Water scarcity, climate change and potential collaboration in water management in the Middle East

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Water scarcity, climate change and potential collaboration in water management in the Tigris-Euphrates River basin

1. Introduction

Today, 3.6 billion people (47% of the global population) live in areas that suffer water scarcity for at least one month each year, and by 2050 this share will increase to 57% (UNESCO 2018). Globally, transboundary rivers carry almost 60% of freshwater flows and are crucial in ensuring people have an adequate water supply (Economist Intelligence Unit 2020). These shared resources need to be managed in a sustainable, equitable, and collaborative manner. Of the seven transboundary river systems ranked by how well countries manage transboundary water resources, the Tigris-Euphrates (TE) river basin has the lowest score (Economist Intelligence Unit 2020). The two rivers and their tributaries run mainly through Turkey, Syria, Iraq, and Iran. Transboundary water management in the basin is particularly difficult due to climate change, weak cooperation among riparian countries, intensive hydropower development, inefficient agricultural practices, and political instability (Shamout and Lahn 2015). While the construction of new dams and increases in water needs in Turkey could affect the flow of water to downstream countries, particularly in Iraq and Syria, by midcentury climate change may result in a 20 percent reduction in rainfall over the river basin (IPCC 2013) and the availability of water for irrigation may decline by 13-28 percent (Haqiqi 2019).

While the water supply has generally declined across the Middle East over time (Bozorg-Haddad et al., 2019), demand for water has increased rapidly across the region. In Iran and Turkey, the largest water users in the region, water withdrawal doubled between the early 1970s and 2020 (Aquastat, 2022). Water is largely used for irrigation in the Middle East. For example, the share of irrigation in total water withdrawal in Iran, Iraq, Jordan, Lebanon, Saudi Arabia, Syria, and Turkey are currently about 92.2%, 91.5%, 53.1%, 38%, 79.2%, 87.5%, and 87.1%, respectively (Aquastat, 2022). In the Middle East, due to climate conditions and low productivity of rainfed cropping, crop production relies heavily on irrigation. This suggests that a reduction in water supply due to climate change would further harm agricultural activities in the region.

While the existing literature has addressed this important issue globally (Rockström et al., 2009; Rosenzweig et al., 2004; Mekonnen and Hoekstra, 2016; Liu, 2022), the extent to which climate change could affect water scarcity in the Middle East has not been fully quantified yet. Taheripour et al. (2020) have examined the impacts of water scarcity on the economies of the Middle East. However, these authors have made no effort to quantify the potential consequences of climate change on water scarcity. Instead, Taheripour et al. (2020) have only considered several hypothetical water scarcity assumptions in their analyses. Unlike the earlier studies in this area, this paper uses a hydrological model (Haqiqi 2019) based on Water Balance Model (WBM) (Vörösmarty et al.; 1998, Grogan 2016; Grogan et al., 2022) to quantify the expected changes in water scarcity under alternative climate scenarios for the countries of the Middle East and their river basins, including the TE river basin.

In this region, the adverse consequences of water scarcity induced by climate change will not be limited to the losses in crop production. With no proper mitigation policies in place and without having an effective water management plan, reductions in agricultural output would negatively affect the whole supply chain of food production and associated economic activities, leading to less demand for labor and increases in unemployment in the region, lowering the productivity of capital assets (machinery and infrastructure) across agricultural and non-agricultural industries, and generating idle capacities across economic sectors. With no water for irrigation, a portion of agricultural production capacity will be lost, and people will leave rural areas. This will make the rural area's infrastructure idle. With less water supply, the entire water facilities become less efficient, the hydro-electricity capacity will be decreased, and water-intensive industries will not operate at full capacity or may be unable to produce at all.

In a stylized manner, Figure 1 demonstrates how climate change will affect water resources, economic activities, and primary factors of production in the TE riparian countries and other Middle Eastern counties. It also represents the links between these economies and their connections to the rest of the world through the trade of goods and services. In this figure, the red circles show climate change, representing changes in temperature and precipitation. The strongest and weakest climate change effects appear in Iran and Turkey, respectively. The light blue ovals show water resources. For the TE riparian countries, water resources are divided into two segments. For these countries, the solid dark blue circles show TE water resources, and dotted fill pattern light blue circles represent non-TE water resources. The sizes of the blue circles roughly show their current importance in total water withdrawal in the Middle East. For example, Iran has the largest and smallest water withdrawals from the non-TE and TE basins, respectively. The dark blue arrows show the flow of water across the TE riparian countries. The thickness of each of these arrows roughly demonstrates the magnitude of water flow. For example, the tinniest arrow among these arrows illustrates that a weak stream of TE water goes from Iraq to Iran. The tiny black, blue, and blue arrows show the links and interaction.

Figure 1 shows that climate change is expected to affect the TE and Non-TE water resources to various extents across the Middle East. This includes but is not limited to reductions in water availability from the surface and below-ground resources. On the other hand, as shown in Figure 1, climate change could affect all agricultural and non-agricultural activities. For example, the demand for water for irrigation is expected to increase as more water is needed to maintain irrigated crop yields in the future warmer and drier conditions. Also, more water could be demanded to expand irrigated areas as the productivity of rainfed crops declines due to less precipitation and higher temperature. Even, due to climate change, the industrial and service activities could demand more water to continue to operate. As shown in Figure 1, climate-induced changes in economic activities could affect markets for labor, land, and capital or the productivity of these resources. For example, a damaged agricultural sector due to climate change could demand less labor, and that causes unemployment. That could occur in other activities as well.

The climate induced change in economic activities is expected to affect the trade flows of goods and services (food and non-food items) among the TE riparian countries, between TE and non-TE countries in the Middle East, and eventually between the Middle East and the rest of the world. The changes in international trade could partially mitigate a portion of the climate change impacts (Liu et al. 2013). Mitigation policies, collaborations among the TE riparian countries to better manage water uses, and improvements in water use efficiency could help to control or reduce the adverse consequences of climate change on the economies of these countries and the whole Middle East.

The main goal of this paper is to assess these economic effects and evaluate the extent to which potential collaboration among the riparian countries of the TE river basin could help to reduce the negative impacts of climate change. However, since water scarcity is expected to surge in other river basins of Iran, Iraq, Syrian, Turkey, and the rest of the Middle East, and given that climate change affects crop yields and other economic activities, this paper develops a more comprehensive analysis for the entire Middle East. This paper has several objectives. First, it evaluates the impacts of climate change on water scarcity in the TE and other river basins within the Middle East region under alternative climate futures. It translates ensuing changes in water supply into economic outcomes. Then, it evaluates the economic outcomes of transboundary water allocation scenarios and considers cooperation plans that can be implemented to reduce controversies over water allocation in the TE river basin. In addition to the contribution to resource policy literature, this paper offers a unique coupling of a complex economic model with a hydrological model. The combined economic and hydrologic model in the current study improves the literature since most of the studies, like Dezfuli et al. (2022), focused only on a hydrology and climate change model. Moreover, this paper extends the earlier analysis in Taheripour et al. (2020) by estimating changes in water availability with a hydrological model and by analyzing new scenarios of water allocation and agreements among countries in the region.

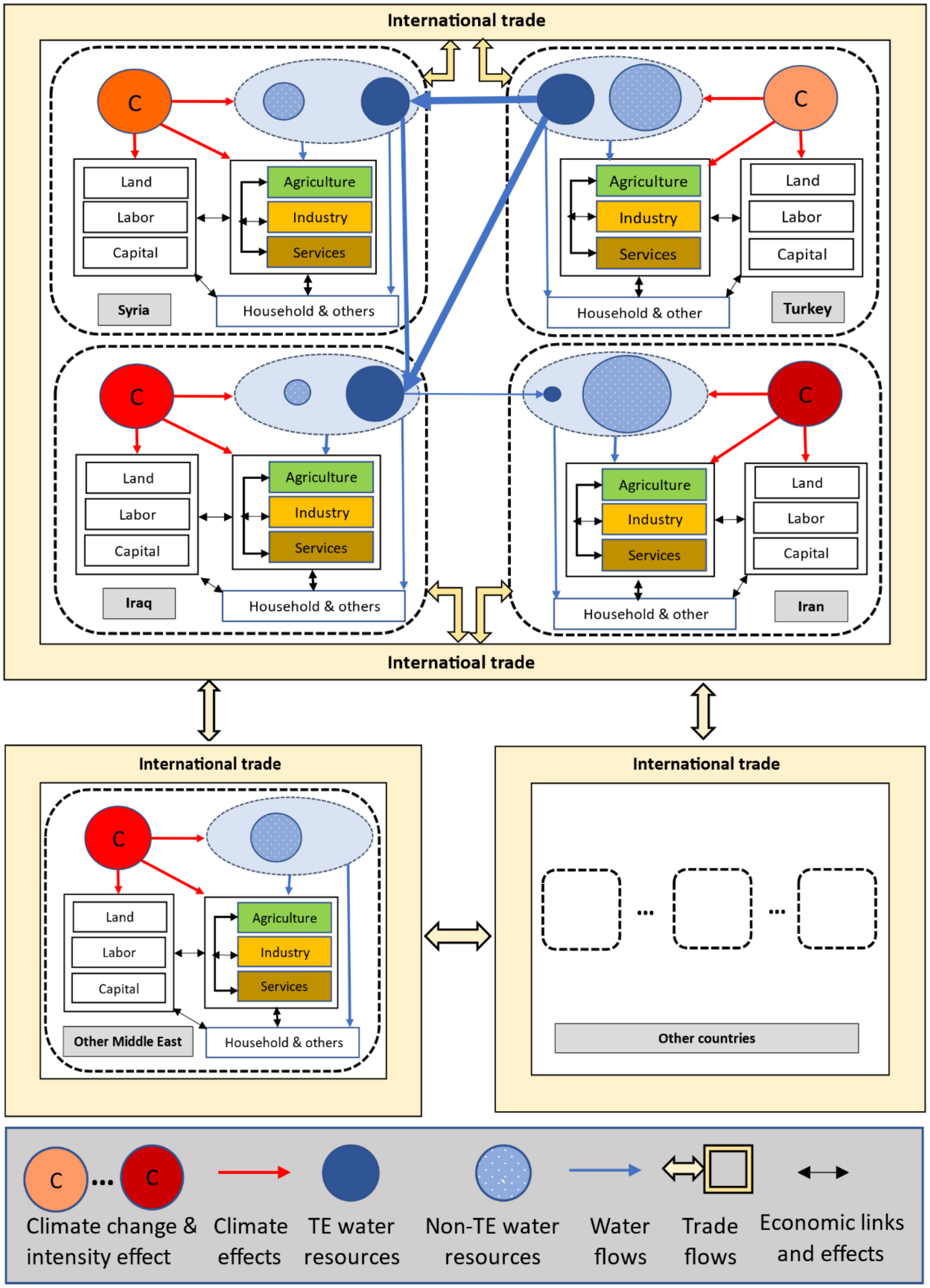

Figure 1. Water and economic flows inside and between TE countries, other middle east, and the rest of the world

2. Materials and Methods

To accomplish the goals of this paper, a unique hybrid modeling approach has been developed and implemented (Figure 2). The modeling approach consists of: 1) future projections for climate variables under alternative climate scenarios and socio-economic pathways; 2) taking into account future changes in crop yields; 3) a hydrological model (Haqiqi 2019) to project future changes in surface water, sustainable underground water, and unsustainable underground water withdrawals at each river basin in the Middle East; and 4) a Computable General Equilibrium (CGE) GTAP-BIO-W model (Taheripour et al. 2020) to quantify the economic consequences of the future changes in climate conditions. The assessments of economic damages have been examined under baselines and climate scenarios in combination with policy choices (policy scenarios).

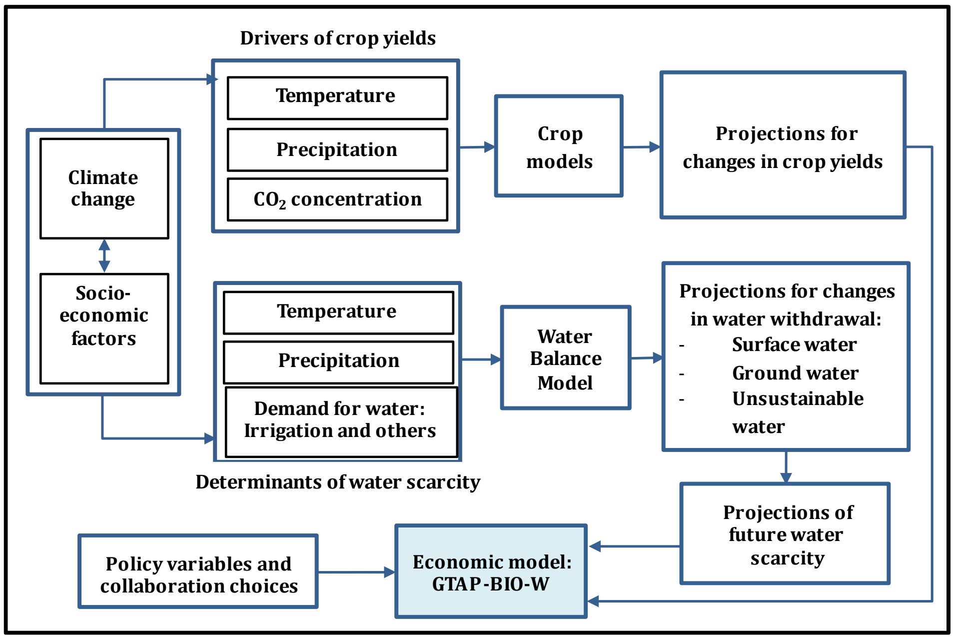

Figure 2. Modeling approach

Using this modeling approach, we quantify the impacts of climate change on crop yields and water scarcity across the Middle East and evaluate their economy-wide impacts. Then, we analyze collaborative and noncollaborative scenarios of transboundary water management in the TE river basin. In particular, we analyze the economic impacts of Turkey's water management plans on the riparian countries of the TE river basin, as this country can control the headwater of these basins.

2.1. Projections of Climate Variables

As we will explain in the next section, we use a hydrological model to quantify the impacts of future changes in climate variables on water scarcity in the Middle East under alternative climate scenarios. Projections of future changes in temperature and precipitation are needed to accomplish this task. We followed two alternative approaches to obtain the required data. We refer to these approaches as ***Ensemble Average*** and ***Selected Model***.

The Ensemble approach relies on the climate dataset prepared by (Boyko, O., Reggiani, P., Todini, E. 2022) using the methodology documented in (Reggiani et al. 2021). This data set is constructed using the output of 19 (Coupled Model Inter-comparison Project Phase 5) CMIP5 models for RCP4.5 and RCP8.5 climate scenarios. These series are mutually weighted and bias-corrected using ERA5 reanalysis data (Hersbach et al. 2020). This method yields unbiased and sharper predictive distributions for climatological variables in comparison to using the unprocessed ensemble distribution (Reggiani et al. 2021).

The Selected Model approach relies on the dataset provided by the National Aeronautics Space Administration (NASA) of the United States. This data set provides gridded future projections on daily temperature and precipitation for the whole world, NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) (Thrasher, B. et al. 2021; 2022). This data set includes downscaled climate scenarios for the globe that are derived from various General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 6. The dataset compiles climate projections from various CMIP6 GCMs for the period from 2015 to 2100. Following a validation process, we learned that the projections made by a model in the MIROC family (MIROC-ESM-CHEM) have the least deviation from actual observations for the Middle East region over the 1980-2005 period. Hence, based on the implemented validation test, we used the future daily temperature and precipitation projections made by this model for the examined RCP4.5 and RCP8.5 climate scenarios.

Taheripour et al. (2020) studied the extent to which climate change could affect the productivity of irrigated and non-irrigated crops across the Middle East by river basin and AEZ under RCP4.5 and RCP8.5 climate scenarios. In this paper, we use the findings of Taheripour et al. (2020) to represent the effects of climate change on crop yields.

2.2.Hydrological Model

The hydrological model used in this paper is an extended version of the Water Balance Model (WBM) that was originally developed at the University of New Hampshire, Durham (Vörösmarty et al.; 1998, Grogan 2016; Grogan et al., 2022). This model simulates both the vertical exchange of water between the ground and the atmosphere and the horizontal transport of water through runoff and stream networks at the grid cell level. The model separates surface water and groundwater and traces water withdrawals in three categories: Surface Water (SW), Shallow Groundwater (GW), and Unsustainable Groundwater (UGW). With less precipitation, less SW and GW will be available, which will be compensated for by larger withdrawals from UGW. Total Water Withdrawal (WW) is the sum of the three types of water withdrawals. Changes in these variables along with changes in other hydrological variables, such as the natural water runoff of the river basins of the region due to climate change, are quantified using a version of the WBM (Haqiqi 2019) modified for the TE river basin. The changes in the two categories of SW and GW do not represent water scarcity, as with less availability of water from these resources, more water will be extracted from UGW resources. Hence, we define and calculate an index for changes in water scarcity using the following formula:

$$S = -\left(\frac{UGW_2 - UGW_1}{WW_1}\right) \times 100 \qquad (1)$$

In this formula, the subscripts of "1" and "2" represent 2016 and 2050, respectively. We use the hydrological model projections to calculate the magnitude of water scarcity for the TE river basin and each country. To accomplish this task, first, we determined annual projections for WW and UWG using the hydrological model from 2016 (base year) to 2055 (the last year of the simulation) for a given combination of climate scenarios and data sources. Then, we determined linear trends for WW and USW using simple regression. Using the estimated trend lines, we determined quantities of WW and UGW for 2016 and 2050. Finally, we calculated percent changes in water scarcity using equation 1 and the estimated quantities determined in the previous step.

Figure 3 presents the overall structure of the hydrological model in assessing the implications of climate changes for agronomic and hydrological water supply. As shown in Figure 3, there are interlinkages between water resources and agriculture through irrigation.

The irrigation withdrawal decision is based on an agronomic module assuming a general functional form for evapotranspiration on a given irrigated area. The agronomic demand module is based on the evaporative gap between potential and actual evapotranspiration (PET and AET), taking into account daily changes in soil moisture without irrigation. The values of these variables depend on temperature and precipitation. Then, the irrigation runoff goes back to the water system depending on irrigation efficiency parameters splitting the non-beneficial irrigation into groundwater recharge and surface water runoff.

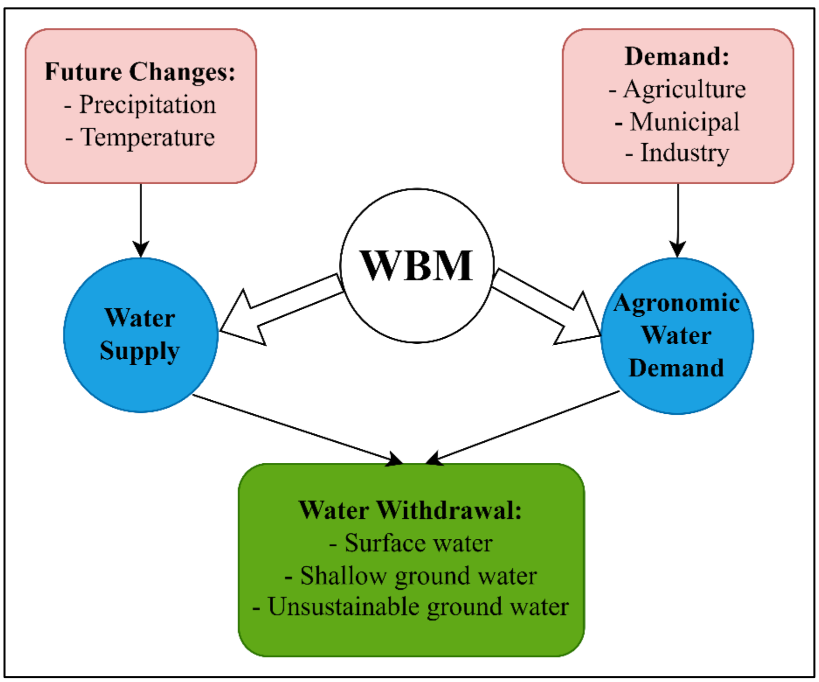

Figure 3. Overall structure of the hydrological model

To quantify the impacts of climate change on hydrological water supply and agronomic water requirements, the Modified WBM for the TE river basin is used to project future crop water requirements and their implications for water resources at five arc-min grid cells and then aggregate them to the scale of river-basin by country.

The hydrological model's projections are used to evaluate future water scarcity. This model takes care of water stress on crops and determines additional water needed to maintain the irrigated area with no reduction in yield due to water stress. In determining the need for additional water, the hydrological model takes into account water use efficiency and assumes it remains fixed over the time horizon of the analysis. The additional water withdrawal will not necessarily be all used by crops. Water use efficiency is usually low in the Middle East. Therefore, a portion of the additional water withdrawal will be lost through the irrigation system. It is also important to note that with less precipitation (less rainfall), more water is needed for irrigation on the same area of irrigated land.

2.3. Economic Model

The GTAP-BIO-W model is used to quantify the economy-wide impacts of future changes in climate variables on Middle Eastern economies. This model has been used in various publications (Taheripour et al., 2013; Liu et al., 2013, and Taheripour et al., 2020). The latest improved version of this model has been used and introduced by Taheripour et al. (2020).

The GTAP-BIO-W model is a static Computable General Equilibrium (CGE) model which combines economic and biophysical information on land and water. It is designed to examine the nexus between agricultural activities, industrial and energy sectors, and trade in the presence of climate change and water scarcity by country at a global scale. The GTAP-BIO-W model carries several unique characteristics. It is the only global CGE model that explicitly traces water consumption by sector and country at the river basin level by Agro-Ecological Zones (AEZs). It incorporates water into the production functions of agricultural and non-agricultural activities. Unlike all other existing global CGE models, this model distinguishes between rainfed and irrigated crops to better capture the links between demands for irrigation and food supply. A set of nested Constant Elasticity of Substitution (CES) production functions is used in this model. A nested Constant Elasticity of Transformation (CET) functional form is also used to model the supply side of water resources. The CET function allocates water between agricultural and non-agricultural uses at a river basin level. In each river basin, water goes to livestock and irrigated crops by agro-ecological Zones (AEZs). This approach allows the model to take into account the real-world rigidities in water allocation across users.

2.4. Scenarios

2.4.1. Baseline scenarios

To quantify the economic consequences of water scarcity and changes in crop yields induced by climate change, we examined 8 different baseline scenarios. These scenarios represent all combinations of two climate scenarios (RCP4.5 and RCP8.5), two approaches of projecting climate variables (Ensemble Average and Selected Model), and two scenarios on the extent to which water scarcity may affect the productivity of capital in each country under each climate scenario[1]. For more details about the baseline scenarios, please refer to the section S3 in the Supplementary Materials (SM).

[1] Given the uncertainty on this line of water scarcity effect, two relatively small elasticity values of 0.1 and 0.15 are representing the two scenarios examined in this context. Check section S1 in SM for more details.

2.4.2. Alternative policy scenarios

The alternative policy scenarios capture the effects of the designed policies on the baseline results. The examined policies are only applied to the riparian countries of the TE river basin to focus on water transboundary issues.

The first set of policy simulations represent the implications of changes in water use efficiency (WUE). As mentioned before, the rate of WUE in irrigation is usually low among the riparian countries of the TE river basin. The first set of policy scenarios studies the extent to which collaboration among these countries improves WUE (by 10% and 20%). This could open a pathway to control the adverse impacts of water scarcity. To have a more complete picture, this set of scenarios considers a reduction in water use efficiency by -10% as well. Hence, 3 rates of changes in WUE (-10%, 10%, and %20) in combination with the 8 baseline scenarios leads to 24 scenarios.

The next set of policy scenarios represents collaboration and examines the extent to which free trade agreements among the riparian countries of the TE river basin could help them to use their agricultural and non-agricultural resources more effectively. Two trade policies have been examined: 1) import tariff removal on agricultural and food products, and 2) import tariff removal on all goods and services. These two trade policies in combination with 8 baseline scenarios results in to 16 different scenarios.

Turkey has access to the headwater of TE river basin and hence its water management plans could elevate the intensity of water scarcity in Iraq, Syria, and Iran. Given this situation, a *simple stylized water management plan has been defined to assess the extent to which* Turkey's water policy for the TE river basin could alter water scarcity in the downstream countries of these basins. The stylized plan considers 20% reduction in water flow from upstream to downstream in the TE river basin. The hydrological model has been used to study the effects of this policy on the index of water scarcity in Iraq, Syria, and Iran under the examined climate scenarios in combination with the alternative data sources and the two assumptions about the productivity of capital stock. Hence, this set of scenarios included 8 simulations.

In addition to the above cases, a "no collaboration" scenario has also been defined. This scenario assumes: 1) no collaboration on transboundary water in the TE river basin, 2) no import tariff removal; 3) a reduction in WUE by 10%, 4) assuming a larger reduction in the productivity of capital due to water scarcity, and 5) 20% reduction in water flow from upstream to downstream in the TE river basin. We examined this case with the ensembled approach under RCP4.5 and with the selected model under SSP5-RCP8,5.

The conventional GTAP-BIO-W model is used to study the country-by-country economic impacts of all of the experiments defined above. On the other hand, to develop a full collaboration experiment in the TE river basin, we constructed a new version of this model that aggregates the economies of Iran, Iraq, Syria, and Turkey into one aggregated region. This aggregation allows the pooling of resources of the riparian countries of the TE river basin, removes all the existing barriers among these countries in resource allocation, and merges their markets for all goods and services. This set-up provides an environment for full collaboration in resource allocation, including water, in the ET riparian countries. Using this version of the model, an optimistic experiment has been developed. This optimistic case assumes a 10% increase in WUE due to collaboration. We examined this case with the ensembled approach under RCP4.5 and with the selected model under SSP5-RCP85. For more details about the alternative scenarios, please refer to the SM.

3. Results

The SM represents the full results of all the examined baseline and policy scenarios. Here, the results of ensemble and selected models under RCP8.5 scenario with $\propto = 0.1$ (the elasticity of water scarcity and productivity of capital=0.1) are presented and discussed.

3.1.Water scarcity

A comprehensive display of the results, categorized by country and river basin, is provided in the SM. Table 1 presents the water scarcity results between 2016-2050 for the TE river basin by country only under RCP8.5. It gives the results for both ensembled and selected models of the baseline scenarios. In terms of comparable climate scenarios, the ensembled approach exhibits a lower intensity of water scarcity compared to the selected model. Moreover, the intensity of water scarcity is lower under the RCP 4.5 scenario compared to the RCP 8.5 scenario, regardless of the approach employed. These findings indicate that regardless of the implemented approach or climate scenario, climate change is expected to significantly exacerbate water scarcity across the Middle East.

Table 1. Index of water scarcity by country under RCP8.5 and the baseline scenarios*

Country	Ensembled	Selected
Iran	-7.7	-29.6
Iraq	-10.6	-17.1
Syria	-10.3	-14.3
Turkey	-9.4	-26.9

* Figures represent % changes in the index of water scarcity between 2016-2050

3.2.Impacts on GDP

Once the extent of water scarcity in the TE river basin caused by climate change is understood, it becomes crucial to explore the consequences of this phenomenon. In this section, we analyze the implications of water scarcity and changes in crop yields on the GDP of countries using ensemble and selected models. The results for all models can be found in section S5 in SM.

Table 2 provides insights into the changes in real GDP at constant prices for baseline scenarios for both ensemble and selected models under RCP8.5 and capital productivity of 0.1. Due to water scarcity, GDP is expected to decrease across all Middle Eastern countries. The overall GDP of the Middle East is expected to decline 1.02% to 2.50%, representing a range of economic loss between \$33.6 billion and \$82.5 billion. However, the extent of reduction varies depending on the country and scenario. Iran and Turkey are projected to experience more substantial impacts with potential reductions up to 4.82% and 5% for Iran and Turkey, respectively. It will be a monetary loss of \$20.2 billion and 43.2 billion, consecutively. The augmented GDP change predicted in Iran and Turkey can be primarily attributed to their significant role as prominent agricultural producers across the region. On the other hand, Jordan, Lebanon, Saudi Arabia, and the rest of the Middle East (RME) countries, which are smaller agricultural producers, are likely to face comparatively milder declines. Iraq and Syria are expected to undergo moderate reductions, with real GDP declines of up to 2.89%.

In general, the reductions in real GDP become more pronounced as we transition from the ensemble approach to the selected model (see Table 2). Similarly, the magnitude of real GDP reductions increases when moving from the RCP 4.5 scenario to the RCP 8.5 scenario, or from SSP2-RCP4.5 to SSP5-RCP8.5. These findings indicate that negative impacts intensify under more severe climate scenarios. Furthermore, all else being equal, the rate of reduction in real GDP rises alongside the rate of reduction in capital productivity resulting from water scarcity.

Table 2. Changes in the real GDP by country under the baseline scenarios

Country/Scenario	**Ensemble**		**Selected**	
	%	**billion USD**	**%**	**billion USD**
Iran	-1.57	-6.6	-4.82	-20.2
Iraq	-1.39	-2.4	-2.43	-4.1
Jordan	-0.64	-0.2	-0.92	-0.4
Lebanon	-0.76	-0.4	-0.88	-0.5
Saudi Arabia	-0.54	-3.5	-0.62	-4.0
Syria	-2.02	-0.6	-2.89	-0.8
Turkey	-1.52	-13.2	-5.00	-43.2
RME	-0.63	-6.7	-0.86	-9.3
Total	-1.02	-33.6	-2.50	-82.5

The results of all other scenarios of changes in WUE (at -10% +10, and +20% in the TE river basin), tariff removal (for food products only and for all goods and service) and a 20% reduction in water flow from upstream to downstream of the TE river basin on the regional GDP are presented in the SM.

Accordingly, it can be inferred that a 10% decrease in WUE within the TE river basin would exert substantial impacts on the economies of Iraq, Syria, and Turkey, would cascade into wider economic repercussions, leading to a decrease in GDP levels across the aforementioned countries. Enhancements in WUE have the potential to significantly improve the economies of Iraq, Syria, and Turkey. Specifically, a 20% improvement in WUE within the TE river basin would mitigate the previously mentioned GDP reductions. Notably, Iraq and Syria, which heavily depend on water from the TE river basin, would experience substantial savings in terms of GDP losses due to these improved efficiency measures. However, changes in WUE in the TE river basin, will not significantly affect the economy of Iran, as this country has a small share in this basin. Any collaboration to enhance WUE in the TE river basin will help economies of Iraq, Syria, and Turkey to mitigate the negative impacts of the future water scarcity that could be induced due to climate change. While Iran could also get some benefits, for this country the benefits could be minor (for more details check section S5 in SM).

The tariff removal policies, for the case of food products only or the case of all goods and service, could help to mitigate a small portion of the negative impacts of intensified water scarcity and changes in crop yields. However, the gains are small under both ensemble average and the selected model. That is because trade is limited among the Middle East economies. Future expansions in trade could occur due to tariff removal. However, our simulations are not designed to capture these future potential gains.

A 20% reduction in water flow from upstream to downstream of the TE river basin could significantly damage the economies of countries in TE river basin, as these countries heavily rely on water from this basin. The total damage of such policy is estimated to have between 0.59% and 3.26% or $19.5 billion and $107.7 billion. Finally, it is important to note that while the implemented policies directly affect the riparian countries of the TE river basin, other countries are expected to experience indirect effects as well.

3.3.Impacts on sectoral outputs

Table 3 provides the results for changes in the sectoral outputs due to climate change. In almost all cases, it is anticipated that the crop, forestry, and food sectors will witness more significant declines compared to the energy, industry, and service sectors under both selected and ensemble models. Moreover, Iran, Turkey, Iraq, and Syria are projected to experience larger reductions in the crop, forestry, and food sectors when compared to Jordan, Lebanon, Saudi Arabia, and other countries in the RME (Rest of Middle East) region, considering both models. Furthermore, the selected approach, as indicated in Table 3, indicates higher reductions in sectoral outputs when compared to the results obtained from the ensemble model. These observations hold true for other scenarios provided section S6 in in SM as well.

Table 3. Changes (%) in sectoral outputs under baseline ensemble scenarios

Scenario	Country	Crop	Forestry	Food	Energy	Industry	Service
Ensemble	Iran	-3.5	-2.9	-2.1	-0.5	-1.7	-1.8
	Iraq	-11.0	-2.5	-2.9	-0.7	-2.2	-1.8
	Jordan	-1.2	-1.8	-0.3	-0.6	-0.7	-0.7
	Lebanon	-3.7	-1.0	-0.7	-0.7	-0.9	-0.7
	Saudi Arabia	-4.5	-0.8	-1.0	-0.5	-1.2	-0.8
	Syria	-6.3	-2.1	-3.2	0.3	-0.1	-1.6
	Turkey	-7.5	-2.6	-1.9	-1.3	-1.1	-1.4
	RME	-2.4	-0.3	-0.8	-0.2	-0.7	-0.9
Selected	Iran	-8.1	-7.2	-5.4	-0.7	-5.3	-5.8
	Iraq	-16.2	-4.4	-5.0	-1.3	-3.9	-3.2
	Jordan	-0.9	-3.2	-0.3	-0.8	-1.2	-0.9
	Lebanon	-3.6	-1.3	-0.7	-0.9	-1.3	-0.8
	Saudi Arabia	-4.4	-0.9	-1.3	-0.5	-1.5	-1.0
	Syria	-8.6	-3.2	-4.9	0.4	-0.6	-2.3
	Turkey	-20.0	-7.4	-6.0	-4.3	-3.9	-4.8
	RME	-2.4	-0.4	-1.2	-0.2	-1.0	-1.2

As noted above, the policy scenarios that we examined in this section are mainly defined to target the riparian countries of the TE river basin. Therefore, they have limited implications for the rest of the Middle East, as we described for the GDP. It is also important to recognize we find that the tariff removal policies among the riparian countries of the TE river basin have limited economic effects. Hence, we only explain the impacts of changes in WUE (for 10% reduction and 20% improvement) and a 20% reduction in water flow from upstream to downstream of the TE river basin on the sectoral outputs of Iran, Iraq, Syria, and Turkey with the ensembled average and the selected model approaches (section S6 in SM). Accordingly, the ensemble results show lower impacts than the selected model results. Under both modeling approaches, a 10% reduction in WUE causes more reductions in the sectoral outputs compared to the baseline scenarios in Iran, Iraq, Syria and Turkey. However, the additional reductions are relatively large in Iraq, Syria and Turkey, as these three countries heavily rely on the TE river basin.

In Iraq, Syria, and Turkey, a 10% reduction in WUE causes large decreases in the outputs of crop, forestry and food sectors. For example, under the baseline scenario of B-EOC2-S2 the output of crop sector declines by 16.2%, 8.5%, and 19.9% in Iraq, Syria and Turkey, respectively (section S6 in SM). A 10% reduction in WUE also is expected to extent the reductions in the outputs of energy, industry, and service sectors as well. Hence, agricultural and non-agricultural sectors will both lose a portion of their outputs due to reductions in WUE.

While a decline in WUE by 10% magnifies the negative impacts of water scarcity due to climate change, a 20% improvement in WUE in the TE river basin, could partially mitigate these negative impacts on the sectoral outputs (section S6 in SM). In particular, Iraq and Syria could mitigate the adverse impacts of water scarcity and changes in crop yield on their sectoral outputs with a 20% improvement in WUE in the TE river basin. Finally, a 20% reduction in water flow from upstream to downstream of the TE river basin will mainly increase the negative effects of water scarcity and changes in crop yields on the crop sector of Iraq and Syria (section S6 in SM).

3.4.Impacts on demand for labor

It is anticipated that the water scarcity resulting from climate change could lead to the loss of a portion of the existing job opportunities. This section focuses on the potential impacts of increasing water scarcity resulting from climate change on job opportunities for both unskilled and skilled labor in both the agricultural and non-agricultural sectors. Figure 4 consists of Panels A and B, depicting the ensemble model results pertaining to unskilled and skilled labor, respectively. Similarly, Panels C and D, which present the selected model results regarding unskilled and skilled labor, consecutively.

Figure 4 vividly demonstrates that Iran, Turkey, Iraq, and Syria, recognized as major water consumers in TE river basin, are expected to undergo substantial reductions of up to 12% in their demand for both skilled and unskilled labor. This underscores the significant impact that water scarcity and associated factors can have on the labor market dynamics of these countries. In general, the reductions in labor demand are notably more pronounced when considering the results derived from the selected model. With the exception of Iran and Jordan, the changes in the agriculture sector tend to be higher compared to the non-agriculture sector.

In further detail, the agriculture sector in Iraq is projected to experience a significant loss of more than 6% in its unskilled labor under the ensemble model results (Figure 4 - Panel A). This is followed by Syria and Turkey. When examining skilled labor under the ensemble model, Syria is projected to suffer the most decline of 5.43% (Figure 4 - Panel B). Therefore, skilled labor will be more severely affected in Syria compared to other countries; however, it is unskilled labor in Iraq that is anticipated to face the most substantial loss. For the selected model, the highest impacts will be observed for unskilled labor in agriculture sector of Turkey with a loss of 14.65% and skilled labor in non-agriculture sector of Iran with a loss of 10% leads (Figure 4 – Panels C and D). In almost all cases, the least impacts are observed in Jordan and Lebanon (Figure 4). These highlight the differentiated impacts on labor categories within the agricultural and non-agriculture sectors across selected and ensemble models.

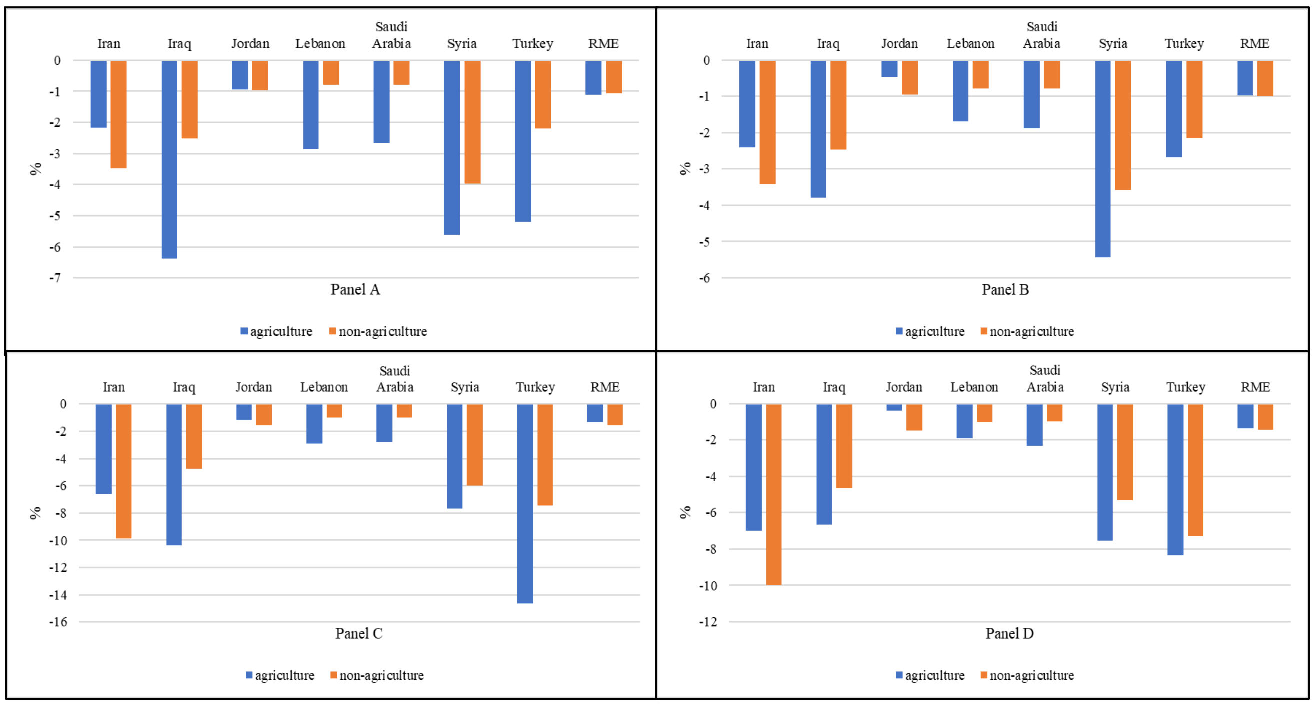

Figure 4. Changes (%) in demand for labor by country. Panel A: Ensemble results for unskilled labor. Panel B: Ensemble results for skilled labor. Panel C: Selected model

The results of the policy scenarios examined, including variations in WUE, the removal of tariffs, and a 20% reduction in water flow from upstream to downstream are provided in section S7 of SM. A reduction in WUE in the TE river basin by 10% is expected to intensify the reductions in demand for unskilled labor in agricultural activities in Iraq, Syria, and Turkey. On the other hand, improvements in WUE could eliminate a portion of the adverse effects of water scarcity on the demand for labor. These results suggest that collaborations in the TE river basin to improve WUE could save job opportunities for the unskilled labor in agricultural activities in Iraq and Syria and to some extent in Turkey. Note that changes in WUE in the TE river basin, will not significantly affect the labor market in Iran, as this country has a small share in this basin (Section S7 in SM).

Similar to the impacts on GDP, the tariff removal policies, could help to mitigate a small portion of the losses the demand for unskilled labor in agricultural activities (Section S7 in SM). As mentioned before, that is because trade is limited among the Middle East economies. Finally, the policy scenario examined so far may have no significant effects on the job market in the non-riparian countries of the TE river basin.

3.5.Impacts on crop prices

The intensification of water scarcity and changes in crop yields are expected to have notable impacts on both the consumer's and producer's crop price indices. Figure 5 specifically highlights the regional consequences of climate change on the consumer's and producer's price indices for crops. Accordingly, both indices are expected to increase significantly under both selected and ensemble models and across the region. Also, the increases are expected to be considerably larger in Iran, Iraq, Syria, and Turkey. Finally, the regional increases in the producer's price index are commonly larger than the consumer's price indices (Figure 5). That is due to the fact a portion of the demand for these products will be imported from outside the Middle East.

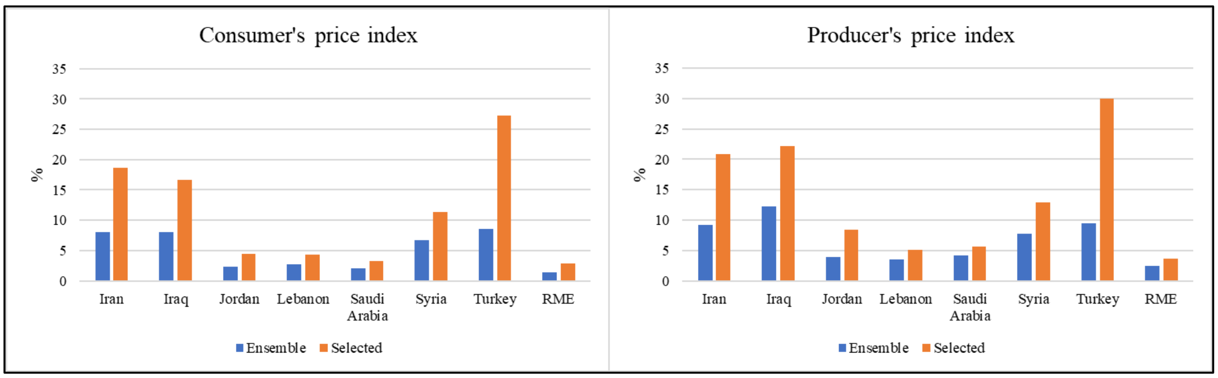

Figure 5. Changes (%) in consumer's and producer's crop price indices by country

From the results presented in section S8 of SM, we can assess the impacts of other scenarios. Evidently, a 10% reduction in WUE will magnify the projected price impacts of the baseline scenarios. On the other hand, the price impacts will be lower with the improvements in WUE. These effects are more visible in Iraq, Syria and Turkey. Moreover, the tariff removal policies will slightly alter the projected price impacts of the baseline scenarios. These minor effects can be more visible in the riparian countries of the TE river basin. Finally, a 20% reduction in water flow from upstream to downstream of the TE river basin will mainly increase the projected price impacts of the baseline scenarios in Iraq and Syria.

3.6.Impact on trade balance of food products

Reductions in agricultural products due to intensified water scarcity and changes in crop yields are expected to increase the net imports of food products. It is important to note that increases in the net imports of food products show that countries in the Middle East will import more food products in response to climate-driven water scarcity and reductions in crop yields. This means that trade buffers food security of the region. Table 4 provides information regarding the net imports of food products (including all crops, livestock, and processed food and feed) for ensemble and selected models under baseline scenario across the Middle East. Evidently, more changes are expected under the selected model. The whole region is expected to experience a rise of $3,799 million and $8,621 million in net import under ensemble and selected models, respectively. Turkey with $1,879 million under ensemble model and $5,451 million under selected model will experience the highest increase in net import. These highlight the importance of having a policy in place to define proper trade relationships in food production with other countries.

Unlike the general pattern, the net imports of food products decline in Jordan (Table 4). The country is expected to export high-value food products (e.g., fruits and vegetables) to its neighbors as the severity of water scarcity grows in the region and imports fewer valuable products from the world market.

Table 4. Changes in net imports ($million) of food by country

Country	Ensemble	Selected
Iran	649	1,306
Iraq	788	1,298
Jordan	-34	-87
Lebanon	34	28
Saudi Arabia	134	200
Syria	124	138
Turkey	1,879	5,451
RME	225	287
Total	3,799	8,621

The results of other scenarios are provided in section S9 in SM. In general, the changes in the net imports are not very sensitive across models (i.e., ensemble average versus selected model or the size of $\propto$). Accordingly, the increases in net imports of food products are expected to be considerably larger in Iran, Iraq, and Turkey. For the worst-case climate scenarios (from RCP4.5 to RCP8.5 with the ensemble approach and from SSP2-RCP4.5 to SSP5-RCP8.5 with the selected model), the Middle East needs more food to import from other countries.

3.7.Results of no collaboration versus full collaboration scenarios in the TE river basin

Here we summarize the outcomes of two possible cases of no collaboration and full collaboration in the TE river basin, under RCP4.5 with the ensemble average approach and SSP5-RCP8.5 with the selected model approach. Since the full collaboration case aggregates the riparian countries of the TE river basin in one aggregated region, we represent the results of both no collaboration and full collaboration with the flowing geographical arpeggiation scheme: TE Region, Jordan, Lebanon, Saudi, and RME. Note that under each scenario, for the non-TE countries, their corresponding baseline assumptions have been implemented. Similar to the baseline and policy scenarios examined above, the results of these comparative static policy simulations capture the difference between the base year (i.e., 2016) and the 2050, as the implemented climate shocks (in water scarcity or crop yields) represent the difference between these two years.

Table 5 shows the economic consequences of no collaboration versus full collaboration in the TE river basin for the whole Middle East in terms of change in the real GDP under the examined climate scenarios and the implemented modeling approaches. Table 5 shows that in the absence of collaboration among the riparian countries of the TE river basin, the economies of this basin will significantly suffer from the projected changes in water scarcity, changes in crop yields, and potential losses in WUE due to climate change, regardless of the modeling approach and the climate scenarios. The overall economic losses for the entire TE countries could vary between 2.2% (or $21.9 billion per year) to 6.8% (or -$101.1 billion) of the real GDP of these countries.

In contrast, with a full collaboration among the riparian countries of the TE river basin, the economies of this basin could mitigate all or a portion of the economic costs of changes in water scarcity, changes in crop yields, and potential losses in WUE due to climate change. Also, the overall economic losses for the entire TE countries could turn to an economic gain by 0.9% (or $13 billion per year) of the real GDP of the TE countries under the RCP4.5 with the ensemble approach. Finally, for the case of SSP5-RCP8.5 with the selected model the economic losses drop to 2.9% (or $42.7 billion) of the real GDP of the TE countries. Indeed, a full collaboration could reduce the economic costs of climate change.

As a result, the net economic gain of collaboration with the ensemble approach under RCP4.5 is about $42.8 billion ($4 billion with collaboration minus -$38.8 billion with no collaboration) and with the selected model approach under SSP5-RCP8.5 is about $56.8 billion ($-61.4 billion with collaboration minus -$120. billion with no collaboration). These significant benefits justify additional investments to facilitate collaboration in water use, water allocation, and conservation approached to save water.

Interestingly, the net economic gain from collaboration with the selected model under SSP5-RCP8.5 is larger than the gain with the ensemble approach under RCP4.5, $56.8 billion versus $34.8 billion. These results suggest that collaboration among the TE countries is more impactful under the more extreme climate scenarios. While under the more extreme climate scenario (e.g., RCP8.5) collaboration among the TE countries generates larger economic gains, these gains only partially mitigate the adverse impacts of climate change. This means that in addition to collaboration, countries in the basin should take more precautionary steps and define aggressive conservation policies to save their water resources obtained from the TE river basin and other river basins. This is particularly important for Iran and Turkey that use water from both TE and other basins.

Collaboration among the TE countries leads to some gains for other countries of the Middle East as well. Hence, collaboration among the TE countries has the potential to enhance the economies of TE and non-TE countries of the Middle East.

From the results presented in section S10 in SM, we can outline several important conclusions in comparing the results of the no collaboration and full collaboration scenarios, besides the impacts on GDP. According to the results, it is possible to save more jobs with collaboration, in particular for unskilled workers in agricultural sectors. Collaboration can lower price impacts for food products and more food security can be provided. It also helps that less food will be imported. Finally, the existing infrastructure can be used more effectively with less idled production capacities.

Table 5. Changes in real GDP under the examined collaboration scenarios

Description	Region	Panel A: Ensemble average results under RCP4.5		Panel B: Selected model results under SSP5-RCP8.5	
		No collaboration	Full collaboration	No collaboration	Full collaboration
Change in real GDP (%)	TE countries	-2.18	0.88	-6.85	-2.88
	Jordan	-0.62	-0.46	-1.23	-1.13
	Lebanon	-0.50	-0.39	-1.17	-1.13
	Saudi Arabia	-0.50	-0.48	-0.89	-0.90
	RME	-0.55	-0.51	-1.11	-1.11
	Total	-1.27	0.12	-3.64	-1.86
Change in real GDP ($ million)	TE countries	-29,132	13,034	-101,141	-42,700
	Jordan	-240	-178	-476	-436
	Lebanon	-257	-201	-603	-583
	Saudi Arabia	-3,271	-3,140	-5,801	-5,909
	RME	-5,923	-5,492	-11,992	-11,914
	Total	-38,823	4,022	-120,012	-61,541

4. Conclusions

The Middle East is one of the most water-scarce regions in the world. The gap between the demand for and supply of water has significantly increased over time across this region. This gap is expected to get wider in the future. This paper examines the extent to which climate change could limit the supply of water resources in the Middle East over time towards the midcentury. It also evaluates the extent to which collaboration in transboundary water management could eliminate the adverse impact of climate change on water shortage. In particular, this paper quantifies the potential economic gains due to collaboration in the TE river basin. The results of this paper suggest that collaboration in the TE river basin could eliminate all or a portion of the adverse impact of climate change on water supply, depending on the climate scenarios and the implemented modeling approaches. A unique hybrid modeling approach has been developed and implemented to achieve the goal of this paper.

Note that the CGE model used in this paper, similar to other existing CGE models, only assesses the marketable and traded economic benefits of economic activities (all goods and services produced, traded, invested, and consumed). Therefore, this model does not fully capture the economic, environmental, and social gains that collaboration could generate and are not traded or marketable. Further research is needed to assess those gains as well.

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