A New Approach of Carbon Emission Allocation among Stakeholders: An Expansion of Multiregional and Multisectoral Dynamic Energy Economic Model THERESIA

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Abstract

This paper aims at the assessment of the sectoral/regional partial participation in the global warming coalition applying the Multiregional and Multisectoral Dynamic Energy Economic Model THERESIA based on GTAP data base, dealing with 15 world regions and 12 non-energy industry sectors and 7 energy sectors to assess the middle-to-long term global warming policies. This study consists of the following three steps: firstly, I distribute the carbon emission of power generation sector to the consumer and the generator according to the conversion efficiency, i.e. the generator is responsible for (1.0-efficiency)*(total carbon emission) and the consumer is for the rest. Secondly, based on the above carbon emission allocation, the carbon emission of the certain industry is embodied in the products. Thus indirect carbon trading embodied in the commodities can be calculated. Finally, THERESIA simulations generate and compare the outcomes of regional/sectoral participation where (1) only iron and steel industry, chemical industry and power generation industry (2) only ANNEX-I regions in Kyoto protocol participate in the warming coalition, and (3) other various participation scenarios. The simulation results suggest that (1)this method clearly shows the indirect carbon emission embodied in the production structure reflecting the difference in the energy supply structure, (2) the carbon emission accounting method influences the international industry structure and GDP losses under the global carbon emission policies, and (3)when carbon emission is embodied in the products, indirect "carbon export" often exceeds the "carbon import" embodied in the commodities in the OECD regions.

Keywords: dynamic CGE, energy economy model, sectoral approach, carbon leakage

1. Introduction

Uniform carbon tax and cap-and-trade system are the first choices according to the Kyoto-Protocol when the policy makers consider the carbon control policies. As is well known, these two options theoretically give identical carbon emission distribution. However, in reality, carbon tax has hardly been accepted by industries while emission certificate as a part of cap-and-trade system such as EU-ETS has been implemented in some limited regions. The realization of these carbon emission control policies is still far from the "covering all commodities and regions" stage.

When carbon control policy is implemented in the limited countries, so called "carbon leakage" phenomenon arises where high carbon intensity industries move to those countries where no carbon policy exists and import the products. According to the current measurement scheme of carbon emission based on the primary energy consumption based, or upstream based, "exporting firms and importing products" strategy is natural, but this strategy could increase the global GHG emission since energy efficiency in developing regions tends to be lower than in developed countries. Demand-side based emission assessment has been proposed by embodying the energy consumption into the tradable commodities in order to avoid the above loophole.

The basic formulation to embody the emission in the commodity is as follows: according to the standard input-output framework, domestic production relationships are represented by

$$\mathbf{Ax} + \mathbf{f} = \mathbf{x}$$

$$\mathbf{x} = (I - A)^{-}\mathbf{f} = [\mathbf{b}_1 \vdots \mathbf{b}_2 \vdots \cdots \vdots \mathbf{b}_n] \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix} = f_1\mathbf{b}_1 + f_2\mathbf{b}_2 \cdots f_n\mathbf{b}_n \qquad (1)$$

where **A**, **x** and **f** denote input-output coefficient matrix, production vector, and final demand vector respectively. Introducing **c** as the direct GHG emission coefficient vector of each sector, total GHG emission is represented by

$$\mathrm{GHG} = \mathbf{c}^{\mathrm{T}}\mathbf{x} = (\mathrm{I} - \mathrm{A})^{-}\mathbf{f} = f_1\mathbf{c}^{\mathrm{T}}\mathbf{b}_1 + f_2\mathbf{c}^{\mathrm{T}}\mathbf{b}_2 \cdots f_{\mathrm{n}}\mathbf{c}^{\mathrm{T}}\mathbf{b}_{\mathrm{n}} \qquad (2)$$

where GHG emission is distributed among final demand sectors.

The above procedure can easily be expanded to the bilateral trade by decomposing the final demand vector **f** into domestic final demand and international trade. When we deal with the multi-regional global trade market where a certain commodity could be imported from multiple regions with different technologies and energy sources, more complex method is needed.

Peters and Hertwich (2007) proposed the procedure to embody the energy consumptions in the international trade based on the multiregional input-output tables (MRIO). Then they define the consumption-based emission inventory as the total emissions occurring from economic consumption within a country r as follows:

$$f_r^{cons} = f_r^{prod} - f_r^{e} + f_r^{m} = f_r - f_r^{BEET} \qquad (3)$$

where $f_r^{cons}, f_r^{prod}, f_r^{e}, f_r^{m}$ and f_r^{BEET} represent the total consumption based emission, emission caused by the domestic production, total export to other regions, total import from other regions and Balance of Emissions Embodied in Trade, respectively.

Liu et.al.(2010) expanded the above approach by applying the structural decomposition analysis (SDA) to see the dynamic structural changes in China. Tang et al (2013) also estimate the international trade of UK applying the embodied energy analysis from the view of national energy security.

It should be noted that the above method based on the input-output analysis focuses on the allocation of fossil fuel consumption among commodities. The emissions and the technological improvement on energy efficiency of the energy conversion sectors, such as power generation sector and petroleum products industry, are not explicitly dealt with. Furthermore, when we consider the distribution of the emission responsibility and the evaluation of the efforts to reduce the GHG emissions, more concrete evaluation procedure is needed. The effects of the partial participation in the GHG control scheme in the different accounting method will then appear.

2. Allocation of Emission Responsibility - No Responsibility, No Incentive

In addition to the above trans-border indirect emission issue, emission allocation issue between secondary energy producer and consumers also arises, since the effort to reduce GHG emission should be compatible with the emission responsibility. No responsibility would generate no incentive. In May, 2009, a governmental committee in

Japan (EPA, 2009) summarized and compared the following four allocation options:

1- Upstream allocation: the producers and importers of primary energy sources are responsible for all carbon emissions.
It is easy to measure the national level carbon emission while each consumer including firm is not responsible for carbon emission. Therefore, the carbon emission reduction incentive of demand side is indirect.

2- Downstream allocation: the purchasers of energy are fully responsible for carbon emission.
When all responsibility of emission is allocated among demand side, the emission reduction incentive of power generation would disappear. Monitor and control costs would be high since the emissions of so many stakeholders should be covered.

3- Upstream allocation for non-electric energy source producers and downstream allocation for power generation companies.
Although the number of stakeholders is less than the above second option, the emission reduction incentive of electricity consumers is still indirect.

4- Carbon emission is distributed between energy conversion companies and consumers according to the conversion efficiency.
This is theoretically most rational but no example exists until today.

For instance, when let ε, μ and EP be the energy conversion efficiency, carbon intensity of primary energy and primary energy input, respectively, the responsible carbon emissions of conversion firm (Ce) and consumer (Cd) are represented by

$$\begin{aligned} Ce &= EP \times \mu \times (1-\varepsilon) \\ Cd &= EP \times \mu \times \varepsilon = (EP \times \varepsilon) \times \mu = ES \times \mu \end{aligned} \tag{4}$$

where ES denotes secondary energy demand. One can thus evaluate the responsible carbon emission of energy conversion sector as well as the responsible carbon intensity of secondary energy.

It should be noted that none of the above four options takes into account the trans-border issue in the introduction shown in the section 1.

In this study, I employ the option 4 in the above to allocate the emission responsibility between energy conversion sector and secondary energy consumers including industry sectors as intermediate input producers and final demand sectors. The indirect emissions embodied in the products are then evaluated by sector considering the international trade. An expansion of the integrate assessment model THERESIA - Toward Holistic Economy, Resource and Energy Structure for Integrated Assessment developed by the authors (Mori et.al., 2011) is then employed for the numerical calculation.

3. Trans-border carbon emission and embodied carbon emission in the commodities

This paper aims at the distribution of the carbon emission responsibility among market players from demand side view. It should be noted that the emissions from primary fossil fuel energy are distributed according to the energy conversion efficiency in this study as previously described. Thus, for example, total carbon emission of power conversion sector CT_e and the carbon intensity of electric power CI_e are defined by

$$CT_e = \sum_i F_i \times CF_i , \quad \mu_e = \frac{ELC}{\sum_i F_i}, \quad CI_e = \frac{\mu_e \times C_e}{ELC} = \frac{\sum_i F_i \times CF_i}{\sum_i F_i} \qquad (5)$$

where μ_e, CFi, Fi and ELC denote power conversion efficiency, carbon intensity of primary energy input of type i (see Table 1(c)), input of primary energy i and total electric power supply. Thus, total allocated emission of the consumer C_c and the power producer C_e are

$$C_c = CI_e \times E_c \quad , \quad C_e = (1-\mu_e)\times CT_e \quad . \qquad (6)$$

where E_c represents electric power consumption of consumer c. Similarly, the carbon emission from petroleum products is distributed among consumers according to the conversion efficiency. This is also essential when the market share of the biomass-based fuel in the total transportation energy supply increases.

Next, I describe the carbon emission accounting methods. Let Fi and Cf denote the aggregated energy input for industry sector i and carbon intensity of the energy. Then the carbon intensity of the products CI_i is

$$CI_i \times Q_i = CI_i \times (X_i + FD_i + ex_i - im_i)\times Q_i = F_i \times Cf = C_i \qquad (7)$$

where C_i, Q_i, X_i, FD_i, ex_i and im_i represent producer based carbon emission, output, intermediate input total, final demand, export and import of commodity i respectively.

On the other side, from the view of consumers, total domestic emission of commodity i in the region r, say $CN_{i,r}$, is represented by

$$CN_{i,r} = CI_{i,r} \times (X_{i,r} + FD_{i,r} - im_{i,r}) + \sum_{r' \neq r} CI_{i,r'} \times TRD_i(r', r) \qquad (8)$$

where $TRD_i(r',r)$ represents trade matrix of commodity i between region r' and r. The average carbon intensity of the domestic market $CIM_{i,r}$ can be then calculated by

$$CN_{i,r} = CI_{i,r} \times (X_{i,r} + FD_{i,r} - im_{i,r}) + \sum_{r' \neq r} CI_{i,r'} \times TRD_i(r', r) = CIM_{i,r} \times (X_{i,r} + FD_{i,r}) \qquad (9)$$

An alternative of indirect carbon emission $CM_{i,r}$ can be calculated as follows where energy consumption is embodied in the commodity flow.

$$CM_{i,r} = \sum_k CIM_{k,r} \times XIO_r(k,i) \qquad (10)$$

where $XIO_r(k,i)$ represent intermediate input from sector k to sector i. The responsible carbon emission in the final demand sectors can be calculated in a same way,

The above three emissions give identical values in the world total.

4. Brief introduction of an energy-economy model THERESIA

An integrated assessment model THERESIA - Toward Holistic Economy, Resource and Energy Structure for Integrated Assessment which deals with 15 world regions, 12 non-energy industry sectors and 7 energy sectors has been developed by the authors (Mori et.al., 2011) to assess the middle-to-long term global warming policies including the calculation of sectoral economic impacts and energy technology strategies. THERESIA includes energy technologies explicitly like existing bottom-up models and generates inter-temporal optimization solution. Thus, THERESIA enables us to see the middle-to-long term investment strategies which often appear in the energy technologies. THERESIA also provides inter regional transactions by tradable goods. This section briefly describes the structure of this model.

Figure.1 shows the conceptual framework of THERESIA. In Figure.2, the energy flows in the energy technology block is briefly shown. Both the primary and the secondary energy inputs are formulated in physical terms including multiple energy conversion technology options exhibited in Figure 2 unlike the existing CGE models. THERESIA assumes that all primary energy sources are once converted into secondary energies, i.e., thermal energy, petroleum products and electricity although some sectors actually use primary energy sources directly. Table 1 shows the definitions of the world disaggregated regions, industry sectors and energy sources.

Under the constraints on monetary balance conditions and technological constraints, THERESIA maximizes the discounted sum of the aggregated consumption functions. Further details are seen in the reference (Mori et.al., 2011).

THERESIA is currently constructed on the GTAP 5 database with 1997 base year while the newest version of GTAP 8 provides 2007 data. Since THERESIA gives dynamic optimization pathways, the calculated values of the second and the third periods can be compared with historical data. Some fundamental parameters such as technological progress and some cost assumptions can be thus calibrated.

			Intermediate Inputs				Final demand			
			Non-energy sectors		Energy sectors		trade	Invest-ments	Con-sumption	Output
			1	2	Primary	Secondary	m	I	C	Q
Int. Inputs	Non-energy Sectors	1	$X_{11}=Q_1 \cdot a_{11}$	$X_{12}=Q_2 \cdot a_{12}$	0	0	m_1	I_1	C_1	Q_1
		2	$X_{21}=Q_1 \cdot a_{21}$	$X_{22}=Q_2 \cdot a_{22}$	0	0	m_2	I_2	C_2	Q_2
	Energy Sectors	Primary	0	0	0	X_{pe}	m_p	0	0	EC_pre= P_pS
		Secondary	$X_{e1}=P_eE_1$	$X_{e2}=P_eE_2$	0	0	0	0	$C_e=P_eE_c$	EC= P_eE
Value Added		Capital K	$P_K \cdot K_1$	$P_K \cdot K_2$	VA_pre	VA_E				Y
		Labour L	$P_L \cdot L_1$	$P_L \cdot L_2$						
Output		Q	Q_1	Q_2	EC_pre= P_pS	EC= P_eE				Q

Figure 1. Conceptual framework of THERESIA (simplified)

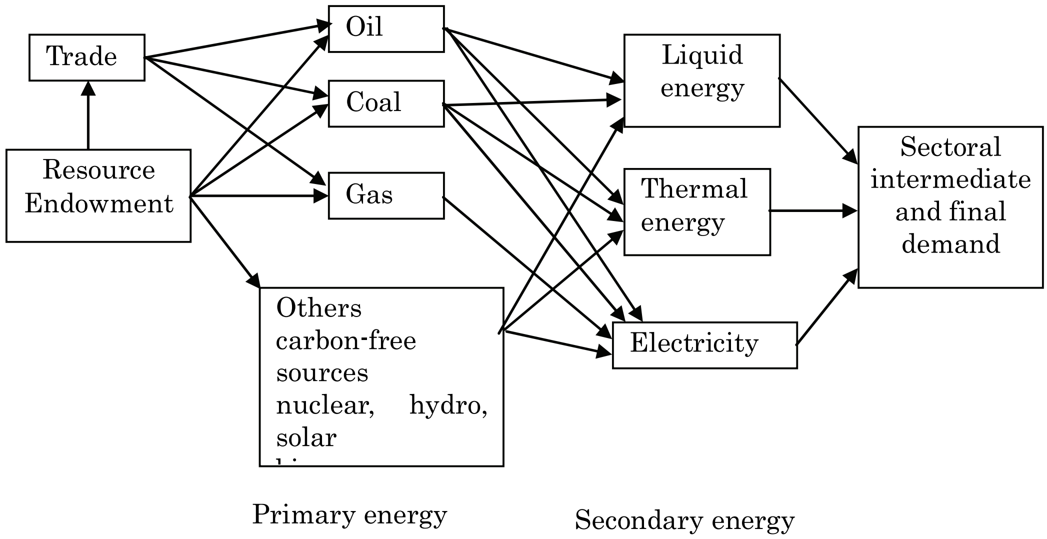

Figure.2 Energy flows in the THERESIA

Table 1 Definition of regions, industry sectors and energy

(a) Region

Code	Region
USA	USA, Canada
MCM	Central America
BRA	Brazil
SAM	South America
WEP	Western Europa
EEP	Eastern Europa
FSU	Former USSR
AFR	Africa
JPN	Japan
CHN	China
ASN	East-South Asia
IND	India
TME	Middle-East
ANZ	Oceania
XAP	Rest of the world

(b) Industry sectors

Code	Industry
INS	Iron and Steel
CPG	Chemical products, Paper Glass and Cement
TRN	Transportaion Machinery
OME	Other machinery
FPR	Food and Beverage
CNS	Construction
TWL	Textiles
OMF	Other manufacturing
AGR	Agriculture and Fishery
T_T	Transportation services
BSR	Business services
SSR	Social services

(c) Energy

	Code	Description
Primary	Coal	Coal
	Oil	oil
	Gas	Natural gas
	RNW	nuclear and renewables
Secondary	P_C	Oil products
	THM	Thermal energy
	ELC	Electricity

5. Simulation Results of THERESIA

5.1 BAU simulations

Firstly, I employ the option-4 for the allocation of carbon emission between energy conversion industry and other consumers including intermediate inputs and final consumption sectors. The equations in Section 3 are then imposed into the THERESIA model.

In this paper, as a preliminary result, I show the BAU simulations of THERESIA model for 1997-2057. Table 2(a) and Table 2(b) show the world total emissions of C, CN and CM. Total numbers are identical in all cases.

Table 3,4 and 5 show those of USA, JPN and CHN. Depending on the trade and industry structure, Ci, CNi and CMi show slightly different numbers by region.

In case of regional emissions, since the fossil consumption based carbon emissions, i.e. the conventional producer-based accounting, shown in the right side of the tables, denoted by "production based", include the secondary energy trade assuming the uniform carbon intensity, it does not show the same value to the sum of C_EmsSct, corresponding to the $C_{i,r}$ which are calculated based on the trade matrix reflecting the differences of carbon intensity among regions.

Figure 3 shows the comparison of CO2 emission by region and accounting measures in BAU. Figure 4 summarizes the relative emission of different accounting methods to the conventional producer-based values Ci.

Table 2 Comparison of carbon emission Ci, CNi and CMi in billion tons of carbon (World total)

(a) Industry sectors

World

C_EmsSct(t,WORLD, I_sct) production based sectoral carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.3430	0.4359	0.0163	0.0651	0.0823	0.0228	0.0342	0.2275	0.1353	0.7515	0.2237	0.2606	**6.4156**	**6.4156**
2007	0.6007	0.6609	0.0197	0.0947	0.0908	0.0380	0.0404	0.3185	0.1696	1.0832	0.3149	0.3482	**8.4576**	**8.4576**
2017	0.8494	0.9533	0.0272	0.1314	0.1064	0.0460	0.0513	0.4556	0.1966	1.3798	0.4610	0.4943	**11.1503**	**11.1503**
2027	1.0376	1.1369	0.0341	0.1643	0.1130	0.0490	0.0645	0.5676	0.2049	1.5929	0.5779	0.6398	**13.9207**	**13.9207**
2037	1.2894	1.3173	0.0411	0.1898	0.1156	0.0562	0.0758	0.6915	0.2160	1.8666	0.7034	0.8148	**17.2031**	**17.2031**
2047	1.4187	1.4112	0.0463	0.2037	0.1231	0.0477	0.0885	0.7615	0.2278	2.1075	0.8047	0.9803	**19.5737**	**19.5737**
2057	1.4980	1.3608	0.0499	0.1779	0.1387	0.0342	0.1035	0.7431	0.2342	2.1584	0.8525	1.0223	**20.4567**	**20.4567**

CI_EmsSct(t,WORLD, sct) sectoral domestic+import carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.3430	0.4359	0.0163	0.0651	0.0823	0.0228	0.0342	0.2275	0.1353	0.7515	0.2237	0.2606	**6.4156**	**6.4156**
2007	0.6007	0.6609	0.0197	0.0947	0.0908	0.0380	0.0404	0.3185	0.1696	1.0832	0.3149	0.3482	**8.4576**	**8.4576**
2017	0.8494	0.9533	0.0272	0.1314	0.1064	0.0460	0.0513	0.4556	0.1966	1.3798	0.4610	0.4943	**11.1503**	**11.1503**
2027	1.0376	1.1369	0.0341	0.1643	0.1130	0.0490	0.0645	0.5676	0.2049	1.5929	0.5779	0.6398	**13.9207**	**13.9207**
2037	1.2894	1.3173	0.0411	0.1898	0.1156	0.0562	0.0758	0.6915	0.2160	1.8666	0.7034	0.8148	**17.2031**	**17.2031**
2047	1.4187	1.4112	0.0463	0.2037	0.1231	0.0477	0.0885	0.7615	0.2278	2.1075	0.8047	0.9803	**19.5737**	**19.5737**
2057	1.4980	1.3608	0.0499	0.1779	0.1387	0.0342	0.1035	0.7431	0.2342	2.1584	0.8525	1.0223	**20.4567**	**20.4567**

CM_EmsSct(t,WORLD, sct) sectoral demand based carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.1530	0.2259	0.0564	0.1939	0.1057	0.1622	0.0440	0.0384	0.0579	0.1402	0.2071	0.1284	**6.4156**	**6.4156**
2007	0.2648	0.3357	0.0892	0.3491	0.1283	0.2932	0.0586	0.0538	0.0717	0.2029	0.2991	0.1846	**8.4576**	**8.4576**
2017	0.3727	0.4671	0.1365	0.4785	0.1482	0.4073	0.0745	0.0692	0.0835	0.2557	0.4198	0.2495	**11.1503**	**11.1503**
2027	0.4515	0.5544	0.1739	0.5785	0.1526	0.4637	0.0893	0.0802	0.0873	0.2941	0.5115	0.3056	**13.9207**	**13.9207**
2037	0.5652	0.6416	0.2139	0.6808	0.1537	0.5378	0.1056	0.0960	0.0911	0.3391	0.6102	0.3761	**17.2031**	**17.2031**
2047	0.6164	0.6931	0.2365	0.7211	0.1595	0.4598	0.1199	0.1067	0.0940	0.3764	0.6854	0.4363	**19.5737**	**19.5737**
2057	0.6251	0.6886	0.2283	0.7046	0.1726	0.3575	0.1363	0.1092	0.0968	0.3842	0.7106	0.4526	**20.4567**	**20.4567**

(b) Energy and final demand sectors

C_EmsSct(t,WORLD, I_sct) production based sectoral carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0000	0.0075	0.0038	0.5864	1.5091	0.1033	0.5588	0.5588	0.0000	1.6063	0.0000	**6.4156**	**6.4156**
2007	0.0000	0.0107	0.0062	0.7972	1.6771	0.1424	1.3876	1.3876	0.0000	2.0441	0.0000	**8.4576**	**8.4576**
2017	0.0000	0.0130	0.0085	1.1079	2.0563	0.1961	1.9893	1.9893	0.0000	2.6406	0.0000	**11.1503**	**11.1503**
2027	0.0000	0.0142	0.0129	1.8331	2.5426	0.2394	2.3602	2.3602	0.0000	3.1513	0.0000	**13.9207**	**13.9207**
2037	0.0000	0.0157	0.0159	2.6960	3.1699	0.2878	2.7405	2.7405	0.0000	3.7335	0.0000	**17.2031**	**17.2031**
2047	0.0000	0.0173	0.0146	3.2170	3.7116	0.3145	3.1424	3.1424	0.0000	4.1957	0.0000	**19.5737**	**19.5737**
2057	0.0000	0.0500	0.0309	3.6569	3.7515	0.3233	3.0507	3.0507	0.0000	4.4302	0.0000	**20.4567**	**20.4567**

CI_EmsSct(t,WORLD, sct) sectoral domestic+import carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0000	0.0075	0.0038	0.5864	1.5091	0.1033	0.5588	0.5588	0.0000	1.6074	0.0000	**6.4156**	**6.4156**
2007	0.0000	0.0107	0.0062	0.7972	1.6771	0.1424	1.3876	1.3876	0.0000	2.0442	0.0000	**8.4576**	**8.4576**
2017	0.0000	0.0130	0.0085	1.1079	2.0563	0.1961	1.9893	1.9893	0.0000	2.6164	0.0000	**11.1503**	**11.1503**
2027	0.0000	0.0142	0.0129	1.8331	2.5426	0.2394	2.3602	2.3602	0.0000	3.0959	0.0000	**13.9207**	**13.9207**
2037	0.0000	0.0157	0.0159	2.6960	3.1699	0.2878	2.7405	2.7405	0.0000	3.6404	0.0000	**17.2031**	**17.2031**
2047	0.0000	0.0173	0.0146	3.2170	3.7116	0.3145	3.1424	3.1424	0.0000	4.0780	0.0000	**19.5737**	**19.5737**
2057	0.0000	0.0500	0.0309	3.6569	3.7515	0.3233	3.0507	3.0507	0.0000	4.2706	0.0000	**20.4567**	**20.4567**

CM_EmsSct(t,WORLD, sct) sectoral demand based carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0043	0.0197	0.0067	0.5957	1.5190	0.1068	0.4154	0.4154	0.0943	2.4139	0.1421	**6.4156**	**6.4156**
2007	0.0063	0.0331	0.0120	0.8109	1.6905	0.1468	0.5250	0.5250	0.1882	3.0420	0.1967	**8.4576**	**8.4576**
2017	0.0093	0.0417	0.0173	1.1245	2.0725	0.2014	0.6964	0.6964	0.2536	3.9977	0.2698	**11.1503**	**11.1503**
2027	0.0113	0.0467	0.0278	1.8523	2.5602	0.2450	0.7976	0.7976	0.2997	4.8040	0.3314	**13.9207**	**13.9207**
2037	0.0138	0.0546	0.0366	2.7172	3.1888	0.2932	0.9747	0.9747	0.3245	5.7607	0.4026	**17.2031**	**17.2031**
2047	0.0159	0.0650	0.0368	3.2382	3.7308	0.3195	1.1009	1.1009	0.2718	6.7420	0.4487	**19.5737**	**19.5737**
2057	0.0138	0.1029	0.0519	3.6793	3.7708	0.3275	0.8898	0.8898	0.1442	7.2680	0.4320	**20.4567**	**20.4567**

Table 3 Comparison of carbon emission Ci, CNi and CMi in billions of carbon (USA)

(a) Industry sectors

USA

C_EmsSct(t,rgn, I_sct) production based sectoral carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.0491	0.1054	0.0057	0.0145	0.0164	0.0016	0.0058	0.0289	0.0165	0.2622	0.0769	0.0795	**1.6843**	**1.6702**
2007	0.1000	0.1522	0.0080	0.0217	0.0180	0.0018	0.0077	0.0443	0.0169	0.3030	0.0885	0.0969	**2.0110**	**1.9985**
2017	0.1356	0.2042	0.0105	0.0285	0.0232	0.0023	0.0105	0.0616	0.0171	0.3334	0.1144	0.1245	**2.4066**	**2.4066**
2027	0.1436	0.2499	0.0137	0.0382	0.0259	0.0022	0.0172	0.0802	0.0158	0.3361	0.1499	0.1568	**3.0496**	**3.0497**
2037	0.1534	0.2891	0.0162	0.0417	0.0211	0.0020	0.0188	0.1030	0.0135	0.3206	0.1651	0.1734	**3.6140**	**3.6140**
2047	0.1556	0.2723	0.0169	0.0421	0.0173	0.0016	0.0180	0.1413	0.0116	0.2827	0.1732	0.1805	**3.9333**	**3.9333**
2057	0.1398	0.2055	0.0177	0.0342	0.0147	0.0009	0.0169	0.1891	0.0118	0.2943	0.1694	0.1680	**3.7771**	**3.7771**

CI_EmsSct(t,rgn, sct) sectoral domestic+import carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.0521	0.1032	0.0054	0.0144	0.0163	0.0016	0.0074	0.0433	0.0151	0.2447	0.0771	0.0791	**1.6687**	**1.6702**
2007	0.0894	0.1418	0.0072	0.0196	0.0170	0.0018	0.0083	0.0400	0.0154	0.3043	0.0910	0.0974	**1.9725**	**1.9985**
2017	0.1177	0.1929	0.0098	0.0264	0.0172	0.0023	0.0109	0.0546	0.0166	0.3437	0.1214	0.1235	**2.3766**	**2.4066**
2027	0.1291	0.2357	0.0131	0.0352	0.0189	0.0022	0.0167	0.0707	0.0162	0.3455	0.1579	0.1571	**3.0169**	**3.0497**
2037	0.1331	0.2665	0.0156	0.0394	0.0149	0.0020	0.0183	0.0925	0.0133	0.3308	0.1764	0.1733	**3.5708**	**3.6140**
2047	0.1445	0.2573	0.0163	0.0409	0.0118	0.0016	0.0178	0.1304	0.0117	0.2937	0.1860	0.1810	**3.9128**	**3.9333**
2057	0.1264	0.1935	0.0172	0.0327	0.0097	0.0009	0.0160	0.1789	0.0120	0.3031	0.1777	0.1668	**3.7619**	**3.7771**

CM_EmsSct(t,rgn, sct) sectoral demand based carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.0205	0.0586	0.0191	0.0426	0.0223	0.0342	0.0068	0.0046	0.0099	0.0453	0.0654	0.0337	**1.6643**	**1.6702**
2007	0.0388	0.0796	0.0285	0.0693	0.0247	0.0441	0.0090	0.0069	0.0109	0.0563	0.0760	0.0409	**1.9474**	**1.9985**
2017	0.0513	0.0999	0.0359	0.0867	0.0300	0.0636	0.0120	0.0092	0.0117	0.0614	0.0937	0.0493	**2.3492**	**2.4066**
2027	0.0537	0.1155	0.0421	0.1015	0.0298	0.0673	0.0186	0.0108	0.0120	0.0634	0.1132	0.0562	**2.9868**	**3.0497**
2037	0.0575	0.1258	0.0471	0.1019	0.0234	0.0727	0.0198	0.0133	0.0113	0.0625	0.1198	0.0587	**3.5299**	**3.6140**
2047	0.0573	0.1180	0.0496	0.1042	0.0195	0.0666	0.0183	0.0183	0.0103	0.0568	0.1209	0.0577	**3.8931**	**3.9333**
2057	0.0501	0.0962	0.0526	0.0850	0.0185	0.0338	0.0166	0.0253	0.0093	0.0571	0.1177	0.0533	**3.7218**	**3.7771**

(b) Energy and final demand sectors

C_EmsSct(t,rgn, I_sct) production based sectoral carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0000	0.0005	0.0012	0.1344	0.4462	0.0154	0.0306	0.0449	0.0000	0.4097	0.0000	**1.6843**	**1.6702**
2007	0.0000	0.0005	0.0009	0.1590	0.4742	0.0208	0.0003	0.0130	0.0000	0.4840	0.0000	**2.0110**	**1.9985**
2017	0.0000	0.0006	0.0010	0.1791	0.5561	0.0265	0.0003	0.0005	0.0000	0.5774	0.0000	**2.4066**	**2.4066**
2027	0.0000	0.0007	0.0013	0.4530	0.6846	0.0319	0.0003	0.0004	0.0000	0.6487	0.0000	**3.0496**	**3.0497**
2037	0.0000	0.0006	0.0012	0.7911	0.7841	0.0348	0.0003	0.0004	0.0000	0.6840	0.0000	**3.6140**	**3.6140**
2047	0.0000	0.0005	0.0007	0.9935	0.8852	0.0340	0.0003	0.0004	0.0000	0.7061	0.0000	**3.9333**	**3.9333**
2057	0.0000	0.0000	0.0003	0.8453	0.9279	0.0271	0.0003	0.0004	0.0000	0.7140	0.0000	**3.7771**	**3.7771**

CI_EmsSct(t,rgn, sct) sectoral domestic+import carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0000	0.0020	0.0013	0.1344	0.4462	0.0154	0.0306	0.0449	0.0000	0.4097	0.0000	**1.6687**	**1.6702**
2007	0.0000	0.0005	0.0007	0.1590	0.4742	0.0208	0.0003	0.0130	0.0000	0.4840	0.0000	**1.9725**	**1.9985**
2017	0.0000	0.0002	0.0002	0.1791	0.5561	0.0265	0.0003	0.0005	0.0000	0.5773	0.0000	**2.3766**	**2.4066**
2027	0.0000	0.0000	0.0007	0.4530	0.6846	0.0319	0.0003	0.0004	0.0000	0.6486	0.0000	**3.0169**	**3.0497**
2037	0.0000	0.0000	0.0008	0.7911	0.7841	0.0348	0.0003	0.0004	0.0000	0.6839	0.0000	**3.5708**	**3.6140**
2047	0.0000	0.0000	0.0009	0.9935	0.8852	0.0340	0.0003	0.0004	0.0000	0.7061	0.0000	**3.9128**	**3.9333**
2057	0.0000	0.0000	0.0128	0.8453	0.9279	0.0271	0.0003	0.0004	0.0000	0.7140	0.0000	**3.7619**	**3.7771**

CM_EmsSct(t,rgn, sct) sectoral demand based carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0013	0.0025	0.0015	0.1400	0.4502	0.0174	0.0783	0.0811	0.0217	0.6258	0.0439	**1.6643**	**1.6702**
2007	0.0022	0.0029	0.0012	0.1660	0.4789	0.0233	0.0488	0.0743	0.0319	0.7277	0.0539	**1.9474**	**1.9985**
2017	0.0031	0.0031	0.0012	0.1865	0.5610	0.0293	0.0517	0.0803	0.0407	0.8817	0.0664	**2.3492**	**2.4066**
2027	0.0034	0.0031	0.0016	0.4616	0.6896	0.0346	0.0536	0.0849	0.0493	1.0116	0.0792	**2.9868**	**3.0497**
2037	0.0036	0.0029	0.0015	0.7999	0.7887	0.0372	0.0521	0.0941	0.0483	1.0920	0.0839	**3.5299**	**3.6140**
2047	0.0035	0.0027	0.0009	1.0013	0.8895	0.0358	0.0679	0.0880	0.0443	1.1545	0.0834	**3.8931**	**3.9333**
2057	0.0010	0.0001	0.0004	0.8520	0.9325	0.0285	0.0367	0.0643	0.0113	1.2316	0.0765	**3.7218**	**3.7771**

Table 4 Comparison of carbon emission Ci, CNi and CMi in billions of carbon (JPN)

(a) Industry sectors

JPN														
C_EmsSct(t,rgn, I_sct) production based sectoral carbon emission														
	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	**Total**	**PrimBase**
1997	0.0374	0.0319	0.0000	0.0063	0.0037	0.0041	0.0000	0.0110	0.0051	0.0369	0.0061	0.0135	**0.3229**	**0.3545**
2007	0.0770	0.1053	0.0000	0.0077	0.0044	0.0049	0.0000	0.0139	0.0059	0.0426	0.0082	0.0179	**0.4775**	**0.5248**
2017	0.1328	0.1972	0.0000	0.0092	0.0046	0.0057	0.0000	0.0172	0.0057	0.0475	0.0102	0.0225	**0.7281**	**0.7446**
2027	0.1578	0.2341	0.0000	0.0111	0.0071	0.0059	0.0000	0.0195	0.0060	0.0511	0.0127	0.0301	**0.8792**	**0.8796**
2037	0.1779	0.2626	0.0000	0.0113	0.0076	0.0056	0.0000	0.0219	0.0064	0.0557	0.0145	0.0382	**0.9974**	**0.9832**
2047	0.1808	0.2730	0.0000	0.0095	0.0083	0.0031	0.0000	0.0205	0.0067	0.0531	0.0135	0.0402	**0.9943**	**0.9672**
2057	0.1373	0.2117	0.0000	0.0067	0.0077	0.0024	0.0000	0.0205	0.0086	0.0556	0.0146	0.0405	**0.7776**	**0.8290**
CI_EmsSct(t,rgn, sct) sectoral domestic+import carbon emission														
	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	**Total**	**PrimBase**
1997	0.0392	0.0334	0.0002	0.0057	0.0047	0.0041	0.0010	0.0138	0.0063	0.0512	0.0065	0.0140	**0.3794**	**0.3545**
2007	0.0694	0.0999	0.0003	0.0083	0.0044	0.0049	0.0004	0.0127	0.0060	0.0480	0.0083	0.0183	**0.5174**	**0.5248**
2017	0.1201	0.1767	0.0003	0.0099	0.0045	0.0056	0.0002	0.0155	0.0057	0.0514	0.0131	0.0224	**0.7178**	**0.7446**
2027	0.1426	0.2217	0.0004	0.0124	0.0038	0.0058	0.0008	0.0174	0.0070	0.0648	0.0216	0.0305	**0.8730**	**0.8796**
2037	0.1573	0.2465	0.0005	0.0126	0.0033	0.0056	0.0008	0.0193	0.0065	0.0609	0.0278	0.0385	**0.9610**	**0.9832**
2047	0.1657	0.2562	0.0006	0.0107	0.0029	0.0032	0.0010	0.0177	0.0066	0.0586	0.0302	0.0405	**0.9525**	**0.9672**
2057	0.1179	0.1972	0.0002	0.0067	0.0075	0.0024	0.0000	0.0167	0.0085	0.0584	0.0229	0.0403	**0.7956**	**0.8290**
CM_EmsSct(t,rgn, sct) sectoral demand based carbon emission														
	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	**Total**	**PrimBase**
1997	0.0173	0.0138	0.0053	0.0197	0.0062	0.0165	0.0014	0.0027	0.0018	0.0067	0.0151	0.0090	**0.4027**	**0.3545**
2007	0.0337	0.0336	0.0106	0.0330	0.0084	0.0302	0.0028	0.0054	0.0026	0.0070	0.0242	0.0166	**0.5104**	**0.5248**
2017	0.0568	0.0611	0.0175	0.0495	0.0102	0.0528	0.0042	0.0087	0.0034	0.0086	0.0322	0.0234	**0.6902**	**0.7446**
2027	0.0667	0.0724	0.0213	0.0596	0.0168	0.0627	0.0048	0.0103	0.0041	0.0109	0.0404	0.0308	**0.8663**	**0.8796**
2037	0.0737	0.0799	0.0248	0.0612	0.0176	0.0650	0.0056	0.0118	0.0045	0.0113	0.0442	0.0383	**0.9387**	**0.9832**
2047	0.0710	0.0834	0.0266	0.0596	0.0204	0.0415	0.0057	0.0119	0.0051	0.0115	0.0424	0.0418	**0.9377**	**0.9672**
2057	0.0573	0.0685	0.0227	0.0373	0.0160	0.0226	0.0070	0.0102	0.0049	0.0099	0.0432	0.0387	**0.7680**	**0.8290**

(b) Energy and final demand sectors

C_EmsSct(t,rgn, I_sct) production based sectoral carbon emission													
	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	**Total**	**PrimBase**
1997	0.0000	0.0000	0.0000	0.0454	0.0607	0.0023	0.0373	0.0059	0.0000	0.0901	0.0000	**0.3229**	**0.3545**
2007	0.0000	0.0000	0.0000	0.0486	0.0789	0.0060	0.1693	0.1223	0.0000	0.1032	0.0000	**0.4775**	**0.5248**
2017	0.0000	0.0000	0.0000	0.0667	0.0987	0.0112	0.0165	0.0001	0.0000	0.1155	0.0000	**0.7281**	**0.7446**
2027	0.0000	0.0000	0.0000	0.0785	0.1231	0.0134	0.0004	0.0001	0.0000	0.1291	0.0000	**0.8792**	**0.8796**
2037	0.0000	0.0000	0.0000	0.0877	0.1413	0.0153	0.0004	0.0146	0.0000	0.1374	0.0000	**0.9974**	**0.9832**
2047	0.0000	0.0000	0.0000	0.0870	0.1306	0.0159	0.0004	0.0274	0.0000	0.1252	0.0000	**0.9943**	**0.9672**
2057	0.0000	0.0000	0.0000	0.0623	0.1209	0.0119	0.2041	0.1568	0.0000	0.1242	0.0000	**0.7776**	**0.8290**
CI_EmsSct(t,rgn, sct) sectoral domestic+import carbon emission													
	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	**Total**	**PrimBase**
1997	0.0000	0.0007	0.0003	0.0454	0.0607	0.0023	0.0373	0.0059	0.0000	0.0899	0.0000	**0.3794**	**0.3545**
2007	0.0000	0.0000	0.0002	0.0486	0.0789	0.0060	0.1693	0.1223	0.0000	0.1029	0.0000	**0.5174**	**0.5248**
2017	0.0000	0.0000	0.0004	0.0667	0.0987	0.0112	0.0165	0.0001	0.0000	0.1154	0.0000	**0.7178**	**0.7446**
2027	0.0000	0.0000	0.0001	0.0785	0.1231	0.0134	0.0004	0.0001	0.0000	0.1291	0.0000	**0.8730**	**0.8796**
2037	0.0000	0.0000	0.0000	0.0877	0.1413	0.0153	0.0004	0.0146	0.0000	0.1374	0.0000	**0.9610**	**0.9832**
2047	0.0000	0.0000	0.0000	0.0870	0.1306	0.0159	0.0004	0.0274	0.0000	0.1252	0.0000	**0.9525**	**0.9672**
2057	0.0000	0.0000	0.0006	0.0623	0.1209	0.0119	0.2041	0.1568	0.0000	0.1212	0.0000	**0.7956**	**0.8290**
CM_EmsSct(t,rgn, sct) sectoral demand based carbon emission													
	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	**Total**	**PrimBase**
1997	0.0000	0.0000	0.0000	0.0461	0.0614	0.0023	0.0365	0.0122	0.0088	0.1406	0.0039	**0.4027**	**0.3545**
2007	0.0000	0.0000	0.0000	0.0493	0.0796	0.0060	0.0140	0.0208	0.0122	0.1572	0.0050	**0.5104**	**0.5248**
2017	0.0000	0.0000	0.0000	0.0676	0.0995	0.0112	0.0133	0.0404	0.0144	0.1901	0.0063	**0.6902**	**0.7446**
2027	0.0000	0.0000	0.0000	0.0797	0.1240	0.0135	0.0341	0.0408	0.0173	0.2295	0.0081	**0.8663**	**0.8796**
2037	0.0000	0.0000	0.0000	0.0889	0.1422	0.0153	0.0331	0.0553	0.0159	0.2513	0.0092	**0.9387**	**0.9832**
2047	0.0000	0.0000	0.0000	0.0882	0.1315	0.0159	0.0531	0.0679	0.0101	0.2772	0.0088	**0.9377**	**0.9672**
2057	0.0000	0.0000	0.0000	0.0632	0.1218	0.0119	0.0141	0.0410	0.0020	0.2494	0.0083	**0.7680**	**0.8290**

Table 5 Comparison of carbon emission Ci, CNi and CMi in billions of carbon (CHN)

(a) Industry sectors

CHN

C_EmsSct(t,rgn, I_sct) production based sectoral carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.1013	0.1185	0.0048	0.0165	0.0150	0.0040	0.0135	0.0115	0.0242	0.0436	0.0210	0.0460	**0.9008**	**0.9256**
2007	0.1955	0.1580	0.0022	0.0189	0.0072	0.0050	0.0151	0.0080	0.0282	0.1158	0.0219	0.0368	**0.9453**	**1.1330**
2017	0.2447	0.1891	0.0039	0.0223	0.0037	0.0056	0.0173	0.0056	0.0287	0.1514	0.0270	0.0496	**1.1041**	**1.3710**
2027	0.3031	0.2196	0.0054	0.0259	0.0021	0.0054	0.0189	0.0057	0.0277	0.1681	0.0306	0.0559	**1.5392**	**1.6474**
2037	0.4238	0.2631	0.0065	0.0285	0.0025	0.0056	0.0205	0.0067	0.0279	0.1787	0.0332	0.0626	**2.0355**	**2.0125**
2047	0.5180	0.2908	0.0087	0.0355	0.0048	0.0062	0.0249	0.0083	0.0305	0.1789	0.0376	0.0724	**2.4825**	**2.3962**
2057	0.6765	0.3858	0.0154	0.0516	0.0145	0.0081	0.0400	0.0112	0.0382	0.1929	0.0598	0.1165	**3.0464**	**3.1478**

CI_EmsSct(t,rgn, sct) sectoral domestic+import carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.1021	0.1135	0.0046	0.0139	0.0146	0.0040	0.0104	0.0096	0.0242	0.0445	0.0193	0.0456	**0.9117**	**0.9256**
2007	0.1914	0.1380	0.0025	0.0175	0.0114	0.0050	0.0118	0.0298	0.0296	0.0903	0.0217	0.0382	**1.1084**	**1.1330**
2017	0.2377	0.1638	0.0043	0.0211	0.0146	0.0056	0.0145	0.0703	0.0314	0.1131	0.0274	0.0494	**1.3767**	**1.3710**
2027	0.2956	0.1863	0.0059	0.0249	0.0145	0.0054	0.0164	0.0896	0.0313	0.1236	0.0313	0.0556	**1.6665**	**1.6474**
2037	0.3814	0.2192	0.0070	0.0276	0.0148	0.0056	0.0188	0.1100	0.0314	0.1340	0.0371	0.0625	**2.0117**	**2.0125**
2047	0.4451	0.2486	0.0092	0.0346	0.0181	0.0062	0.0229	0.1278	0.0339	0.1443	0.0429	0.0722	**2.3938**	**2.3962**
2057	0.6655	0.3782	0.0154	0.0499	0.0238	0.0081	0.0359	0.1331	0.0420	0.1742	0.0610	0.1162	**3.2447**	**3.1478**

CM_EmsSct(t,rgn, sct) sectoral demand based carbon emission

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total	PrimBase
1997	0.0421	0.0516	0.0069	0.0504	0.0111	0.0415	0.0135	0.0068	0.0144	0.0137	0.0257	0.0164	**0.8979**	**0.9256**
2007	0.0871	0.0852	0.0042	0.0882	0.0079	0.0522	0.0182	0.0059	0.0146	0.0328	0.0375	0.0188	**1.0804**	**1.1330**
2017	0.1169	0.1086	0.0077	0.1083	0.0044	0.0595	0.0224	0.0050	0.0153	0.0434	0.0494	0.0279	**1.3746**	**1.3710**
2027	0.1435	0.1297	0.0115	0.1346	0.0025	0.0613	0.0247	0.0056	0.0152	0.0496	0.0561	0.0324	**1.6690**	**1.6474**
2037	0.1981	0.1565	0.0146	0.1565	0.0030	0.0682	0.0269	0.0068	0.0158	0.0543	0.0611	0.0374	**1.9903**	**2.0125**
2047	0.2430	0.1724	0.0179	0.1799	0.0057	0.0732	0.0314	0.0081	0.0170	0.0553	0.0678	0.0429	**2.3731**	**2.3962**
2057	0.3027	0.2168	0.0346	0.2807	0.0151	0.1116	0.0483	0.0107	0.0230	0.0613	0.0967	0.0641	**3.3318**	**3.1478**

(b) Energy and final demand sectors

C_EmsSct(t,rgn, I_sct) production based sectoral carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0000	0.0000	0.0001	0.0604	0.2236	0.0208	0.0419	0.0173	0.0000	0.2006	0.0000	**0.9008**	**0.9256**
2007	0.0000	0.0000	0.0001	0.0696	0.2132	0.0235	0.1882	0.0002	0.0000	0.2144	0.0000	**0.9453**	**1.1330**
2017	0.0000	0.0000	0.0001	0.1137	0.2235	0.0277	0.3367	0.0675	0.0000	0.2595	0.0000	**1.1041**	**1.3710**
2027	0.0000	0.0000	0.0001	0.2210	0.2266	0.0334	0.3776	0.2709	0.0000	0.2965	0.0000	**1.5392**	**1.6474**
2037	0.0000	0.0000	0.0001	0.3098	0.2626	0.0427	0.4052	0.4297	0.0000	0.3363	0.0000	**2.0355**	**2.0125**
2047	0.0000	0.0000	0.0001	0.3517	0.4078	0.0493	0.4203	0.5079	0.0000	0.3694	0.0000	**2.4825**	**2.3962**
2057	0.0000	0.0000	0.0001	0.3641	0.5956	0.0701	0.1012	0.0002	0.0000	0.5073	0.0000	**3.0464**	**3.1478**

CI_EmsSct(t,rgn, sct) sectoral domestic+import carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0000	0.0002	0.0001	0.0604	0.2236	0.0208	0.0419	0.0173	0.0000	0.2005	0.0000	**0.9117**	**0.9256**
2007	0.0000	0.0000	0.0026	0.0696	0.2132	0.0235	0.1882	0.0002	0.0000	0.2126	0.0000	**1.1084**	**1.1330**
2017	0.0000	0.0000	0.0065	0.1137	0.2235	0.0277	0.3367	0.0675	0.0000	0.2522	0.0000	**1.3767**	**1.3710**
2027	0.0000	0.0002	0.0094	0.2210	0.2266	0.0334	0.3776	0.2709	0.0000	0.2957	0.0000	**1.6665**	**1.6474**
2037	0.0000	0.0001	0.0112	0.3098	0.2626	0.0427	0.4052	0.4297	0.0000	0.3360	0.0000	**2.0117**	**2.0125**
2047	0.0000	0.0001	0.0100	0.3517	0.4078	0.0493	0.4203	0.5079	0.0000	0.3691	0.0000	**2.3938**	**2.3962**
2057	0.0000	0.0000	0.0059	0.3641	0.5956	0.0701	0.1012	0.0002	0.0000	0.5060	0.0000	**3.2447**	**3.1478**

CM_EmsSct(t,rgn, sct) sectoral demand based carbon emission

	COL	OIL	GAS	P_C	ELC	THM	Imp	Exp	Cpf	Csm	GcS	Total	PrimBase
1997	0.0010	0.0006	0.0001	0.0613	0.2243	0.0208	0.0216	0.0353	0.0115	0.2751	0.0229	**0.8979**	**0.9256**
2007	0.0007	0.0008	0.0002	0.0709	0.2141	0.0235	0.0510	0.0765	0.0154	0.3086	0.0193	**1.0804**	**1.1330**
2017	0.0007	0.0009	0.0002	0.1161	0.2245	0.0277	0.1006	0.0962	0.0166	0.3909	0.0241	**1.3746**	**1.3710**
2027	0.0006	0.0009	0.0002	0.2237	0.2275	0.0335	0.1242	0.1123	0.0185	0.4590	0.0267	**1.6690**	**1.6474**
2037	0.0007	0.0011	0.0002	0.3129	0.2636	0.0427	0.1509	0.1611	0.0185	0.5323	0.0293	**1.9903**	**2.0125**
2047	0.0007	0.0012	0.0002	0.3549	0.4088	0.0493	0.1718	0.1826	0.0216	0.5993	0.0335	**2.3731**	**2.3962**
2057	0.0023	0.0044	0.0002	0.3693	0.5969	0.0702	0.1644	0.0715	0.0247	0.8544	0.0511	**3.3318**	**3.1478**

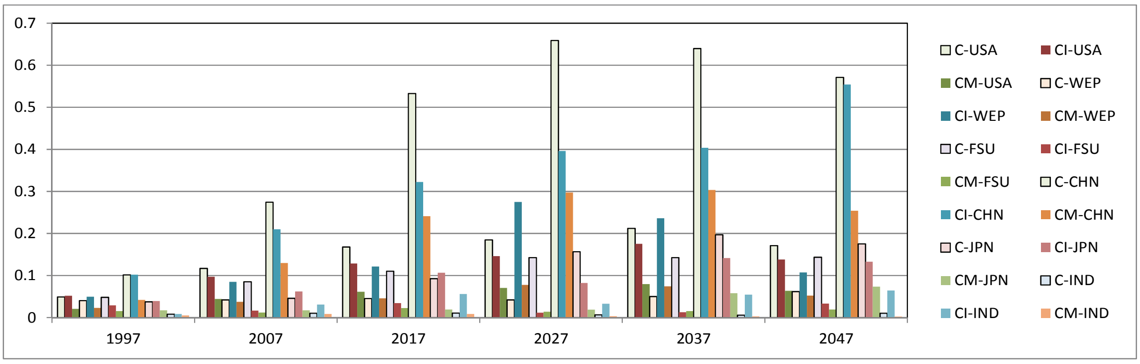

Figure.3 Comparison of CO2emission ; by accounting measure in BAU

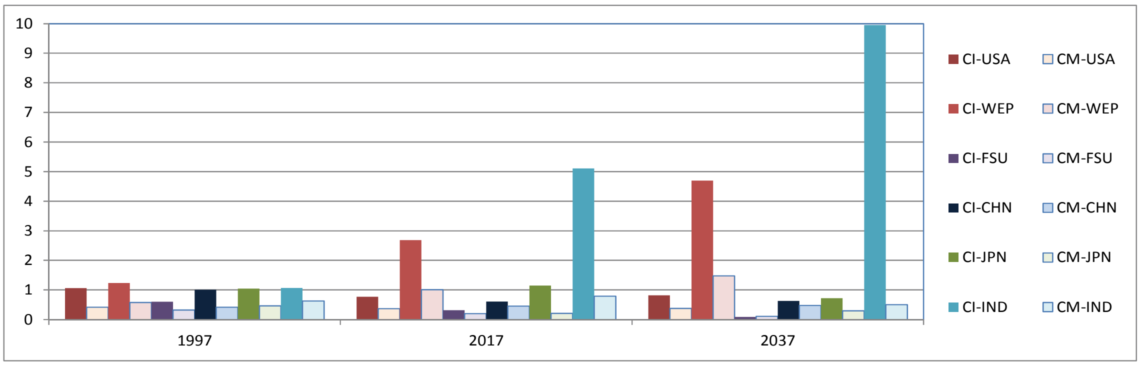

Figure 4 Relative emission of CI and CM : when C<CI indirect emission of import is large.

5.2 The effects of carbon accounting methods in the partial participation cases

In this study, I calculate various simulation cases based on the above three accounting policies under different carbon control targets, different sectoral participation cases and different regional participation cases. The global carbon control policy scenarios with different carbon emission reduction are the following W-85 and W-70.

Scenario W-85 : All regions and all industry sectors (except for energy conversion sectors) participate in carbon emission reduction by 15% from baseline (BAU) after 2017.

Scenario W-70 : All regions and all industry sectors (except for energy conversion sectors) participate in carbon emission reduction by 30% from baseline (BAU) after 2017.

Next, I employ the scenarios where partial sectors and regions participate in the carbon control policies.

Scenario A1-85: Only INS (iron and steel) and CPG (chemical products) industries participate in carbon reduction by 15% from BAU based on producer-based (C_Ems) accounting.

Scenario A2-85: Only INS (iron and steel) and CPG (chemical products) industries participate in carbon reduction by 15% from BAU based on trade-adjusted (CI_Ems) accounting.

Scenario A3-85: Only INS(iron and steel) and CPG(chemical products) industries participate in carbon reduction by 15% from BAU based on commodity-embodied (CM_Ems) accounting.

where 9 regions of world 15 regions shown in Table 6 participate in the emission control agreement.

Table 6 Regional partial participation cases in scenario-A

1	0	1	0	1	1	1	0	1	1	0	1	0	1	0
USA	MCM	BRA	SAM	WEP	EEP	FSU	AFR	JPN	CHN	IND	ASN	TME	ANZ	XAP

1: participate 2:not participate

Similarly, scenario A1-70, A2-70 and A3-70 represent the 30% carbon reduction cases corresponding to A1-85, A2-85 and A3-85, respectively.

In the scenario-B, MCM, SAM and IND join the emission control agreement. Thus 12 regions of world 15 regions participate in emission control. Scenario-C involves the participation of power generation industry in addition to the scenario-A. Both in scenario-B and scenario-C, 15% and 30% carbon reduction cases are calculated.

Thus, I calculate 21 scenarios in total, i.e., BAU, W-85, W-70, A1-85, A2-85, A3-85, B1-85, B2-85, B3-85, C1-85, C2-85, C3-85, A1-70, A2-70, A3-70, B1-70, B2-70, B3-70, C1-70, C2-70 and C3-70.

Figure 5 shows the comparison of global GDP losses from BAU. Since the global uniform reduction cases, W-70 and W-85, show high economic losses, In Figure 6 these two are omitted to see the comparison among accounting cases clearly. In these figures A2 and B2 cases, trade-adjusted (CI_Ems) accounting, show smaller GDP losses than others.

Figure 7 and Figure 8 compare the carbon emission reduction profiles from BAU in INS (iron and steel industry) sector and world total, respectively. The emission reduction of INS sector in A2 is apparently smaller than A1 and A3in Figure 7. However, world total emissions are not significantly different among accounting cases.

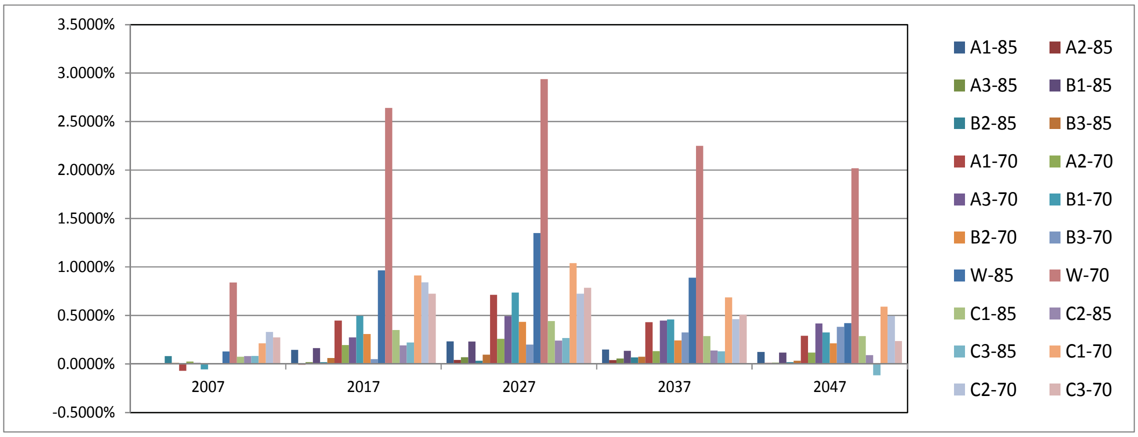

Figure 5 Comparison of GDP Losses among scenarios from BAU

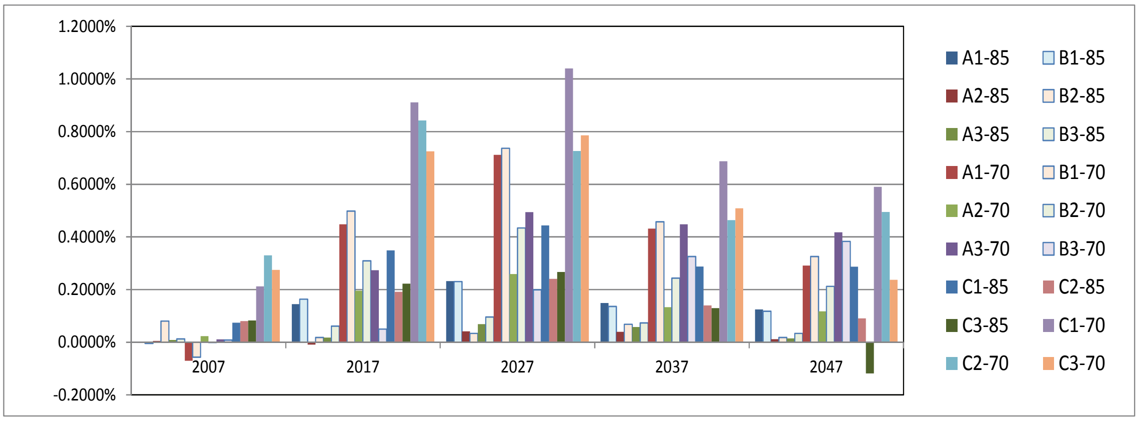

Figure 6 Comparison of GDP Losses among scenarios from BAU
(W-85 and W-70 are omitted.)

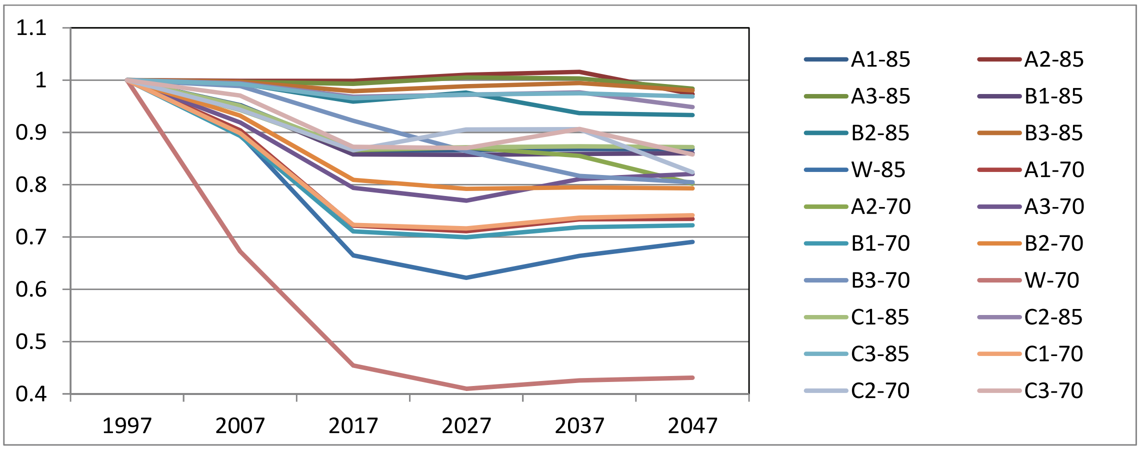

Figure 7 Relative carbon emission reductions to BAU
in INS (iron and steel industry) sector

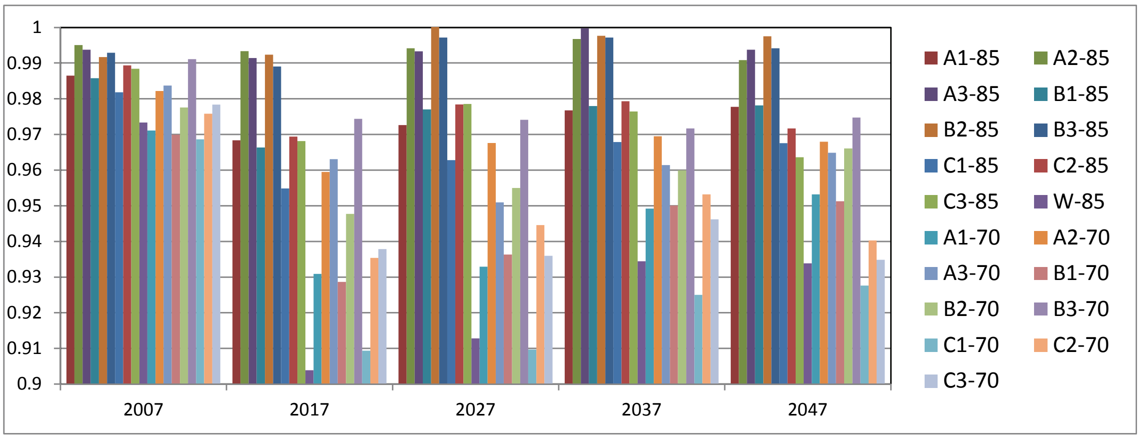

Figure 8 Relative carbon emission reductions to BAU in world total

Figure 9 shows the relative carbon emission reductions to BAU. It is shown that Carbon emission in power generation sector is almost constant among scenarios except for C-scenarios (direct carbon emission control for ELC sector) while around 30% of carbon emission of power generation sector is attributed to customer even in W-85 and W-70 scenarios. In other words, carbon control policy in only INS and CPG sectors does not affect the power generation sector behavior. We cannot hope the indirect effects of the carbon control policies when limited sectors participate in the agreement.

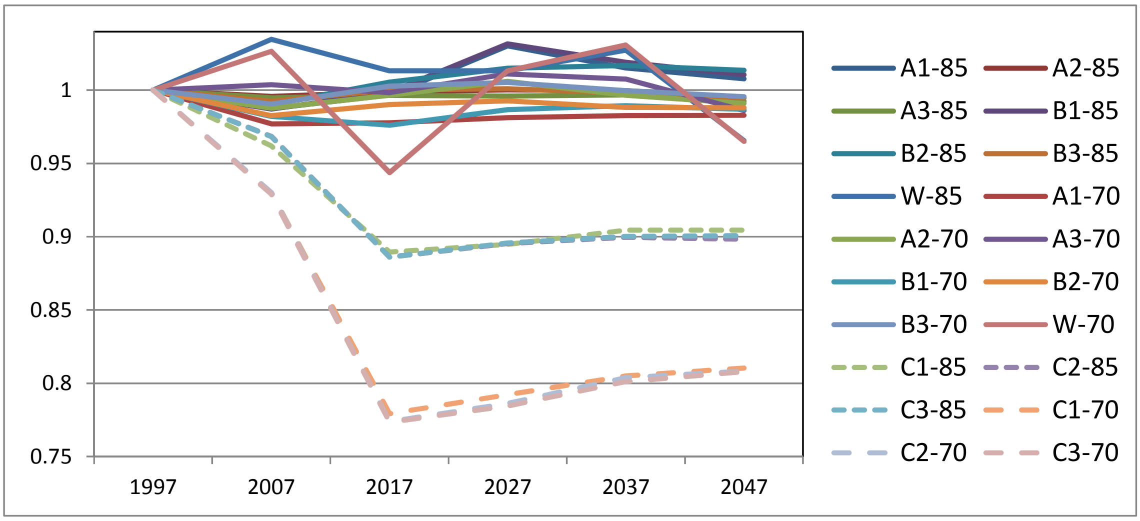

Figure 9 Relative carbon emission reductions to BAU in power generation sector

Finally, I compare the carbon emissions of INS (iron and steel industry) sector among scenarios in Table 7 (a) and (b) to see how the "carbon leakage" differently appears depending on the accounting method. Table 7(c) shows the world carbon emissions in three accounting method in scenario-A.

Table 7(a) Carbon emissions of INS (Iron & Steal industry) sector in Group-A regions (in billion tons of carbon)

	BAU (Gt-C)		A1-85		A2-85	
	C0_GroupA	CI_GroupA	**C0_GroupA**	CI_GroupA	C0_GroupA	**CI_GroupA**
1997	0.313	0.311	**100.0%**	**100.0%**	100.0%	100.0%
2007	0.618	0.552	**95.0%**	101.0%	100.2%	**105.5%**
2017	1.022	0.894	**85.0%**	87.1%	99.8%	**84.9%**
2027	1.295	1.168	**85.0%**	84.0%	101.5%	**83.9%**
2037	1.389	1.213	**85.0%**	88.3%	102.1%	**85.0%**
2047	1.230	1.123	**85.0%**	86.3%	97.2%	**85.0%**

Table 7(b) Carbon emissions of INS (Iron & Steal industry) sector in world total (in billion tons of carbon)

	BAU (Gt-C)		A1-85		A2-85	
	C0_World	CI_World	**C0_World**	CI_World	C0_World	**CI_World**
1997	0.343	0.343	**100.0%**	100.0%	100.0%	**100.0%**
2007	0.669	0.669	**95.2%**	95.2%	99.9%	**99.9%**
2017	1.116	1.113	**86.3%**	86.5%	99.5%	**99.8%**
2027	1.434	1.436	**86.6%**	86.6%	101.2%	**101.0%**
2037	1.559	1.561	**86.8%**	86.8%	101.7%	**101.6%**
2047	1.397	1.398	**86.7%**	86.7%	97.3%	**97.3%**

Table 7(c) Global carbon emission in total (in billion tons of carbon)

	BAU	A1-85	A2-85	A1-85	A2-85
1997	6.416	6.416	6.416	100.0%	**100.0%**
2007	8.563	8.448	8.521	98.7%	**99.5%**
2017	11.811	11.437	11.733	96.8%	**99.3%**
2027	14.680	14.278	14.594	97.3%	**99.4%**
2037	17.456	17.050	17.400	97.7%	**99.7%**
2047	19.224	18.797	19.048	97.8%	**99.1%**

These figures show and suggest some interesting findings: first, accounting policy on “producer based” causes “carbon import”. or "carbon leakage" as has been pointed out. Second, carbon control on “trade-adjusted” or "demand based" emission accounting causes larger “carbon export”. Third, the outcome of partial participation seems small. These findings suggest how the carbon control measures should be implemented.

6. Conclusion

This study proposes two alternatives for the evaluation of indirect responsible carbon emission by sector. I described a method to evaluate the partial participation in terms of "region" and "sector". The allocation of carbon emission responsibility between energy conversion sector and consumers are also shown. Then the effects of carbon emission accounting are evaluated based on the expanded THERESIA model. The findings are summarized as follows:

First, the effects of sectoral emission control under partial participation are small, but "producer based" accounting seems to suppress the carbon emission in total.

Second, trade adjusted carbon emission accounting seems to cause larger "carbon export" than the "carbon import" which appears in the "producer based" accounting.

The "carbon leakage" or "indirect carbon import" issue has often been pointed out and thus demand-side based emission accounting is prosed as an alternative. However, "carbon export" appears more seriously in this study. Since "carbon leakage" might promote foreign direct investment and technology transfer comparing with "carbon export" situation, it is still a question whether the demand-based accounting is more preferable to the conventional producer based one. Further research is needed to compare these accounting measures.

The next stage of this study is how the difference of emission allocation options affects the industry and technology allocation by the carbon emission control policy.

Acknowledgement

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