the supply potential of the current infrastructure is projected to decrease by 17% (from 421 Mm^3 to 351 Mm^3; Figure 7) and by 11% at +2 °C according to RCP4.5 and RCP8.5, respectively. This is attributed mainly to the decline of water groundwater availability that is the major source of the system supply. This decline is foreseen to be more pronounced (-25%) at +3 °C of global warming. The implementation of future infrastructure projects will increase the supply potential. Ignoring the effect of climate change the additional availability is shaped to 506 Mm^3 (+20%) according to SSP1, 544 Mm^3 (+29%) under SSP2 and 588Mm^3 (+40%) for SSP3. The corresponding cost of the water engineering projects for the respective RCP-SSP period is included in Table 6 and Table 7. Including the information of climate change impact on current water supply and future exploitation potential, as described in the previous section, the projected supply potential could range from 432 Mm^3 (+3%) to 537 Mm^3 (27%) depending on the RCP-SSP combination. It is important to note, for example according to the RCP4.5 at +2 °C combined to SSP1, despite the implementation of infrastructure of +80.9 Mm^3 additional water resources the resulting availability is shaped to 432 Mm^3 (+3%) compared to current supply. This is due to the impact of climate change on the availability of groundwater resources and thus to the current supply system (that depends mostly). The proposed infrastructure plans are based mainly (80%) on the exploitation of surface water through dams and reservoirs and can substantially alter the timing of water resource availability, compensating the inefficiency of the existing situation.

The impact of climate change on the hydrology of the region and thus to the supply potential ranges from -51.3 Mm^3 to -75.4 Mm^3 under 2 °C of global warming, depending on the RCP-SSP formulation. The impact is more pronounced for RCP4.5 (compared to RCP8.5) probably due to the ten years later crossing of the +2 °C and the further loss in terms of discharge from groundwater aquifers. The expected deficit under the RCP-SSP formulation ranges from 20% to 37% (Table 7), mainly due to increasing irrigation demand. The least cost effective scenario in terms of investment cost for additional availability per Mm^3 is the business as usual RCP4.5-SSP2 scenario (10.95 M€/Mm^3). The RCP4.5-SSP1 high sustainability combination, despite the high investment cost due to the increase in GDP, is simulated as the most cost effective option but with a high deficit rate (33%). The second most cost effective option, for the warming level of +2 °C is the RCP8.5-SSP3 with the lower projected deficit which, however, assumes rapid adaptation in terms of investments in water resources infrastructure of high cost. Nevertheless, this high end scenario leads to higher deficit rates (37%) at global warming levels around +3 °C.

5 Limitations

With respect to the methodology tested here, certain limitations have been identified in the evaluation of impacts of climate change, such as the following:

- Simplifications in water management that can be overcome with the use of a more complex and data demanding utility management model (Garrote et al., 2015; Pulido-Velazquez et al., 2011) taking into account simultaneously temporal, spatial heterogeneity of the hydrological components, demands and the location of the infrastructures.

- Assumptions regarding the regionalization of hydrologic modelling parameters that can only be overcome with denser surface water gauging.
- Simplifications regarding the groundwater component of the modelling approach that is a tradeoff of modeling parsimony versus complexity and future uncertainty.
- Simplifications regarding the impact of major surface storage infrastructure on the hydrologic regime and by extension on hydrologic modelling that will be overcome with future observations of in recently built infrastructure..
- Adaptation considered in the present study is limited to constructions and not on soft measures (we do not cover the full range of adaptation options).
- Assumptions on local water demand are based on expert judgement and best reasoning but there is always uncertainty regarding current and future policy implementation outcomes, as end user preferences often depend on personal, sociocultural, socioeconomic, institutional and bio-physical factors rather than technical ones (Panagea et al., 2015).

The above limitations can also serve as suggestions for further research.

6 Conclusions

While mitigation and adaptation policies to restore sustainability are usually centrally planned, their success invariably depends on the implementation efficiency at local level where awareness and perception often pose barriers (Betzold, 2015; La Jeunesse et al., 2015). Especially in the case of adaptation, mobilization incentives are highly local and the mediating the local impact of climate change induced threats is challenging (Agrawal, 2010). In this context, communicating relevant and targeted climate change information to stakeholders and decision makers is crucial for converting and gaining commitment on the field. This work makes a first attempt to translate global scale SSPs to the context of local development scenarios in order to overcome their limitations in providing information on future water use and thus impact directly to local administration and end users. The close collaboration with the local water authority has covered a major part of this process, but it is also a major requirement that results on water availability and its expected future costs in relation to demand are disseminated to end users.

Similar to all Mediterranean islands, Crete is largely dependent on groundwater resources (MED-EUWI WG on groundwater, 2007). This extend dependence (50% on average), and the simultaneous scarcity of alternative freshwater sources may pose grave risks on the water intensive agricultural sector. Despite remarkable technological progress and specialization (Daliakopoulos and Tsanis, 2014), and a significant natural comparative advantage, the agricultural sector of Crete faces similar challenges with the agriculture of the southern regions of Greece. The major problem, common to all the municipalities of Crete, is the scarcity of irrigation resources, a factor impairing the restructuring and intensification of cultivations, and often risking saltwater intrusion in the coastal aquifers. This work confirms and updates previous findings of a robust signal for water scarcity (Koutroulis et al., 2015, 2013; Tsanis et al., 2011) that is bound to aggravate the current deficit of water resources in the island and increase tensions among sectors and users.

Given the fact that water stress in the island arises only due to the spatial and temporal variability of precipitation, infrastructure such as dams and reservoirs can substantially alter the timing of water resource availability seem to present a viable solution for the island. On the other hand, the intensification of agricultural production aimed for the needs of globalized markets has led to some extent to the loss of self-sufficiency (Daliakopoulos & Tsanis, 2014). For this reason, feasibility studies need to be undertaken to determine the degree to which the costs and risks of proposed infrastructure and agricultural restructure can be sustained by the resulting additional production. For example, the conversion of all olive trees to irrigated (estimated additional demand of over 250 Mm^3 per year) may eventually subside production resilience to drought and require in capitals (estimated over 1 billion €) disproportionate to the long term social and financial profits.

It is also possible that high infrastructure costs can be avoided with the use of alternative water resources (such as reuse or decentralized rainwater harvesting) for irrigation, and advocating for water resources conservation. Such approaches may include deficit or precision irrigation, taking into account the sensitivity of each crop to water stress (e.g. diverting excess irrigation from resilient crops such as olive trees), switching production to more drought tolerant crops or optimizing it to lower risk endogenous cultivations. Nevertheless, these sustainable practices require a high level of sophistication and significant dedication and restraint from the side of the end user against irresponsible actions such as illegitimate water use. In this context, the projected water scarcity highlights the important role for development and deployment of water conservation technologies and practices (Hejazi et al., 2014) and the need for strategic resources planning from global to regional and local scales. Eventually, awareness of the practical implications of each SSP in the not so distant future may be the key to shift user perception and preference towards a more sustainable direction.

Acknowledgements

The research leading to these results has received funding from IMPACT2C project of the European Union Seventh Framework Programme 2007-2013 under grant agreement no 282746.

References

Agrawal, A., 2010. Local institutions and adaptation to climate change. Soc. Dimens. Clim. Chang. Equity vulnerability a Warm. world 173–198.

Alexander, L. V, Allen, S.K., Bindoff, N.L., Bréon, F.-M., Church, J.A., Cubasch, U., Emori, S., Forster, P., Friedlingstein, P., Gillett, N., 2013. Summary for policymakers.

Allen, R.G., Pruitt, W.O., 1986. Rational Use of The FAO Blaney-Criddle Formula. J. Irrig. Drain. Eng. 112, 139–155. doi:10.1061/(ASCE)0733-9437(1986)112:2(139)

Andriotis, K., 2003. Tourism in Crete: A Form of Modernisation. Curr. Issues Tour. 6, 23–53. doi:10.1080/13683500308667943

Arnell, N.W., Lowe, J.A., Brown, S., Gosling, S.N., Gottschalk, P., Hinkel, J., Lloyd-Hughes, B., Nicholls, R.J., Osborn, T.J., Osborne, T.M., Rose, G.A., Smith, P., Warren, R.F., 2013. A global assessment of the effects of climate policy on the impacts of climate change. Nat. Clim. Chang. 3, 512–519. doi:10.1038/nclimate1793

Bates, B.C.B., Kundzewicz, Z.Z.W.Z., Wu, S., Palutikof, J.P., 2008. Climate Change and Water [WWW Document]. Tech. Pap. Intergov. Panel Clim. Chang. IPCC Secr. Geneva, 210 pp.

Betts, R. a, Collins, M., Hemming, D.L., Jones, C.D., Lowe, J. a, Sanderson, M.G., 2011. When could global warming reach 4°C? Philos. Trans. A. Math. Phys. Eng. Sci. 369, 67–84. doi:10.1098/rsta.2010.0292

Betzold, C., 2015. Adapting to climate change in small island developing states. Clim. Change. doi:10.1007/s10584-015-1408-0

Chang, H., Praskievicz, S., Parandvash, H., 2014. Sensitivity of urban water consumption to weather and climate variability at multiple temporal scales: The case of Portland, Oregon. Int. J. Geospatial Environ. Res. 1, 7.

Chartzoulakis, K., 2001. Water resources management in the Island of Crete, Greece, with emphasis on the agricultural use. Water Policy 3, 193–205. doi:10.1016/S1366-7017(01)00012-5

Christensen, O.B., Goodess, C.M., Harris, I., Watkiss, P., 2011. European and global climate change projections: discussion of climate change model outputs, scenarios and uncertainty in the EC RTD ClimateCost project. Clim. Proj. Final Rep. 1.

Ciscar, J.-C., Feyen, L., Soria, A., Lavalle, C., Raes, F., Perry, M., Nemry, F., Demirel, H., Rozsai, M., Dosio, A., others, 2014. Climate Impacts in Europe-The JRC PESETA II project.

Cleridou, N., Benas, N., Matsoukas, C., Croke, B., Vardavas, I., 2014. Water resources of Cyprus under changing climatic conditions: Modelling approach, validation and limitations. Environ. Model. Softw. 60, 202–218. doi:10.1016/j.envsoft.2014.06.008

Daliakopoulos, I.N., Coulibaly, P., Tsanis, I.K., 2005. Groundwater level forecasting using artificial neural networks. J. Hydrol. 309, 229–240.

Daliakopoulos, I.N., Tsanis, I.K., 2014. Greece: Agro-pastoral over-exploitation and its implications in Messara Valley (Crete). CIHEAM Watch Lett. 28.

Diffenbaugh, N.S., Giorgi, F., 2012. Climate change hotspots in the CMIP5 global climate model ensemble. Clim. Change 114, 813–822. doi:10.1007/s10584-012-0570-x

Diffenbaugh, N.S., Pal, J.S., Giorgi, F., Gao, X., 2007. Heat stress intensification in the Mediterranean climate change hotspot. Geophys. Res. Lett. 34, L11706. doi:10.1029/2007GL030000

Dokou, Z., Karatzas, G.P., 2012. Saltwater intrusion estimation in a karstified coastal system using density-dependent modelling and comparison with the sharp-interface approach. Hydrol. Sci. J. 57, 985–999.

Fabre, J., Ruelland, D., Dezetter, a., Grouillet, B., 2015. Simulating past changes in the balance between water demand and availability and assessing their main drivers at the river basin scale. Hydrol. Earth Syst. Sci. 19, 1263–1285. doi:10.5194/hess-19-1263-2015

Field, C.B., Barros, V.R., Mach, K., Mastrandrea, M., 2014. Climate Change 2014 Impacts, Adaptation, and Vulnerability. Work. Gr. II Contrib. to IPCC 5th Assess. Report-Technical Summ. 1–76.

García-Ruiz, J.M., López-Moreno, J.I., Vicente-Serrano, S.M., Lasanta–Martínez, T., Beguería, S., 2011. Mediterranean water resources in a global change scenario. Earth-Science Rev. 105, 121–139. doi:10.1016/j.earscirev.2011.01.006

Garrote, L., Granados, A., Iglesias, A., 2015. Strategies to reduce water stress in Euro-Mediterranean river basins. Sci. Total Environ. doi:10.1016/j.scitotenv.2015.04.106

Giorgi, F., 2006. Climate change hot-spots. Geophys. Res. Lett. 33, L08707. doi:10.1029/2006GL025734

Grillakis, M.G., Koutroulis, A.G., K, S.D., Tsanis, I.K., 2015a. Winners and losers in the European summer tourism under a 2 degrees warmer world. (submitted). Clim. Serv.

Grillakis, M.G., Koutroulis, A.G., Tsanis, I.K., 2015b. The 2 degrees global warming effect to the summer European tourism through different indices. (submitted). Clim. Change.

Grouillet, B., Fabre, J., Ruelland, D., Dezetter, a., 2015. Historical reconstruction and 2050 projections of water demand under anthropogenic and climate changes in two contrasted Mediterranean catchments. J. Hydrol. 522, 684–696. doi:10.1016/j.jhydrol.2015.01.029

Haerter, J.O., Hagemann, S., Moseley, C., Piani, C., 2011. Climate model bias correction and the role of timescales. Hydrol. Earth Syst. Sci. 15, 1065–1079. doi:10.5194/hess-15-1065-2011

Hagemann, S., Chen, C., Clark, D.B., Folwell, S., Gosling, S.N., Haddeland, I., Hanasaki, N., Heinke, J., Ludwig, F., Voss, F., Wiltshire, A.J., 2013. Climate change impact on available water resources obtained using multiple global climate and hydrology models. Earth Syst. Dyn. 4, 129–144. doi:10.5194/esd-4-129-2013

Hanasaki, N., Fujimori, S., Yamamoto, T., Yoshikawa, S., Masaki, Y., Hijioka, Y., Kainuma, M., Kanamori, Y., Masui, T., Takahashi, K., 2013. A global water scarcity assessment under Shared Socio-economic Pathways–Part 1: Water use. Hydrol. Earth Syst. Sci. 17, 2375–2391.

Hanasaki, N., Fujimori, S., Yamamoto, T., Yoshikawa, S., Masaki, Y., Hijioka, Y., Kainuma, M., Kanamori, Y., Masui, T., Takahashi, K., Kanae, S., 2013. A global water scarcity assessment under Shared Socio-economic Pathways - Part 2: Water availability and scarcity. Hydrol. Earth Syst. Sci. 17, 2393–2413. doi:10.5194/hess-17-2393-2013

Hansen, H., Herrmann, R., 2012. The two dimensions of policy impacts on economic cohesion: Concept and illustration for the CAP. Food Policy 37, 483–491. doi:10.1016/j.foodpol.2012.02.008

Harrison, P.A., Holman, I.P., Cojocaru, G., Kok, K., Kontogianni, A., Metzger, M.J., Gramberger, M., 2012. Combining qualitative and quantitative understanding for exploring cross-sectoral climate change impacts, adaptation and vulnerability in Europe. Reg. Environ. Chang. 13, 761–780. doi:10.1007/s10113-012-0361-y

Hejazi, M., Edmonds, J., Clarke, L., Kyle, P., Davies, E., Chaturvedi, V., Wise, M., Patel, P., Eom, J., Calvin, K., Moss, R., Kim, S., 2014. Long-term global water projections using six socioeconomic scenarios in an integrated assessment modeling framework. Technol. Forecast. Soc. Change 81, 205–226. doi:10.1016/j.techfore.2013.05.006

Iglesias, A., Garrote, L., Flores, F., Moneo, M., 2007. Challenges to manage the risk of water scarcity and climate change in the Mediterranean. Water Resour. Manag. 21, 775–788.

Ignaciuk, A., Mason-D'Croz, D., 2014. Modelling Adaptation to Climate Change in Agriculture.

KC, S., Lutz, W., 2014. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Glob. Environ. Chang. doi:10.1016/j.gloenvcha.2014.06.004

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World map of the Köppen-Geiger climate classification updated. Meteorol. Zeitschrift 15, 259–263.

Kourgialas, N.N., Karatzas, G.P., 2015. Groundwater contamination risk assessment in Crete, Greece, using numerical tools within a GIS framework. Hydrol. Sci. J. 60, 111–132.

Koutroulis, A.G., Grillakis, M.G., Tsanis, I.K., Jacob, D., 2015. Exploring the ability of current climate information to facilitate local climate services for the water sector. Earth Perspect. Submitted .

Koutroulis, A.G., Tsanis, I.K., Daliakopoulos, I.N., Jacob, D., 2013. Impact of climate change on water resources status: A case study for Crete Island, Greece. J. Hydrol. 479, 146–158. doi:10.1016/j.jhydrol.2012.11.055

La Jeunesse, I., Cirelli, C., Aubin, D., Larrue, C., Sellami, H., Afifi, S., Bellin, a., Benabdallah, S., Bird, D.N., Deidda, R., Dettori, M., Engin, G., Herrmann, F., Ludwig, R., Mabrouk, B., Majone, B., Paniconi, C., Soddu, a., 2015. Is climate change a threat for water uses in the Mediterranean region? Results from a survey at local scale. Sci. Total Environ. doi:10.1016/j.scitotenv.2015.04.062

MED-EUWI WG on groundwater, 2007. Mediterranean Groundwater Report. Technical report on groundwater management in the Mediterranean and the Water Framework Directive http://www. semide. net/topics/groundwater/Mediterranean_Groundwater_Report_final_150207. pdf [Accessed 15 Mar 2012].

Metzger, M.J., Leemans, R., Schröter, D., 2005. A multidisciplinary multi-scale framework for assessing vulnerabilities to global change. Int. J. Appl. Earth Obs. Geoinf. 7, 253–267. doi:10.1016/j.jag.2005.06.011

Mieczkowski, Z., 1985. The tourism climatic index: a method of evaluating world climates for tourism. Can. Geogr. Géographe Can. 29, 220–233.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747–56. doi:10.1038/nature08823

O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M., Solecki, W., 2015. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob. Environ. Chang. doi:10.1016/j.gloenvcha.2015.01.004

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2013. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Clim. Change 122, 387–400. doi:10.1007/s10584-013-0905-2

Panagea, I.S., Daliakopoulos, I.N., Tsanis, I.K., Schwilch, G., 2015. Evaluation of soil salinity amelioration technologies in Timpaki, Crete: a participatory approach. Solid Earth Discuss. 7, 2775–2805. doi:10.5194/sed-7-2775-2015

Papagrigoriou, S., Kaimaki, S., Perleros, S., Papageorgiou, N., Lazaridis, L., 2001. Integrated Water Resources Management of Crete, 2001 (in Greek).

Parry, M.L., 2007. Climate Change 2007: impacts, adaptation and vulnerability: contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Piontek, F., Müller, C., Pugh, T.A.M., Clark, D.B., Deryng, D., Elliott, J., Colón González, F. de J., Flörke, M., Folberth, C., Franssen, W., Frieler, K., Friend, A.D., Gosling, S.N., Hemming, D., Khabarov, N., Kim, H., Lomas, M.R., Masaki, Y., Mengel, M., Morse, A., Neumann, K., Nishina, K., Ostberg, S., Pavlick, R., Ruane, A.C., Schewe, J., Schmid, E., Stacke, T., Tang, Q., Tessler, Z.D., Tompkins, A.M., Warszawski, L., Wisser, D., Schellnhuber, H.J., 2014. Multisectoral climate impact hotspots in a warming world. Proc. Natl. Acad. Sci. U. S. A. 111, 3233–8. doi:10.1073/pnas.1222471110

Podger, G., 2004. RRL Rainfall Runoff Library users guide. Cooperative Research Centre for Catchment Hydrology.

Pulido-Velazquez, D., García-Aróstegui, J.L., Molina, J., Pulido-Velazquez, M., 2015. Assessment of future groundwater recharge in semi-arid regions under climate change scenarios (Serral-Salinas aquifer, SE Spain). Could increased rainfall variability increase the recharge rate? Hydrol. Process. 29, 828–844.

Pulido-Velazquez, D., Garrote, L., Andreu, J., Martin-Carrasco, F.-J., Iglesias, A., 2011. A methodology to diagnose the effect of climate change and to identify adaptive strategies to reduce its impacts in conjunctive-use systems at basin scale. J. Hydrol. 405, 110–122.

Ranjan, P., Kazama, S., Sawamoto, M., 2006. Effects of climate change on coastal fresh groundwater resources. Glob. Environ. Chang. 16, 388–399.

Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., Rafaj, P., 2011. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. Clim. Change 109, 33–57. doi:10.1007/s10584-011-0149-y

Sanford, T., Frumhoff, P.C., Luers, A., Gulledge, J., 2014. The climate policy narrative for a dangerously warming world. Nat. Clim. Chang. 4, 164–166.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N.W., Clark, D.B., Dankers, R., Eisner, S., Fekete, B.M., Colón-González, F.J., Gosling, S.N., Kim, H., Liu, X., Masaki, Y., Portmann, F.T., Satoh, Y., Stacke, T., Tang, Q., Wada, Y., Wisser, D., Albrecht, T., Frieler, K., Piontek, F., Warszawski, L., Kabat, P., 2014. Multimodel assessment of water scarcity under climate change. Proc. Natl. Acad. Sci. U. S. A. 111, 3245–50. doi:10.1073/pnas.1222460110

Schneider, C., Laizé, C.L.R., Acreman, M.C., Flörke, M., 2013. How will climate change modify river flow regimes in Europe? Hydrol. Earth Syst. Sci. 17, 325–339. doi:10.5194/hess-17-325-2013

Special Secretariat for Water, 2014. Draft water resources management plan for Crete Water District (RG13). Main issues.

Thomson, A.M., Calvin, K. V., Smith, S.J., Kyle, G.P., Volke, A., Patel, P., Delgado-Arias, S., Bond-Lamberty, B., Wise, M.A., Clarke, L.E., Edmonds, J.A., 2011. RCP4.5: a pathway for stabilization of radiative forcing by 2100. Clim. Change 109, 77–94. doi:10.1007/s10584-011-0151-4

Tsagarakis, K.., Dialynas, G.., Angelakis, A.., 2004. Water resources management in Crete (Greece) including water recycling and reuse and proposed quality criteria. Agric. Water Manag. 66, 35–47. doi:10.1016/j.agwat.2003.09.004

Tsanis, I.K., Koutroulis, A.G., Daliakopoulos, I.N., Jacob, D., 2011. Severe climate-induced water shortage and extremes in Crete. Clim. Change 106, 667–677. doi:10.1007/s10584-011-0048-2

Van Vuuren, D.P., Riahi, K., Moss, R., Edmonds, J., Thomson, A., Nakicenovic, N., Kram, T., Berkhout, F., Swart, R., Janetos, A., Rose, S.K., Arnell, N., 2012. A proposal for a new scenario framework to support research and assessment in different climate research communities. Glob. Environ. Chang. 22, 21–35. doi:10.1016/j.gloenvcha.2011.08.002

Vargas-Amelin, E., Pindado, P., 2013. The challenge of climate change in Spain: Water resources, agriculture and land. J. Hydrol. 518, 243–249. doi:10.1016/j.jhydrol.2013.11.035

Varouchakis, E.A., Karatzas, G.P., Giannopoulos, G.P., 2015. Impact of irrigation scenarios and precipitation projections on the groundwater resources of Viannos Basin at the island of Crete, Greece. Environ. Earth Sci. 73, 7359–7374.

Vautard, R., Gobiet, A., Sobolowski, S., Kjellström, E., Stegehuis, A., Watkiss, P., Mendlik, T., Landgren, O., Nikulin, G., Teichmann, C., Jacob, D., 2014. The European climate under a 2 °C global warming. Environ. Res. Lett. 9, 034006. doi:10.1088/1748-9326/9/3/034006

Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S.K., 2011. The representative concentration pathways: an overview. Clim. Change 109, 5–31. doi:10.1007/s10584-011-0148-z

Wang, Q.J.Q., 1997. Using genetic algorithms to optimise model parameters. Environ. Model. Softw. 12, 27–34. doi:10.1016/S1364-8152(96)00030-8

Warszawski, L., Frieler, K., Huber, V., Piontek, F., Serdeczny, O., Schewe, J., 2014. The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP): project framework. Proc. Natl. Acad. Sci. U. S. A. 111, 3228–32. doi:10.1073/pnas.1312330110

Tables

Table 1: CORDEX RCMs, their driving GCMs and the timing of +2 °C under the RCP4.5 and RCP8.5. GCMs that do not reach the +3 °C under RCP 4.5 are indicated with N/R, unavailable data are indicated with N/A.

Driving GCM	**RCM**	**+2 °C time-slice**		**+3 °C time-slice**	
		RCP4.5	**RCP8.5**	**RCP4.5**	**RCP8.5**
EC-EARTH-r1	KNMI-RACMO22E	2042-2071	2028-2057	N/R	2052-2081
EC-EARTH-r12	SMHI-RCA4	2042-2071	2027-2056	N/R	2052-2081
IPSL-CM5A-MR-r1	IPSL-INERIS-WRF331F	2028-2057	N/A	N/R	N/A
HadGEM2-ES-r1	SMHI-RCA4	2023-2052	2016-2045	2055-2084	2037-2066
MPI-ESM-LR-r1	CSC-REMO	2050-2079	2030-2059	N/R	2053-2082

Table 2: Historical and projected local hydrol-meteorological response to different global warming scenarios and levels.

	Parameter	5th%ile	25th%ile	Median	75th%ile	95th%ile
Baseline	Temperature (°C)	18.11	18.46	18.61	18.91	19.15
	Precipitation (mm)	766	830	903	981	1054
	Availability (mm)	138	172	218	274	330
	Potential Evapotranspiration (mm)	1,443	1,452	1,464	1,474	1,484
RCP4.5 @ +2 °C	Temperature change (°C)	1.71	1.82	1.69	1.77	1.76
	Precipitation (mm)	698	759	846	926	1,063
	Precipitation change (%)	-7.3%	-6.9%	-5.9%	-6.0%	-1.5%
	Potential Evapotranspiration (mm)	1,514	1,529	1,536	1,547	1,556
	Potential Evapotranspiration (%)	4.8%	5.2%	4.9%	5.0%	5.0%
	Availability (mm)	104	129	176	244	329
	Availability change (%)	**-20.9%**	**-21.0%**	**-18.0%**	**-10.7%**	**-5.0%**
RCP8.5 @ +2 °C	Temperature change (°C)	1.79	1.78	1.80	1.82	1.79
	Precipitation (mm)	675	756	849	968	1109
	Precipitation change (%)	-11.9%	-8.9%	-6.0%	-1.3%	5.2%
	Potential Evapotranspiration (mm)	1,520	1,531	1,541	1,551	1,558
	Potential Evapotranspiration (%)	5.2%	5.1%	5.2%	5.2%	5.1%
	Availability (mm)	104	142	192	270	377
	Availability change (%)	**-24.6%**	**-17.1%**	**-12.1%**	**-1.4%**	**14.3%**
RCP8.5 @ +3 °C	Temperature change (°C)	2.74	2.81	2.86	2.91	2.99
	Precipitation (mm)	629	700	787	897	1023
	Precipitation change (%)	-17.9%	-15.7%	-12.9%	-8.5%	-3.0%
	Potential Evapotranspiration (mm)	1,558	1,571	1,584	1,595	1,606
	Potential Evapotranspiration (%)	7.8%	7.9%	8.1%	8.2%	8.4%
	Availability (mm)	87	118	160	228	322
	Availability change (%)	**-37.3%**	**-31.4%**	**-26.8%**	**-16.9%**	**-2.6%**

Table 3: Impact of climate change on water availability for each type of infrastructure per RCP-SSP combination.

	Dam	**Reservoir**	**Groundwater**
RCP4.5 @ +2 °C (2037-2066) SSP1	-0.57%	-1.12%	-18.00%
RCP4.5 @+2 °C (2037-2066) SSP2	-0.57%	-1.12%	-18.00%
RCP4.5 @ +2 °C (2037-2066) SSP3	-0.57%	-1.12%	-18.00%
RCP8.5 @ +2 °C (2026 - 2055) SSP3	-0.60%	-1.18%	-12.10%
RCP8.5 @ +3 °C (2047 - 2076) SSP3	-0.94%	-1.84%	-26.80%

Table 4: Number of future water resources infrastructure by exploitation type (GW: Groundwater; SW: Surface Water; TW: Total Water Resources), RCP – SSP combination, total capacity and construction cost.

	Number			**Capacity (Mm^3)**			**Cost (M€)**		
	GW	**SW**	**TW**	**GW**	**SW**	**TW**	**GW**	**SW**	**TW**
RCP4.5 @ +2 °C (2037-2066) SSP1	24	15	39	16.52	64.36	80.88	64.54	548.13	612.67
RCP4.5 @ +2 °C (2037-2066) SSP2	28	23	51	19.90	97.79	117.69	81.84	1,207.28	1,289.12
RCP4.5 @ +2 °C (2037-2066) SSP3	29	39	68	20.73	140.74	161.46	35.93	1,321.28	1,357.21
RCP8.5 @ +2 °C (2026 - 2055) SSP3	29	39	68	21.84	140.69	162.53	33.92	1,251.99	1,285.92
RCP8.5 @ +3 °C (2047 - 2076) SSP3	29	39	68	18.32	140.17	158.49	36.62	1,345.16	1,381.78

Table 5: Historical (1990-2011) and projected overnight stays (×1,000) for different RCP-SSP combination and warming levels after Grillakis et al (2015) for the island of Crete.

Scenario		5th%ile	25th%ile	Median	75th%ile	95th%ile
Baseline (1990 - 2011)				11,796		
RCP4.5 @ +2 °C (2037-2066) SSP1	(stays)	16,805	17,126	17,957	18,532	18,564
	(%)	+40%	+41%	**+42%**	+43%	+43%
RCP4.5 @ +2 °C (2037-2066) SSP2	(stays)	18,079	18,438	19,368	20,014	20,050
	(%)	+51%	+52%	**+54%**	+55%	+55%
RCP4.5 @ +2 °C (2037-2066) SSP3	(stays)	19,651	20,057	21,110	21,842	21,884
	(%)	+65%	+66%	**+68%**	+70%	+70%
RCP8.5 @ +2 °C (2026 - 2055) SSP3	(stays)	14,978	17,309	19,680	20,410	20,648
	(%)	+45%	+50%	**+55%**	+57%	+57%
RCP8.5 @ +3 °C (2047 - 2076) SSP3	(stays)	15,230	18,681	22,726	24,239	24,428
	(%)	+60%	+69%	**+79%**	+83%	+84%

Table 6: Current (2010) and projected (RCP-SSP combinations) annual water demand in Mm^3.

	2010	RCP4.5 @+2 °C (2037-2066) SSP1	RCP4.5 @+2 °C (2037-2066) SSP2	RCP4.5 @ +2 °C (2037-2066) SSP3	RCP8.5 @ +2 °C (2026 - 2055) SSP3	RCP8.5 @ +3 °C (2047 - 2076) SSP3
Domestic	65.49	77.53	74.82	64.61	69.89	63.44
Tourism	6.58	10.45	11.30	12.37	11.48	14.18
Industry	4.10	4.11	4.97	5.70	4.68	6.85
Olive mills	0.93	1.15	1.21	1.32	1.22	1.40
Energy	0.20	0.24	0.20	0.18	0.21	0.20
Livestock	8.70	11.45	11.47	11.51	11.70	11.38
Irrigation	439.62	543.76	571.94	623.47	576.08	661.42
Total	525.62	648.69	675.91	719.16	675.25	758.87

Table 7: Total water supply per RCP-SSP combination, the effect of climate change on the supply potential, the total demand, the absolute deficit and as percent of demand, the additional availability, the total construction cost and the cost of the additional availability.

	RCP4.5 @ +2 °C (2037-2066) SSP1	**RCP4.5 @ +2 °C (2037-2066) SSP2**	**RCP4.5 @ +2 °C (2037-2066) SSP3**	**RCP8.5 @ +2 °C (2026-2055) SSP3**	**RCP8.5 @ +3 °C (2047-2076) SSP3**
Supply under SSP w/out CC(Mm^3)	506.2	544.0	588.2	588.2	588.2
Supply under SSP and CC (Mm^3)	432.2	469.0	512.7	536.9	475.5
CC effect (Mm^3)	-74.1	-75.0	-75.4	-51.3	-112.7
Demand (Mm^3)	648.7	675.9	719.2	675.3	758.9
Deficit (Mm^3)	-216.5	-206.9	-206.4	-138.4	-283.4
Deficit as % of demand	-33%	-31%	-29%	-20%	-37%
Additional availability (Mm^3)	80.9	117.7	161.5	162.5	158.5
Construction Cost (M€)	612.7	1,289.1	1,357.2	1,285.9	1,381.8
Cost (M€) per additional Mm^3 of availability*	7.57	10.95	8.41	7.91	8.72

* in case of no constructions

Figures

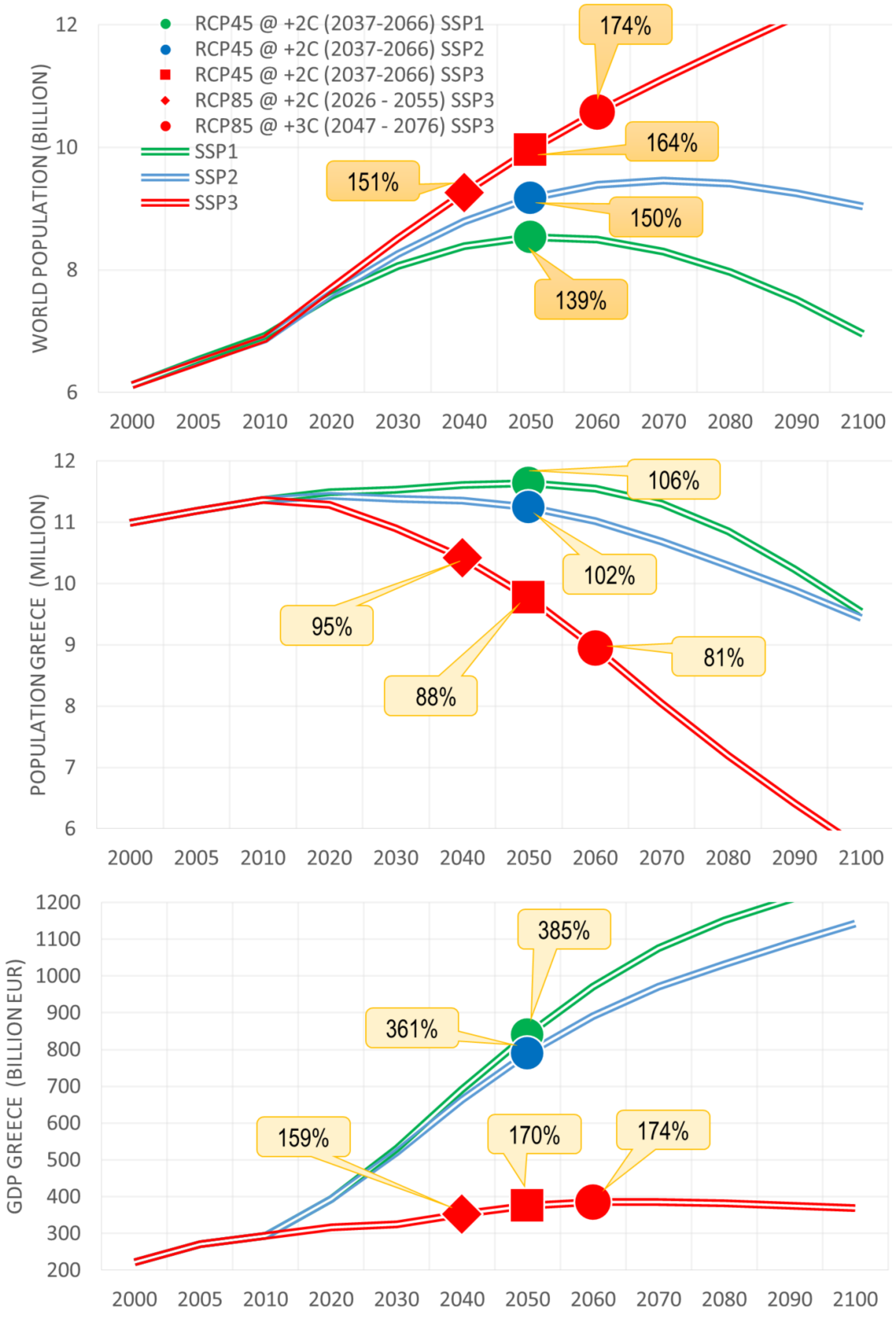


Figure 1: Global population (top), population of Greece (middle) and GDP of Greece (bottom) according to the three analyzed SSPs. Markers represent the projected mean value of population and GDP for each investigated scenario.

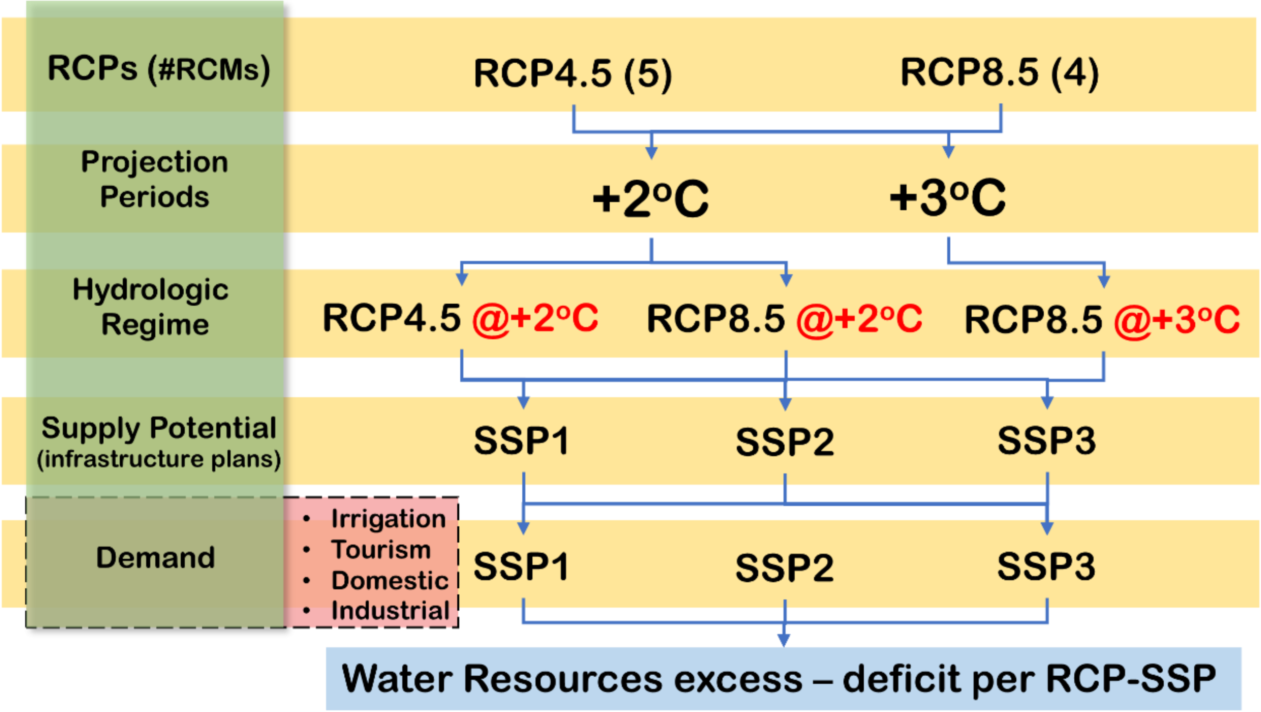


Figure 2: Framework of a cross – sectoral climate change impact study of 2 °C and 3 °C global warming on Water Resources for the island of Crete

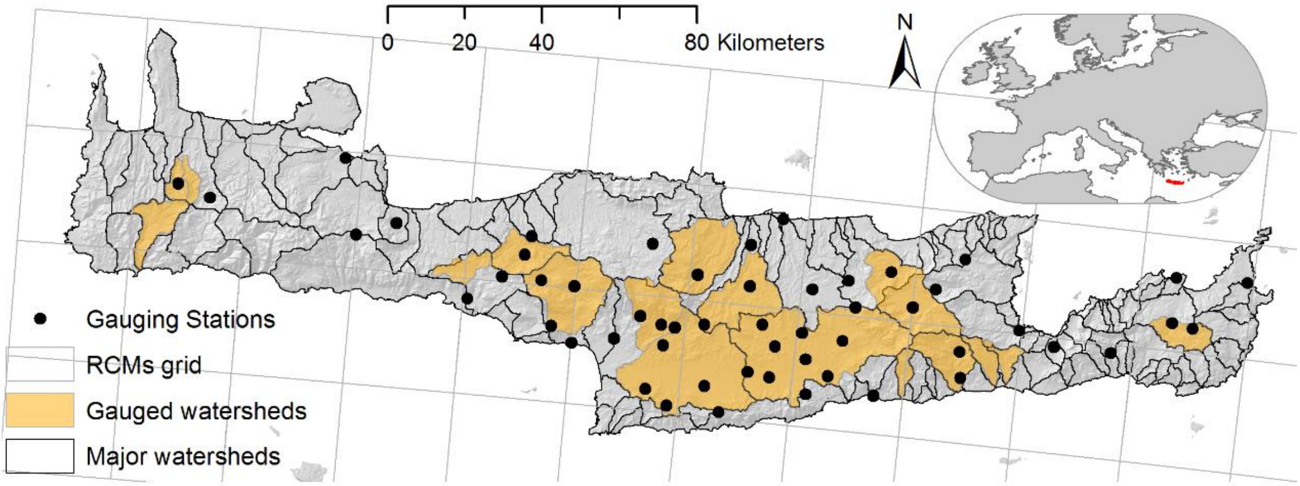


Figure 3: Location of Crete Island, precipitation gauging network, major watersheds and the grid mesh of the RCMs used in this study. Yellow areas represent gauged watersheds at the outlets.

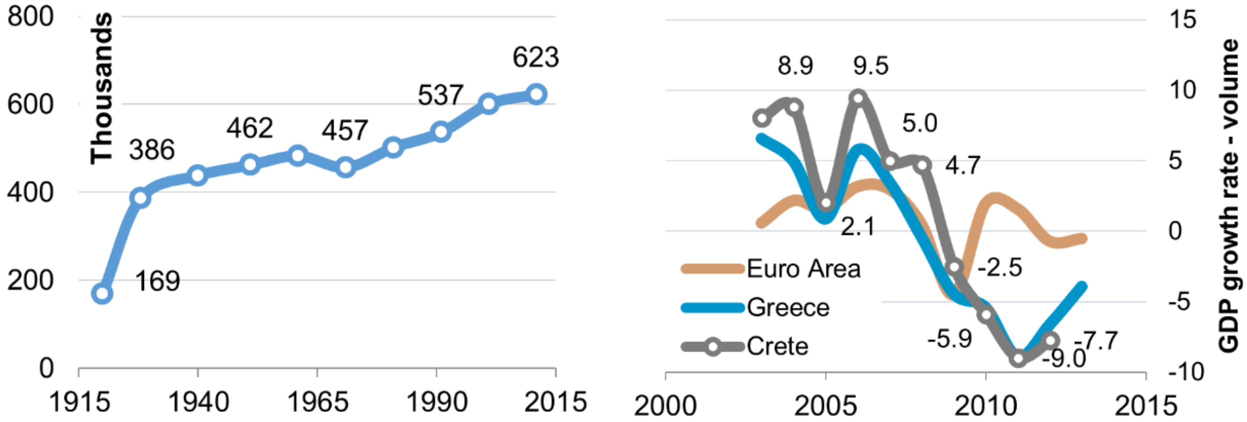


Figure 4: left: Population of the Region of Crete (RoC) from 1920 to 2011. Source (HSA, 2015[1]); right Real GDP growth rate - volume - Percentage change on previous year" for the Euro Area, Greece and Crete (Source: EUROSTAT, 2015[2]; HSA, 2015).

---

[1] HSA, 2015. Hellenic Statistic Authority, Population Census. Retrieved from http://statistics.gr in June 2015.

[2] EUROSTAT, 2015. Real GDP growth rate - volume - Percentage change on previous year. Retrieved from http://ec.europa.eu in June 2015.

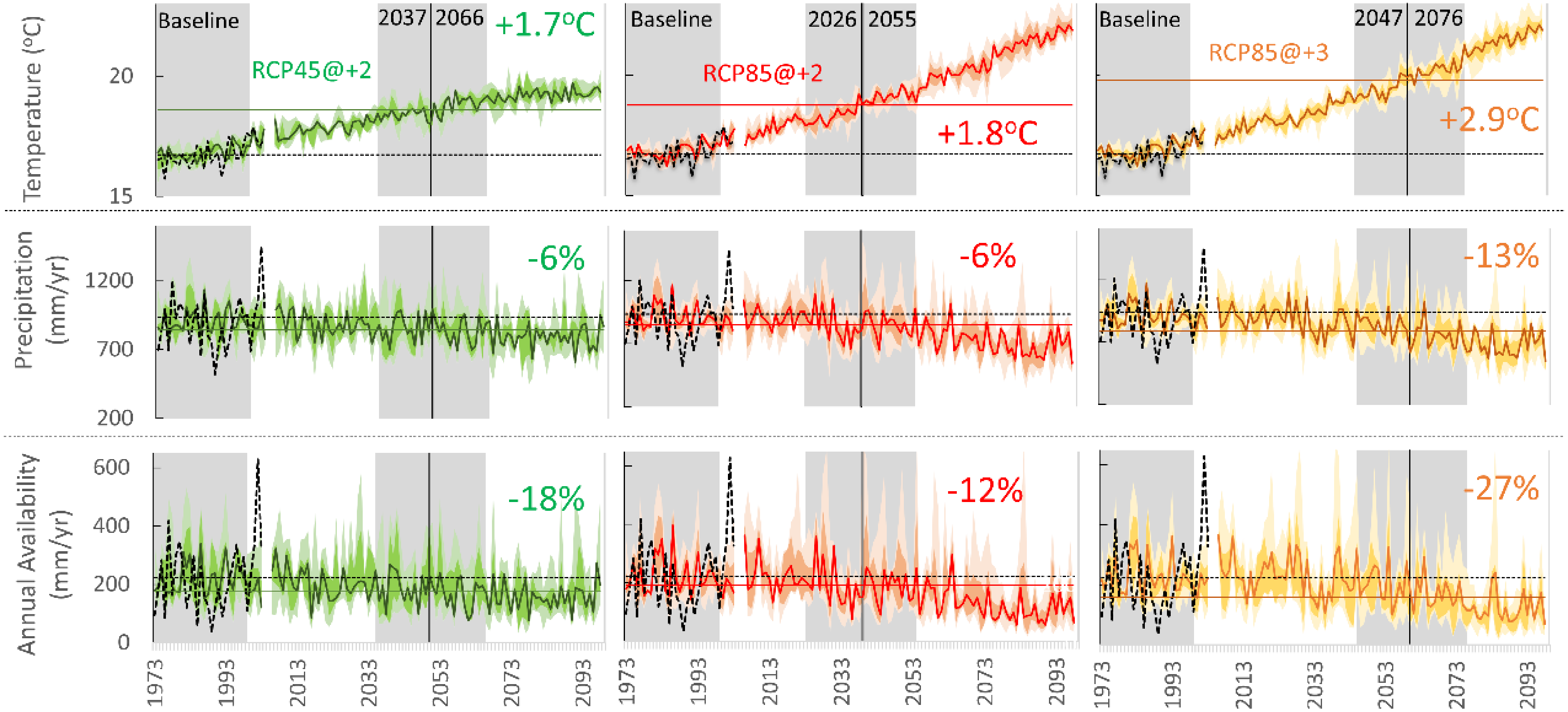


Figure 5: Transient response of temperature, precipitation and water availability at local scale (Crete) according to RCP4.5 and RCP8.5. The strong dashed line represent local observations, colored line correspond to the multi-model median, the strong shaded envelope to the interquartile range and the light shaded envelope to the 5th to 95th percentile range.

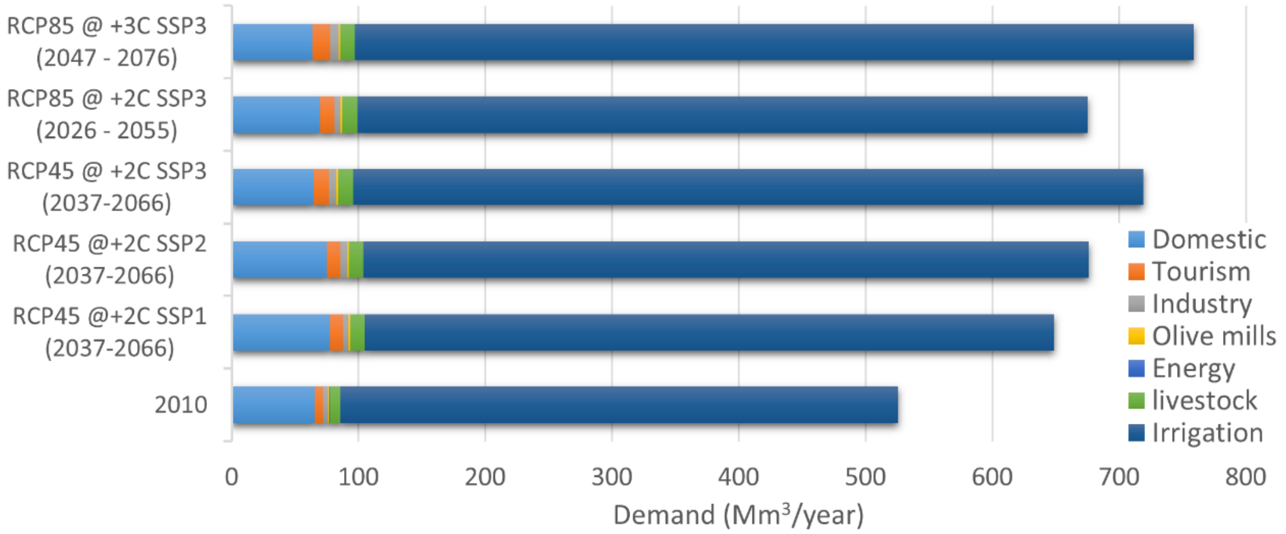


Figure 6: Total and sectorial water demand for present and future scenarios.

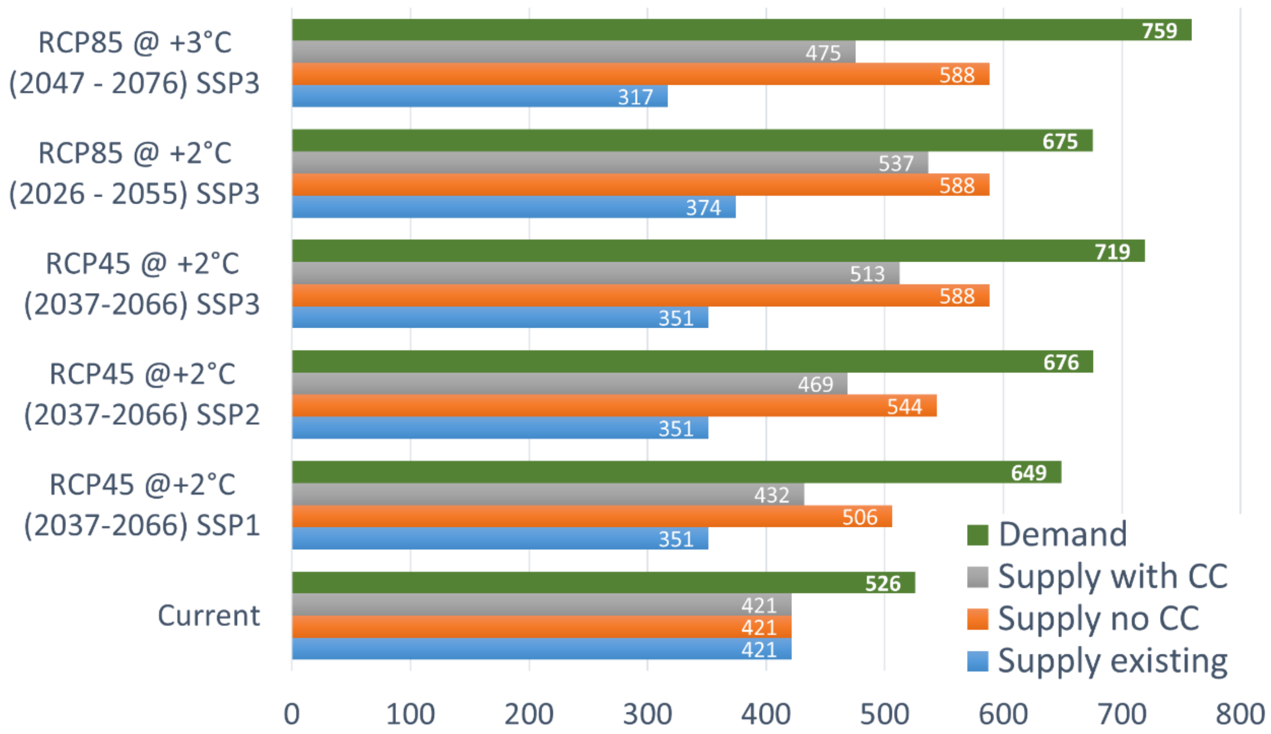


Figure 7: Water resources demand, supply under existing infrastructure including the effect of climate change, supply potential according to infrastructure implementation for each SSP without the effect of climate change (no CC) and with CC.

7 APPENDIX

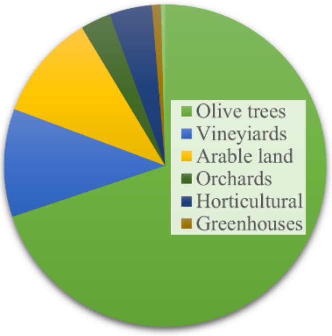
Table A1: Estimation of current and projected livestock water consumption (Papagrigoriou et al., 2001).

		Number of animals			Water demand Mm^3/yr							
	Daily consumption lt/day	1985-1991	2000	2009	1985-1991	2000	2009	RCP4.5 @+2 °C SSP1 (2037-2066)	RCP4.5 @+2 °C SSP2 (2037-2066)	RCP4.5 @ +2 °C SSP3 (2037-2066)	RCP8.5 @ +2 °C SSP3 (2026 - 2055)	RCP8.5 @ +3 °C SSP3 (2047 - 2076)
Equidae*	20	13273	2,339	983	0.10	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Bovinae**	60	1856	2,207	2403	0.04	0.05	0.05	0.08	0.08	0.09	0.08	0.10
Caprinae*	100	57320	61,220	46738	2.09	2.23	1.71	1.43	1.43	1.43	1.61	1.29
Sheeps**	7	1258254	1,498,377	1877680	3.21	3.83	4.80	7.01	7.01	7.01	7.01	7.01
Goats**	7	545449	627,258	632523	1.39	1.60	1.62	2.36	2.36	2.36	2.36	2.36
Rabbits*	3	769479	405,971	294925	0.84	0.44	0.32	0.27	0.27	0.27	0.31	0.24
Poultry**	0.3	1219732	1,430,662	1818466	0.13	0.16	0.20	0.29	0.31	0.34	0.32	0.37
	TOTAL				**7.81**	**8.33**	**8.70**	**11.45**	**11.47**	**11.51**	**11.70**	**11.38**

* For equidae, caprinae and rabbits a decreasing rate (affected only by the evaporation climatic factor) was adopted due to limited production trends affected by imports of lower prices.

** For bovinae, sheeps, goats and poultry, the increasing rate of global population of each SSP is adopted as a demand driver along with a climatic index of potential evaporation change (increase) according to the livestock watering method.

Table A2: Crop water demand, extend of cultivation types and irrigated areas (Papagrigoriou et al., 2001)

Cultivation type	Irrigation needs (m^3/ha/yr)	Area (ha)	Irrigated (ha)	
Vineyards	3,000-3,500	27,665	10,912	
Arable land	7,000	27,236	7,856	
Olive trees	2,500	178,401	68,949	
Horticultural	4,500	10,910	10,032	
Greenhouses	6,500	2,286	2285.2	
Orchards	5,000	7,748	6,910	