

Regional and Sectoral Impacts of Global Warming and Agricultural Production: A Case of CGE Analyses

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The objective is to assess the economic effects of global warming upon agriculture and global economy under various Shared Socioeconomic Pathways, using EMEDA simulations. The EMEDA has 16 regions and 16 sectors, including five agricultural sectors. Our main outcomes are: all sectors in USA, EU25 and East Asia, and some sectors in Japan, Russia, South Korea, Oceania, and North America will experience economic growth, while the other regions only offset direct agricultural damages by global warming. USA, China and India can positively participate in the COP for the 2°C target in future for obtaining their own potential large advantages.

Key words: agricultural production, CGE models, global warming

1. Introduction

Global warming and its many related issues pose immense challenges, not only to scientific organizations and governments, but to citizens around the world. Since the early nineties, various scholars have researched the global, regional, and sectoral economic impacts of global warming and climate change using integrated assessment models (IAMs). The United Nations Intergovernmental Panel on Climate Change (IPCC) has been leading the way in the analysis of future socio-economic scenarios and evaluation of global warming policy options. The United Nations Framework Convention on Climate Change (UNFCCC) has the Conference of the Parties (COP) to assess progress in dealing with climate change for achieving a legally binding and universal agreement on climate such as reducing CO₂ emissions.

Nordhaus (1991) first attempted to estimate the cost of climate change for the USA and the rest of world. After that, many scholars evaluated adaptation costs, mitigation costs and economic damages caused by global warming and climate change (Frankhauser, 1994; Tol, 1995; Nordhaus and Yang, 1996). Recent studies focus on regional impacts on global warming and climate change. Schlenker et al. (2009) analyze the potential impacts on U.S. farmland values under various global warming scenarios. Zhai and Zhuang (2009) simulate the agricultural impacts of climate change in Southeast Asia including Indonesia, Malaysia, Philippines, Singapore, Thailand and Vietnam. Dinar et al. (2008)

assessed agricultural impacts in Africa. Kunimitsu (2015) estimates the regional impacts of global warming upon rice production in Japan using a dynamic computable general equilibrium (CGE) approach. However, the authors have not identified any study which evaluates both the regional and sectoral agricultural damages caused by global warming and climate change.

The objective of this study is to assess the economic effects of global warming upon agriculture and the global economy, using Evaluation Model for Environmental Damage and Adaptation (EMEDA) simulations. First, we develop estimates of the direct damages on agricultural production by climate change. Then, we simulate the future indirect global impacts of direct agricultural damages within 16 global regions, with each region broken down into 16 sectors including secondary and tertiary sectors.

2. Methodology

1) EMEDA

A CGE analysis simulates not only direct impacts, but also assesses to what extent direct impacts can be offset through world trade. The EMEDA is a CGE model to simulate global economics including the economic impacts on international trade (Washida et al., 2014). The EMEDA has 16 world regions and each region has 16 sectors. The purpose of this study is to understand how direct agricultural damages caused by global warming and climate change may affect global economies. One of the advantages of using the

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EMEDA is that we can assess not only the direct damages on agriculture caused by global warming, but also the indirect damages upon international trade, by regions and sectors. Therefore, when compared to previous models, the EMEDA simulations provide a more realistic analysis of regional and sectoral consequences.

Following Washida et al. (2014) who investigated a static EMEDA with damage index, a value-added production function of EMEDA is as:

$$V_{j,r} = (1 - B_{j,r})\pi_{j,r}^V \left\{ \alpha_{j,r}^V K_{j,r}^{\frac{\beta_{j,r}^V - 1}{\beta_{j,r}^V}} + (1 - \alpha_{j,r}^V) L_{j,r}^{\frac{\beta_{j,r}^V - 1}{\beta_{j,r}^V}} \right\}^{\frac{\beta_{j,r}^V}{\beta_{j,r}^V - 1}}, \quad (1)$$

where $V_{j,r}$ is value-added, and $B_{j,r}$ is the damage index which is positive. $K_{j,r}$ and $L_{j,r}$ are capital and labor, respectively. A sector $j = 1, \dots, 16$ and a region $r = 1, \dots, 16$. EMEDA calibration obtains a scale parameter $\pi_{j,r}^V$ and a distribution parameter $\alpha_{j,r}^V$. An elasticity of substitution $\beta_{j,r}^V$ is obtained from the GTAP7 data base.⁽¹⁾ Table 1 shows 16 regions and 16 sectors for EMEDA. Following the Paris Agreement under the UNFCCC, this research uses the 2°C target in the year 2100, and we analyze at the year 2050 as more realistic future.⁽²⁾

2) Agricultural Damage Index

Similar to the impacts of climate change on agriculture by Anthoff and Tol (2014), this study focuses on direct agricultural impacts by global warming. Following Anthoff and Tol (2014), we assume same magnitudes among sectoral (*Paddy Rice*, *Wheat*, *Cereal Grain n.e.c.*, *Grains and Crops*, and *Meat and Livestock*) damages in agriculture and use regional direct damages in each region. Arranged agricultural damage index for EMEDA in the year 2050 is as:

$$B_{j,r} = A_{j,r}^{2050} \frac{GAP_{2050,r}}{Y_{2050,r}}, \quad (2)$$

where $A_{j,r}^{2050}$ is an impact of climate change in 2050, split into three parts, $A_{j,r}^{2050} = A_{j,r}^{2050,r} + A_{j,r}^{2050,l} + A_{j,r}^{2050,f}$: damage to agricultural production by a rate of climate change, $A_{j,r}^{2050,r}$; damage to agricultural production by a level of climate change, $A_{j,r}^{2050,l}$; and damage to agricultural

Table 1. EMEDA 16 regions and 16 sectors

Regions	Sectors
1 Japan	1 Paddy Rice
2 China	2 Wheat
3 USA	3 Cereal Grain n.e.c. ^{a)}
4 India	4 Grains and Crops
5 Russia	5 Meat and Livestock
6 South Korea	6 Forestry
7 EU_25	7 Fishing
8 Oceania	8 Mining and Extraction
9 East Asia	9 Processed Rice
10 Southeast Asia	10 Processed Food
11 South Asia	11 Textile and Clothing
12 North America	12 Light Manufacturing
13 Latin America	13 Heavy Manufacturing
14 Middle East and North Africa	14 Utilities and Construction
15 Sub-Saharan Africa	15 Transport Communication
16 Rest of World	16 Other Services

Note: a) n.e.c. is “not elsewhere classified”.

production by CO₂ fertilization effect, $A_{j,r}^{2050,f}$ in 2050. A_j is agricultural sectors. $GAP_{2050,r}/Y_{2050,r}$ is the share of agricultural production to total income, where gross agricultural production $GAP_{2050,r}$ is divided by gross domestic product $Y_{2050,r}$ in 2050.⁽³⁾

The impact of the rate of climate change on agriculture for EMEDA in 2050 is as:

$$A_{j,r}^{2050,r} = \alpha_r \left(\frac{\Delta T_{2050}}{0.04} \right)^\beta + \left(1 - \frac{1}{\rho} \right) A_{j,r}^{2049,r}, \quad (3)$$

where α_r is a regional change parameter in agricultural production for an annual warming of 0.04°C. ΔT_{2050} denotes the change in mean temperature between the year 2049 and 2050 from global mean temperature change relative to 1986 to 2005 reference period (IPCC 2013). It is 0.804 (1.137°C in 2050 – 0.333°C in 2004).⁽⁴⁾ β is the non-linearity parameter of reaction to temperature and ρ is the speed parameter of adaptation. Parameters are from Anthoff and Tol (2014). For the EMEDA, the year 2050 impact adjusted due to the level of climate change is as:

$$A_{j,r}^{2050,l} = \delta_r^l T_{2050} + \delta_r^q T_{2050}^2, \quad (4)$$

where δ_r^l and δ_r^q are the regional change parameter in agricultural production and the optimal temperature parameter for agriculture, respectively, from Anthoff and Tol (2014). T denotes the change in regional mean temperature

1) See Washida et al. (2014) for more detail EMEDA equations.

2) Conference of the Parties Twenty-first (COP21) session agreed that “Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly

reduce the risks and impacts of climate change (UNFCCC 2015: p.22. Article 2. 1. a).”

3) See Anthoff and Tol (2014: p.5-7) for more details.

4) Global mean temperature in the year 2050 is from RCP2.6 (IPCC 2013: p.1444).

relative to the year 2004. The static EMEDA uses the base year 2004, modified from the original model base year of 1990 used by Anthoff and Tol (2014). Adjusted damages to agricultural production due to CO₂ fertilization effect for the EMEDA is as:

$$A_{j,r}^{2050,f} = \gamma_r \ln \frac{CO_{2050}}{275}, \quad (5)$$

where γ_r is a regional change parameter in CO₂ fertilization effect from Anthoff and Tol (2014). CO_{2050} denotes the year 2050's atmospheric concentration of carbon dioxide in parts per million (ppm) by volume. 275 ppm denotes the pre-industrial atmospheric concentration of carbon dioxide.

The adjusted share of agricultural production to total income for the EMEDA is as:

$$\frac{GAP_{2050,r}}{Y_{2050,r}} = \left(\frac{GAP_{2004,r}}{Y_{2004,r}} \right) \left(\frac{y_{2004,r}}{y_{2050,r}} \right)^\epsilon, \quad (6)$$

where GAP is gross agricultural production, Y is gross domestic product, y is gross domestic product per capita, and ϵ is the income elasticity parameter of the share of agriculture in the economy. Each region's gross agricultural production is obtained by EMEDA simulation without global warming damages, and each region's gross domestic product (GDP) and population are from the SSP Database by International Institute for Applied Systems Analysis (IIASA).⁵⁾ This research simulates on various Shared Socioeconomic Pathways (SSPs), SSP1: sustainability and low costs for adaptation and mitigation, SSP2: the middle of the road for adaptation and mitigation, and SSP3: fragmentation and high costs for adaptation and mitigation, and uses GDP-market exchange rate (MER) for EMEDA. Table 2 shows the percent of initial agricultural damages by socioeconomic scenarios using arranged agricultural damage index for EMEDA simulations.

3. Results

One feature of a CGE approach is to incorporate interrelationships among regions. Therefore, simulated EMEDA results are affected by both direct and indirect impacts inserted as a damage index (Washida et al., 2014).

If a particular sector in the simulated EMEDA results has a *negative* value, it suffers indirect economic damages by global warming and direct agricultural damages, while it is economically beneficial if a value has a *positive*. If a value is zero, there is no change between the baseline and the results

Table 2. Calculated agricultural damage index for EMEDA in the year 2050 (unit: percent)

Regions	Socioeconomic Scenario		
	SSP1	SSP2	SSP3
1 Japan	0.1363444	0.1426589	0.1473321
2 China	0.4521363	0.5025294	0.5615517
3 USA	0.0965816	0.0996318	0.0977771
4 India	0.7633031	0.8600606	1.0047448
5 Russia	0.2495740	0.2661334	0.2833495
6 S. Korea	0.1402398	0.1416418	0.1467536
7 EU_25	0.1448289	0.1473041	0.1501616
8 Oceania	0.2523024	0.2620442	0.2650883
9 East Asia	0.0830131	0.0838237	0.0900487
10 SE. Asia	0.4839392	0.5406221	0.6151723
11 South Asia	0.8998984	1.0278098	1.1990900
12 N. America	0.2057044	0.2152307	0.2313532
13 L. America	0.3668093	0.4006841	0.4497386
14 MENA	0.2938718	0.3151224	0.3432708
15 SSA	0.6248022	0.7373771	0.8776373
16 ROW	0.3516724	0.3738678	0.4066592

Note: S. Korea, SE. Asia, N. America, L. America, MENA, SSA, and ROW are South Korea, Southeast Asia, North America, Latin America, Middle East and North Africa, Sub-Saharan Africa, and the Rest of the World, respectively.

with direct agricultural damages caused by global warming. Table 3 shows damage differences between the EMEDA baseline and the EMEDA with SSP2 direct agricultural damages in the year 2050.⁶⁾

1) Agricultural sectors

There are total eighty in agricultural sectors (*five agricultural sectors * sixteen regions*). Sixty-five per cent of agricultural sectors including *paddy rice*, *wheat*, *cereal grain n.e.c.*, and *grains and crops* in each 16 regions are negative, indicating there are economic damages after incerting direct agricultural impacts. However, most magnitudes are less than fifteen million dollars except *paddy rice* in India and Southeast Asia, *wheat* in India, and *cereal grain n.e.c.* in Sub-Saharan Africa, which are around thirty million dollars.

Twenty three of 64 that are agricultural sectors in these regions are positive values including fourteen million dollars *wheat* benefits in USA. Therefore, these sectors in regions will enjoy some economic benefits by CO₂ fertilization effects from 1.14 degree Celsius temperature rise in 2050.

Interestingly, the *meat and livestock* sector has a variety of impacts. China, India and Sub-Saharan Africa are more than 100 million dollars economic damages, while USA and

5) Data is available at: <https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about>

6) Because damage differences for all scenarios are same signs

and there are page limitations, we mainly discuss damage differences for SSP2. Damage differences for SSP1 and SSP3 are available upon request.

Table 3. Damage differences between the EMEDA baseline and the EMEDA with SSP2 agricultural damages in 2050 for each region (2004US\$million)

	Japan	China	USA	India	Russia	S. Korea	EU_25	Oceania	East Asia	SE Asia	South Asia	N. America	L. America	MENA	SSA	ROW
Paddy Rice	-2,570	-14,470	1,534	-34,630	0,002	-0,004	2,220	0,072	0,571	-31,040	-13,014	-0,137	-3,179	-0,892	-7,970	-1,205
Wheat	0,000	-8,487	13,731	-30,102	-2,617	0,026	2,355	-0,768	0,008	-2,765	4,916	0,868	-9,072	-9,793	-7,114	-9,828
Cereal Grain n.e.c.	0,019	-4,119	3,343	-18,528	-4,230	0,103	1,010	-0,402	0,076	-5,060	-0,304	-3,815	-10,742	-3,802	-30,158	-8,780
Grains & Crops	-0,821	-4,763	0,909	-14,310	0,003	-0,021	1,079	0,257	0,150	-6,957	-5,131	0,030	-0,756	-0,063	-0,724	0,156
Meat & Livestock	-0,650	-148,540	51,710	-279,140	7,680	1,850	65,400	-0,907	4,018	-78,600	-73,490	-7,180	-88,940	-33,710	-219,210	-53,500
Forestry	1,872	-84,950	0,950	-56,260	-9,145	0,184	6,530	-5,220	1,592	-24,940	-37,720	-8,990	-59,340	-17,160	-35,980	-28,620
Fishing	0,017	-10,680	-0,069	-4,716	-0,274	0,011	-0,650	-0,197	0,000	-2,262	-0,592	-0,344	-1,090	-0,266	-2,809	-0,899
Mining & Extraction	0,097	-9,000	0,089	-2,601	-0,154	0,017	-0,270	-0,101	0,005	-3,490	0,104	-0,630	-1,696	-0,859	-3,046	-1,044
Processed Rice	-0,271	-38,430	-1,800	-57,780	-3,280	-0,666	-14,610	-5,050	-1,428	-25,660	-6,626	-9,860	-37,030	-1,800	35,000	-29,800
Processed Food	0,200	-42,580	4,700	-53,270	-4,867	0,010	-4,300	-1,360	1,320	-30,430	-10,153	-11,310	-37,420	-8,080	-22,200	-19,420
Textile & Clothing	11,660	-61,160	28,150	-35,200	0,502	7,227	41,100	1,635	13,040	-2,670	-67,680	10,290	-0,620	1,021	-3,046	2,640
Light Manufacturing	0,300	-75,400	-1,800	-37,170	-1,110	-2,560	-29,000	-3,140	-0,250	-11,560	-5,171	-6,400	-19,600	-3,680	-11,410	-13,910
Heavy Manufacturing	-2,395	-152,073	11,105	-71,731	-2,638	-13,808	-42,056	-4,343	-14,024	-59,686	-8,430	-19,523	-45,632	-2,879	-17,745	-27,232
Utilities & Const.	-13,300	-56,200	-33,900	-70,860	-8,770	-2,390	-40,200	-6,460	-1,490	-4,680	-11,770	-7,860	-23,200	-15,620	-13,990	-24,100
Trans. Comm.	-29,000	-136,600	-53,000	-140,100	-15,400	-10,230	-65,000	-15,600	-4,800	-33,900	-61,900	-17,700	-44,600	-25,300	-63,720	-51,800
Other Services	-55,000	-119,400	-217,000	-116,300	-17,900	-8,300	-300,000	-29,300	-5,200	-15,400	-5,020	-45,600	-63,800	-53,100	-85,100	-67,500

EU25 are over fifty million dollars economic benefits. This is one feature of EMEDA simulations that there are both advantages and disadvantages in a sector through trading and its indirect impacts. USA and EU25 can expand livestock industry sizes with increasing temperature (e.g., they can ranch more livestock in north regions). However, *meat and livestock* industries will suffer in China, India and Sub-Saharan Africa because these regions are difficult to expand their businesses by land or religious issues, and will reduce their market sizes by both direct and indirect impacts through global warming.

2) Other sectors

Over eighty per cent of damage differences in other sectors are negative values. Therefore, most of other sectors in the world will suffer indirect economic damages by direct agricultural impacts by global warming. Especially, Chinese *heavy manufacturing* and *transport communications*, and Indian *transport communications* reduce over 100 million dollars in 2050 when there are direct agricultural damages by global warming. Similar to the agricultural sectors, China and India receive large indirect damages, indicating that these countries take many disadvantages (e.g., firms may shift their factories and businesses) through global warming. Additionally, all regions are negative values in *other services* sector, and four regions (China, USA, India and EU25) are over 100 million dollars reduction. Therefore, *other services* sector such as *real estate*, *renting* and *business activities* receive many indirect economic damages in the world.

There are some economical benefits by direct agricultural impacts in the secondary and tertiary industries. Ten regions in *textile and clothing* are positive values, and Japan, USA, EU25, East Asia and North America are over 10 million dollars gains in *textile and clothing* sector. This is probably textile industries move their (overseas) bases from India, South Asia including Banguradish, and China, where have large textile markets, to other countries after receiving huge indirect damages. Others, as a result, have relatively small effects in *textile and clothing* sector.

3) Offset agricultural benefits/damages?

Damage differences shows how much differences after inserting agricultural impacts in all sectors. However, damage differences cannot show how much these direct impacts are offset by global economy. To assess the offset impacts of global warming upon agricultural production, we use an offset ratio between pre- and post-global warming agricultural damages (Washida et al., 2014) that:

$$[1 - (V_{j,r}^1/V_{j,r}^0)]/B_{j,r} \geq 1, \quad (7)$$

where $V_{j,r}^0$ and $V_{j,r}^1$ are value-added with pre- and post-global warming damages on agricultural sectors by EMEDA, respectively. Under the EMEDA simulation, if an offset ratio is *more* than one, a j sector in r region has increased damages, while damages are offset if the ratio is *less* than one. There is no change for pre- and post-damages if it *equals* one.⁷⁾ Offset mechanism in EMEDA is to decrease inputs such as capital and labor in non-agricultural sectors and to increase inputs in agriculture for preventing agricultural production declining largely.

Table 4 shows the offset ratio between pre- and post-damages for each region in the agricultural sectors: *paddy rice*, *wheat*, *cereal grain nec*, *grains and crops*, and *meat and livestock* under various SSP scenarios. The calculated offset ratio are all less than one, indicating that the offset impacts of global warming work in all agricultural sectors. We divide calculated offset ratio into two: one is positive value and less than one, and the other is negative offset ratio. For analyzing each offset impact clearly, we mainly discuss offset ratio under the SSP2: the middle of the road for adaptation and mitigation. Magnitudes of the offset ratio for all five sectors, *paddy rice*, *wheat*, *cereal grain n.e.c.*, *grains and crops*, and *meat and livestock*, in China, India, Southeast Asia, South Asia, Latin America, Middle East and North Africa, Sub-Saharan Africa, and the rest of the world are positive but less than one, indicating that these regions offset their own direct damages caused by global warming.

Negative offset impacts mean opposite effects of the original direct impacts of global warming. There is *economic benefits (damages)* if the direct impacts are *damages (benefits)* in the EMEDA simulations (Washida et al., 2014). Since direct agricultural impacts by global warming are all damages (see Table 2), negative offset ratio indicates *economic benefits*. All sectors in USA, EU25 and East Asia, *cereal grain nec* and *wheat* in Japan, *paddy rice* in Russia, *wheat*, *cereal grain n.e.c.*, *grains and crops*, and *meat and livestock* in South Korea, *paddy rice* in Oceania, and *wheat* in North America are negative scores that indicate they will take advantage such as economic growth in these sectors through offset mechanism, international trade and spilling over to other domestic sectors in each region.

Compared offset ratio under the SSP scenarios, it has turned out that more than half of them including eleven regions in *paddy rice*, six regions in *wheat*, six regions in

Table 4. Offset ratio between pre- and post-damages by the EMEDA with agricultural damages in 2050

Regions	SSP1				
	Rice	Wheat	Cereals	Crops	Livestock
Japan	0.00162	0.00000	-0.00254	0.00031	-0.00122
China	0.00233	0.00430	0.00197	0.00326	0.00339
USA	-0.01855	-0.02978	-0.00331	-0.00818	-0.00006
India	0.00398	0.00377	0.00522	0.00456	0.00455
Russia	0.00015	0.00403	0.00338	0.00289	0.00358
S. Korea	0.00035	-0.00892	-0.00821	-0.00114	-0.00055
EU_25	-0.02598	-0.00254	-0.00082	-0.00346	-0.00031
Oceania	-0.00449	0.00266	0.00224	0.00078	0.00164
East Asia	-0.00967	-0.00212	-0.00589	-0.01141	-0.00560
SE. Asia	0.00388	0.02284	0.00326	0.00474	0.00361
South Asia	0.00258	0.00478	0.00306	0.00528	0.00343
N. America	0.01635	-0.00153	0.00265	0.00215	0.00252
L. America	0.00270	0.00848	0.00391	0.00389	0.00424
MENA	0.00259	0.00690	0.00430	0.00376	0.00350
SSA	0.00594	0.01279	0.00444	0.00698	0.00421
ROW	0.00400	0.00392	0.00339	0.00346	0.00319
Regions	SSP2				
	Rice	Wheat	Cereals	Crops	Livestock
Japan	0.00157	0.00000	-0.00270	0.00014	-0.00132
China	0.00234	0.00438	0.00199	0.00327	0.00341
USA	-0.02034	-0.03192	-0.00357	-0.00900	-0.00015
India	0.00399	0.00377	0.00523	0.00457	0.00455
Russia	-0.00008	0.00403	0.00338	0.00280	0.00358
S. Korea	0.00001	-0.00890	-0.00953	-0.00183	-0.00069
EU_25	-0.02947	-0.00278	-0.00100	-0.00420	-0.00049
Oceania	-0.00513	0.00147	0.00198	0.00043	0.00142
East Asia	-0.01092	-0.00250	-0.00671	-0.01311	-0.00627
SE. Asia	0.00387	0.02374	0.00327	0.00477	0.00363
South Asia	0.00258	0.00487	0.00310	0.00531	0.00342
N. America	0.01605	-0.00237	0.00263	0.00190	0.00247
L. America	0.00270	0.00858	0.00392	0.00390	0.00426
MENA	0.00218	0.00696	0.00430	0.00367	0.00347
SSA	0.00605	0.01320	0.00443	0.00707	0.00424
ROW	0.00397	0.00393	0.00338	0.00339	0.00319
Regions	SSP3				
	Rice	Wheat	Cereals	Crops	Livestock
Japan	0.00150	0.00000	-0.00284	-0.00014	-0.00149
China	0.00234	0.00448	0.00200	0.00327	0.00342
USA	-0.02426	-0.03752	-0.00429	-0.01096	-0.00042
India	0.00399	0.00378	0.00523	0.00458	0.00456
Russia	-0.00044	0.00393	0.00336	0.00261	0.00357
S. Korea	-0.00031	-0.00655	-0.01079	-0.00246	-0.00072
EU_25	-0.03431	-0.00312	-0.00125	-0.00516	-0.00071
Oceania	-0.00629	-0.00076	0.00146	-0.00022	0.00098
East Asia	-0.01146	-0.00071	-0.00676	-0.01388	-0.00639
SE. Asia	0.00386	0.02496	0.00328	0.00480	0.00366
South Asia	0.00258	0.00497	0.00311	0.00534	0.00342
N. America	0.01626	-0.00237	0.00265	0.00177	0.00250
L. America	0.00272	0.00877	0.00396	0.00395	0.00430
MENA	0.00169	0.00707	0.00431	0.00356	0.00343
SSA	0.00614	0.01359	0.00442	0.00715	0.00425
ROW	0.00395	0.00397	0.00338	0.00333	0.00319

Note: Rice, Wheat, Cereals, Crops and Livestock are *Paddy Rice*, *Wheat*, *Cereal Grain n.e.c.*, *Grains and Crops*, and *Meat and Livestock*, respectively.

7) Offsetting agricultural benefits can be interpreted as reducing

agricultural benefits in the case of negative damages.

cereal grain *n.e.c.*, nine regions in *grains and crops*, and ten regions in *meat and livestock* are right downward tendency (e.g., 0.00162, 0.00157, and 0.00150 for SSP1, SSP2 and SSP3 in Japanese *paddy rice* sector, respectively). This indicates that global economy absorbs more damages by global warming through a CGE analysis. This is consistent with Rozenberg et al. (2014) that the SSP3 society is the exact opposite of the SSP1, and adapts to a new environment with offsetting its direct impacts by global warming and climate change.

4. Conclusion

Global warming and climate change have various effects including upon agriculture. This paper simulates the direct and indirect effects of impacts on agricultural production by various global warming scenarios using the EMEDA model.

Through the EMEDA analysis, we found that all sectors in USA, EU25 and East Asia, and some sectors in Japan, Russia, South Korea, Oceania, and North America will experience economic growth. Other regions only offset direct agricultural damages caused by global warming. There is not much difference in offset ratio among various SSP scenarios. However, we found that the more society challenges adaptation and mitigation, the more direct agricultural impacts by global warming and climate change are offset.

With the goal of limiting temperature rise to within 2°C by 2100, the world economies in 2050 can benefit from international trade which will offset direct and indirect agricultural damages caused by global warming.

Acknowledgement

We thank the journal reviewers for their comments. We also thank Dr. Yixing Zhang and Mio Yamaura for their assistance. Financial assistance from the Environment Research and Technology Development Fund (S10) of the Ministry of the Environment, Japan, is gratefully acknowledged.

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