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Economic Implications of Avoiding Dangerous Climate Change: An Analysis Using the AIM/CGE [Global] Model

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Abstract: The purpose of this study is to analyze economic impacts of reducing greenhouse gases emissions significantly. A large amount of emissions reductions are required throughout this century to avoid dangerous climate change, and understanding the economic consequences under such situations is important and meaningful. The AIM/CGE [Global] model, a recursive dynamic computable general equilibrium model on a global scale, is applied to analyze carbon prices and changes in GDP when implementing five policy scenarios represented by emissions pathways, respectively. As a result of the analysis, higher carbon prices and larger decreases in GDP compared to the baseline emissions scenario are observed when emissions are reduced more deeply. However, such GDP losses are rather small and insignificant compared to the GDP growth observed throughout the century. These results suggest that although it is challenging to reduce emissions until the level to avoid dangerous climate change, there is a sufficient possibility to achieve it from economic perspectives.

Key words: Economic impact, carbon price, GDP, dangerous climate change, emissions reduction, global CGE model.

1. Introduction

The Objective (Article 2) of the United Nations Framework Convention on Climate Change (UNFCCC) says that "the ultimate objective of this convention is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". With this statement in mind, limiting global warming below 2 Celsius degrees has been considered to be a target of climate change policies globally. For example, the European Union has released a statement [1] and a brochure [2] indicating its aim to achieve the target. In the G8 Summit held in L'Aquila in July 2009, the G8 Leaders Declaration expressed that global average temperature should not exceed 2 Celsius degrees above the pre-industrial levels [3]. Furthermore, it should be remembered that significance of this target to achieve the ultimate objective of the UNFCCC is emphasized in the Copenhagen Accord [4].

Taking this viewpoint into consideration, the AVOID Programme was launched in UK in 2009 [5, 6]. The purposes of this project are to promote understanding of dangerous climate change and its implications including impacts, economic, and social consequences and responses, to further encourage the integration and communication of scientific and socioeconomic research on climate, and to accumulate policy-relevant evidence to achieve international agreement on greenhouse gases (GHGs) emissions reduction. In order to achieve these purposes, AVOID addresses the following key questions [6]: how much climate change is too much? what level of global climate change should be avoided? what does the world need to avoid such levels of climate change? and what is considered as an acceptable risk of climate

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change impacts for different regions and communities?

In AVOID, more than 150 emissions scenarios have been developed [7, 8] and five policy scenarios out of them are selected for economic and impact assessment, which is a study involved in the Work Stream 1 of AVOID [8, 9]. In the Work Stream 1, the climatic consequences of defined climate policies, damages and impacts under these defined policies and targets and damages avoided by them, and the economic characteristics of the inferred mitigation strategies and their economic consequences are mainly estimated. From economic aspects of the research, three economic models, namely the PAGE2002 model [10], the E3MG model [11, 12] and the AIM/CGE [Global] model [13, 14], analyze economic consequences under the five policy scenarios. Under the baseline scenario, it is very likely that global mean temperature would exceed 3 Celsius degrees and there are even chances that the temperature would rise by 4 Celsius degrees by the end of this century. Under the most severe (the lowest emissions) policy scenario, there are 45% chances to keep the temperature rise below the 2-degree target [7, 9]. These details will be described in the following sections.

The purpose of this paper is to show the results and implications from economic analysis implemented for the Work Stream 1 of AVOID using the AIM/CGE [Global] model. In this study, the analysis is implemented until 2100 and the results on carbon prices and GDP, mainly on a global basis, are provided. These results are then compared with those of the E3MG model.

The rest of this paper is organized as follows. The methods and assumptions of the analysis are described in the second section. The results of the analysis are shown and discussed in the third section. Finally, the fourth section includes some concluding remarks with a brief comparison of the results of this paper with those of the E3MG model.

2. Methods

2.1 Model

In this study, the AIM/CGE [Global] model is used for the analysis [13, 14]. This model is a recursive dynamic computable general equilibrium (CGE) model on a global scale. Although it is a classical CGE model (i.e., a top-down approach, equilibrium, full employment, and exogenous technological change), it includes energy and environmental components. On the other hand, it does not include climate feedback effects directly. The model consists of 21 industrial sectors (Table 1), 24 world regions (Table 2), and 4 production factors (Table 3). These definitions are based on the GTAP 6 database [15, 16]. The other data sources used for the base year in the model are the Energy Balances of the International Energy Agency for energy [17], the EDGAR 3.2 Fast Track 2000 database of the Netherlands Environmental Assessment Agency for emissions [18], and the FAOSTAT of the Food and Agriculture Organization for land use [19].

The basic mechanism of this model is similar to the GTAP model [20] and the GTAP-E model [21], such as use of CES (Constant Elasticity of Substitution) production functions. However, the structure is different from these models. Some significant differences can be summarized as follows: dynamic structure is considered; not only CO_2 emissions but also other GHGs, aerosol, and chemicals emissions are incorporated; power generation by various resources such as fossil fuels, nuclear, hydro, and other renewables (e.g., geothermal, solar, wind, and biomass), and also that with CCS technology are considered; bio-energy production and consumption, including both traditional and modern types, are considered; and international markets are modeled for international trade of some fossil fuels. Considering the dynamics in the model, the acceleration principle is applied to determine the investment and autonomous energy efficiency improvement is adopted for the technology progress.

Table 1 Structure of industrial sectors.

Code	Including sectors	Code	Including sectors
Energy sectors		Non-energy sectors	
COA	Coal	AGR	Agriculture
OIL	Crude oil	LVK	Livestock
GAS	Natural gas	FRS	Forestry
P_C	Petroleum & coal products	FSH	Fishery
GDT	Gas manufacture & distribution	EIS	Energy intensive industries
ELY	Electricity	OMN	Other mineral mining
		M_M	Metals & manufacture
		FOD	Food processing
		OMF	Other manufacture
		CNS	Construction
		TRT	Transportation
		CMN	Communication
		WTR	Water
		OSG	Governmental services
		SER	Other services

Table 2 Structure of world regions.

Code	Including countries	Code	Including countries
Annex I*		Non-Annex I	
AUS	Australia	CHN	China & Hong Kong
NZL	New Zealand	KOR	Korea
JPN	Japan	XRA	Rest of Asia-pacific
CAN	Canada	IDN	Indonesia
USA	United States of America	THA	Thailand
XE15	15 Western EU countries	XSE	Rest of Southeast Asia
RUS	Russia	IND	India
XE10	10 Eastern EU countries	XSA	Rest of South Asia
XRE	Rest of Europe	ARG	Argentina
		BRA	Brazil
		MEX	Mexico
		XLM	Rest of Latin America
		XME	Rest of Middle East
		ZAF	South Africa
		XAF	Rest of Africa

*The Annex I countries are those defined in the UNFCCC.

In this study, the base year is 2001 in line with the GTAP 6 database. A simulation analysis is then implemented until 2100 with 10-year time steps except for the first 9 years.

2.2 Baseline Scenario

The IPCC (Intergovernmental Panel on Climate Change) SRES (Special Report on Emissions Scenarios) A1B scenario is adopted for the baseline scenario as the basic assumption of AVOID. It is expected that the global mean temperature rise will be 3-4 Celsius degrees under this scenario (Table 4 in the

Table 3 Structure of production factors.

Code	Explanations
Mobile	
LAB	Labor
CAP*	Capital
Sluggish	
LND	Land
RES	Natural resources

*In the model, capitals are mobile if newly introduced but sluggish if they have already existed through the dynamic process.

next section). We use population and potential GDP growth projections of the A1B scenario for the drivers toward the future in this study (Figs. 1 and 2). As these figures show, the world total population declines after it increases until around 2060, while GDP continuously increases during the century. Since parameters and some other assumptions such as the rates of technological change are based on the original settings as used in the previous studies [13, 14], on the other hand, it is not possible to duplicate the original A1B emissions by the model calculation. Thus, the calculated results are considered to be the baseline and policy scenarios, explained in the next section, which are structured based on it. In the scenario, CO_2, CH_4, N_2O, NO_X, NMVOC, CO, SO_2, and some F-gases targeted in the Kyoto Protocol are the target gases. Since the AIM/CGE [Global] model cannot handle F-gases inside the model, these gases are exogenously treated. However, this influence is negligible considering the importance of the other gases, especially CO_2.

The model is run using the above drivers and assumptions without any emissions constraints for the baseline scenario.

2.3 Policy Scenarios

In this study, five policy scenarios are considered based on the following three parameters: the year in which emissions peak globally; the rate of emissions reduction after the peak year (R); and the minimum level to which emissions are eventually reduced (H: High or L: Low). The five scenarios are named 2016R2H, 2016R4L, 2016R5L, 2030R2H, and 2030R5H. For example, 2016R2H means that the peak year is 2016, the rate of emissions reduction is 2%, and the eventually achieved (long-run) minimum emissions level is high. The CO_2 emissions profiles of these scenarios are shown in Fig. 3 and the details of the process to develop the emissions scenarios are explained by Gohar and Lowe [22-24]. The probabilities of the global mean temperature rise below 2 Celsius degrees under these scenarios are expected to be about 7-45% (Table 4).

As mentioned in the previous section, the calculated baseline emissions pathways are different from the original A1B emissions pathways, thus the relationships between the original baseline and policy scenarios are not kept at all. However, it is significant to maintain the relationships (i.e., percentage differences between them) when calculating since one of the parameters of the policy scenarios is the rate of emissions reduction. Hence, the percentage reduction in emissions that occurs between the original baseline scenario and the particular policy scenario, for each gas (not only CO_2, but also the other gases) in each time period, is first calculated, and then these percentage reductions are applied to the calculated baseline scenario to derive the constraints for each gas over the century. For example, if the original baseline and policy emissions in 2050 are 100 and 50 respectively and the calculated baseline emission is 95 in 2050, 47.5 is used for the emission in 2050 to calculate the corresponding policy scenario.

For each policy scenario, the model is run under the corresponding emissions constraints using the parameter settings identical to the baseline scenario. In addition, emissions trading is assumed in the model.

3. Results and Discussion

Since five policy scenarios are calculated in this study, we mainly focus the results on a global scale in this section.

Fig. 4 shows global carbon prices. Since emissions trading is assumed, these prices hold true for all regions.

Table 4 Global mean temperature rise in 2100 (central estimate).

	Baseline	2016R2H	2016R4L	2016R5L	2030R2H	2030R5L
Probability of remaining below 2 degrees	1%	30%	43%	45%	7%	17%
Probability of remaining below 3 degrees	7%	87%	91%	91%	63%	76%
Probability of remaining below 4 degrees	46%	98%	99%	99%	93%	96%

Source: Revised version of Table A in Warren et al. [9]

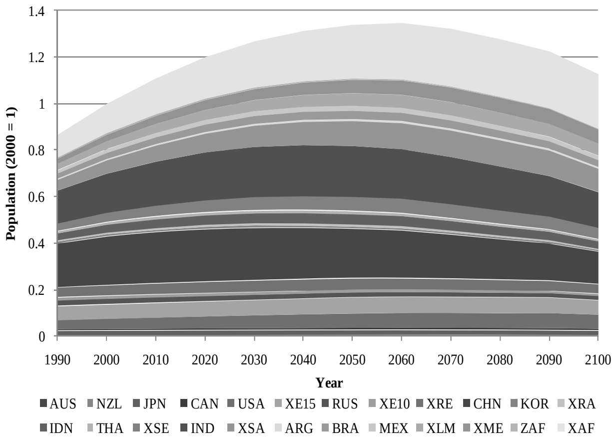

Fig. 1 Population growth (world total in 2000 = 1).

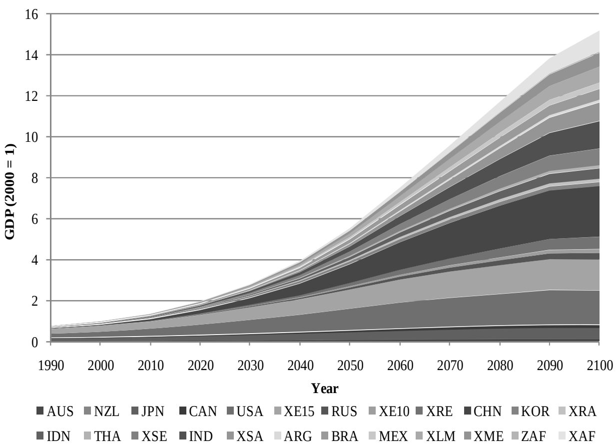

Fig. 2 Potential GDP growth (world total in 2000 = 1).

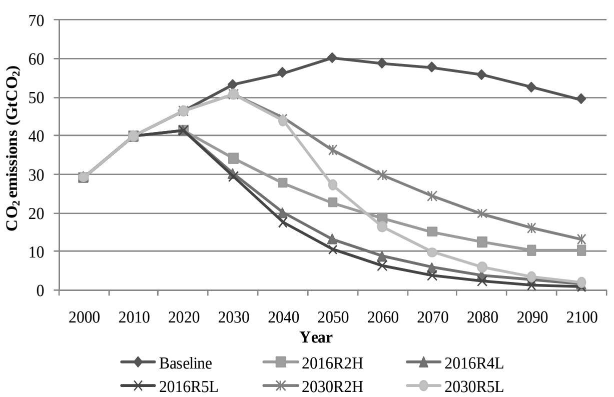

Fig. 3 CO_2 emissions pathways of baseline and policy scenarios.

Carbon prices represent the cost of CO_2 emissions determined by the market forces of supply and demand under a certain policy reducing the emissions. As the figure shows, higher carbon prices are required to cause emissions to peak in 2016 compared to 2030, and also required to reduce emissions more significantly. That is to say, the larger the emissions reduction amounts, the higher the prices (2016R5L is the highest scenario and 2030R2H is the lowest scenario). Of course, carbon prices are zero for the baseline scenario in which emissions are not controlled. In the figure, it is also shown that the carbon prices tend to fall at the end of the century for all scenarios. This reason is considered to be that although the percentage reductions in emissions required are increasing throughout the century for the policy scenarios, the absolute emissions reduction amounts decrease due to the emissions reduction seen in the latter half of the century for the baseline scenario (Fig. 3 in the previous section).

Fig. 5 shows global total GDP. As the figure shows, GDP decreases for all policy scenarios compared to the baseline scenario. The rates of decrease in 2100 are 2.9% for 2016R2H, 6.1% for 2016R4L, 7.0% for 2016R5L, 2.0% for 2030R2H, and 5.0% for 2030R5L. However, the rates are not so large and GDP is still increasing over time. In addition, the differences between the policy scenarios are small. As well as the carbon prices shown above, the larger decreases are observed from the 2016-peak cases compared to the 2030-peak cases and also when the emissions are reduced more deeply. In other words, the larger the amount of emissions reductions, the higher the rates of decrease.

Observing the changes in GDP by region (Fig. 6), the tendencies are almost the same with the above global results. Although only the baseline results are shown in the figure (Fig. 6-A), these tendencies hold true for the policy scenarios. In addition, the larger the amount of global emissions reductions, the higher the rates of decrease in all regions (Fig. 6-B) except for MEX where slight increases in GDP are observed for the less severe scenarios.

4. Concluding Remarks

In this study, we analyzed economic impacts of reducing GHG emissions relative to the baseline applying the AIM/CGE [Global] model. One baseline scenario based on the SRES A1B scenario and five policy scenarios based on the peak year of emissions, the rate of emissions reduction, and the long-term minimum level of emissions were considered. The results we especially focused on were carbon prices and GDP, which can represent the economic costs to implement the policy scenarios. As a result of the analysis, higher carbon prices and larger decreases in GDP were observed as the peak year of global emissions came earlier and more emissions were reduced, while the probability to achieve the 2-degree target became higher under such scenarios. However, the decreases in GDP were relatively small and insignificant even for the most severe policy case (i.e. 2016R5L) compared to the increases in global GDP by the end of the century. It was also indicated that the carbon prices and the changes in GDP increased over time. These results therefore suggest that while significant emissions reduction is indispensable to aim to avoid dangerous climate change, that is global mean temperature rise below 2 Celsius degrees, and it seems a challenging issue, the economic damage to achieve the level is rather small and there is still a possibility to achieve it.

In the AVOID Programme, our results are compared with those of the E3MG model as mentioned above. Although we do not show their detailed results here, the

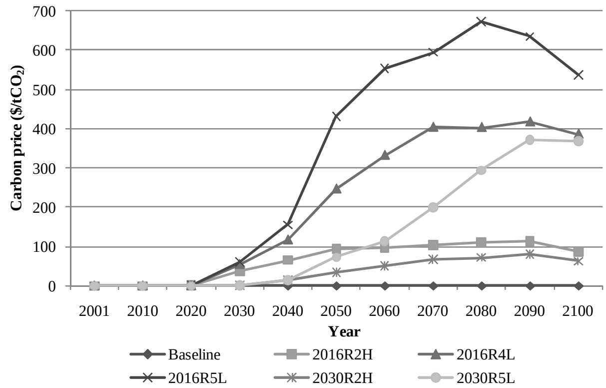

Fig. 4 Carbon prices of baseline and policy scenarios.

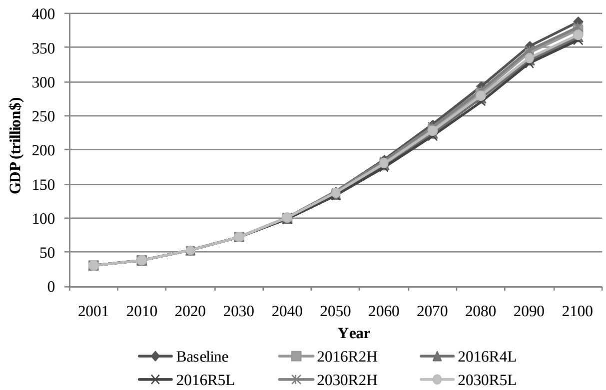

Fig. 5 Global total GDP of baseline and policy scenarios.

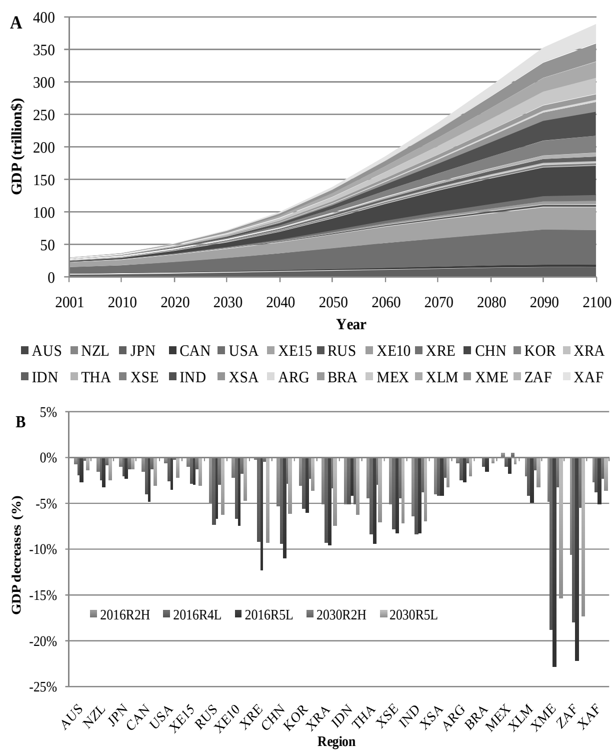

Fig. 6 Some GDP results by region (A: baseline GDP, B: GDP decreases from baseline in 2100).

notable results can be summarized as follows [9]: carbon prices in the E3MG model are constant in real terms from 2020 to 2100, and they are higher than those of the AIM/CGE [Global] model until around 2050 and become lower in the latter half of the century; and the E3MG model shows increases in GDP for the policy scenarios relative to the baseline scenario (about 2 to 5%), and the higher increases are observed in the more severe scenario. These results are economically more positive for reducing emissions than our results. Economic models showing such results are few so far in the literature [25, 26]. Such significant differences in the results between the two models, especially observed in the long run, are caused by the following reasons: technological change-while technological change is exogenous in the AIM/CGE [Global] model, it is endogenous and induced by introducing policies in the E3MG model; revenue recycling-a lump-sum payment of revenues from emissions trading to consumers is assumed in the AIM/CGE [Global] model, whereas the revenues are used to lower indirect taxes and provide incentives to invest additionally in low-carbon technology in the E3MG model; timing of emissions reductions-emissions are reduced later in the AIM/CGE [Global] model than the E3MG model; modeling approach-the AIM/CGE [Global] model is a CGE model so that an optimum equilibrium condition (i.e. a first-best world) is assumed, while the E3MG model is a non-equilibrium macroeconomic model in which a unique optimal condition does not exist (i.e., a second-best world).

For the future study, it will be important to consider climate feedback effects and damages due to climate change in the model in order to understand and accumulate economic implications of avoiding dangerous climate change more deeply.

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