AWESOME
WATER-ECOSYSTEM-FOOD

CGE MODEL FOR DETAILED WATER-FOOD REPRESENTATION

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LIST OF ACRONYMS

Abbreviations

AP: Aquaponics
CC: Climate Change
CES: Constant Elasticity of Substitution
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
QC: Quality Control
QM: Quality Management
RO: Reversed Osmosis
RP: Reporting Period
SDG: Sustainable Development Goals
WEFE: Water-Energy-Food-Ecosystem
WP: Work Package

EXECUTIVE SUMMARY

Following the objective of the UN SDGs and the WEFE nexus to ensure sustainable development through better management of linked resources, the focus of this study in progress is to learn about the economic modelling of the WEFE linkage in the Mediterranean Sea basin. A variety of modelling approaches that embed water into a CGE framework is available [1, 2]. However, only a limited number of studies incorporate into the economic analyses the external effects on the ecosystem and the ecosystem's ability to continue and provide water and food in the future. In addition, the role of alternative water sources within the WEFE nexus is overlooked.

Linking the micro-level ecosystem's attributes with the macro-level economy-wide water-food analysis is especially challenging when the national accounts reflect water provisioning as one sector and rarely consider alternative water sources as part of the CGE analysis. The deliverable reports on the preparation of baseline and model calibration. Starting from a global CGE model alternative water sources, including cost specifications and substitutability for agricultural production, are introduced. Using a water-focused CGE model allows capturing not only the direct effects of increased water access (e.g. on agricultural production) but also indirect effects of a growing economy such as additional production in upstream and downstream sectors, increased demand for labor, adjustments of the government budget, and overall effects on household income and expenditure. The deliverable reports on the unique ongoing effort to introduce natural water and alternative water sources in the global CGE modeling framework. The updated model and database will allow analyzing more accurately the research questions of AWESOME and policy considerations.

1. INTRODUCTION

Climate change and population growth are imposing an increasing 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 alongside an underestimation of their negative externalities may lead to ecosystem services (ES) degradation, risking water and food provisioning [3, 4]. The UN sustainable development goals (SDGs) highlighted zero hunger and clean water supply within the six most important development goals [5]. 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, and the rest are irrigated using water bodies such as rivers and groundwater aquifers, which also rely heavily on climatic conditions [6]. Hence, agriculture is one of the most climate-sensitive sectors of an economy. It responds to temperature, precipitation, soil radiation, and other attributes that are directly associated with climate change risks [7]. The link between climate change and natural water shortage that impacts agriculture, food and the economy is widely discussed [8, 9].

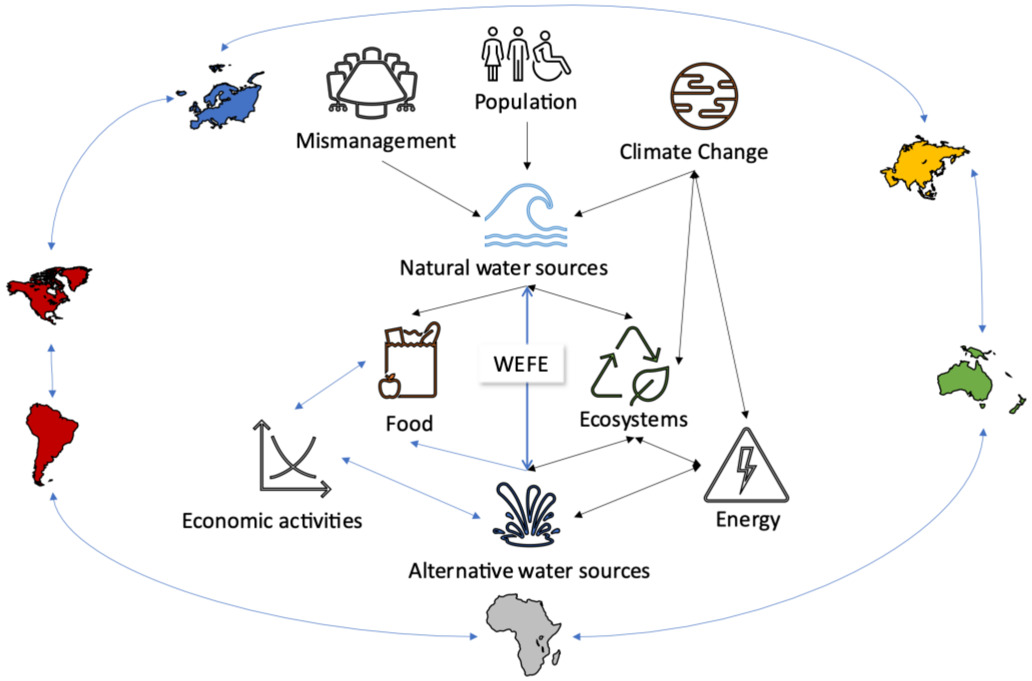

Figure 1 -The role of alternative water sources in WEFE analysis within a global economic context

To increase water availability and support food provisioning, alternative water sources were developed. Recent articles argue that desalinated and treated brackish water should be included in the blue-water category that originally included only groundwater and surface water [10]. For example, 53 percent of the water demand in Israel in 2019 was for agricultural use, with 20% being fresh water and the rest 33% being alternative water sources such as treated wastewater and desalinated water [11]. 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 of high importance in water-stressed countries such as the Mediterranean region, where the further decline of natural freshwater availability is expected due to climate change [12, 13]. Several studies address the diversification of alternative water sources (e.g. desalinated and reused water) that aim to meet the demand [8, 6]. However, the costs and benefits attached to each of the alternative water sources should consider both direct impacts and externalities. The direct costs are mainly energy consumption costs at the desalination and purification plants. 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 [14, 15]. Recent articles highlighted an increase in salinity: near desalination plants due to saline wastes and in croplands using wastewater irrigation [16, 17].

While alternative water sources 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 in the decision process to build a water-provisioning plant [11]. The regulation of the quality and quantity of natural water is one type of ES [18] 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 [19, 20]. The externalities associated with the overexploitation of natural water, especially on the ecosystems, are often being ignored when compared with the perceived marginal benefit of a new alternative water source. However, the change in the ecosystem's ability to supply food or water may alter the contribution of these ecosystems to human well-being [21, 18].

Aiming to better manage linked resources and following the UN SDGs, the UN declared the WEFE nexus as a focus area for sustainable development [22]. Sustainable water management policies along with innovative agricultural technologies can be the driver toward secure provisioning of food and water, following the objectives of the WEFE nexus. 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 [23].

Precise agriculture 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 [24, 25], driving nutrient management and crop rotation plans [26], and implementing soil-less cultivation in hydroponic and aquaponic plants [27]. Aquaponics (AP) 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, that was produced by the aquaculture plant, usually growing fish [27]. The economic viability of AP in the Mediterranean Sea basin (MSB) is higher compared to other colder locations, as on top of the reduced costs of water and land, the warm temperatures reduce the costs of energy consumption [28].

Economy-wide analyses of the effect of water management on food security rarely consider alternative water sources, precise agriculture practices, or the social costs and benefits of water and food provisioning [9, 2]. 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 and human wellbeing [29, 30]. To the best of our knowledge, no previous study has investigated the role of alternative water sources (e.g. treated, desalinated) in managing water shortages and food security while focusing on the WEFE nexus in the MSB.

The primary goal of this analysis is to study the impacts of climate change on food security given the potential supply of alternative water sources: desalination and reused (treated) water within the WEFE nexus in the MSB. This report illustrates the work in progress to model the global economy by quantitatively and qualitatively analysing the potential effects of alternative water sources on the WEFE nexus. The methodological approach and the data for implementation are presented along with model verification results.

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 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 [31, 32]. CGE is a macro modeling approach that takes into consideration the interdependencies between regional and national aspects of trade among multi-sectoral markets to project the potential socioeconomic scenarios of human well-being.

General equilibrium, which dates to Leon Walras (1834–1910) [33], 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. 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 depend 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 [34].

One example of a CGE model is the GTAP that is a multi-region, multi-sector model, with perfect competition and constant returns to scale [35]. 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 [9, 32]. Different closures may be used to represent different economic environments, or for different 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 [36].

CGE models can provide considerable insight into how water-related distortions (e.g., droughts) and departures from a counterfactual equilibrium can influence food provisioning and global economic growth [37]. However, most CGE-based studies have difficulties trying to adequately represent the value of water, especially in water-abundant countries that lack an explicit economic value of water [8]. In most studies, potable water is the only type of water modelled [2]. A recent article highlighted the difference between rainfed and irrigated agriculture by focusing on a single type of irrigation water [38]. 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 water shortage.

To analyse the water-food-ecosystem interdependencies, the CGE models are usually linked to partial equilibrium (PE) or physical non-economic models that detail the water and agricultural attributes [23]. Most of the articles use scenario analysis to assess the micro-level, ecosystem-specific attributes that affect the macro-level CGE [29]. 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 [39].

Among all the studies that were surveyed in Bardazzi and Bosello [1], only one [40] addressed explicitly and in their entirety the Water-Energy-Food Nexus nodes. The authors acknowledged the objective difficulties in modelling the complex interdependencies involved and in gathering good quality data.

Although many CGE-based studies evaluate the potential impacts of climate change, 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 [3] compared a 2050 baseline scenario projected by a GTAP model with a climate-change induced effect on temperature and precipitations that alters biodiversity impacts on cropland productivity in different Mediterranean regions. A recent unique effort accounted for the non-market values of potential climate-change-induced loss by using a dynamic CGE framework with a consistent market evaluation [41]. The GHG concentration and the emission path were exogenously provided by a physical model 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.

Zhang, et al., [42]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. However, their analysis did not focus on the effect of policy on the water quality and quantity regulation ability along time, but on food provisioning costs and benefits, based on the trade-offs between economic and ecological water demands.

The studies that explicitly introduce water as an endowment usually perform a single economy analysis, e.g. Israel [8, 43, 44], or Morocco [40]. Kahsay et al. [30] assessed how changes in water demand affect the different sectors in the countries using the water of the Nile river's basin. Using the STAGE2 model the implication of water and land quality management on crops yield and related costs in Egypt were assessed [45]. 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 water and land quality costs 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 [44]. 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 [46], most of the studies are concentrating on the analysis of the water-food implications for agriculture while neglecting the other sectors [1] and the impacts on ecosystems. Bardazzi and Bosello [1] 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. 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 country level CGE models. The following sections outline the methodological concept and the data gathered so for this study in progress.

3. METHODOLOGY

The first step of the analysis is to explicitly introduce desalination and treated water into the global CGE model and database. The resulted modelling framework will be used as the basis of the second step, where the externalities associated with the different water sources will be incorporated into the modelling framework.

The platform used in this study is the Global Trade Analysis Project (GTAP) for CGE model [47]. The GTAP project also maintains a global database. The database of a computable general equilibrium model has two main components. One is the Social Accounting Matrix (SAM) reporting the value of all transactions as a circular flow of national income and spending in an economy over a specified period of time, usually a year. The second component of a CGE model database provides the elasticity parameters that describe producer and consumer responsiveness to changes in relative prices and income [65]. Accordingly, to add an economic sector or activity, the study needs to add the relevant data to SAM while maintaining equality of economic transactions. In addition, the new sector should be presented through the model parameters and structural interdependences.

Using the standard GTAP model [36] and GTAP10A dataset [48], the water sector was divided into three main categories using the standard procedure of SplitCom application [49] into (a) natural water that refers to ground and surface water, (b) desalinated water that refers mostly to seawater desalination and (c) treated water that refers primarily to wastewater and brackish water treatment.

To introduce alternative water sources in the CGE, several assumptions were made. Desalinated water is produced from the abundant resource – seawater. Therefore, the scarcity value that is attributed to depletable natural resources is not applicable. Accordingly, desalinated water production can be treated as a sector disaggregated from the existing water sector in the GTAP database. The economic activities of the desalination sector are reported as part of the water sector (sectors' code 36, 37) in the input-output tables [50].

Like desalination, treated water is produced by the reuse and purification of wastewater and brackish water that entered the system. Therefore, rather than a natural resource, treated water is referred to as another economic industry. For example, in official statistics of Input-output tables, treated water is reported as a part of the water sector (sectors' code 36, 37) [50].

The production structure of water uses in agriculture (Figure 1) follows a previous estimation by Baum, et al., [8]. The nested structure of CES indicates that fresh, tertiary-treated wastewater, secondary-treated wastewater, and brackish water inputs are not equally substitutable in agricultural production. Moreover, the estimated rates of substitution are not high, reflecting the constraints associated with crop salinity tolerance and food safety regulations.

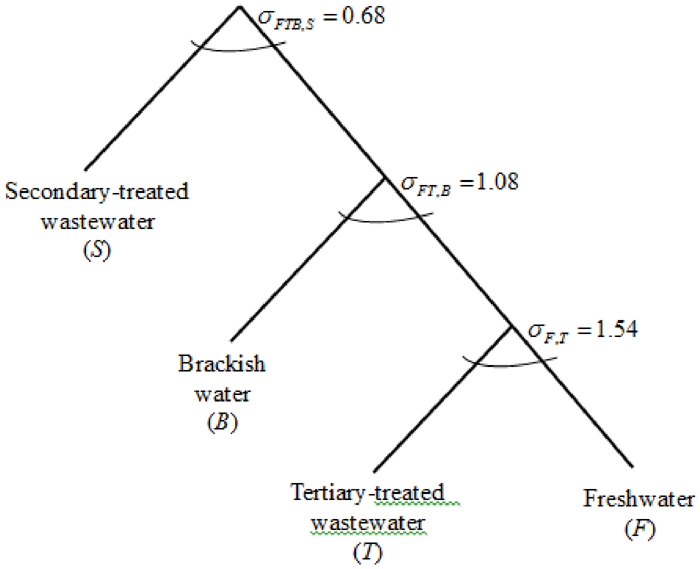

Figure 1 - Nested CES structure of water inputs to agriculture *[8]*.

No global CGE is representing the water sector in this comprehensive way [23]. As no studies evaluated the elasticities of substitution between fresh and alternative water sources for other regions, we assume the same functional structure as in Figure 2 to the MSB and other world regions in our model.

3.1. Stages of database transformation

The methodological steps in GTAP to transform the database, include:

a) Disaggregating the MSB countries from their regions using GTAPAgg2
b) Disaggregating the water and electricity sectors out of their industry groups using GTAPAgg2
c) Splitting the water sector into three sub-sectors: Natural, desalinated, and treated water.
d) Splitting the GrainCrops sector into irrigated and non-irrigated crops.
e) creating a baseline for future state of the economy in 2050:
    a. Incorporating into RunGTAP the updated (split) database (ver 6)
    b. Incorporating into the data the projected change in the 2050 values, per the IPCC external effects on the ecosystems and sectors, that contribute to water and food provisioning (i.e., Real GDP, Population, Labor force, Physical capital and Arable land).

c. Formulating the 2050 baseline and measuring the potential change in the economy.

The starting point for carrying out the simulation is by calibrating the model to the state of the economy in 2050 in benchmark equilibrium according to the RCP4.5 baseline scenario [51]. We fed into the model, at this initial state, a projected accumulated change in key economic indicators to represent the development projected for the year 2050. The climate change-induced variation in the precipitations and evapotranspiration violates the equilibrium conditions prevailing in the benchmark, while alternative water sources and aquaponics can moderate the impact (Figure 3).

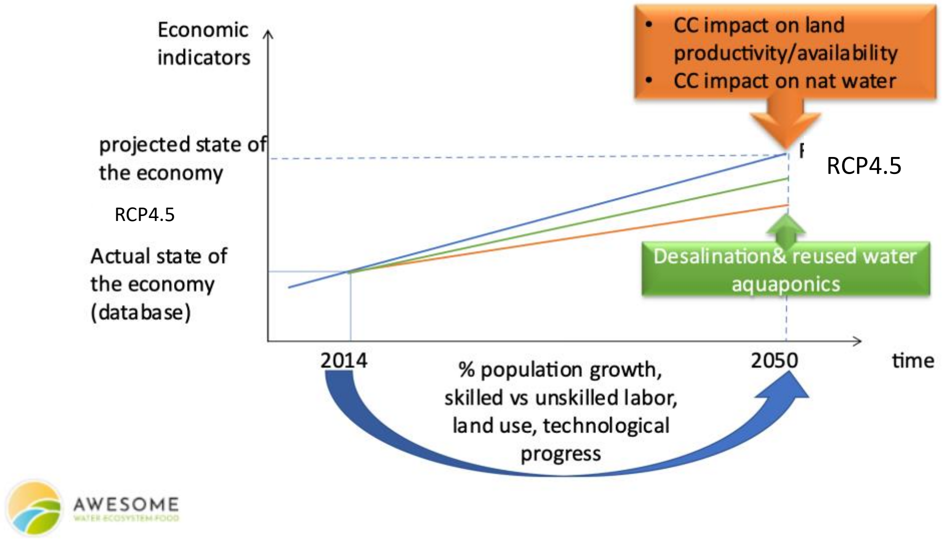

Figure 2 - Climate Change impact analysis in the CGE framework.

For the next deliverable, we will proceed with the evaluation of climate change impact performing a comparative static analysis of the projected state of the economy in the year 2050 according to RCP scenarios.

3.2. SPLITCOM data management methods

The water sector's data in GTAP includes monetary figures of supply and demand parameters. The challenge was to split these figures between the three new sectors of natural, desalinated, and treated water, based on the percentage of each type of water in the water supply of each country. Natural water in the split refers to precipitation, surface and ground water, excluding seawater and treated water.

Since what we needed was the share of each new sector as part of the original total sector, in the case that no monetary data was available, we used the relative amount shares of the actual water quantities data in each country. This way, the Supply % data was mainly based on AQUASTAT using 2014 figures, the demand data was mainly based on [52]. Desalinated water sources were mainly based on seawater or brackish water [53].

- Where demand data was not available, demand was aligned by the supply data from AQUASTAT [54].
- CROSS usage data on desalination was updated mainly for the MSB countries [53].
- The regional data, in case that no regional figure was available, was based on the sum of the largest areas in these regions per the GTAP database, i.e., Brazil in South America, China in East Asia, India in South Asia; Sub-Sahara-Africa (SSA) data was based on Sudan, South Africa, Zambia, and Congo; North Africa data was based on Algeria and Libya; North America was based on the USA and Canada; Latin America was based on Brazil; Oceania was mainly based on Australian data; The rest of the world's data was based on Russia, Uzbekistan, Switzerland, and Norway.

The water split was performed in two stages updating a different level of information in the GTAP tables. The objective was to examine the change we formulate in the data step by step. The first split was using the general supply, demand, and self-use tables (COLC, ROWC, and CROSSC, accordingly) feeding general data for all the regions. The second split updated each MSB country and general region with country/region specific data in detailed tables (COLB, ROWB, and CROSSB). The assumptions were:

- Capital and labour data were following several available sources for the characteristics of each country/region [55, 43, 52, 56].
- Where data was missing, educated guess for estimates was taken. For example, where economic data was missing, water supply and usage ratios were implemented instead. The economic differences between the water sources were then updated as part of the capital supply costs per each country/region based on the available data for similar countries.

4. DATA

The core of the analysis is the impact of climate change on the WEFE nexus in the MSB. To focus the global GTAP-based model on the economies of the region, our regional disaggregation represents in detail Mediterranean countries, while other economies are aggregated into several corresponding regions, as seen in the split into the different shares of each source of water (Table 1).

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

	GTAP abbreviation	Region/Country	Natural[a] water	Desalination[b]	Treated[c] water
1	Oceania	Oceania	95%	4%	1%
2	EastAsia	East Asia	99%	0%	1%
3	SouthAsia	South Asia	85%	0%	15%

	GTAP abbreviation	Region/Country	Natural[(a)] water	Desalination[(b)]	Treated[(c)] water
4	NAmerica	North America	99%	0%	1%
5	LatinAmer	Latin America	99%	1%	0%
6	hrv	Croatia	61%	0%	39%
7	fra	France	85%	0%	15%
8	gre	Greece	100%	0%	0%
9	ita	Italy	100%	0%	0%
10	esp	Spain	97%	1%	2%
11	RestofEU28	Rest of EU28	100%	0%	0%
12	isr	Israel	64%	15%	21%
13	tur	Turkey	100%	0%	0%
14	egy	Egypt	83%	0%	17%
15	mar	Morocco	94%	0%	6%
16	tun	Tunisia	97%	1%	2%
17	RestofMENA	Rest of MENA	84%	0%	16%
18	eth	Ethiopia	100%	0%	0%
19	RestofSSA	Rest of SSA (Sub Sahara Africa)	91%	0%	9%
20	alb	Albania	100%	0%	0%
21	RestofWorld	Rest of the World	95%	4%	1%

(a) Natural water refers mainly to precipitation, surface and ground water.
(b) Desalinated water refers mainly to sea and brackish water.
(c) Treated water refers mainly to reused water.

4.1. Water sectors

Like any other sector, the water sector in GTAP includes monetary transactions between the sector and other industries and economic agents [47]. The challenge was to split these figures between the three new sectors, i.e., natural, desalinated, and treated water. The share of each new sector in the original sector is required. In case no financial data were available, the actual water consumption shares were applied as the closest estimate. The Supply data was mainly based on [54] and the demand data was mainly based on [52, 53]. Where demand data was not available, the estimate was aligned by the supply data from AQUASTAT (Table 1). The water sources used for the desalinated water production (CROSS table) were available mainly for the MSB countries [53]. The average data for the regional estimates were based on the largest countries in these regions (as detailed in the previous section).

Figure 3 presents the demand share of sectoral (including agriculture) and private consumption of all water sources [52, 54].

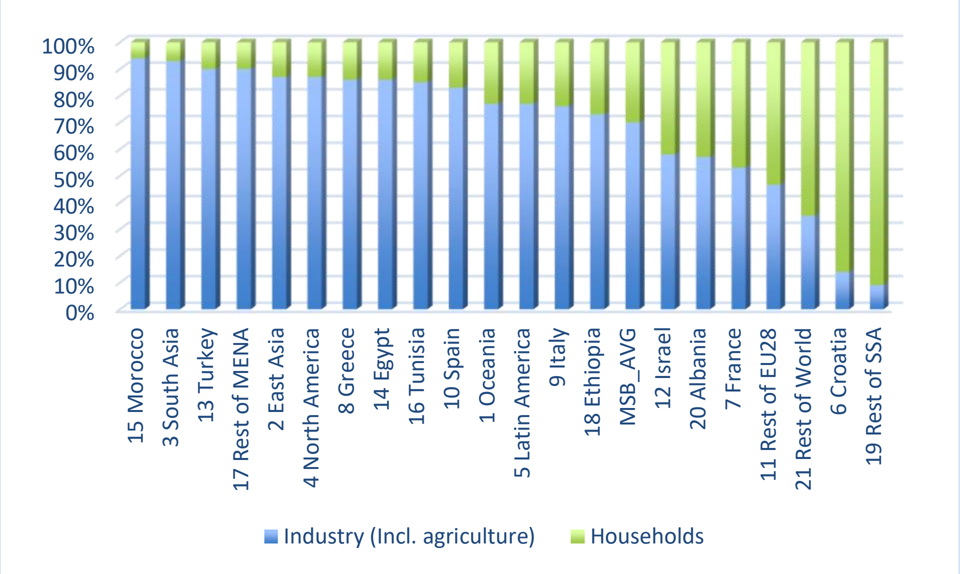

Figure 3 - Share of Water consumption by households and industry

Source: based on *[52]*.

Table 2 presents the cross usage of water in percentages. The share of natural and wastewater sources is according to shares used by the desalination plants in the MSB, disregarding the seawater amounts as a source for desalination [53].

Table 2 – Use of natural water and wastewater for desalination disregarding seawater amounts

CROSS %	1 Natural water	2 Treated water*
7 France	73%	27%
8 Greece	35%	65%
9 Italy	32%	68%
10 Spain	24%	76%
11 Rest of EU28	14%	86%
12 Israel	19%	81%
13 Turkey	10%	90%
14 Egypt	23%	77%
15 Morocco	0%	100%
16 Tunisia	0%	100%
17 Rest of MENA**	26%	74%
MSB_AVG	23%	77%

* Treated water refers to wastewater and brackish water
** MENA = Middle east and North Africa
Source: based on [53]

Data presented in Tables 1,2 and Figure 3 were the basis for the first SplitCom update of the monetary values of the three water sources. COLC and ROWC reflect the partial shares for the new columns/rows of the national matrix, and CROSSC reflects the partial shares for the new intersection of the national matrix.

4.2. Costs

The variation in the costs of different water sources is evident in the Israeli water sector. Potable water is produced from natural fresh water and desalination, whereby the latter is more expensive due to its high energy cost-share [43].

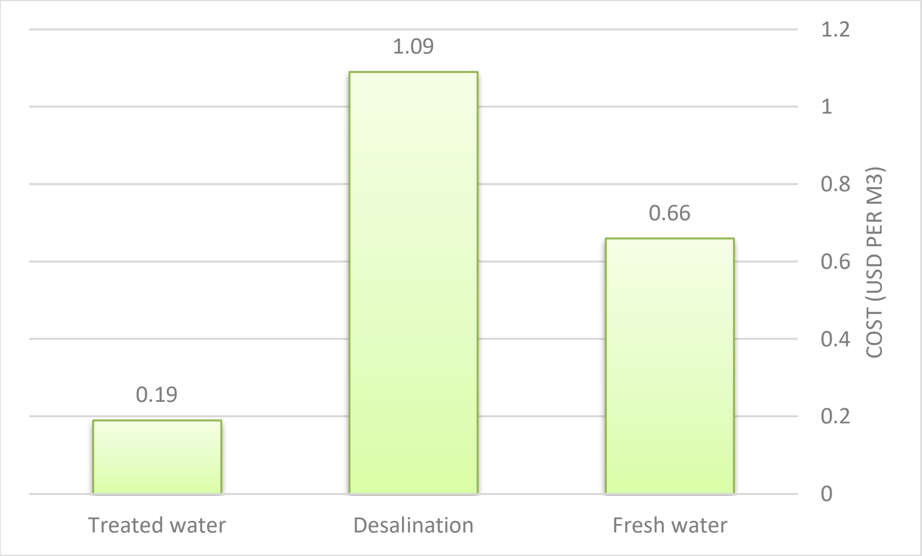

Figure 4 - Costs of water sources (USD per m^3)

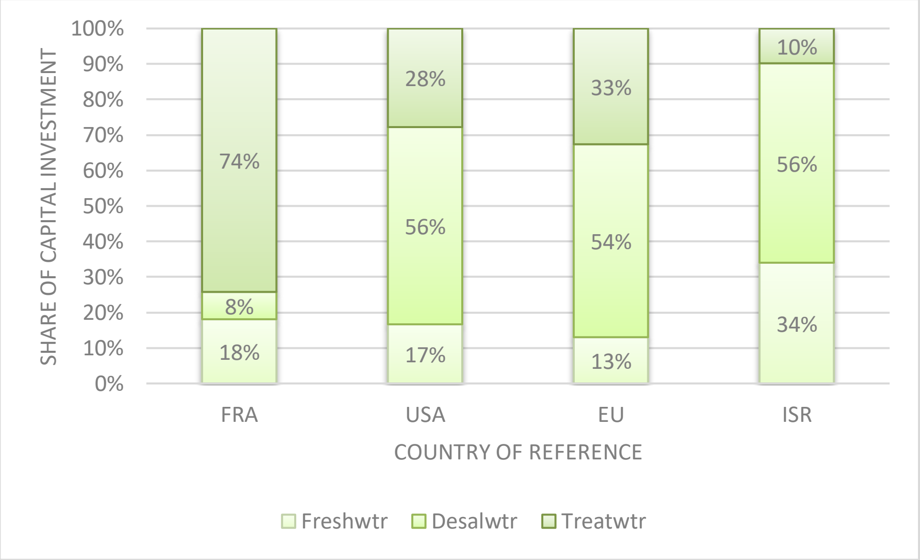

Figure 5A – The share of water sources in the capital investment of France *[52]*, USA *[57]*, EU *[58]* and Israel *[43]*.

The applied desalination technology, capital and operational costs, production capacity, and water salinity are just a few factors determining the final cost of desalinated water that varies around the world between $0.45–2.51 per m^3 [59]. The regional analysis for selected leading countries in the desalination market reveals significant differences (Figure 6) driven by country-specific parameters for energy prices, costs of materials and equipment, interest rates for building a desalination plant, etc.

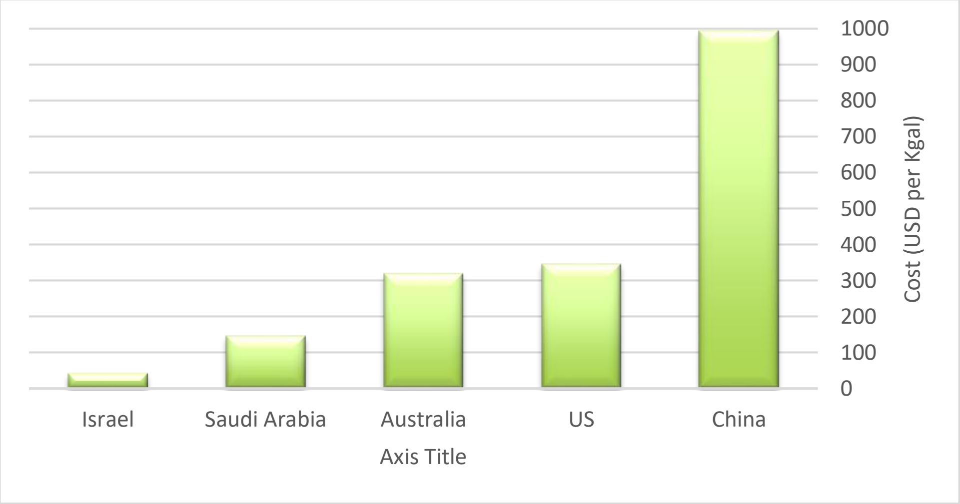

Figure 6 - Normalized average capital costs of RO desalination technology per unit of produced water in selected countries in 2013 *[59]*.

The main change in the second stage of the water split was the supply table, COLB, that detailed the sectors investing in water supply, the capital and labour split percentages per country or region. Table 3 shows as an example the share of inputs to the production of the water types, based on the data from Israel water satellite accounts [55].

Table 3 – COLB – water supply in Israel by sectors and factors of production, including land, capital, and labor

SUPPLY %	1 Natural water	2 Desal. water	3 Treat. water
1 Grains and Crops	67%	33%	0%
2 Meat and livestock	67%	33%	0%
3 Extraction (i.e., fish and gold)	44%	22%	34%
4 Processed Food	67%	33%	0%
5 Textile and wearing apparel	67%	33%	0%
6 Light Manufacturing	100%	0%	0%
7 Heavy Manufacturing	67%	33%	0%
8 Electricity	67%	33%	0%
9 Utilities and Construction	57%	29%	14%
10 Transmission and Communication	100%	0%	0%
11 Other Services	100%	0%	0%

SUPPLY %	1 Natural water	2 Desal. water	3 Treat. water
12 Land	0%	0%	0%
13 Un-skilled Labor	34%	56%	10%
14 Skilled Labor	34%	56%	10%
15 Capital	34%	56%	10%
16 Natural Resources	0%	0%	0%
17 PTAX	77%	9%	14%

Source [55].

The demand and self-use tables (Table 4 and Table 5) represent specific share estimates by country/region in focus. Here the data for Israel are presented as an example. Similar tables were updated per each country and region. Table 4 reflects the share of water types demanded by industry and final users.

Table 4 – ROWB – demand for water types by users

DEMAND %	Industry (INT)	Households (HOU)	Investment (INV)	Government (GOV)
1 Natural water	57%	67%	34%	64%
2 Desalinated water	28%	33%	56%	15%
3 Treated water	15%	0%	10%	21%

Sources: [55, 53, 52]

Table 5 presents the use of water type by each of the water sectors. For example, the row of "Desal. Water" reflects that the desalination sector uses 28 MCM of natural waters and 170 MCM of treated waters to produce desalinated water.

Table 5 – Self-use and cross-use of the different water sectors

Self-use MCM	1 Natural water	2 Desalinated water	3 Treated water
1 Natural water	2,081	28	0
2 Desalinated water	0	0	0
3 Treated water	0	170	231

Tables 3-5 were the basis for the newly created SplitCom tables updated using country level data, as for example for Israel, and creating the same series of tables per each country and region. COLB and ROWB reflect the partial shares for the new columns/rows of the national matrix, and CROSSB reflects the partial shares for the new intersection of the national matrix.

4.3. Split of the "GrainCrops" sector

To link between the natural and treated waters, the agricultural yield was divided into two groups: irrigated and rainfed agriculture.

Two main parameters were used to update the split matrices with the agricultural data, (1) the share of the cultivated area equipped for irrigation, and (2) the irrigated to rainfed yield ratio, representing the added value of irrigation to yield of crops [54].

Table 6 – Share of irrigated land, irrigated crops, and yield ratio by 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%
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 World	9%	1.8	15%	85%
AVERAGE	27%	1.8	36%	64%

Source: based on [51]

The country-specific tables were based on the understanding that the costs of inputs and outputs in the cultivation cycles vary between crop types, land type, area and rain volumes, irrigation type, and even the type of cultivation practices. Therefore, the average estimation was assuming that:

a. the market price of irrigated and non-irrigated (rainfed) crops is similar [13]. The only known exception is hydroponic crops, which are not included in this stage of the analysis.

b. the investment in irrigated crops is according to the yield ratio [60, 61], especially as the yield grows due to several cultivation cycles each year in irrigated cropland as compared to one seasonal cultivation in most rainfed croplands.

c. the industry sector (that includes agriculture) is the main group consuming irrigation, as compared to households and government demand (GTAP data).

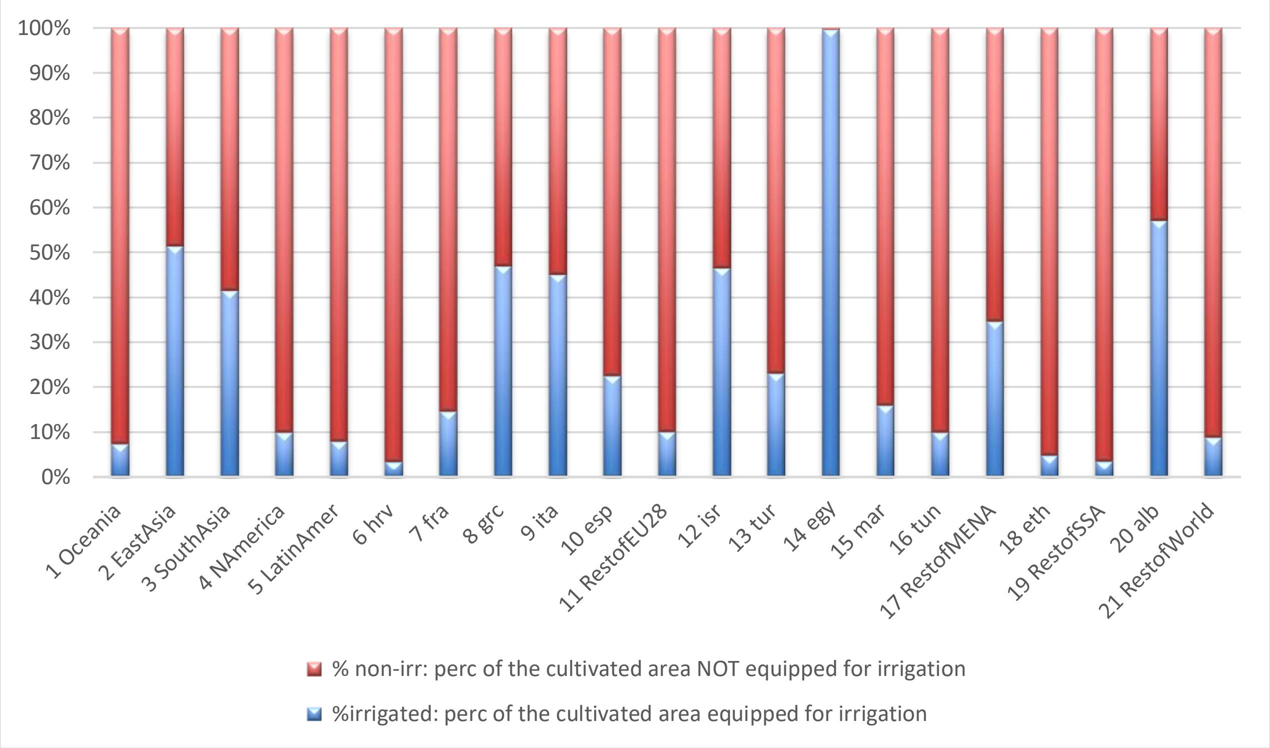

Figure 7 - Share of irrigated land, irrigated crops

Following the data in Table 6 and assumptions above, Tables 7, 8, and 9 were constructed to show the supply, demand, and cross-usage in the new split tables feeding the CGE matrices. The column Total shows how unsplit inputs of the original GrainCrops industry are divided between the new irrigated and rainfed GrainCrops sectors.

Table 7 – The inputs to the GrainCrops sector are divided between the new irrigated and rainfed agricultural industries by region (in million USD, 2014).

COLC	1 irrigated GrainCrops	2 rainfed GrainCrops	Total
1 Oceania	4,214	24,501	28,715
2 East Asia	353,225	216,350	569,576
3 South Asia	307,434	198,605	506,039
4 North America	40,493	202,476	242,969
5 Latin America	34,407	231,176	265,583
6 Croatia	48	777	825
7 France	6,940	22,658	29,598
8 Greece	4,144	2,619	6,763
9 Italy	13,141	9,025	22,167

COLC	1 irrigated GrainCrops	2 rainfed GrainCrops	Total
10 Spain	9,015	17,459	26,474
11 Rest of EU28	18,657	93,525	112,183
12 Israel	3,089	1,851	4,940
13 Turkey	8,689	18,008	26,697
14 Egypt	47,281	110	47,390
15 Morocco	4,160	12,198	16,358
16 Tunisia	726	3,072	3,798
17 Rest of MENA	51,329	43,225	94,555
18 Ethiopia	1,018	14,721	15,740
19 Rest of SSA	22,510	310,666	333,176
20 Albania	870	368	1,238
21 Rest of World	15,952	89,965	105,917

Source: self-calculated based on Table 6 and the original data in GTAP10A

The row weight (ROWC) shows how each unsplit user's use of the original split commodity is divided among the new GrainCrops commodities (**Error! Reference source not found.**).

Table 8 – ROWC – demand for irrigated and rainfed GrainCorp's sectors by users

ROWC	Industry (INT)	Households (HOU)	Investment (INV)	Government (GOV)	Total
irrigated GrainCrops	1,051,442	810,770	16,238	4,188	1,882,638
rainfed GrainCrops	577,053	444,967	8,912	2,298	1,033,230
Total	1,628,495	1,255,737	25,150	6,486	2,915,868

Source: self-calculated based on [54] and the original data in GTAP10A

The cross weight (CROSS) records each new GrainCrops industry's use of each new GrainCrops commodity ***Table 9***).

Table 9 – Self-use and cross-use of the irrigated and rainfed grain-crop sectors

CROSSC	1 irrigated GrainCrops	2 rainfed GrainCrops	Total
1 irrigated GrainCrops	94,652	94,652	189,305
2 rainfed GrainCrops	94,652	94,652	189,305
Total	189,305	189,305	378,610

Source: self-calculated based on [54] and the original data in GTAP10A

4.4. Baseline 2050

To analyse 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 RPC4.5. The RCP4.5 describes a middling pathway of global socioeconomic development, with moderate achievements and challenges in achieving economic growth and development, maintaining the capacity of global institutions, and undertaking mitigation and adaptation to climate change. The growth in key economic indicators according to the baseline scenario was imposed and the baseline equilibrium in 2050 was generated.

Table 10 - Accumulated percentage growth of indicators between the base year 2014 and 2050 by region.

Region	Real GDP	Population	Unskilled Labor	Skilled Labor	Physical capital	Irrigated Arable land
Oceania	85%	13%	-37%	-3%	62%	11%
East Asia	383%	19%	-51%	42%	166%	2%
SouthAsia	383%	19%	-51%	42%	166%	2%
North Amer.	85%	13%	-44%	-5%	62%	11%
Latin Amer.	194%	26%	-54%	30%	153%	12%
Croatia	76%	-7%	-50%	29%	169%	12%
France	158%	19%	-61%	3%	79%	11%
Greece	144%	-1%	-53%	22%	115%	11%
Italy	155%	1%	-54%	19%	26%	11%
Spain	144%	13%	-59%	8%	26%	11%
Rest of EU_28	85%	13%	-59%	8%	62%	11%
Israel	180%	47%	-60%	18%	279%	11%
Turkey	156%	28%	-55%	33%	312%	48%
Egypt	291%	47%	-55%	46%	517%	48%
Morocco	164%	14%	-43%	84%	188%	48%
Tunisia	206%	19%	-45%	77%	340%	48%
Rest of MENA	365%	81%	-63%	22%	401%	48%
Ethiop.	363%	79%	-63%	23%	292%	48%
Rest of SSA	365%	81%	-63%	22%	401%	48%
Albania	76%	0%	47%	121%	303%	11%
Rest of World	209%	30%	-64%	-4%	126%	12%
Reference	[62]	[62]	[63]	[64]	[64]	[64]

The GDP growth should be considered to illustrate the meaning of the percent change reported in Table 10.

Table *11* presents the actual GDP in million USD in 2014 that is represented in the baseline data of GTAP for 2014. According to the projections by IIASA [64], the regional/ country GDP is projected to grow in cumulative percentage if the world develops following the SSP2 (comparable to RCP4.5) trajectory. Following the established procedure [65] we introduced the growth of primary factors of production (Table 10) and calibrated the model to replicate the projected GDP growth in 2050 as reported in Table 11. Real GDP is an endogenous variable in the GTAP model.

Table 11 - Accumulated percentage growth of indicators between the base year 2014 and 2050 by region.

Region/ country	GDP in 2014 (Mil USD, GTAP)	cumulative Real GDP growth % 2014-2050 (SSP2, IIASA)	projected GDP in 2050 (Mil USD 2014)
Oceania	1,705,947	85%	3,161,205
East Asia	17,282,053	383%	83,526,048
South Asia	5,090,149	383%	24,601,247
North America	20,437,780	85%	37,872,229
Latin America	5,098,837	194%	15,000,987
Croatia	57,135	76%	100,825
France	2,843,937	158%	7,331,563
Greece	235,572	144%	574,570
Italy	2,138,531	155%	5,450,285
Spain	1,381,330	144%	3,374,049
Rest of EU28	11,876,129	85%	22,007,061
Israel	305,674	180%	856,370
Turkey	798,794	156%	2,042,689
Egypt	301,499	291%	1,179,404
Morocco	110,009	164%	290,373
Tunisia	47,603	206%	145,767
Rest of MENA	2,713,937	365%	12,631,479
Ethiopia	55,612	363%	257,585
Rest of SSA	1,687,955	365%	7,856,252
Albania	13,278	76%	23,431
Rest of World	4,044,353	209%	12,486,206

The results of this experiment are the baseline scenario for the world economy in 2050. The model output allows tracking the change in the production of each of the sectors of the economy. For example, Figure 8 presents the projected change in GrainCrops production before and after the split of the sector into irrigated and rainfed grain crops. This figure allows verification of the consistency of results where the change in production of the split sectors resembles that of the original, while in the follow-up analysis of the climate shocks irrigated crops are expected to suffer a larger impact.

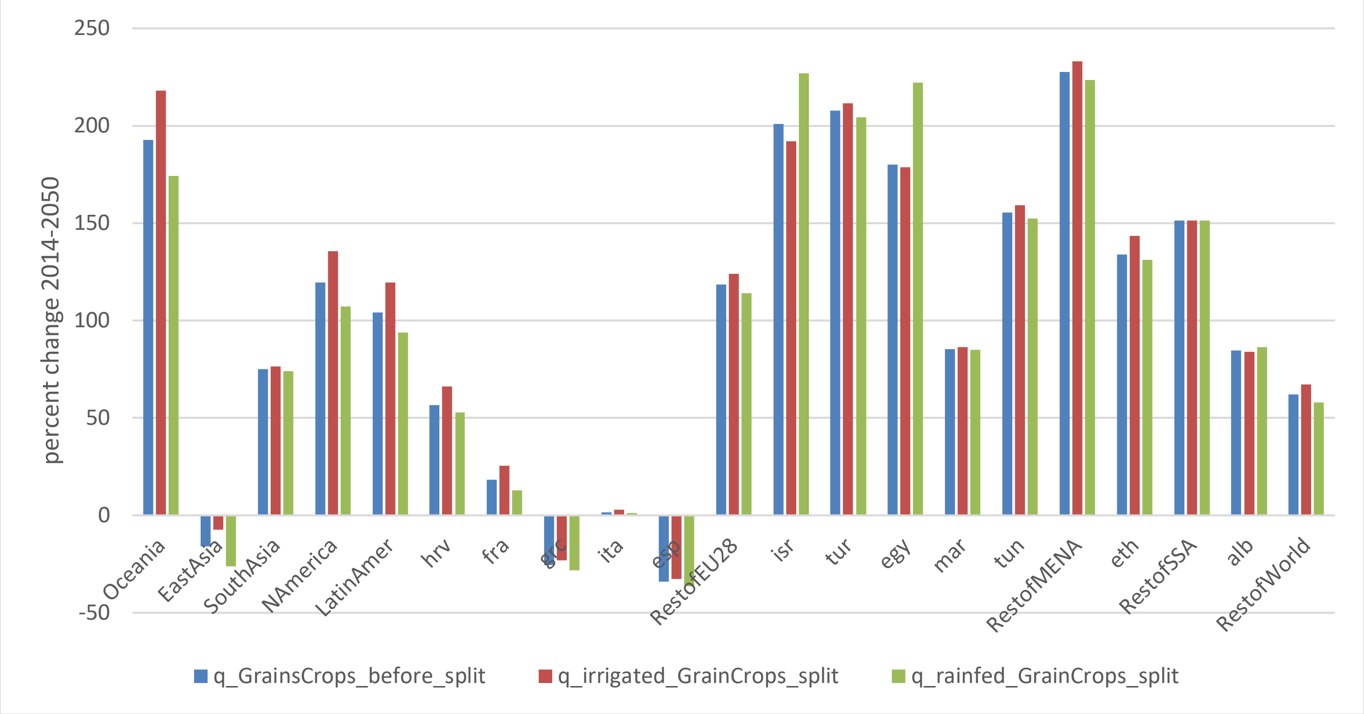

Figure 8 – Projected percent change in the production of irrigated and rainfed crops in the baseline scenario between 2014-2050

Legend: q_GrainCrops_before_split refers to GrainCrops quantity of industry's output in the dataset before splitting, q_irrigated_GrainCrops_split and q_rainfed_GrainCrops_split refer to irrigated and rainfed GrainCrops industry outputs, for the version including split, respectively.

The projected change in electricity according to the baseline scenario is presented in Figure 9. This figure also verifies consistency of results where the change in electricity production is not altered by the split of grain crop sectors.

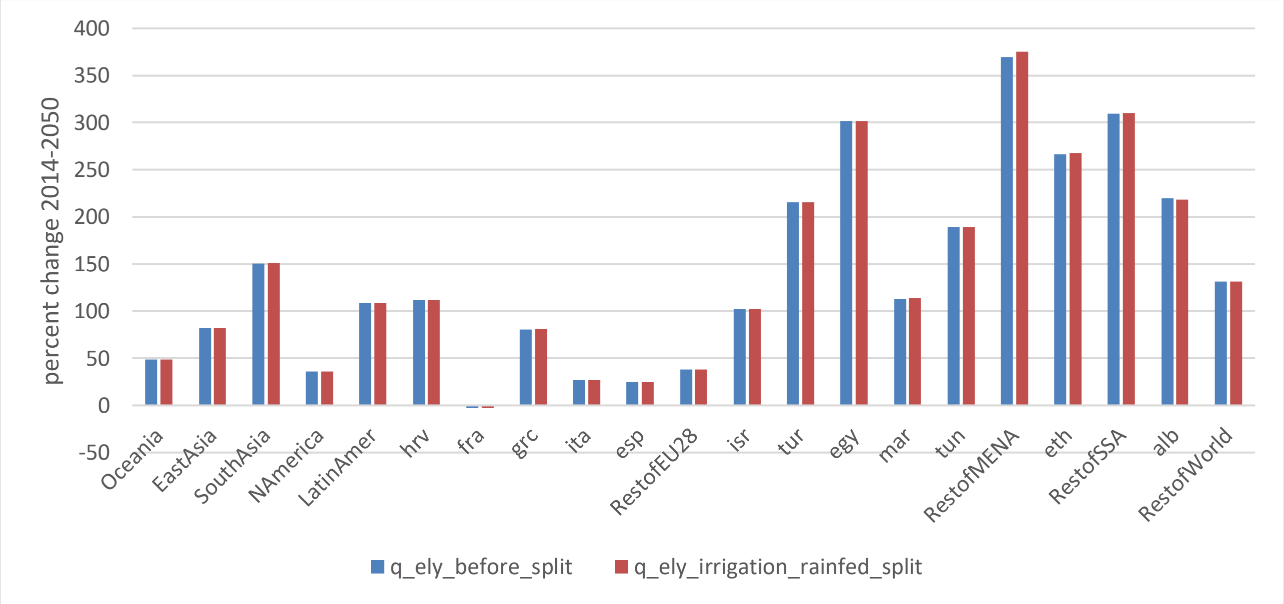

Figure 9 – Projected percent change in electricity output by region in the baseline scenario between 2014-2050

Legend: q_ely_before_split refers to electricity industry output (quantity) in the original dataset, q_ely_irrigation_rainfed_split refers to electricity industry output, for the version including split

In the following period of the AWESOME project, we are going to carry out an economic analysis of climate change as a part of an integrated modelling framework that links the impacts from global climate models, through biophysical crop models to the economic model.

A comparison of results between the baseline scenario and the counterfactual, climate-change experiment will describe the effects of climate change on economies in 2050. The model will describe producer and consumer responses to the decline in crop yields projected by the WP2 WATNEEDS model. The decrease in crop production is expected to cause prices to rise. Producers will respond to higher prices by intensifying their cultivation practices (and raising yields) and by expanding their cultivated area. These economic responses are expected to moderate the projected yield and production impacts from climate change that are estimated in the biophysical models. Our CGE modelling exercise will indicate the consumers' reaction to higher food prices by reducing the quantity of food demanded. In addition, international trade has a role in bridging supply and demand across regions.

5. DISCUSSION

Following the objective of the UN SDGs and the WEFE nexus to ensure sustainable development through better management of linked resources, the focus of this study in progress is to learn about the economic modelling of the WEFE linkage in the MSB. A variety of modelling approaches were identified. A vast literature on water modelling using the CGE framework is available [1, 2]. However, only a limited number of studies incorporate into the economic analyses the external effects of alternative water sources on the ecosystem and the ecosystem’s ability to continue and provide water and food in the future. In addition, the role of alternative water sources within the WEFE nexus is overlooked.

Linking the micro-level ecosystem’s attributes with the macro-level economy-wide water-food analysis is especially challenging when the national accounts reflect water provisioning as a single sector [32, 66]. In many cases, the estimations of climate change damages are lower-bound estimates. Damages to cultural heritage, ecosystem services, and increased mortality are difficult to evaluate in precision and monetize [51]. Indeed, non-market costs can explain most of the discrepancies among existing studies. Accordingly, the inclusion of both market and non-market components is essential for a comprehensive climate cost measurement, notwithstanding the problems with non-market estimation [41].

Deliverable D3.3 reports on the study in progress. Starting from a global CGE model, alternative water sources, including cost specifications and substitutability for agricultural production, are introduced. Using a water-focused CGE model allows capturing not only the direct effects of increased water access (e.g., on agricultural production) but also indirect effects from a growing economy such as additional production in upstream and downstream sectors, increased demand for labour, adjustments of the government budget, and overall effects on household income and expenditure [43].

In further steps, the characteristics of aquaponics as well as linking the impacts on ES will be introduced. Finally, the impact of climate change focusing on WEFE in MSB will be analysed according to a comparative static procedure. A comparison of results between the baseline scenario and the counterfactual, climate-change experiment will describe the effects of climate change on economies in 2050. Following the results, measures aimed at reinforcing ecosystem services, ad hoc regulation of human interventions, and farmers' participation will be discussed.

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