GTAP-EW7 – A model to assess the impacts of climate change on world water availability and usage throughout the agricultural sectors of the world economies

Hiroshi Hamasaki[1]
Truong Phuoc Truong[2]

Abstract

We use the latest version 7 GTAP model to develop an extension to look at world water usage in agricultural economic activities; the extended model is referred to as GTAP-EW7. With the likelihood of world climate change, water availability for agricultural economic activities is likely to be affected through the so-called 'precipitate rate' which affects rainfall. We use the WRI (World Resources Institute) Aqueduct Water Stress Projections, RCP8.5 and SSP3, to estimate the likely impacts of climate change on precipitate rate throughout the world, by each country-region, and also by each agricultural economic zone (AEZ). The GTAP-EW7 model is then used to predict the re-allocation of agricultural economic activities resulting from the changes in precipitate rate, and hence the economic impacts of this re-allocation. As one of the goals of sustainable economic development (Sustainable Development Goal 6.4) is to "*substantially increase water-use efficiency across all sectors and to ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity*" by the year 2030, it is expected that this will stimulate competition throughout the world economies to secure water for their economic activities. How this will affect the achievement of the SDG 6.4 and the overall welfare of the peoples around the world is a critical issue and we use the GTAP-EW7 to study this issue. In the research we take two climate change scenarios, RCP4.5 and RCP8.5. Model simulated results indicate that the impacts of water availability and usage on the agricultural sectors of the world economies can be significant depending on the different structures of the economies as well as on the different patterns and intensities of water usage throughout these economies.

[1] Senior Research Fellow, Economic Research Centre, Fujitsu Research Institute, Tokyo, Japan
[2] Honorary Professor, Institute of Transport and Logistics Studies, The University of Sydney, Sydney, Australia

Introduction

As one of the goals of sustainable economic development (Sustainable Development Goal 6.4) is to *"substantially increase water-use efficiency across all sectors and to ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity"* by the year 2030, it is expected that this will stimulate competition throughout the world economies to secure water for their economic activities.

Figure 1 SDGs

CGE Model with Water Sector

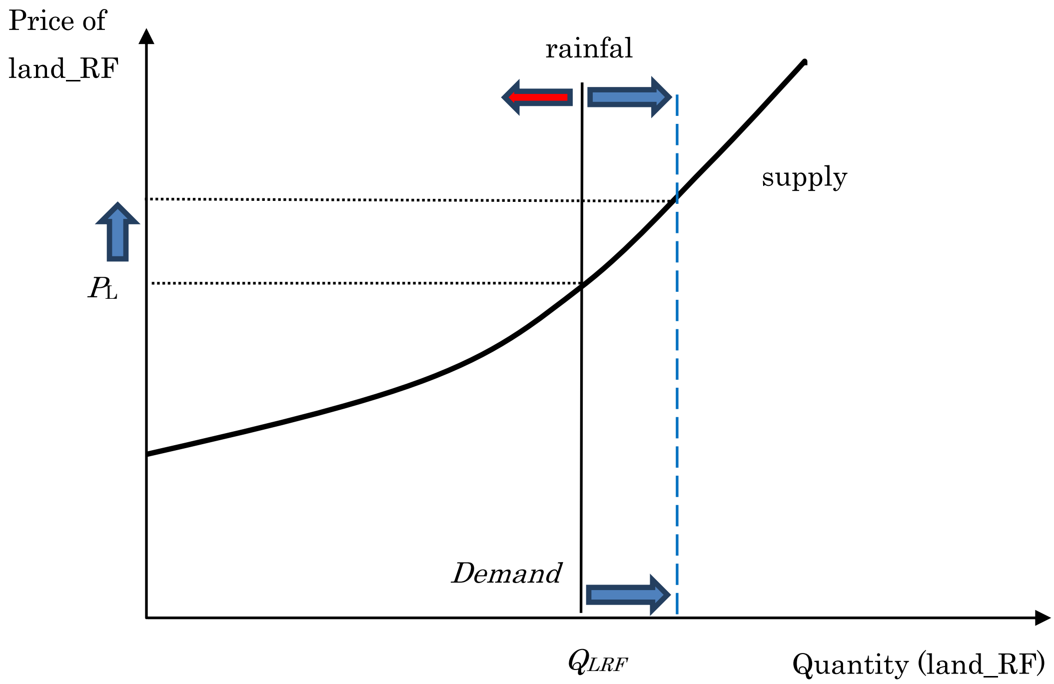

Figure 2 Impact of rainfall on the demand for rainfed land (land_RF)

As the demand for rainfed land increases (decreases) the supply curve for irrigated land shifts in the opposite direction.

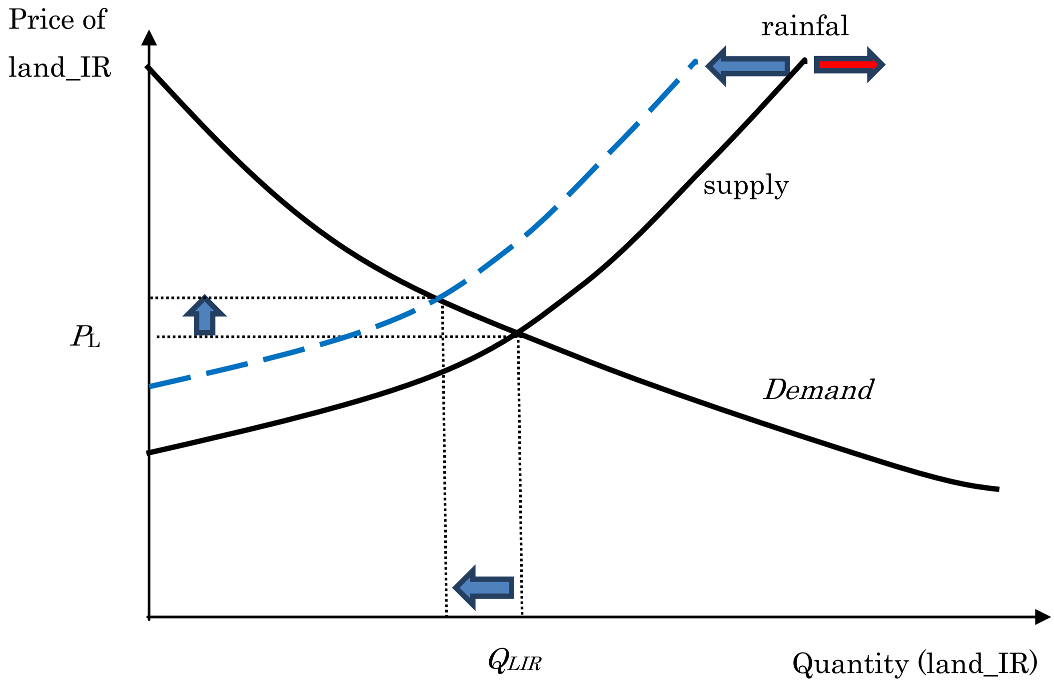

Figure 3 Impacts of changes in the demand for rainfed land on the supply of irrigated land.

The demand for irrigated water moves in the same direction as the demand for irrigated land (land_IR) (production effect) but also moves in the opposite direction to some extent due to the substitution effect between land and water (W) and other inputs to land (such as fertiliser and feedstock (F))

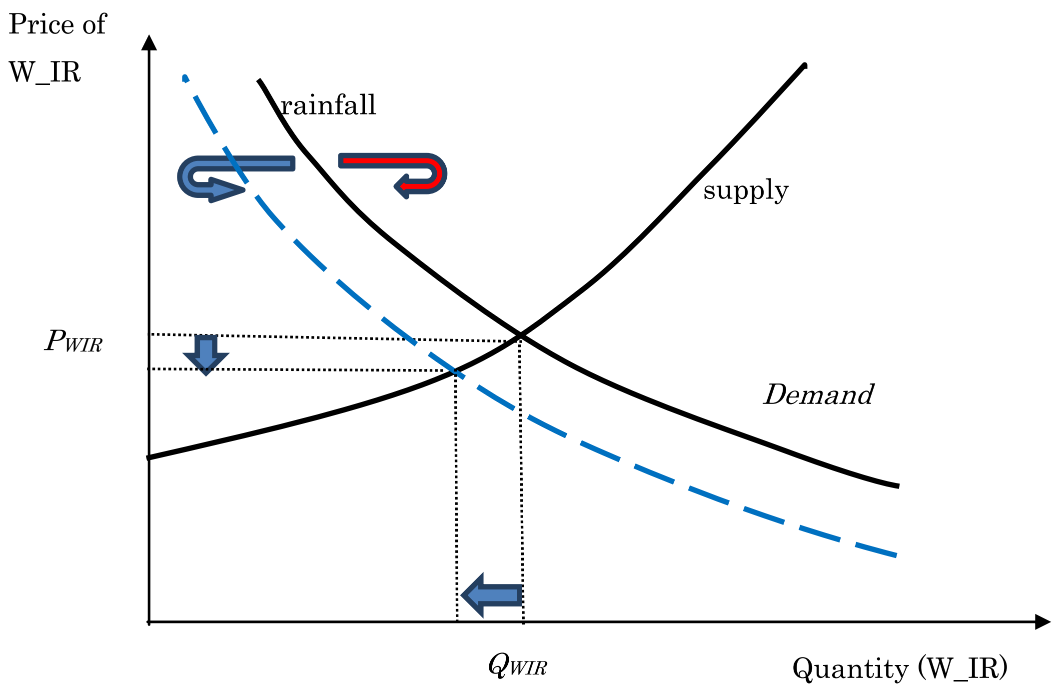

Figure 4 demand for irrigated water

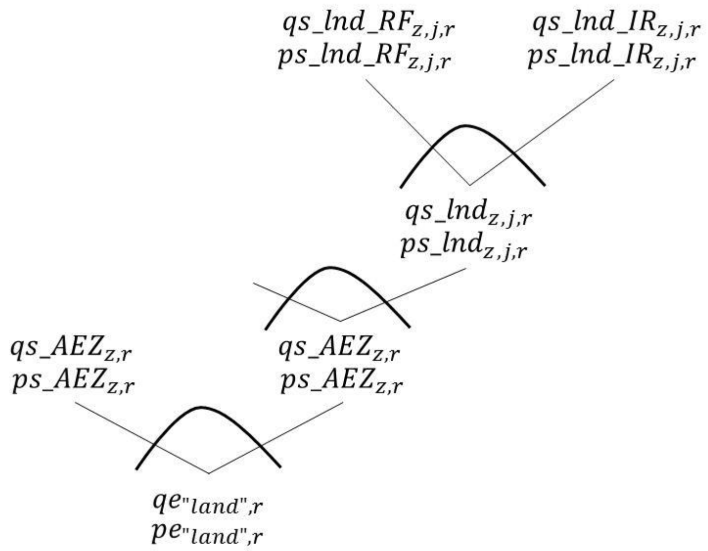

Figure 5 Supply of land to various AEZs with their transformation into different LANDUSES and finally into different land types

$qe_{\text{land},r}$: quantity change of endowment "Land" in region r

$pe_{\text{land},r}$: price change of endowment "Land" in region r

$qs\_AEZ_{z,r}$: quantity change of land in AEZ z and region r

$ps\_AEZ_{z,r}$: price change of land in AEZ z and region r

$qs\_lnd_{z,j,r}$: quantity change of land in AEZ z, Agricultural Product j and region r

$ps\_lnd_{z,j,r}$: price change of land in AEZ z, Agricultural Product j and region r

$qs\_lnd\_RF_{z,j,r}$: quantity change of Rain-fed land in AEZ z, Agricultural Product j and region r

$ps\_lnd\_RF_{z,j,r}$: quantity change of Rain-fed land in AEZ z, Agricultural Product j and region r

$qs\_lnd\_IR_{z,j,r}$: quantity change of Irrigated land in AEZ z, Agricultural Product j and region r

$ps\_lnd\_IR_{z,j,r}$: quantity change of Irrigated land in AEZ z, Agricultural Product j and region r

Precipitation rate determines water input into rainfed land (lnd_RF) which in turn determines the extent of its use (i.e demand).The demand for lnd_RF then impacts on the supply for lnd_IR (as a residual supply). The use of water (W) in lnd_IR is substitutable to some extent with the use of other intermediate inputs such as fertiliser and feedstock (F). The composite of water and these other intermediate inputs (WF) is then considered as Leontief with lnd_IR in its cost structure.

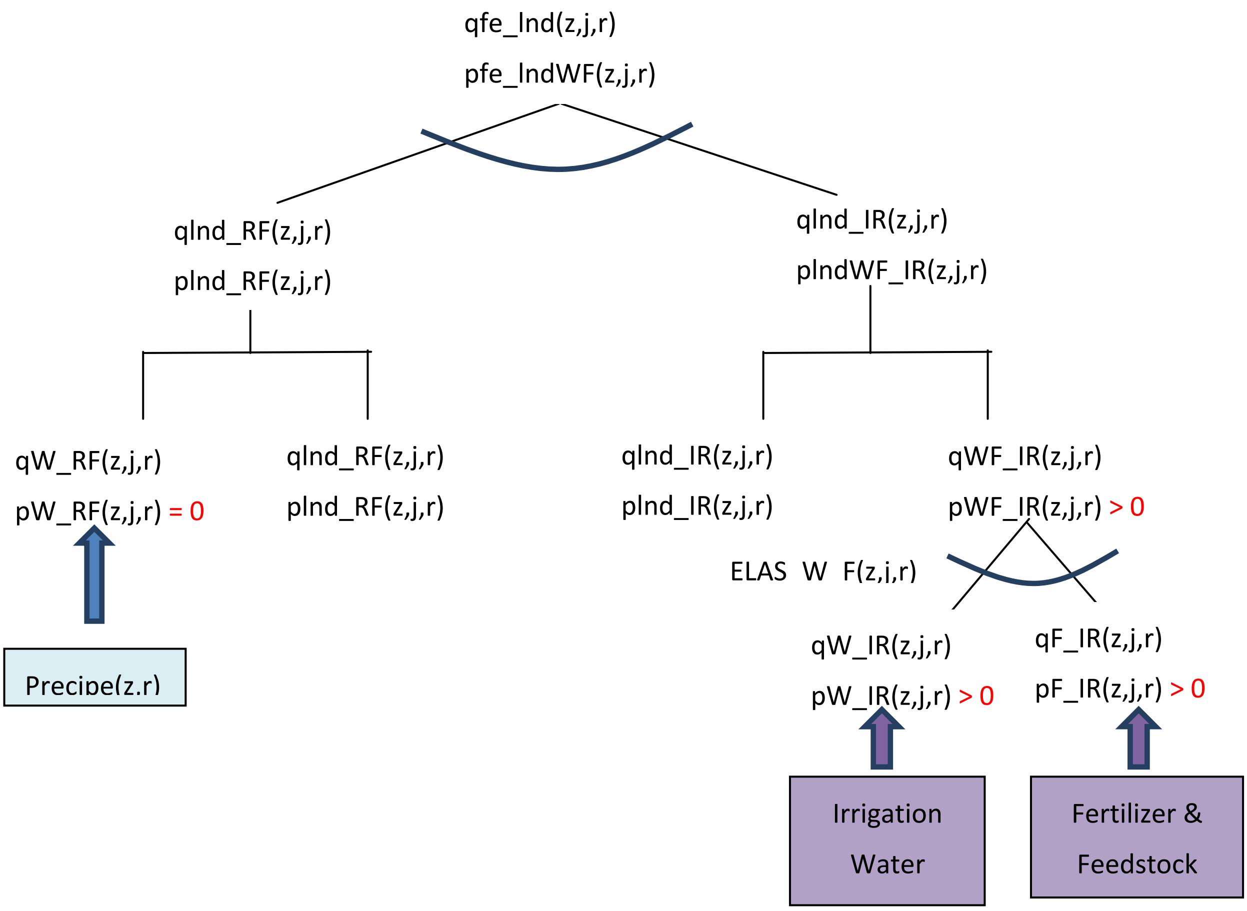

Figure 6 Cost structure in the demand for land and other intermediate inputs..

$qW\_IR_{z,j,r}$: quantity change of water for irrigated land in AEZ z, product j and region r

$pW\_IR_{z,j,r}$: price change of water for irrigated land in AEZ z, product j and region r

$qW\_IR_{z,j,r}$: quantity change of non-water intermideate inputs for irrigated land in AEZ z, product j and region r

$pW\_IR_{z,j,r}$: price change of non-water intermideate inputs for irrigated land in AEZ z, product j and region r

$qWF\_IR_{z,j,r}$: quantity change of intermideate inputs for irrigated land in AEZ z, product j and region r

$pWF\_IR_{z,j,r}$: price change of intermideate inputs for irrigated land in AEZ z, product j and region r

$qlnd\_IR_{z,j,r}$: quantity change of irrigated land used in AEZ z, produt j and region r

$plnd\_IR_{z,j,r}$: price change of irrigated land used in AEZ z, product j and region r

$qW\_RF_{z,j,r}$: quantity change of water inputs for rain-fed land in AEZ z, product j and region r

$pW\_IR_{z,j,r}$: price change of water inputs for rain-fed land in AEZ z, product j and region r

$qlnd\_RF_{z,j,r}$: quantity change of rain-fed land used in AEZ z, product j and region r

$plnd\_RF_{z,j,r}$: price change of rain-fed land used in AEZ z, product j and region r

$qfe\_lnd_{z,j,r}$: quantity change of land used in AEZ z, product j and region r

$pfe\_lnd_{z,j,r}$: price change of land used in AEZ z, product j and region r

Finally, it is the overall composite of land and W, F inputs which is then considered as a factor input into production activities (in place of the usual (pure) factor land input) in its combination with other capital, labour, material and natural resources inputs .

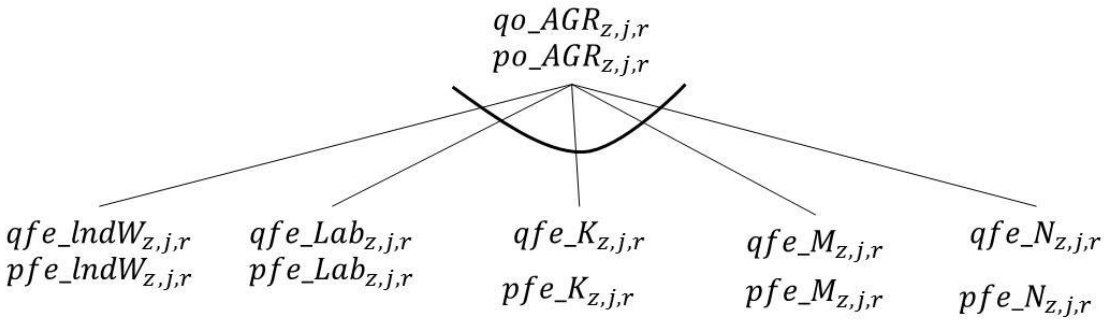

Figure 7 Composite of land and other factors, materials, and natural resources inputs

$qfe\_lndW_{z,j,r}$: quantity change of land and water composite input in AEZ z, product j and region r

$pfe\_lndW_{z,j,r}$: price change of land and water composite input in AEZ z, product j and region r

$qfe\_lab_{z,j,r}$: quantity change of labour input in AEZ z, product j and region r

$pfe\_labW_{z,j,r}$: price change of labour input in AEZ z, product j and region r

$qfe\_K_{z,j,r}$: quantity change of capital input in AEZ z, product j and region r

$pfe\_K_{z,j,r}$: price change of capital input in AEZ z, product j and region r

$qfe\_M_{z,j,r}$: quantity change of material input in AEZ z, product j and region r

$pfe\_M_{z,j,r}$: price change of material input in AEZ z, product j and region r

$qfe\_N_{z,j,r}$: quantity change of capita input in AEZ z, product j and region r

$pfe\_N_{z,j,r}$: price change of capital input in AEZ z, product j and region r

In the model, we have employed GTAP 9 Database and aggregated regions and sectors into 15 and 19 as show in following tables.

Table 1 the List of Countries/Regions

Region	Description
CHN	China
IND	India
JPN	Japan
KOR	Korea
RAO	Rest of Asia
USA	US
LSA	Latin America
ANZ	Australia and NZ
FRA	France
DEU	Germany
GBR	UK
REU	Rest of Europe
RUS	Russia
CEU	Central and Eastern Europe
RoW	Rest of the World

Table 2 the List of Sectors

Sector	Description
coa	Coal
oil	Oil
gas	Gas
p_c	Petroleum & Coal Product
ely	Electricity
pdr	Paddy Rice
wht	Wheat
gro	Cerials and Grains
v_f	Vegitable & Fruits
osd	Oil Seeds
c_b	Sugar cane, sugar beet
meat	Meat
OthAGR	Other Agricultural Products
Extractn	Extraction inc. Fishery and Forestry

lightIND	Light Industry
HeavyIND	Heavy Industry
Wtr	Water
CnsTTCom	Construction, Trade, Transport, Communication
OthServs	Other Services

To estimate water requirements by agricultural product and virtual water including export of virtual water through agricultural product exports, we have used average water intensity as shown in Table 3. The intensities are water intensity coefficients" (WIC), which express the amount of water consumed (or otherwise "used") per unit of output in different industries in various regions of the world (Roson and Damania, 2016).

Table 3 Average Water Intensity (m3/1,000US$)

pdr	31.7
wht	15
gro	3.89
v_f	7.05
osd	12.9
c_b	11.3

Source: Roson and Damania (2016)

Simulation Design and Discussions

To understand relationships between water, land and agriculture, we have employed GTAP version 9 Land Use and Land Cover Database for year 2011 (Baldos, 2017).

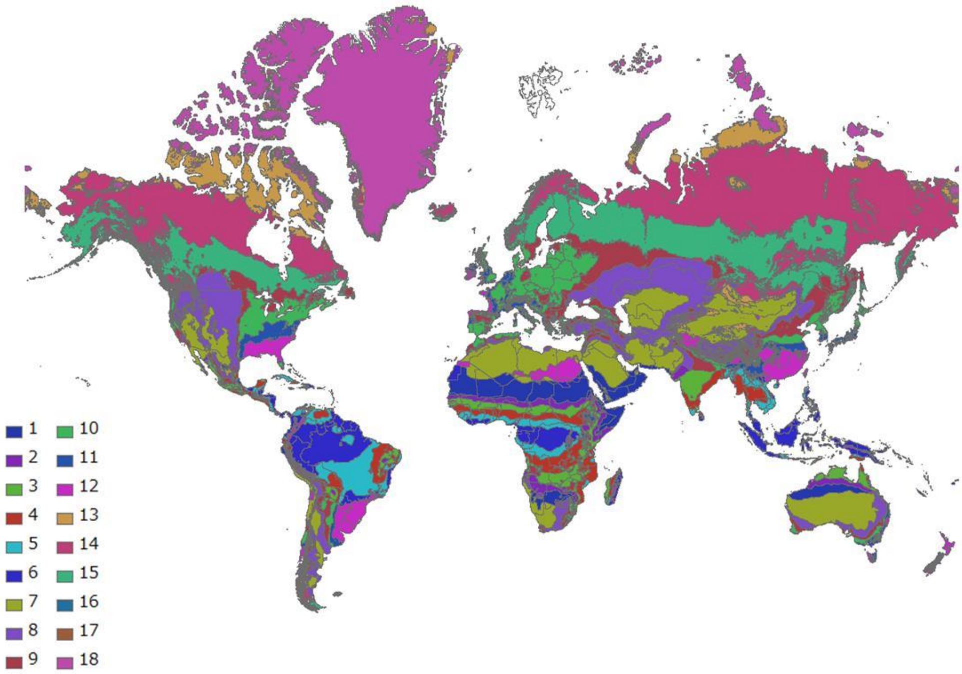

Figure 8 AEZs

We use renewable water supply forecasts from WRI database[3]. Representative concentration pathways (RCPs) are scenarios of the increase in radiative forcing through 2100. The scenarios are based on a combination projected water supply based on change in climate factors and water demand based on change in socioeconomic drivers (Luck et. al., 2015).

To identify the different impacts on the economy through water scarcity due to climate change, we have used two representative concentration pathways (RCPs), RCP8.5 and RCP4.5.

RCP8.5 is a "business-as-usual" scenario of relatively unconstrained emissions. The temperature increase 2.6-4.8 degree centigrade by 2100 relative to 1986-2005 levels. RCP4.5 represents a "cautiously optimistic" scenario. Temperature rise 1.1-2.6 degree centigrade by 2100 (Luck et. al., 2015).

We have used the data of the period centred on 2040.

---

[3] For the detailed description of the database, refer to Luck et. al.,2015).

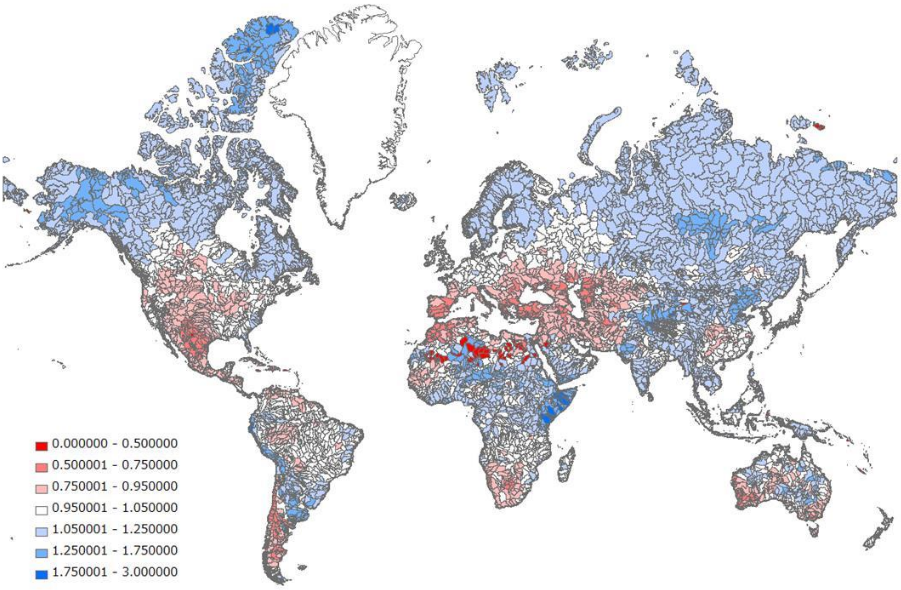

Figure 9 Renewable Water Supply Change (RCP 8.5)

Using ArcGIS, we have estimated the following matrix (see Table 4) which shows renewable water supply change to a combination of AEZ and country. This reflects possible changes to regional characteristics including agricultural product types and renewable water supply changes due to climate change.

Table 4 Renewable Water Supply Change (RCP8.5)

	CHN	IND	JPN	KOR	RAO	USA	LSA	ANZ	FRA	DEU	GBR	REU	RUS	CEU	RoW
AEZ1	0	32.1	0	0	7.44	0	9.24	2.76	0	0	0	0	0	0	15.4
AEZ2	0	13.8	0	0	0	0	−4.32	2.37	0	0	0	0	0	0	10.3
AEZ3	0	6.74	0	0	−1.23	0	−1.53	1.11	0	0	0	0	0	0	3.92
AEZ4	0	5.75	0	0	7.32	0	−2.99	1.75	0	0	0	0	0	0	6.64
AEZ5	4.84	12.2	0	0	6.32	3.23	−1.68	−5.43	0	0	0	0	0	0	6.95
AEZ6	0	0	0	0	−1.5	0	−2.17	0	0	0	0	0	0	0	8.09
AEZ7	20.4	38.3	0	0	−1.59	−15.1	−12.8	−1.17	0	0	0	0	0	−17.3	−13.8
AEZ8	25.1	2.29	0	0	−10.7	−10.9	2.32	−6.29	0	0	0	−10.7	−8.79	−1.73	−15.4
AEZ9	19.6	3.98	0	0	0	−0.01	−15.2	−11.9	0	0	0	−5.13	−0.92	−20.6	−9.74
AEZ10	7.17	6.08	0.09	−8.37	7.01	−4.22	5.17	−8.36	−6.82	1.9	3.14	−9.94	2.14	−14.7	0.72
AEZ11	−2.94	10.2	0.31	−4.7	6.12	0.82	−0.81	−7.16	0.24	0	3.53	−1.53	0	−10.7	8.99
AEZ12	23.9	28.9	−19.3	0	3.49	3.05	7.57	0.11	−4.47	0	0	−1.52	0.17	−7.15	−21.1
AEZ13	18.1	0	0	0	11.6	14.7	−16	0	0	0	0	5.32	13.1	−3.9	18
AEZ14	32.7	0	0	0	8.59	6.07	5.09	0	0	0	0	3.35	12.7	4.14	9.12

AEZ15	15.7	0	0	0	14.6	15.1	3.03	0	0	0	0	16.9	9.9	0	2.82
AEZ16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AEZ17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AEZ18	0	0	0	0	0	32.2	−4.91	0	0	0	0	0	9.44	18.5	22.5

RCP8.5 Scenario

In this section, we examine the simulation results of RCP8.5 scenario.

The impacts of agricultural products differ by country. In China, all agricultural production increases. For example, rice and wheat production increases by 1.26% and 1.63%, respectively. On the other hand, the US and ANZ decrease their production in all agricultural products.

Table 5 Percentage Change of Agricultural Products (RCP8.5)

	Rice	Wheat	Cereal	Veritable & Fruit
CHN	1.26	1.63	1.18	1.41
IND	1.32	−1.44	1.14	1.30
JPN	−0.32	−0.56	−0.18	−0.54
KOR	−1.25	−1.87	−0.98	−1.06
RAO	0.37	3.42	0.59	0.53
USA	−3.59	−1.72	−1.36	−1.28
LSA	0.01	−0.13	0.08	−0.57
ANZ	−1.57	−3.70	−2.05	−2.03
FRA	−9.03	−1.92	−0.64	−1.02
DEU	−5.81	−0.65	−0.34	−0.83
GBR	−11.71	−0.03	−0.06	−0.62
REU	−4.77	−0.32	−0.48	−0.79
RUS	−0.33	2.37	0.07	0.16
CEU	−2.92	−2.49	−1.98	−1.28
RoW	−1.15	−1.14	−0.97	−1.06

China capital demands for water irrigation decreases by 0.86%. The major factor of the lower capital demand is mainly due to more sustainable water supply in China. The US and ANZ capital demands for water irrigation are expected to increase, which means that these countries suffer from water scarcity due to climate change and increase irrigated water to offset agricultural product decrease in rain-fed land.

Table 6 Capital Demands for Irrigation water Supply (%)

CHN	−0.86
IND	6.37
JPN	0.56
KOR	0.17
RAO	0.70
USA	2.91
LSA	−0.67
ANZ	0.53
FRA	0.70
DEU	−0.14
GBR	−0.15
REU	1.00
RUS	0.60
CEU	4.18
RoW	4.98

Table 7 GDP Changes (%)

CHN	0.50
IND	−2.09
JPN	−0.26
KOR	−0.13
RAO	−0.26
USA	−0.77
LSA	0.27
ANZ	−0.26
FRA	−0.28
DEU	0.05
GBR	0.04
REU	−0.45

RUS	−0.19
CEU	−1.79
RoW	−2.23

Table 8 Real GDP Decomposition in the US

Consumption	−0.27
Investment	2.22
Government	−0.43
Export	−5.49
Import	1.49
GDP	−0.77

Table 9 Agricultural Product Export Changes in the US (%)

pdr	−4.60
wht	−1.77
gro	−1.10
v_f	−4.08
meat	−7.42

Comparison between RCP 4.5 and RCP 8.5

Table 10 shows renewable water supply under RCP4.5 and RCP 8.5 scenarios. The directions of renewable water supply changes are the same, but the magnitude of the change is bigger in RCP4.5 as compared to RCP8.5. This is as expected because RCP4.5 assumes average temperature rise of 1.1-2.6 degree centigrade by 2100 while that of RCP8.5 is about 2.6-4.8 degree. According to UNEP (2017), full implementation of the unconditional NDCs[4] and comparable action afterwards is consistent with a temperature increase of about 3.2°C by 2100 relative to pre-industrial levels. RCP4.5 is therefore an optimistic scenario under countries action toward the Paris Agreement target. Tables 11-12 show the expected changes in outputs for different agricultural products in different AEZs and also expected changes in real GDP for different regions/countries. These changes are all in the directions as expected and the magnitudes are also larger for RCP8.5 as compared to RCP4.5.

---

[4] Nationally determined Contributions (NDCs) is actions by countries ratifying the Paris Agreement

Table 10 Comparison of Renewable Water Supply between RCP4.5 and RCP8.5 in Major Countries/Regions

	CHN		USA	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5
AEZ1	0	0	0	0
AEZ2	0	0	0	0
AEZ3	0	0	0	0
AEZ4	0	0	0	0
AEZ5	2.48	4.84	1.28	3.23
AEZ6	0	0	0	0
AEZ7	10.3	20.4	−10.8	−15.1
AEZ8	10.3	25.1	−3.57	−10.9
AEZ9	10.3	19.6	−2.15	−0.01
AEZ10	5.49	7.17	−0.49	−4.22
AEZ11	−0.35	−2.94	0.28	0.82
AEZ12	13.3	23.9	1.52	3.05
AEZ13	12	18.1	8.87	14.7
AEZ14	13.4	32.7	1.78	6.07
AEZ15	4.17	15.7	10.3	15.1
AEZ16	0	0	0	0
AEZ17	0	0	0	0
AEZ18	0	0	17.1	32.2

Table 11 Agricultural Products Output Change (%)

	Rice		Wheat		Cereal		Vegetable & Fruit	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
CHN	0.89	1.26	1.02	1.63	0.90	1.18	0.97	1.41
IND	0.20	1.32	−0.83	−1.44	0.21	1.14	0.22	1.30
JPN	−0.31	−0.32	−0.92	−0.56	−0.44	−0.18	−0.32	−0.54
KOR	−0.26	−1.25	−0.29	−1.87	−0.05	−0.98	−0.27	−1.06
RAO	−0.04	0.37	0.61	3.42	0.02	0.59	−0.07	0.53
USA	−0.97	−3.59	−0.48	−1.72	−0.55	−1.36	−0.38	−1.28
LSA	0.06	0.01	−0.66	−0.13	0.05	0.08	−0.44	−0.57
ANZ	−0.26	−1.57	−0.10	−3.70	−0.32	−2.05	−0.45	−2.03
FRA	−2.39	−9.03	−0.53	−1.92	−0.16	−0.64	−0.19	−1.02
DEU	−1.24	−5.81	0.08	−0.65	0.05	−0.34	0.05	−0.83

GBR	−3.32	−11.71	0.10	−0.03	0.05	−0.06	−0.04	−0.62
REU	−1.45	−4.77	−0.33	−0.32	−0.29	−0.48	−0.29	−0.79
RUS	0.04	−0.33	1.36	2.37	0.10	0.07	0.13	0.16
CEU	−1.27	−2.92	−1.14	−2.49	−0.86	−1.98	−0.56	−1.28
RoW	−0.53	−1.15	−0.81	−1.14	−0.47	−0.97	−0.50	−1.06

Table 12 Real GDP Change (%)

	RCP4.5	RCP8.5
CHN	0.55	0.50
IND	−1.04	−2.09
JPN	−0.24	−0.26
KOR	0.07	−0.13
RAO	−0.19	−0.26
USA	−0.36	−0.77
LSA	0.30	0.27
ANZ	−0.09	−0.26
FRA	−0.10	−0.28
DEU	0.07	0.05
GBR	0.02	0.04
REU	−0.24	−0.45
RUS	−0.10	−0.19
CEU	−0.80	−1.79
RoW	−0.98	−2.23

Conclusions

Model simulated results indicate that the impacts of water availability and usage on the agricultural sectors of the world economies can be different depending on the different structures of the economies as well as on the different patterns and intensities of water usage throughout these economies.Even under optimistic scenario, RCP4.5, the directions of renewable water supply changes are as expected and the same for both RCP4.5 and RCP8.5, but these changes are different for different AEZs and for different countries/regions. For example, AEZ11 would suffer negative renewable water supply changes in China, but positive renewable water supply changes in the US. The reverse is true for other AEZs such as AEZ7 to AEZ10. Changes in renewable water supply are then seen as a prime mover for changes in agricultural product outputs and therefore also in GDP for different countries/regions.

In this research, we focused only on renewable water supply changes and their impacts, but noting that changes in demand for agricultural products (such as due to a shift towards more meat dietary or due to rapid growth of population) can also lead to water supply/scarcity changes and therefore posing serious threats to sustainable food supply to achieve SDGs. To study the impacts of these aspects of water supply/demand changes, however, further development of the model developed in this paper would be necessary, for example, a more detailed description of the irrigated water supply/demand system for the agricultural sector, and also more detailed system of water demand/supply for industrial and household customers which may compete with the demand/supply of water for agricultural usages..

References

Baldos, Uris Lantz (2017), Development of GTAP version 9 Land Use and Land Cover database for years 2004, 2007 and 2011, GTAP Research Memorandum No.30, August 2017.

Luck, M., M. Landis, F. Gassert (2015), "Aqueduct Water Stress Projections: Decadal projections of water supply and demand using CMIP5 GCMs." Washington, DC: World Resources Institute.

Roson, Roberto and Richard Damania (2016), Simulating the Macroeconomic Impact of Future Water Scarcity: an Assessment of Alternative Scenarios, Working Paper n.84, February 2016.

UNEP (2017), The Emissions Gap Report 2017, A UN Environment Synthesis Report, November 2017,