AWESOME

WATER-ECOSYSTEM-FOOD

Assessment of the value of alternative water sources

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List of Acronyms

Abbreviations

CC: Climate Change

CEA: Controlled-environment agriculture

CGE: Computable General Equilibrium

DDP: Deliverable Development Plan

DM: Deliverable Manager

EC: European Commission

ES: Ecosystem Services

GHG: Green House Gases

MSB: Mediterranean Sea basin

Mx: Month number

PC: Project Coordinator

PE: Partial Equilibrium

PI: Principal Investigator

PO: Project Officer

PR: Project Review

RCP: Representative Concentration Pathways

SSP Shared Socioeconomic Pathways

SDG: Sustainable Development Goals

WEFE: Water-Energy-Food-Ecosystem

WP: Work Package

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EXECUTIVE SUMMARY

Climate change and population growth are increasing the strain on natural resources in the Mediterranean region to a point where they may compromise the sustainable provisioning of water and food. Following the objective of the UN SDGs and the water-ecosystems-food-energy (WEFE) nexus to ensure sustainable development through better management of linked resources, this study focuses on learning about the economic modelling of the WEFE linkage in the Mediterranean Sea basin (MSB). A variety of modelling approaches that embed water into a Computable General Equilibrium (CGE) framework is available. However, only a limited number of studies incorporate into the economic analyses the alternative water sources (e.g., desalination, treated, brackish) and their potential effect on food security. The costs and benefits of each alternative water source and food production practice should consider both direct impacts and externalities.

Deliverable D3.4 introduces natural and alternative water sources to a global CGE model (GTAP), including cost specifications and substitutability for agricultural production. Next, the impact of climate change and mitigation efforts on the WEFE in the MSB are analyzed according to a comparative static procedure. In addition, the role of novel irrigated and controlled-environment agriculture in saving water and land is investigated and compared to traditional practices. Results show that alternative water sources, precise agriculture and international trade are essential role in CC adaptation even to moderate food security risks in the Mediterranean water-stressed countries. The results of this study can be used in decision making processes to drive an enhanced and sustainable water and agriculture development in CC times.

1. INTRODUCTION

Climate change (CC) and population growth are increasing the strain on natural resources in the Mediterranean region, to a point where they may compromise the sustainable provisioning of water and food. An overestimation of the economic and social benefits of human actions and underestimation of their negative externalities may lead to the degradation of ecosystem services (ES), risking water and food provisioning [1, 2]. The UN sustainable development goals (SDGs) highlighted zero hunger and clean water supply within the six most important development goals [3]. The SDGs promote the achievement of food security, sustainable agriculture, and water management along with urgent action to combat climate change effects and protect marine and terrestrial ecosystems.

Most of the world's food production from agriculture is based on non-irrigated croplands. The share of rainfed croplands by country varies between 70-100 percent. The rest are irrigated using water bodies such as rivers and groundwater aquifers, which rely heavily on climatic conditions [4]. Hence, agriculture is one of the most climate-sensitive sectors of an economy. It responds to temperature, precipitation, soil radiation, and other attributes directly associated with CC risks [5]. The link between CC and natural water shortage that impacts agriculture, food and the economy is widely discussed [6, 7].

To increase water availability and support food provisioning, alternative water sources have been developed. For instance, recent studies argue that desalinated and treated brackish water should be included in the blue-water category that originally included only groundwater and surface water [8]. For example, 53% of the water demand in Israel in 2019 was for agricultural use, with 20% being fresh water and the remaining 33% being alternative water sources such as treated wastewater and desalinated water [9]. Alternative water sources have a substantial economic value due to their role in diminishing natural freshwater shortages and sustaining food provisioning.

In the decades to come, alternative water sources are expected to be highly important in water-stressed countries such as the Mediterranean region, where a further decline in natural freshwater availability is projected due to climate change [10, 11]. Several studies address the diversification of alternative water sources (e.g., desalinated, brackish, and reused water) to meet the demand [6, 4]. However, the costs and benefits of each alternative water source should consider direct impacts, indirect links with the economic activities and externalities. The direct costs are mainly energy consumption costs at the energy-intensive desalination and purification plants. The indirect effects of structural economic change arise due to shifts in the water supply. The external costs relate to the effect of the process' wastes that degrade the quality of ecosystems, land, and water resources, and emit greenhouse gases (GHG) and local air pollutants [12, 13]. For example, besides electricity production and use, the import and export of products that require avian and water transport are considered to be significant contributors to GHG emissions and other pollutants [14].

While alternative water sources might provide many benefits to households, industry, agriculture, and ecosystems through the sustainable use of natural water resources, the full costs and benefits of alternative water provisioning have often been ignored [9]. The regulation of the quality and quantity of natural water is one type of ES [15] that depends on the biophysical condition of the ecosystem and the ability of the ecosystem to continue and provide the same quality level of natural water over the years [16, 17].

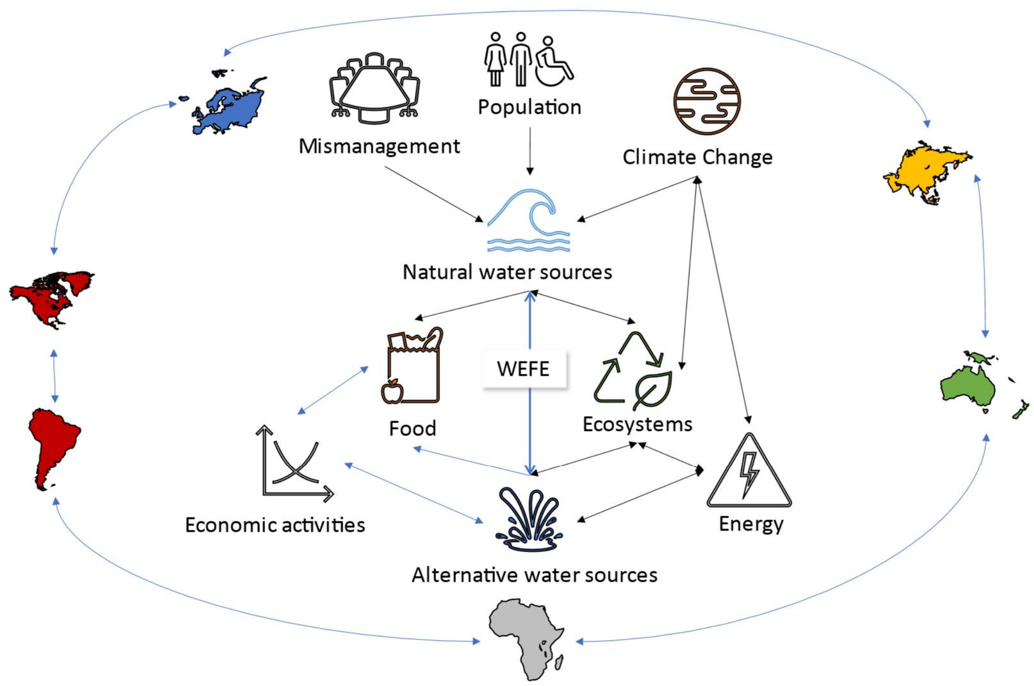

Figure 1 - The role of alternative water sources in WEFE analysis within a global economic context.

Aiming to better manage linked resources and following the UN SDGs, the UN declared the water-ecosystems-food-energy (WEFE) nexus as a focus area for sustainable development [18]. Sustainable water management policies and innovative agricultural technologies, can be the driver toward secure provisioning of food and water, following the objectives of the WEFE nexus (Figure 1). This driver must consider the ecosystem's ability to continue and provide water and food, along with the costs and benefits of each alternative solution [19].

Precise agriculture or controlled-environment agriculture (CEA) is a recent technological approach that examines the methods to enhance food provisioning by the efficient use of natural resources. For example, using drip or precise irrigation instead of crop field flooding and irrigation canals [20, 21], driving nutrient management and crop rotation plans [22], and implementing soil-less cultivation in hydroponic and aquaponic plants [23].

Hydroponics and aquaponics minimize the use of both land and water resources in the food provisioning process, by creating a new semi-closed ecosystem. In this ecosystem, the non-soil hydroponic crops benefit from the fertilizing capabilities of the organic waste produced by the aquaculture plant, usually growing fish or algae [23]. The economic viability of hydroponic and aquaponic practices in the Mediterranean Sea basin (MSB) is higher compared to other colder locations. On top of the reduced costs of water and land, warm temperatures reduce the costs of energy consumption [24].

Economy-wide analyses of the effect of water management on food security rarely consider alternative water sources, CEA practices, or the social costs and benefits of water and food provisioning [7, 25]. However, parameters such as the local physical characteristics of natural resources, national water policies and international relationships can potentially affect the local, regional, and global trade, that in turn impinge food security, energy use, ecosystems, and human wellbeing [26, 27].

The primary goal of this deliverable is to assess the value of alternative water sources - desalination and reused (treated) water - via the evaluation of the impacts of CC on food security given the potential supply of alternative water sources within the WEFE nexus in the MSB. This study illustrates the ongoing work on modeling the global economy by quantitatively and qualitatively analyzing the potential effects of alternative water sources and CEA on the WEFE nexus facing CC.

To the best of our knowledge, no previous study has investigated the role of alternative water sources in managing water shortages and food security while focusing on the WEFE nexus in the MSB. The methodological approach and the data for implementation are presented along with the model and results.

Deliverable D3.4 (Macro level model) is the report describing the strategic model at the macro level and how it interacts with the other project levels (micro and messo). The document builds on the previous Milestone report MS3.3 (CGE model for detailed water-food representation) and develops it further. The work is an outcome of WP3 – specifically, of Task T3.2, in which the main objective is developing a macroeconomic model to simulate the economic value of desalinated and treated water that increase water supply and diminish water shortages of natural freshwater. These results are accounting for the water, food, and energy demands as well as significant regional policies and their potential effect on ecosystem services (WEFE nexus). The report details were based, among all, on AWESOME deliverables D3.3 – setting the CGE baseline with alternative water sources, D2.3 - specifying the expected 2050 water and agricultural yield in North Africa, D2.1 – specifying the demographic projections towards 2050, and the knowledge gathered in WP5 regarding the hydroponic and aquaponic agricultural practices [28, 29, 30, 19].

2. WEFE analysis in Computable General Equilibrium

The literature review presented here focuses on the WEFE analysis in Computable General Equilibrium (CGE) modeling.

Multiple approaches are assessing how water management alters food security and the economy. Economists generally distinguish between Partial Equilibrium (PE) models that focus on a specific market at a time (e.g., water or agriculture) and CGE models, which consider international trade patterns of all markets and sectors [28, 29]. CGE is a macro modeling approach that considers the interdependencies between regional and national aspects of trade among multi-sectoral markets to project the potential socioeconomic scenarios of human wellbeing.

General equilibrium, which dates to Leon Walras (1834–1910) [30], recognizes that there are many markets and that they interact in complex ways so that there are interdependencies among all attributes. CGE models capture nonlinear substitution possibilities and multisectoral supply-demand interactions incorporating macro-variables and mechanisms for achieving balance (equilibrium) among aggregates and in all markets (Figure 1). Thus, the demand for anyone good depends on the prices of all other goods and income. Income, in turn, depends on wages, profits, and rents, which rely on technology, factor supplies, and production, the last of which, in its turn, depends on sales (i.e., demand). Prices depend on wages and profits and vice versa [19].

One example of a CGE model is the Global Trade Analysis Project (GTAP), a multi-region, multi-sector model, with perfect competition and constant returns to scale [31]. The GTAP model also gives users a wide range of closure options considering for example unemployment, tax revenue replacement, and trade balance, and a selection of partial equilibrium closures that facilitate comparison of results to studies based on partial equilibrium assumptions [7, 29]. Different closures may be used to represent different economic environments, or for varios lengths of run. For a short-run simulation, for instance, one might fix the wage rate, while for a long-run simulation, the level of employment might be fixed [32].

CGE models can provide insight into how water-related distortions (e.g., droughts) and departures from a counterfactual equilibrium can influence food provisioning and global economic growth [33]. However, most CGE-based studies have difficulties adequately representing the value of water, especially in water-abundant countries that lack an explicit economic value of water [6, 34] . In most studies, potable water is the only type of water modelled [25]. Haqiqi et al. highlighted the difference between rainfed and irrigated agriculture while focusing on a single type of water for irrigation [35]. This modelling approach does not suit a water economy that relies on alternative water sources as it does not reflect the constraints associated with the utilization of low-quality water sources and overestimates the ability of an economy to cope with an increasing natural water shortage.

To analyze the WEFE interdependencies, the CGE models are usually linked to partial equilibrium (PE) or physical non-economic models that detail the water and agricultural attributes [36]. Most of the studies use scenario analysis to assess the micro-level, ecosystem-specific characteristics that affect the macro-level CGE [26]. For example, to estimate the global economic impacts of soil erosion, a PE model RUSLE was coupled with the CGE model, MAGNET, to feed the CGE with ecosystem-specific parameters [37].

Among all the WEFE studies surveyed in Bardazzi and Bosello, only one [38] addressed explicitly and in their entirety the Water-Energy-Food Nexus nodes [39]. The authors acknowledged the objective difficulties in modelling the complex interdependencies and gathering good quality data.

Although many CGE-based studies evaluate the potential impacts of CC on the economy, only a few CGE articles focus on the implications of the ecosystem's ability to supply the required quality and quantity level of water and food. Palatnik and Nunes [1] compared a 2050 baseline scenario projected by a GTAP model with a CC-induced effect on temperature and precipitations that alters biodiversity impacts on cropland productivity in different Mediterranean regions. Costantini et al. accounted for the non-market values of potential climate-change-induced loss by using a dynamic CGE framework with a consistent market evaluation [40]. A physical model exogenously provided the GHG concentration and emission and interacted with the economic mechanisms via a monetary damage function. The ecosystem's ability to provide the services was included in the model assumptions and integrated into the assessment as sensitivity and risk parameters. Yet, the analysis did not explicitly represent alternative water sources and AP.

Zhang, et al. [41], draw the potential policy implications of water management by decreasing the pumping from rivers and lakes and allowing wetland ecosystems to preserve their ability to provide ES along time. Using CGE modelling and input-output tables, water was a primary resource for all ES supply, including crops yield provisioning [41]. However, their analysis did not focus on the effect of water pumping on the water quality and quantity along time, but on food provisioning costs and benefits and the trade-offs between economic and ecological values.

The studies that explicitly introduce water as an endowment usually perform the analysis for a single economy, e.g. Israel [6, 42, 43], or Morocco [38]. Kahsay et al. assessed how changes in water demand affect the different sectors in the countries using the water of the Nile river's basin [27]. Using the STAGE2 model the implication of water and land quality management on crops yield and related costs in Egypt were assessed [44]. Here again, there was no focus on the ecosystem's ability to continue and provide freshwater (Nile River or groundwater) along time, but on the human actions affecting water and land quality (e.g., salinity level) and on the additional costs of water quality and land required to enable the required crops yield.

Another CGE model for the Israeli economy was employed followed by Monte Carlo analysis to estimate the value of agricultural amenities that were incorporated into the model as by-products of agricultural production, water trade channels and multiple water types [43]. However, the model only distinguished between potable and non-potable water types. No explicit representation of desalination and treated water was implemented.

To conclude, even though CGE models were applied to water policy analyses already in the eighties [45], most of the studies concentrate on analyzing the water-food implications for agriculture while neglecting the other sectors [39] and the impacts on ecosystems. Bardazzi and Bosello also found that most studies employing global CGE models essentially examine a 'first-order' cost evaluation of productivity instead of an explicit loss of water availability [39]. Thus, most of these studies do not capture the resulting 'second-round' effects of structural economic change that arise due to shifts in primary resources, and particularly the water factor. Moreover, the explicit representation of alternative water sources is only available in a few single-country CGE models. To fully evaluate the role of alternative water sources and emerging agricultural practices in the mitigation of and adaptation to CC, the global CGE framework that explicitly represents the water sector is required. The following sections outline the methodological concept and the data gathered for this study in progress.

3. METHODOLOGY

The analysis described in this deliverable explicitly introduces desalination and treated water into the global CGE model and database. The modelling framework projects the potential change in the economy of the MSB countries between the years 2014-2050, following the scenarios of (1) alternative water sources and irrigated agriculture is available in all MSB countries; (2) the climate change effect on the economy as defined by IPCC - the Shared Socioeconomic Pathways (SSPs), (3) the effect of the mitigation efforts to reduce emission using Representative Concentration Pathways (RCPs) and (4) the effect of water-industry efficiency in the agricultural sector, using controlled environment agriculture (CEA) and hydroponics as a case study (Figure 2).

The platform used in this study is GTAP for CGE modeling [46]. The GTAP components used are the database GTAP10A [47] and the standard model RunGTAP version 7 [32].

The GTAP Data Base is a consistent representation of the world economy for a pre-determined reference year, 2014 in this case. The database is based on national input-output (I-O) tables, trade, macroeconomic, energy and protection data. All sources were tailored together to facilitate the operation of economic simulation model and depict the magnitudes of economic variables, that are presented in terms of the aggregates that serve CGE modeling.

The RunGTAP version 7 model incorporates several new features into the standard model in response to the widening array of model applications. These offer greater flexibility, especially with the option for some sectors to produce multiple products, and the option for multiple sectors to produce the same or a closely substitutable product, as in the case of agricultural food production from multiple generation sources such as irrigated and rainfed practices [48].

The datasets used for the following stages are available in the Appendices of this report.

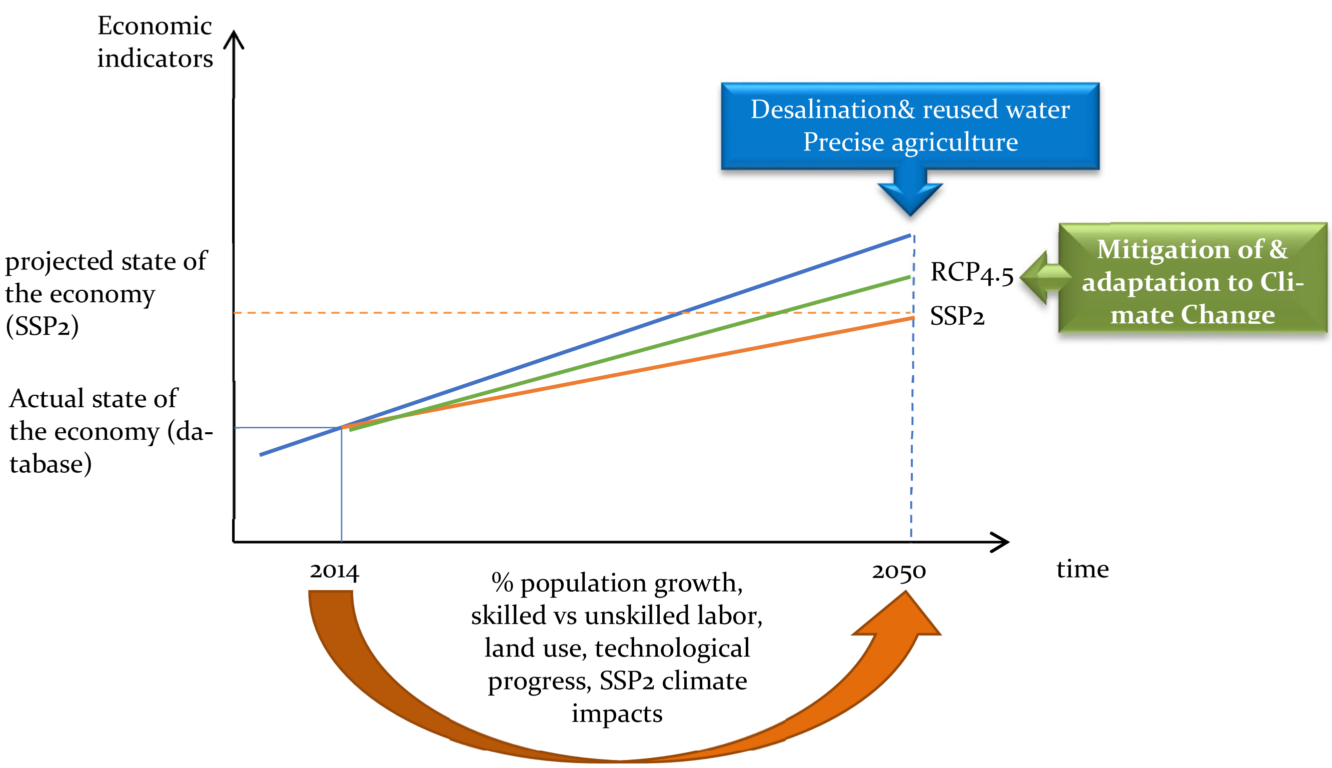

Figure 2 - Methodology

3.1. The pre-set of water-food linkage

In the standard GTAP dataset, the water industry is represented as one sector and the agriculture is represented by several types of crops aggregated into one GrainCrops sector. To simulate an agriculture that benefit from several types of alternative water sources in rainfed and irrigated practices, the water sector was divided into three subsectors and the agriculture was divided into two sub-sectors [49].

To introduce alternative water sources in the CGE, several assumptions were made. The desalination and treated-water sectors are reported in the input-output tables as part of the water sector [50]. Therefore, rather than being defined as a natural resource, the desalinated and treated water activities are referred to as an economic industry, joining the freshwater industry to pump, collect, treat and distribute water to the consumers. For the study, the resulting three sectors of water and two of agriculture are represented as activities and commodities in the GTAP database. The five sub-sectors are affected by the intermediate resources used in the industry, along with the factor endowment of capital, natural resources, labor and land. The contribution of water as a resource in agriculture is assumed to be part of the land endowment that is a dedicated factor of production in agriculture in the GTAP model and database.

The methodological steps in GTAP to transform the database to include alternative water and irrigated crops include:

a) Disaggregating the MSB countries from their regions into specific country and values [51]
b) Disaggregating the water and electricity sectors out of their industry groups [51]
c) Splitting the water sector into three sub-sectors – freshwater, desalinated water and treated water [49, 52, 53, 54].
d) Splitting the GrainCrops sector into irrigated and non-irrigated crops [11].

APPENDIX 1 presents the key data and tools served for splitting water and agricultural sectors. This stage was broadly detailed in AWESOME D3.3 [29].

3.2. 2050 baseline and CC effect

To analyze the projected impacts in the future when climate change impacts are expected to become significant, we created a baseline equilibrium that reflects the state of the economy in the year 2050 according to SSP2-baseline [55]. The SSP2-baseline describes a middling pathway of global socio-economic development, with moderate achievements and challenges in achieving economic growth and maintaining the capacity of global institutions. The growth in key economic indicators according to the baseline scenario was imposed, and the baseline equilibrium in 2050 was generated.

The methodological steps in GTAP to project the 2014-2050 CC effect on the economy include creating a SSP2-baseline with the climate change effects on the future state of the economy in 2050 [56, 57]:

a) Incorporating into RunGTAP the updated (split) database, including the subsectors of rainfed and irrigated agriculture and fresh, desalinated and treated water.
b) Incorporating the projected change in the 2050 values into the data (i.e., Real GDP, Population, Labour force, Physical capital and Arable land). The availability of land as factor of production is heavily dependent on CC effects and therefore represents the state of land-use, land-cover and ecosystem services.
c) Formulating the 2050 baseline and measuring the potential change in the economy, as compared to the non-split data.

APPENDIX 2 presents the key data served for the 2050 SSP2-baseline projection, including D2.1 data specifying the expected demographic changes in 2050..

3.3. RCP Mitigation efforts

The value of all activities and commodities, including the alternative water sectors, might vary according to different climate futures that are best described by Representative Concentration Pathways (RCP) [58]. The RCPs - RCP2.6, RCP4.5, RCP6.0, and RCP8.5 – are labeled after a possible range of radiative forcing values in the year 2100. The mid-range adaptation and mitigation drivers, as expressed in RCP4.5, moderate the climate impact.

This stage of the study involved creating 2014-2050 SSP2 RCP projections of three mitigation scenarios, in which the emissions are reduced to the level of RCP 2.6, 4.5 and 6.0 [56]. CC effects are multiple as they alter water availability and the water sectors, that in turn create variations in land-use, while CC also imposes a direct change in land-use and therefore affects capital investments,

and vice versa. Thus, the 2050 projections of the RCPs differ from SSP2-baseline with their estimated change in GDP, land-use in agriculture and capital investment in energy projects [59].
Using the split database, the methodological steps in GTAP to project the 2014-2050 RCPs effect on the economy, include:

a) Imposing the projected 2050 change using Real GDP, Physical capital and Arable land. The population and labour rates were assumed to be similar to the SSP2-baseline figures.
b) Measuring the potential 2050 change in each RCP and comparing it to the SSP2-baseline.

APPENDIX 3 present the key data served for the 2050 RCPs projection.

3.4. CEA adaptation

CEA practices like hydroponics allow for the efficient use of land and water sources in arid regions. Yet these technologies are intensive in skilled labor and energy compared to traditional agriculture practices [24], leading to potential environmental burdens. However, their industrial-scale production and technical improvements allow for significantly increased output capacities and production efficiencies [60]. Hydroponic technologies are increasingly applied to growing leafy greens and their technological adoption to vegetables is foreseen in the near future. Yet, a major breakthrough is required to employ the technology for other crops such as wheat and tree-fruits. [61, 62, 63, 64, 65, 66]. Coherently with future development of hydroponic technologies, we realize a scenario based on the assumption that by the year 2050, about 30% of irrigated agriculture will follow the productivity and input efficiency of hydroponics along with a growth of 25% in the Skilled labor factor. [67]. With our framework we evaluate the role of CEA adaptation to CC (Figure 2).
Ournovel CEA framework was based on the characteristics of hydroponic cultivation practices, that allow about 2-10 times total factor productivity in the irrigated crops yield and water efficiency increase of up to 60 times better water usage per 1 kg of crop yield in the hydroponic practices, as compared with traditional agriculture [68, 62, 69].
The methodology to project the 2014-2050 effect of the CEA practices on the economy, include:

a) Imposing a water efficiency increase on a third of the irrigated agriculture, based on the feasibility of different crops to be cultivated in hydroponic practices [69, 62, 64, 65, 63, 66, 70, 71]. The list of crops involved in this analysis is based on projected diet in Egypt in 2050, using the AWESOME D2.3 data specifying the expected 2050 water and agricultural yield in North Africa [71, 60]. SeeAppendix 4 for further details.

b) Imposing an increase of skilled labour to formulate an expected growth of services-support to the enhanced agricultural practices of hydroponics [60].

The methodological procedure allows investigating to what extent alternative water sources and novel agricultural practices can contribute to the adaptation to CC and food security.

4. RESULTS

The study offers an economic analysis of CC employing a global GTAP-based model with an explicit representation of alternative water industries and novel agricultural technologies. A comparison of results between the SSP2 baseline scenario and the counterfactual SSP2-RCP2.6, 4.5, 6.0 scenarios describe the effects of mitigation of and adaptation to climate change on economies in 2050. Even though the model is global, the representation focuses on the MSB countries that are in the core of the analysis.

4.1. Water-Food linkage in CC and RCP mitigation scenarios

We start discussing the results with the effect of CC on the volume of output of the agricultural activities in 2050. Figure 3 reflects a comparison between the original (no-split) dataset volumes, and the split dataset. The no-split dataset included one water sector and one agriculture sector, and the split dataset was configured by us to include five sub-sectors, three of water including fresh, desalinated and treated sub-sectors and additional two of rainfed and irrigated agriculture.
The results represent all scenarios with a sum-up of the rainfed and irrigated agriculture sub-sectors. The agriculture split SSP2-baseline reflects an increase in the volumes as compared to the non-split volume, for all MSB countries except for Turkey. These results significantly reflect the benefits of irrigation and alternative water sources to the agricultural sector.

We could expect that mitigation costs of climate change expressed in RCPs reduce agricultural activities in comparison with the SSP2-baseline. However, the agriculture sector production reflects no significant decline and responds differently in each country. The potential reasons for these changes are drawn in the next Figures.

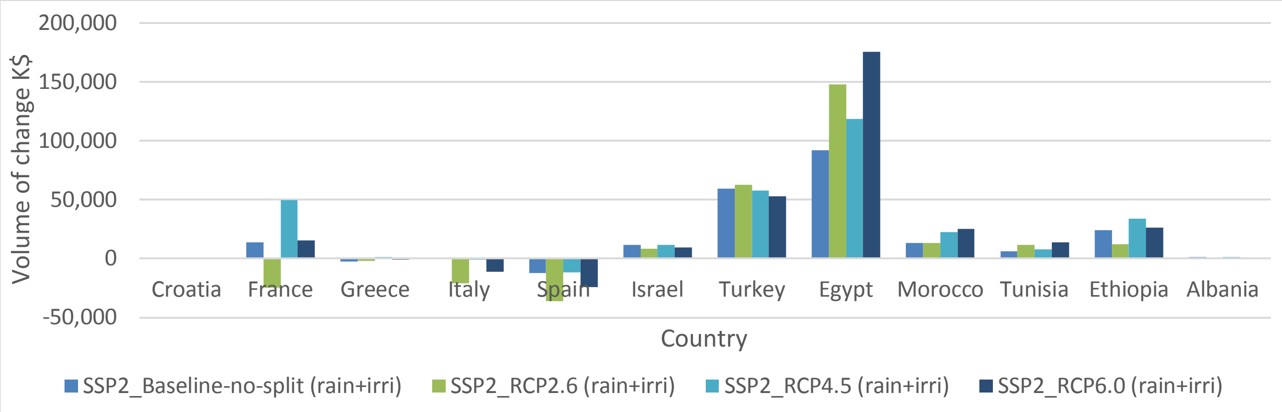

Figure 2 - Change in agricultural production between 2014-2050

Figure 4 represents the change in the private household consumption of imported agricultural products, providing a complementary information to the domestic agricultural production results that were presented in Figure 2. The import results, comparing the no-split to the split baseline, reflect different reaction of the MSB countries to the CC effects in 2050. In France, Egypy and Ethiopia the addition of irrigated agriculture and water sub-sectors in the split baseline lead to lower volumes of import as compared to the original no-split baseline. All other countries show an increase in volumes of import due to CC effects in 2050.

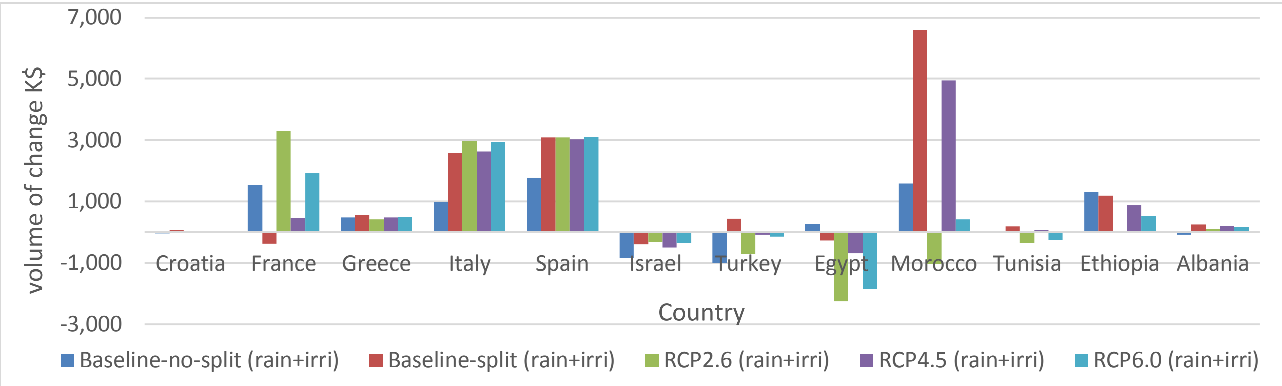

Figure 3 - Change in IMPORT of Agricultural products – between 2014-2050

Looking at the mitigation RCP scenarios, we see a decrease or no change in agricultural import in all RCPs, compared to SSP2-baseline (no mitigation). The RCP results highlight the importance of the mitigation efforts along with the use of alternative water sources and irrigation practices in reducing agricultural import costs, including their related GHG emissions.

4.2. RCP mitigation and CEA adaptation

Figure 5 provides a closer look at the separated volumes of rainfed and irrigated crops with the possibility of CEA technologies. The comparison is between the SSP2-baseline and SSP2-RPC4.5 with and without CEA in irrigated agriculture (Figure 5).

The result clarifies that in most of the MSB countries, the growth in agricultural production between 2014-2050 is mainly driven by rainfed crops compared to the irrigated crops. The two exceptions are Egypt where 99% of the crops are irrigated, and Israel where CEA investments are already in place. Furthermore, most countries show almost no yield reduction in the RCP 4.5 and CEA scenarios.

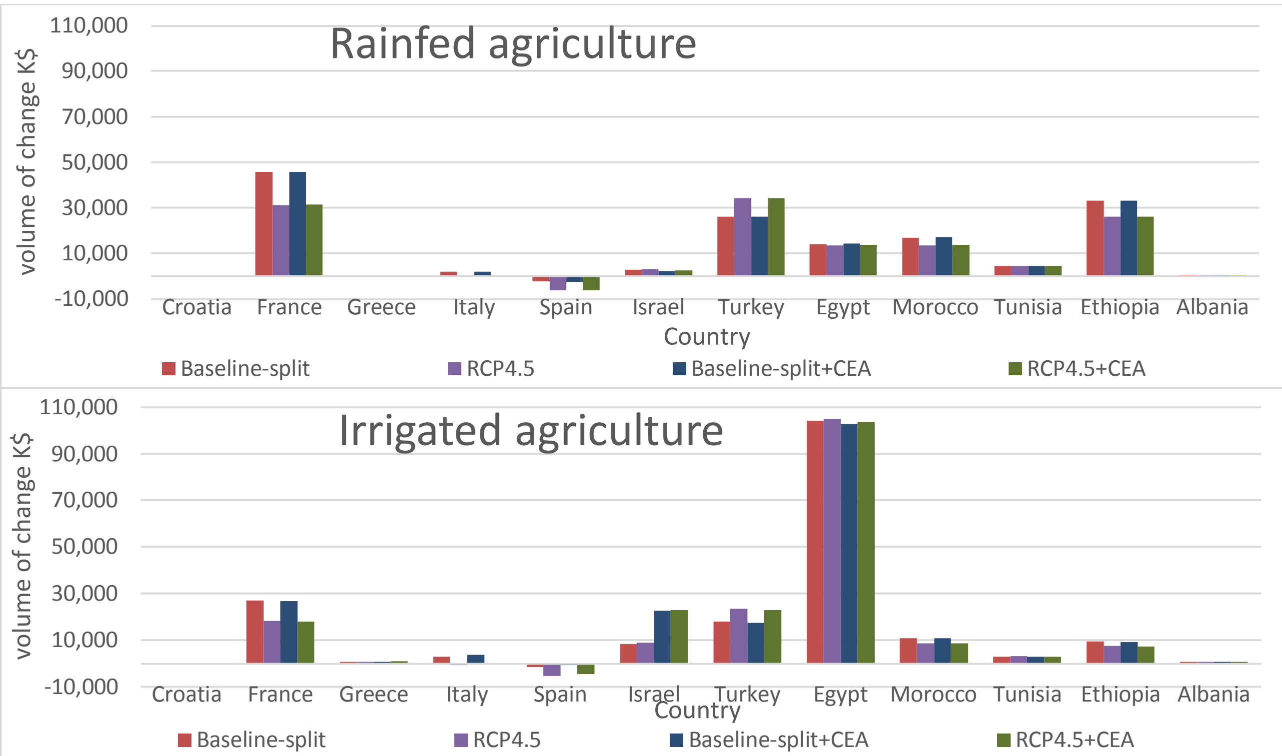

Figure 4 - Rainfed and Irrigated crops – separated volume of change 2014-2050

Despite the expected reduction due to the mitigation costs in RCP4.5, there is still a growth or minimal change in the volume of both rainfed and irrigated sub-sectors in most countries.

Moving to the water sectors, the RCP scenarios reveal remarkable patterns in the alternative water sub-sectors (Figure 6). The addition of alternative water industries and irrigated crops drives an increase in the volumes of the water industry, in most countries, except for France and Spain.

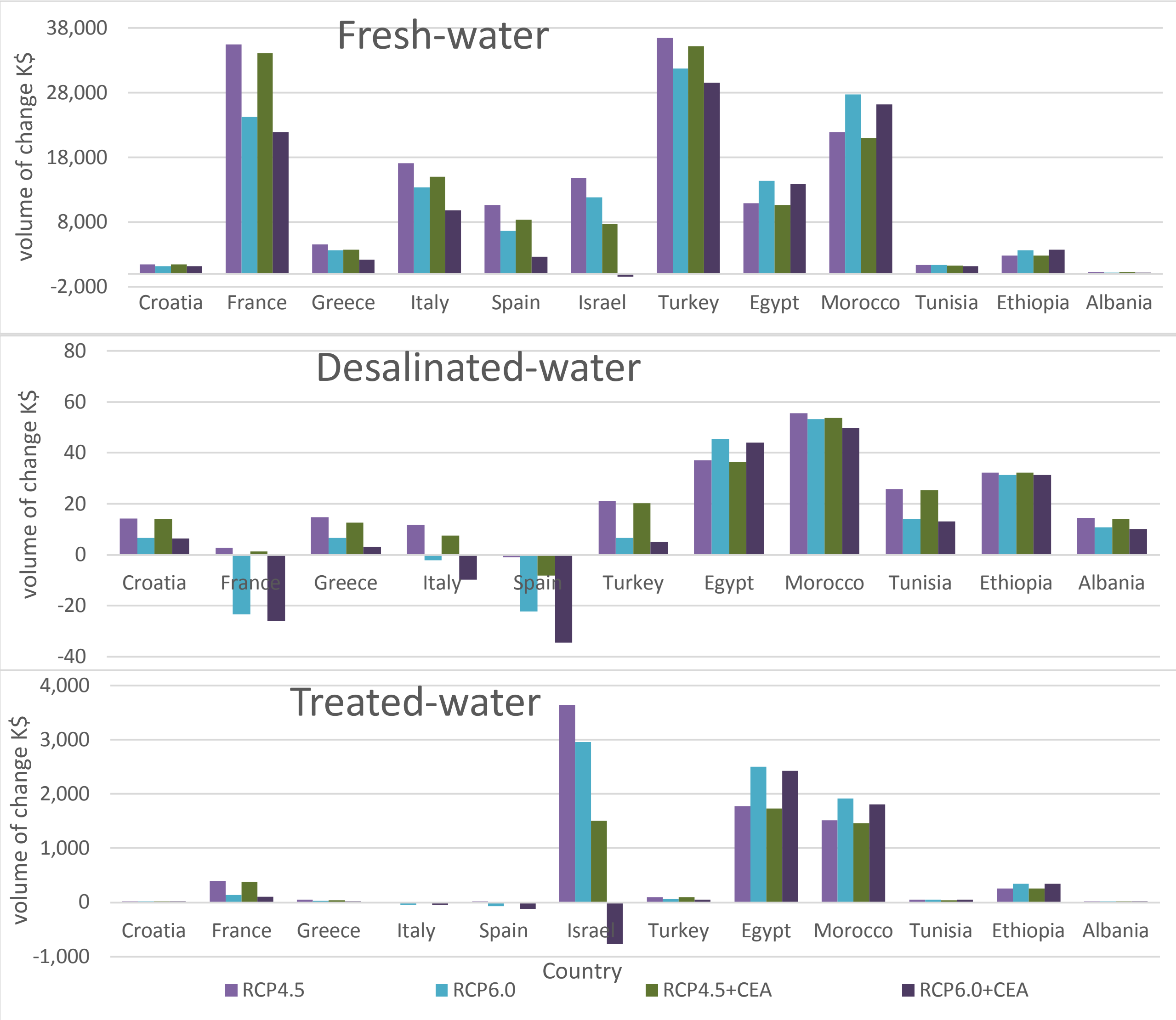

Figure 5 - The change in the water sectors - fresh, desalinated and treated[1]

Overall, the freshwater sub-sector reflects the highest increases in most countries, followed by the treated-water sub-sector and finally the desalinated sub-sector (comparing the volume of change in the different graphs). This change trajectory follows the relative cost of capital investment

[1] Israel was dropped off the desalinated-water graph, as its volumes spiked to 6,000K$ (with similar behavior to treated water) and eliminated the chance to view the potential change in other countries.

required per each sector, meaning that the most economically feasible change will be implemented in the least capital-costly sector, fresh water. And then, out of the alternative water sources, the treated water is preferable to the desalinated one.

Adding the CEA, we expect to see a decrease in the volumes, especially following the imposed efficiency related to the hydroponic practices. However, the water sectors act heterogeneous in each country.

And finally, we examin the change in the electricity sector and overall GDP as a result of the configuration changes and scenarios that were presented so far. Although the share of agriculture in the GDP of most of the world regions is relatively low, the addition of alternative water sources and CEA as a means of adaptation is expected to affect the electricity activity and costs. However, the change in electricity costs depends also on the existence of other electricity-intensive activities in the economy.

In order to focus specifically on the volume of change related to the mitigation and adaptation efforts, the results in Figure 7 reflect the change compared to the values of SSP2-baseline.

Overall, the CEA addition has a neglectable effect on the electricity markets. However, the impact of CC and mitigation efforts vary dramatically by country.

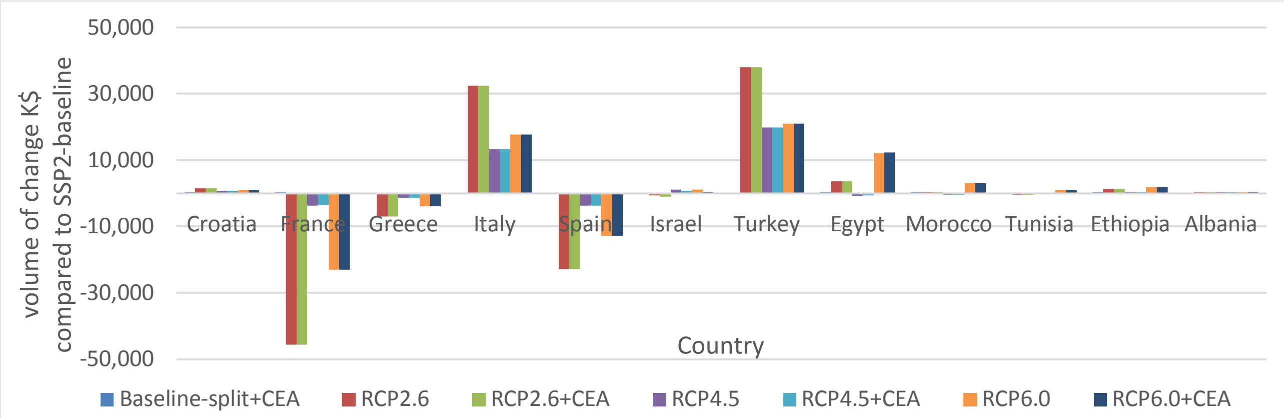

Figure 6 - The change in the electricity sector 2014-2050 compared to SSP2-baseline

We see that RCP 2.6 causes a major decline in electricity volumes in France and Spain, while Italy and Turkey are projected to increase further electricity production as compared to SSP2-baseline.

RCP 6.0 mitigation cause a decrease in the electricity sector's volumes compared to RCP 4.5 in most EU countries and an increase in Italy and the north Africa countries.

Figure 8 represents the 2014-2050 change in the GDP volume in percentages following the effect of CC, RCP mitigation and CEA adaptation. The RCP scenarios determine a different effect in each country. The RCPs have a major GDP effect in the developing countries. RCP 4.5 reflects the middle-of-the-road scenario between the CC effects and the cost of abatements that affect GDP. The CEA technologies diminish the decline in GDP in all scenarios.

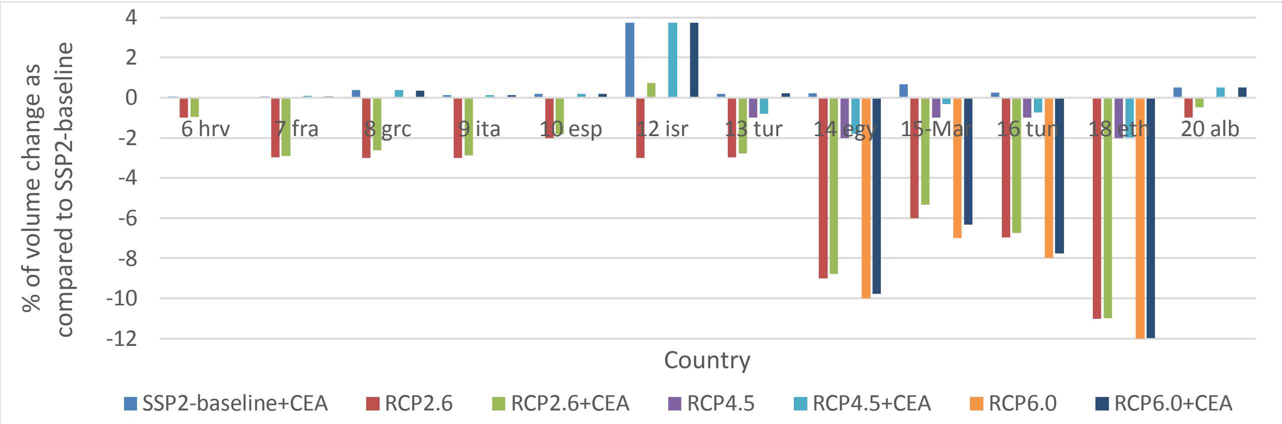

Figure 7 - GDP percentage-change, all scenarios compared to SSP2-baseline

5. CONCLUSIONS and DISCUSSION

Using CGE modeling that focus on adding irrigated agriculture and alternative water sources, this study highlights the benefit of the modelling approach which explicitly distinguishes alternative water sources and CEA as crucial drivers of CC adaptation and food security.

The methodological procedure that is based on enhanced global trade modeling allows investigation to what extent alternative water sources and novel agricultural practices can contribute to the mitigation of and adaptation to CC and support of food security.

This study's results reconfirm that irrigation and alternative water practices drive a positive trajectory in food security and the global economy, while showing that the volume of indirect effects due to energy use are almost neglectable. This evidence was clear also in developing countries in which agriculture is a major GDP sector, such as Ethiopia, Albania, Egypt, Algeria, Tunisia and Turkey (with a share of agricultural secotr out of the total GDP equal to 38.5%, 18.6%, 12.5%, 11.3%, 8.6% and 7.8%, respectively) [72].

In order to better explain the behavior in the different scenarios, a correlation test was imposed between the volume of change in each result and the primary factors that were changed feeding the different scenarios, including the 2014 GDP, land and capital values, the 2014 percentage of irrigated crops out of all crops, and the 2014 percentage of fresh, desalinated and treated water out of all water sources (see details of the updated parameters in each scenario in the Apendix). The correlation values are between 0 to 1, and the closest correlation value to 1 reflect the strongest connection between the results and the influencing parameters examined. All correlation rates in the following examinations were higher than 0.6.

Looking at the results, the volume of change in the rainfed and irrigated agriculture (Figure5) was found to be correlated with the GDP values. The change in water sectors (Figure6) was showing that the desalinated sub-sector was mainly correlated with the original 2014 percentage of desalinated-water out of the total water sources in each country. The change in the treated-water sub-sector was mainly correlated with the country's 2050 projected GDP. The freshwater sub-sector was found to have no significant factor correlation.

Looking at the electricity results, the correlation test show that the electricity changes were mainly correlated (>0.6) with with the country's 2050 projected GDP (Figure 7). And finally, looking at the GDP results (Figure8), the correlation test between the 2050 GDP values in each scenario and the main factors used in our analysis show that the 2050 GDP volumes were mainly correlated (>0.6) with the 2014 GDP values prior to the mitigation efforts. This mainly relate to the fact that the GDP change is affected by all sectors and economic activities in each country, not only by the water and agriculture sectors.

The limitations of this study relate to its strength. The fact that GTAP and CGE can model the whole world's trade makes it a macro level model that must be complemented with micro and meso -level investigations, as demostrated in this report with the use of data produced by AWESOME partners and detailed in reports D2.1 and D2.3. The data in this report was also based on AWESOME D3.3 and the learning from WP5 regarding hydroponic and aquaponic practices.

The implications of this study are mainly the base proof that alternative water sources can drive a positive change, although requiring additional resources to be implemented. These results can be used in decision making processes to contribute to future sustainable agriculture and water practices that support CC adaptation and food security, especially in water-stressed countries like the MSB region.

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7. APPENDICES

In these appendices we share the details of the methodological steps referred to in the Methodology section.

7.1. Data split of water and agriculture sectors

The split was performed using the standard procedure of SplitCom application, in which original dataset tables were reformed to use sub sectors and represent multiple water values (Table1) and multiple agriculture values (Table2).

Data for the water split:

Table 1 - Regional disaggregation and share of water sources in the base year (2014).

	Region/Country	Natural water	Desalinated water	Treated water
1	Oceania	95%	4%	1%
2	East Asia	99%	0%	1%
3	South Asia	85%	0%	15%
4	North America	99%	0%	1%
5	Latin America	100%	1%	0%
6	Croatia	61%	0%	39%
7	France	85%	0%	15%
8	Greece	100%	0%	0%
9	Italy	100%	0%	0%
10	Spain	97%	1%	2%
11	Rest of EU28	100%	0%	0%
12	Israel	64%	15%	21%
13	Turkey	100%	0%	0%
14	Egypt	83%	0%	17%
15	Morocco	94%	0%	6%
16	Tunisia	97%	1%	2%
17	Rest of MENA	84%	0%	16%
18	Ethiopia	100%	0%	0%
19	Rest of SSA	91%	0%	9%
20	Albania	100%	0%	0%
21	Rest of the World	95%	4%	1%

Data for the agricultural split:

Table 2 - Share of irrigated land, irrigated crops, and yield ratio by region

Country or region	Irrigated cultivated area	Irrigation to rainfed yield ratio	% Irrigated crops-yield	% Non-irrigated crops-yield
1 Oceania	7%	2.2	15%	85%
2 East Asia	51%	1.5	62%	38%

Country or region	Irrigated cultivated area	Irrigation to rainfed yield ratio	% Irrigated crops-yield	% Non-irrigated crops-yield
3 South Asia	42%	2.2	61%	39%
4 North America	10%	1.8	17%	83%
5 Latin America	8%	1.7	13%	87%
6 Croatia	3%	1.8	6%	94%
7 France	15%	1.8	23%	77%
8 Greece	47%	1.8	61%	39%
9 Italy	45%	1.8	59%	41%
10 Spain	23%	1.8	34%	66%
11 Rest of EU28	10%	1.8	17%	83%
12 Israel	47%	1.9	63%	37%
13 Turkey	23%	1.6	33%	67%
14 Egypt	100%	1.5	100%	0%
15 Morocco	16%	1.8	25%	75%
16 Tunisia	10%	2.1	19%	81%
17 Rest of MENA	35%	2.2	54%	46%
18 Ethiopia	5%	1.4	6%	94%
19 Rest of SSA	3%	2.0	7%	93%
20 Albania	57%	1.8	70%	30%
21 Rest of the World	9%	1.8	15%	85%

7.2. CC: SSP2 baseline

The baseline used mainly IIASA model results per the SSP assumptions put by IPCC, and AWESOME D2.1 – detailing demographic changes in 2050 [59, 60, 30].

Table 3 - CC SSP2-baseline change rates per country

Country/Region	Real GDP	Population	UnSkilled Labor	Skilled Labor	Physical capital	Land Cover (Cropland)
1 Oceania	85%	13%	-37%	-3%	62%	11%
2 East-Asia	383%	19%	-51%	42%	166%	2%
3 South-Asia	383%	19%	-51%	42%	166%	2%
4 North America	85%	13%	-44%	-5%	62%	11%
5 Latin America	194%	26%	-54%	30%	153%	12%
6 Croatia	76%	-7%	-50%	29%	169%	11%
7 France	158%	19%	-61%	3%	79%	11%
8 Greece	144%	-1%	-53%	22%	115%	11%
9 Italy	155%	1%	-54%	19%	26%	11%
10 Spain	144%	13%	-59%	8%	26%	11%
11 Rest of EU28	85%	13%	-59%	8%	62%	11%
12 Israel	180%	47%	-60%	18%	279%	11%

13 Turkey	156%	28%	-55%	33%	312%	48%
14 Egypt	291%	47%	-55%	46%	517%	48%
15 Morocco	164%	14%	-43%	84%	188%	48%
16 Tunisia	206%	19%	-45%	77%	340%	48%
17 Rest of MENA	365%	81%	-63%	22%	401%	48%
18 Ethiopia	363%	79%	-63%	23%	292%	48%
19 Rest of SSA	365%	81%	-63%	22%	401%	48%
20 Albania	76%	0%	-53%	21%	303%	11%
21 Rest of World	209%	30%	-64%	-4%	126%	12%

7.3. CC: RCPs

The RCP scenarios used mainly IIASA model results per the RCP assumptions put by IPCC [56, 57]. The population and labour volumes were assumed to be similar to the SSP2 baseline data.

Table 4 - RCP change rates per country

RCP	RCP 2.6			RCP 4.5			RCP 6.0		
Country/Region	Real GDP	Capital	Land	Real GDP	Capital	Land	Real GDP	Capital	Land
1 Oceania	83%	135%	1%	85%	103%	14%	85%	104%	17%
2 East-Asia	368%	248%	7%	380%	172%	7%	382%	172%	6%
3 South-Asia	368%	248%	7%	380%	172%	7%	382%	172%	6%
4 North America	83%	135%	1%	85%	103%	14%	85%	104%	17%
5 Latin America	189%	277%	0%	194%	184%	12%	194%	171%	14%
6 Croatia	75%	289%	1%	76%	237%	14%	76%	237%	17%
7 France	155%	159%	1%	158%	124%	14%	158%	125%	17%
8 Greece	141%	211%	1%	144%	169%	14%	144%	169%	17%
9 Italy	152%	82%	1%	155%	57%	14%	155%	58%	17%
10 Spain	142%	82%	1%	144%	57%	14%	144%	58%	17%
11 Rest of EU28	83%	135%	1%	85%	103%	14%	85%	104%	17%
12 Israel	177%	448%	1%	180%	374%	14%	180%	375%	17%
13 Turkey	153%	495%	35%	155%	415%	53%	156%	416%	56%
14 Egypt	282%	993%	47%	289%	595%	50%	281%	999%	49%
15 Morocco	158%	410%	47%	163%	224%	50%	157%	460%	49%
16 Tunisia	199%	680%	47%	205%	396%	50%	198%	757%	49%
17 Rest of MENA	352%	787%	47%	360%	464%	50%	351%	874%	49%
18 Ethiopia	352%	595%	47%	361%	342%	50%	351%	664%	49%
19 Rest of SSA	352%	787%	47%	360%	464%	50%	351%	874%	49%
20 Albania	75%	482%	1%	76%	404%	14%	76%	405%	17%
21 Rest of World	201%	236%	8%	207%	165%	16%	208%	162%	17%

7.4. CEA data

The CEA data used the following data and assumptions:

Table 5 - The data and method to calculate the % of feasible crops for CEA

Crops	% Crops 2014	% Growth 2050	% Hydroponic feasible	Total feasible	Reference
Wheat	0.12	0.06	0.00	0.06	
Maize	0.13	0.06	0.25	0.09	[63]
Rice	0.03	0.04	0.50	0.05	[66]
Sugar beet	0.06	0.05	0.25	0.07	[65]
Soybean	0.05	0.00	0.25	0.01	[64]
Tropical Fruits	0.05	0.07	0.00	0.07	
Potato	0.03	0.03	0.50	0.04	[70]
Vegetables	0.17	0.14	0.75	0.27	[62] [69]
Pulses	0.03	0.00	0.50	0.02	[63]
Sunflower	0.01	0.00	0.00	0.00	
Sugarcane	0.09	0.12	0.00	0.12	
Temperate Fruits	0.03	0.02	0.00	0.02	
Olives	0.04	0.00	0.00	0.00	
Sorghum	0.01	0.01	0.50	0.01	[63]
Banana	0.01	0.01	0.00	0.01	
Groundnuts	0.05	0.00	0.00	0.00	
Fodder grasses	0.11	0.38	0.50	0.43	[63]
Total	**1.00**			**1.29**	

The percentage of the crops yield at years 2014 & 2050 was based on AWESOME D2.3, WATNEEDS modeling report [71], and the hydroponic feasibility assumptions were based on the knowledge gathered in AWESOME WP5 on hydroponic and aquaponic practices and the cited references that were translated into the following grade-sections:

- 0 not feasible in the near future
- 0.25 feasible, in tests
- 0.5 feasible with minor growth in yield
- 0.75 feasible with medium growth in yield
- 1 higher (5-10 times) yield growth, like in lettuce

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