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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 database, 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 participate, (2) only ANNEX-I regions in Kyoto protocol participate in the warming coalition, and (3) there are 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 Background

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

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

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

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

$$\text{GHG} = \mathbf{c}^{\mathrm{T}}\mathbf{x} = (I - A)^{-}\mathbf{f} = f_1\mathbf{c}^{\mathrm{T}}\mathbf{b}_1 + f_2\mathbf{c}^{\mathrm{T}}\mathbf{b}_2 \ldots f_n\mathbf{c}^{\mathrm{T}}\mathbf{b}_n \tag{2}$$

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 multiregional 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 (2008) 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:

$$f_r^{\text{cons}} = f_r^{\text{prod}} - f_r^{e} + f_r^{m} = f_r^{\text{prod}} - f_r^{\text{BEET}} \tag{3}$$

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 allocation 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 emissions—no allocation, 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 allocation. No allocation would generate no incentive. In May, 2009, a governmental committee in Japan (EPA 2008) 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 emission quota 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 μ, N and EP be the energy conversion efficiency, carbon intensity of primary energy and primary energy input, respectively, the carbon emissions allocation of conversion firm (Ce) and consumer (Cd) are represented by

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

where ES denotes secondary energy demand. As can be seen, efficiency-based carbon intensity for the consumer is identical with average primary energy carbon intensity F.

One can thus evaluate the carbon emission allocation of the energy conversion sector as well as the distributed 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 given in Sect. 1.

The emission allocation issue is also focused on by the greenhouse gas protocol, Corporate Value Chain (Scope 3) Accounting–Reporting Standard (Greenhouse Gas Protocol 2013). In order to account and allocate the greenhouse gas emissions in the global supply chains, this report proposes emission accounting standards involving three emission categories, i.e., direct emissions as Scope 1 including emissions from operations that are owned or controlled by the reporting company, Scope 2 including emissions from the generation of purchased or acquired electricity, steam, heating or cooling consumed by the reporting company and Scope 3 including all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions. The Scope 3 report also proposes the procedure to allocate the total emissions of the facility or the company to the factors if needed. The purpose of this study shares the concept of the above Corporate Value Chain Scope 3, even if this deals with the emissions of the certain production system while this study focuses on the macroeconomic impacts of carbon emission policies. Therefore, it is expected that the method proposed in this paper will contribute to the assessment of Scope 3 expanded to the macroeconomic impacts.

In this study, I employ the option 4 in the above to allocate the emission allocation 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 allocation 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

$$\mathrm{CT}_e = \sum\nolimits_i F_{ie} \times \mathrm{NF}_i, \mu_e = \frac{\mathrm{ES}}{\sum_i F_{ie}}, \quad N_e = \frac{\mu_e \times \mathrm{CT}_e}{\mathrm{ES}} = \frac{\sum_i F_{ie} \times \mathrm{NF}_i}{\sum_i F_{ie}} \tag{5}$$

where μ_e, NF_i, F_{ie} and ES denote power conversion efficiency, carbon intensity of primary energy input of type i (see Table 1c), input of primary energy i for conversion sector and total converted secondary energy supply. Again, efficiency-based allocated carbon intensity NI_e is identical with average input primary carbon intensity. Thus, total allocated emission of the consumer C_c and the power producer C_e are

$$C_c = \mathrm{NI}_e \times E_c = \mu_e \times \mathrm{CT}_e, \quad C_e = (1 - \mu_e) \times \mathrm{CT}_e \tag{6}$$

Table 1 Definition of regions, industry sectors and energy

Code	Region
(a) *Regions*	
USA	USA, Canada
MCM	Central America
BRA	Brazil
SAM	South America
WEP	Western Europe
EEP	Eastern Europe
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
Code	**Industry**
(b) *Industry*	
INS	Iron and steel
CPG	Chemical products, paper, glass and cement
TRN	Transportation 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
Code	**Description**
(c) *Energy*	
Primary	
Coal	Coal
Oil	Oil
Gas	Natural gas
RNW	Nuclear and renewables
Secondary	
P_C	Oil products
THM	Thermal energy
ELC	Electricity
Code	**Description**
(d) *Final demand sectors*	
Imp	Import
Exp	Export

Table 1 continued

Code	Description
Cpf	Investment
Csm	Consumption
GcS	Governmental consumption

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 procedure to allocate the carbon emission among industry sectors. Let F_{ki} and Nf_k denote the type k secondary energy input and its carbon intensity for industry sector i. Then, the carbon intensity of the products NI_i is

$$\sum\nolimits_k F_{ki} \times \mathrm{Nf}_k = C_i = \mathrm{NI}_i \times Q_i = \mathrm{NI}_i \times (X_i + \mathrm{FD}_i + \mathrm{ex}_i - \mathrm{im}_i) \times Q_i \tag{7}$$

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. Since C_i accounts for the energy input-based carbon emission, this C_i can be interpreted as "producer-based" accounting.

When the international trade is considered, the above should be expanded to reflect the difference in carbon intensity among regions. Total domestic emission of commodity i in the region r, say $\mathrm{CN}_{i,r}$, is represented by

$$\mathrm{CN}_{i,r} = \mathrm{NI}_{i,r} \times \left(X_{i,r} + \mathrm{FD}_{i,r} - \mathrm{im}_{i,r}\right) + \sum\nolimits_{r' \neq r} \mathrm{NI}_{i,r'} \times \mathrm{TRD}_i(r', r) \tag{8}$$

where $\mathrm{TRD}_i\ (r', r)$ represents trade matrix of commodity i between region r' and r. NI_i is also expanded to $\mathrm{NI}_{i,r}$ to represent the regional difference. This CN_i can be interpreted as "trade-adjusted" accounting.

The average carbon intensity of the domestic market $\mathrm{CIM}_{i,r}$ can be then calculated by

$$\mathrm{CN}_{i,r} = \mathrm{NI}_{i,r} \times \left(X_{i,r} + \mathrm{FD}_{i,r} - \mathrm{im}_{i,r}\right) + \sum\nolimits_{r' \neq r} \mathrm{NI}_{i,r'} \times \mathrm{TRD}_i(r', r) = \mathrm{CIM}_{i,r} \times \left(X_{i,r} + \mathrm{FD}_{i,r}\right) \tag{9}$$

An alternative of indirect carbon emission $\mathrm{CM}_{i,r}$ can be calculated as follows where energy consumption is embodied in the commodity flow. This $\mathrm{CM}_{i,r}$ can be interpreted as "commodity-embodied" accounting.

$$\mathrm{CM}_{i,r} = \sum\nolimits_k \mathrm{CIM}_{k,r} \times \mathrm{XIO}_r(k, i) \tag{10}$$

where $\mathrm{XIO}_r\ (k, i)$ 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,

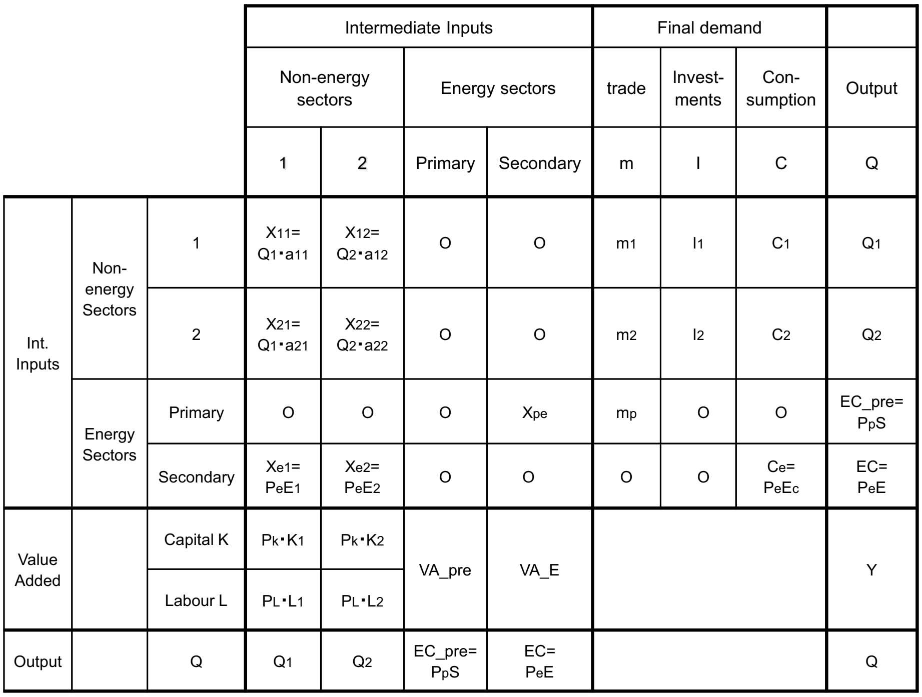
The above three emissions, i.e., C_i, CN_i and CM_i, give identical values in the world total.

4 Brief introduction of an energy-economic 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 with two intermediate sectors, one primary energy inputs and one secondary energy inputs or the certain region. Let *i* denote the non-energy industry sector *i*. Similar to the conventional input–output tables, X_{ij}, a_{ij}, Q_i, m_i, I_i and C_i denote intermediate input from sector *i* to sector *j*, input-out coefficient from industry sector *i* to sector *j*, total output of sector *i*, net import trade of sector *i*, and investment from sector *i*, respectively. The block corresponding to the energy sectors is slightly expanded from conventional IO model.

For the primary energy sector, THERESIA assumes that all primary energies are once input and converted to secondary energy sector. Xpe, mp and EC_Pre represent monetary transaction from primary energy to secondary energy, net import and total output of primary energy industry sector. S and Pb denote total input of primary energy in physical term and price per unit primary energy.



			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	$X_{11}=Q_1\cdot a_{11}$	$X_{12}=Q_2\cdot a_{12}$	O	O	m_1	I_1	C_1	Q_1
		2	$X_{21}=Q_1\cdot a_{21}$	$X_{22}=Q_2\cdot a_{22}$	O	O	m_2	I_2	C_2	Q_2
	Energy Sectors	Primary	O	O	O	X_{pe}	m_p	O	O	EC_pre= P_pS
		Secondary	$X_{e1}=P_eE_1$	$X_{e2}=P_eE_2$	O	O	O	O	$C_e=P_eE_c$	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

Fig. 1 Conceptual framework of THERESIA (simplified)

X_{ej} and C_e denote the monetary input from secondary energy to industry sector j and to the final energy consumption, respectively, while E_j and E_c represent the secondary energy flow in physical term to the industry sector j and final consumption where P_e represents the price of unit secondary energy flow. Thus, $X_{ej} = P_e E_j$ holds. Similarly, for the total output in monetary term of secondary sector EC and the total secondary energy supply E in physical term, $\mathrm{EC} = P_e E$ holds.

In the non-energy industry sectors, value added is distributed to the capital and labor similar to the conventional IO matrix. In THERESIA model, capital costs of energy facilities and labor inputs of energy sectors are aggregated into one value-added sector, since available data source for energy technologies mostly describes annualized capital costs and operation and management (O&M) costs.

Total outputs of the above economy and GDP are then represented by Q and Y.

Since THERESIA explicitly includes the physical energy flow, both the primary and the secondary energy can be disaggregated into more detailed primary energy sources and conversion technologies similar to the existing bottom-up energy technology models such as MARKAL (Loulou et al. 2004) and DNE-21 (Akimoto et al. 2004). In Fig. 2, the energy flows in the energy technology block is briefly shown.

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. Under the constraints on monetary balance conditions and technological constraints, THERESIA maximizes the discounted sum of the aggregated consumption functions.

When carbon emission reduction policy is imposed, fuel switches and the adoption of different energy-related technologies occur as well as the substitution among input factors, i.e., energy, capital and labor and the final consumption, and consumption pattern changes among commodities. International trading also varies. For instance, carbon emission limit causes replacement of conventional coal-fired power generation plant by modern gas fired ones with high costs. Higher electricity price caused by the

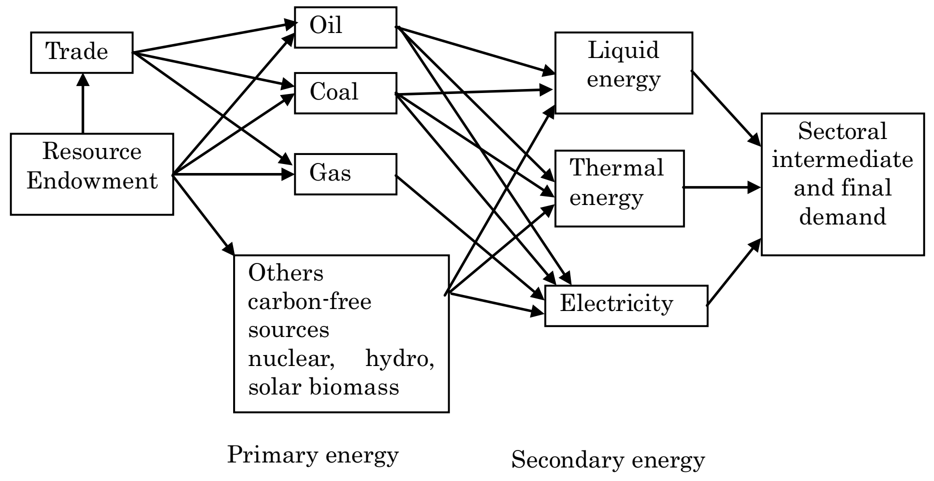


Fig. 2 Energy flows in the THERESIA

technological changes spreads to other relative prices and to the whole economic structure through international trade. Further details are seen in the reference (Mori et al. 2011).

Table 1 shows the definitions of the world disaggregated regions, industry sectors and energy sources.

Since THERESIA includes 15 world regions, 12 non-energy industry sectors and 7 energy sectors, some key equation and parameters are documented in this paper. Other detailed equations and parameters are shown in the exiting paper (Mori et al. 2011).

For the non-energy industry sectors, THERESIA assumes fixed coefficient input relationship between intermediate inputs excluding energy inputs and value-added plus secondary energy input. In THERESIA, the production functions of industry sector i at period t of the region h are represented by

$$\mathrm{YE}_{i,t}^{h} = A_i^h(t) \cdot \left[\left\{ \left(K_{i,t}^{h\;-\mu_i^h} + B_i^h \cdot \mathrm{LH}_{i,t}^{h\;-\mu_i^h} \right)^{-1/\mu_i^h} \right\}^{\lambda_i^h} \mathrm{LL}_{i,t}^{h\;1-\lambda_i^h} \right]^{\beta_i^h} \times \left[\prod_k E_{i,k,t}^{h\;\;\theta_{i,k}^h} \right]^{1-\beta_i^h} \tag{11}$$

where i, $\mathrm{YE}_{i,t}^h$ $\mathrm{LH}_{i,t}^h$ $\mathrm{LL}_{i,t}^h$ $K_{i,t}^h$and $E_{i,k,t}^h$denote value added plus energy cost, capital stock, professional labor input, other non-professional labor input, and k-type secondary energy inputs, respectively. $A_i^h(t), B_i^h, \alpha_i^h, \beta_i^h, \gamma_i^h, \mu_i^h, \lambda_i^h$ and $\theta_{i,j}^h$ are the parameters where $A_{i,t}^h(t)$ incorporates the technological progress. As can be seen in the above, THERESIA basically employs the Cobb–Douglas functions except for the relationship between capital stock and professional labor input represented by the CES function. The elasticity of substitution between capital stock and professional labor input is here assumed to be 0.2 uniformly. Although, needless to say, CES or other sophisticated function type would have been more preferable, however, in order to avoid the uncertainty on the parameter estimation and data availability, THERESIA currently employs the above simplified form. Technological progress rate is adjusted to represent the historical economic growth from 1997 to 2007.

THERESIA employs the aggregated consumption function and maximizes their discount sum as follows:

$$\max \cdot \Phi = \sum\nolimits_t (1-r)^t \sum\nolimits_h w_h \sum\nolimits_i L_t^h \ln \left(\frac{\Pi_i \left(\mathrm{CP}_{i,t}^h \right)^{\mu_i^h}}{L_t^h} \right) \tag{12}$$

where r, $\mathrm{CP}_{i,t}^h$ $L_{i,t}^h$ w_h and μ_i^h represent discount rate, consumption of commodity i, total population, the relative weights among regions and commodities, respectively. THERESIA tentatively assumes r, w_h and μ_i^h to be 5 % per year, the total consumption, and the consumption fraction of commodity i of region h, respectively.

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 the existing historical and the projection data. Some fundamental parameters such as technological progress and some cost assumptions are thus calibrated. Further investigations on the parameter estimation and tuning will provide more realistic information under climate policies.

Other detailed parameters and assumptions are shown in the literature (Mori et al. 2011).

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 Sect. 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. Unlike other integrated assessment models which generate 100-year simulations to assess the climate policies (IPCC 2013), THERESIA currently gives shorter simulation period. There are three reasons: First, THERESIA is designed to see effects of climate policies on the energy strategies and the industry allocation issues around the mid of this century which could be the bifurcation point based on the current technologies. Second, long-term IO tables through twenty-first century to deal the with multi-sectoral model are hard to estimate when considering the economic structure changes. Third, since THERESIA is originally formulated as inter-temporal optimization incorporating multiregions, multisectors and technology implementation strategies. Currently, THERESIA model requires almost two to 3 weeks for one calculation (GAMS-CONOPT on Intel i7-4770 PC). Further expansion of simulation period would cause numerical calculation issues.

Table 2a, b shows the world total emissions of C, CN and CM. Total numbers are identical in all cases by definition. One can observe some difference caused by the accounting method. First, the carbon emission of the capital formation sector appears only in CM_i accounting since energy is not the capital goods. Second, when carbon emission is embodied in the products, the carbon emission from energy-intensive industries, e.g., INS (iron and steel) and CPG (chemical products), decreases around half, while those of TRN (transportation machinery), OME (other machinery) and CNS (construction) increase around five to ten times. AGR (agriculture) and SSR (social services) sectors show similar changes to energy-intensive industries.

Table 3 summarizes the C_i, CN_i and CM_i of USA, JPN, CHN and IND. Depending on the trade and industry structure, it shows slightly different numbers by region. For instance, total carbon emission in China and Japan decreases as the indirect emission is embodied, while that in USA shows opposite direction. It is suggested that the changes in trade structure derive non-straightforward results for Japan and China. In case of India, C_i, CN_i and CM_i spread broadly by industry sector. CN_i of INS gives 0.055 billion tons of carbon in 2037, while those of C_i and CM_i give 0.0055 and 0.0028 billion tons of carbon in 2037. This observation suggests that IND imports large amount of iron and steel and that exports them embodied in other products.

Figures 3 and 4 summarize the relative emission of different accounting methods to the conventional producer-based values C_i. The relative value exceeds unity when C_i is less than CN_i or CM_i where indirect emission of import is large. Figure 3 shows that carbon emissions in EEP and FSU in CN_i and CM_i are lower than other regions. This

Table 2 Comparison of carbon emissions C_i, CN_i and CM_i in billion tons of carbon

	INS	**CPG**	**TRN**	**OME**	**FPR**	**CNS**	**TWL**	**OMF**	**AGR**	**T_T**	**BSR**	**SSR**
(a) *World Total: industry sectors*												
C_i: producer-based accounting												
1997	0.3429	0.4360	0.0163	0.0652	0.0822	0.0228	0.0342	0.2274	0.1353	0.7515	0.2237	0.2605
2007	0.6695	0.6087	0.0190	0.0890	0.0874	0.0405	0.0524	0.2798	0.1774	1.1244	0.3302	0.3611
2017	1.1160	0.8747	0.0269	0.1039	0.1091	0.0503	0.0546	0.3768	0.2039	1.4641	0.4435	0.5480
2027	1.4343	1.0969	0.0328	0.1232	0.1104	0.0527	0.0661	0.4679	0.2094	1.7359	0.5506	0.7377
2037	1.5595	1.2703	0.0346	0.1386	0.1127	0.0548	0.0814	0.5993	0.2228	2.0520	0.6713	0.9222
2047	1.3970	1.2178	0.0322	0.1337	0.1199	0.0392	0.1036	0.5295	0.2348	2.1418	0.7245	1.1106
CN_i: trade-adjusted accounting												
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
2007	0.6693	0.6085	0.0190	0.0889	0.0875	0.0405	0.0524	0.2799	0.1773	1.1248	0.3305	0.3615
2017	1.1126	0.8729	0.0269	0.1037	0.1089	0.0501	0.0544	0.3794	0.2028	1.4639	0.4434	0.5484
2027	1.4356	1.0972	0.0328	0.1228	0.1101	0.0530	0.0660	0.4669	0.2089	1.7397	0.5503	0.7383
2037	1.5610	1.2709	0.0344	0.1378	0.1124	0.0549	0.0808	0.5976	0.2220	2.0580	0.6714	0.9230
2047	1.3981	1.2143	0.0321	0.1329	0.1184	0.0392	0.1034	0.5294	0.2316	2.1534	0.7275	1.1133
CM_i: demand-based accounting												
1997	0.1531	0.2259	0.0564	0.1940	0.1057	0.1622	0.0440	0.0384	0.0579	0.1401	0.2071	0.1284
2007	0.3024	0.3359	0.0890	0.3448	0.1269	0.3053	0.0733	0.0507	0.0724	0.2152	0.3085	0.1832
2017	0.4819	0.4665	0.1430	0.5021	0.1494	0.4522	0.0742	0.0647	0.0838	0.2920	0.3979	0.2602
2027	0.6073	0.5645	0.1829	0.6643	0.1536	0.5299	0.0843	0.0841	0.0878	0.3503	0.4746	0.3502
2037	0.6743	0.6522	0.2212	0.6901	0.1581	0.5451	0.1016	0.0992	0.0922	0.4051	0.5606	0.4359
2047	0.5780	0.6577	0.1957	0.6305	0.1630	0.3679	0.1231	0.0847	0.0905	0.4047	0.5722	0.4836
	COL	**OIL**	**GAS**	**P_C**	**ELC**	**THM**	**Imp**	**Exp**	**Cpf**	**Csm**	**GcS**	**Total**
(b) *World Total: energy and final demand sectors*												
C_i: producer-based accounting												
1997	0.0000	0.0075	0.0038	0.5864	1.5091	0.1033	0.0000	0.0000	0.0000	1.6076	0.0000	6.4156
2007	0.0000	0.0114	0.0059	0.8243	1.6742	0.1447	0.0000	0.0000	0.0000	2.0635	0.0000	8.5635
2017	0.0000	0.0126	0.0116	1.5307	2.0573	0.2024	0.0000	0.0000	0.0000	2.6250	0.0000	11.8111
2027	0.0000	0.0139	0.0155	2.1796	2.4508	0.2596	0.0000	0.0000	0.0000	3.1428	0.0000	14.6801
2037	0.0000	0.0153	0.0185	2.8396	2.8553	0.3010	0.0000	0.0000	0.0000	3.7071	0.0000	17.4560
2047	0.0000	0.0004	0.0205	4.1280	3.1061	0.3040	0.0000	0.0000	0.0000	3.8806	0.0000	19.2239
CN_i: trade-adjusted accounting												
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
2007	0.0000	0.0114	0.0059	0.8243	1.6742	0.1447	1.7916	1.7916	0.0000	2.0628	0.0000	8.5635
2017	0.0000	0.0126	0.0116	1.5307	2.0573	0.2024	2.5324	2.5324	0.0000	2.6292	0.0000	11.8111
2027	0.0000	0.0139	0.0155	2.1796	2.4508	0.2596	2.4118	2.4118	0.0000	3.1392	0.0000	14.6801
2037	0.0000	0.0153	0.0185	2.8396	2.8553	0.3010	2.9964	2.9964	0.0000	3.7023	0.0000	17.4560
2047	0.0000	0.0004	0.0205	4.1280	3.1061	0.3040	2.2629	2.2629	0.0000	3.8717	0.0000	19.2239
CM_i: demand-based accounting												
1997	0.0043	0.0197	0.0067	0.5957	1.5190	0.1068	0.4153	0.4153	0.0943	2.4139	0.1421	6.4156
2007	0.0058	0.0329	0.0114	0.8341	1.6878	0.1487	1.1287	1.1287	0.1746	3.0663	0.1943	8.5635
2017	0.0082	0.0413	0.0241	1.5441	2.0727	0.2070	2.0284	2.0284	0.2395	4.0316	0.2748	11.8111
2027	0.0107	0.0451	0.0328	2.2023	2.4686	0.2650	2.8174	2.8174	0.2673	4.8844	0.3702	14.6801
2037	0.0129	0.0517	0.0408	2.8663	2.8740	0.3064	3.0506	3.0506	0.2583	5.9921	0.4182	17.4560
2047	0.0094	0.0301	0.0517	4.1529	3.1244	0.3084	2.6485	2.6485	0.1416	6.5987	0.4551	19.2239

Table 3 Comparison of carbon emission by industry sector and total emission in C_i, CN$_i$ and CM$_i$ in billions of carbon

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total
(a) *USA: industry sectors*													
C_i: producer-based accounting													
1997	0.0491	0.1054	0.0057	0.0145	0.0164	0.0016	0.0058	0.0289	0.0165	0.2622	0.0770	0.0796	1.67017
2007	0.1168	0.1189	0.0034	0.0271	0.0180	0.0017	0.0035	0.0448	0.0151	0.2930	0.0808	0.0921	1.82704
2017	0.1676	0.1214	0.0089	0.0355	0.0233	0.0022	0.0023	0.0574	0.0150	0.3243	0.1099	0.1211	2.13237
2027	0.1847	0.1324	0.0186	0.0366	0.0230	0.0024	0.0171	0.0800	0.0172	0.3507	0.1634	0.1551	2.83585
2037	0.2123	0.1471	0.0202	0.0476	0.0194	0.0023	0.0198	0.0996	0.0178	0.3802	0.1859	0.1682	3.16238
2047	0.1711	0.1251	0.0186	0.0372	0.0155	0.0011	0.0187	0.1196	0.0140	0.3159	0.1761	0.1471	3.15215
CN$_i$: trade-adjusted accounting													
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	1.66866
2007	0.0972	0.1199	0.0052	0.0202	0.0160	0.0017	0.0062	0.0389	0.0140	0.2507	0.0913	0.0973	1.76758
2017	0.1287	0.1277	0.0082	0.0282	0.0166	0.0021	0.0083	0.0493	0.0136	0.2800	0.1045	0.1442	2.04402
2027	0.1462	0.1470	0.0133	0.0346	0.0160	0.0024	0.0157	0.0682	0.0165	0.4157	0.1415	0.1027	2.77407
2037	0.1752	0.1938	0.0151	0.0389	0.0096	0.0023	0.0175	0.0856	0.0144	0.4108	0.1829	0.2643	3.25178
2047	0.1382	0.1379	0.0135	0.0300	0.0062	0.0011	0.0172	0.1062	0.0113	0.3501	0.1469	0.2012	3.15196
CM$_i$: demand-based accounting													
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	1.66417
2007	0.0444	0.0635	0.0119	0.0851	0.0237	0.0410	0.0038	0.0068	0.0097	0.0546	0.0681	0.0378	1.71457
2017	0.0615	0.0580	0.0271	0.0984	0.0260	0.0538	0.0023	0.0077	0.0099	0.0588	0.0804	0.0433	1.98016
2027	0.0704	0.0581	0.0570	0.0991	0.0266	0.0618	0.0171	0.0109	0.0119	0.0728	0.1171	0.0505	2.71327
2037	0.0793	0.0668	0.0638	0.1315	0.0221	0.0659	0.0205	0.0139	0.0125	0.0746	0.1447	0.0612	3.34266
2047	0.0636	0.0544	0.0560	0.0967	0.0172	0.0307	0.0181	0.0162	0.0096	0.0632	0.1243	0.0471	3.152
(b) *China: industry sectors*													
C_i: producer-based accounting													
1997	0.1013	0.1186	0.0048	0.0165	0.0150	0.0040	0.0135	0.0115	0.0242	0.0437	0.0210	0.0460	0.92555
2007	0.2743	0.1844	0.0019	0.0148	0.0050	0.0056	0.0318	0.0071	0.0319	0.0991	0.0167	0.0380	1.25348

Table 3 continued

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total
2017	0.5324	0.2890	0.0009	0.0072	0.0023	0.0053	0.0246	0.0038	0.0285	0.1860	0.0203	0.0418	2.10271
2027	0.6587	0.3352	0.0007	0.0053	0.0011	0.0052	0.0124	0.0052	0.0256	0.2253	0.0234	0.0565	2.65165
2037	0.6394	0.3400	0.0004	0.0055	0.0016	0.0051	0.0066	0.0063	0.0247	0.2385	0.0322	0.0583	3.00094
2047	0.5710	0.3241	0.0006	0.0387	0.0027	0.0059	0.0304	0.0059	0.0280	0.2040	0.0299	0.0748	3.31796
CN_j: trade-adjusted accounting													
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	0.91172
2007	0.2098	0.1565	0.0025	0.0149	0.0107	0.0056	0.0186	0.0457	0.0324	0.1072	0.0072	0.0350	1.1905
2017	0.3225	0.1877	0.0030	0.0110	0.0134	0.0052	0.0174	0.0621	0.0301	0.1276	0.0244	0.0316	1.7956
2027	0.3962	0.2074	0.0026	0.0109	0.0186	0.0052	0.0139	0.0870	0.0288	0.1319	0.0341	0.0545	2.29793
2037	0.4035	0.2110	0.0017	0.0147	0.0218	0.0052	0.0136	0.1671	0.0314	0.1417	0.0307	0.0699	2.76616
2047	0.5542	0.2510	0.0001	0.0359	0.0228	0.0060	0.0264	0.1213	0.0377	0.1303	0.0423	0.0715	3.30515
CM_j: demand-based accounting													
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	0.89785
2007	0.1302	0.1004	0.0036	0.0690	0.0058	0.0556	0.0397	0.0056	0.0159	0.0293	0.0315	0.0207	1.12529
2017	0.2410	0.1656	0.0019	0.0372	0.0026	0.0594	0.0304	0.0032	0.0149	0.0563	0.0363	0.0223	1.49996
2027	0.2971	0.2076	0.0015	0.0293	0.0013	0.0654	0.0154	0.0050	0.0146	0.0723	0.0419	0.0316	1.9143
2037	0.3033	0.2317	0.0009	0.0319	0.0020	0.0680	0.0089	0.0077	0.0152	0.0808	0.0604	0.0352	2.49349
2047	0.2544	0.2117	0.0012	0.2204	0.0029	0.0820	0.0364	0.0060	0.0172	0.0692	0.0469	0.0376	3.27002
(c) *Japan: industry sectors*													
C_j: producer-based accounting													
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	0.35451
2007	0.0460	0.0434	0.0000	0.0106	0.0046	0.0053	0.0000	0.0153	0.0059	0.0408	0.0091	0.0173	0.42719
2017	0.0928	0.1001	0.0000	0.0149	0.0052	0.0066	0.0000	0.0222	0.0065	0.0458	0.0134	0.0264	0.61006
2027	0.1565	0.1971	0.0000	0.0128	0.0097	0.0059	0.0000	0.0278	0.0058	0.0468	0.0172	0.0340	0.85826
2037	0.1966	0.2729	0.0000	0.0072	0.0112	0.0049	0.0000	0.0266	0.0062	0.0522	0.0146	0.0495	1.02591
2047	0.1753	0.2436	0.0000	0.0037	0.0112	0.0028	0.0000	0.0194	0.0065	0.0470	0.0075	0.0523	0.90671

Table 3 continued

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total
CN_j: trade-adjusted accounting													
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	0.37939
2007	0.0624	0.0557	0.0006	0.0075	0.0045	0.0054	0.0038	0.0136	0.0063	0.0551	0.0083	0.0289	0.48094
2017	0.1064	0.1085	0.0027	0.0112	0.0049	0.0063	0.0000	0.0194	0.0063	0.0516	0.0120	0.0379	0.64064
2027	0.0821	0.1477	0.0031	0.0159	0.0040	0.0059	0.0000	0.0243	0.0098	0.0647	0.0157	0.0392	0.75725
2037	0.1416	0.1657	0.0009	0.0184	0.0034	0.0049	0.0000	0.0229	0.0104	0.0731	0.0261	0.0500	0.90175
2047	0.1329	0.1151	0.0025	0.0101	0.0025	0.0029	0.0000	0.0154	0.0123	0.0636	0.0227	0.0410	0.75836
CM_j: demand-based accounting													
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	0.40264
2007	0.0176	0.0137	0.0102	0.0408	0.0077	0.0262	0.0013	0.0044	0.0022	0.0075	0.0229	0.0122	0.53497
2017	0.0193	0.0167	0.0193	0.0684	0.0095	0.0463	0.0039	0.0077	0.0029	0.0078	0.0322	0.0198	0.67694
2027	0.0187	0.0222	0.0196	0.0501	0.0220	0.0556	0.0049	0.0100	0.0036	0.0102	0.0406	0.0254	0.65614
2037	0.0582	0.0345	0.0261	0.0413	0.0253	0.0545	0.0057	0.0117	0.0040	0.0119	0.0373	0.0390	0.77724
2047	0.0733	0.0300	0.0225	0.0234	0.0260	0.0289	0.0043	0.0085	0.0040	0.0103	0.0193	0.0404	0.60988
(d) *India: industry sectors*													
C_j: producer-based accounting													
1997	0.0081	0.0082	0.0000	0.0006	0.0062	0.0000	0.0013	0.0218	0.0095	0.0124	0.0165	0.0048	0.24927
2007	0.0102	0.0097	0.0000	0.0015	0.0057	0.0000	0.0024	0.0288	0.0136	0.0223	0.0316	0.0081	0.31715
2017	0.0110	0.0107	0.0000	0.0054	0.0072	0.0000	0.0017	0.0356	0.0213	0.0363	0.0194	0.0286	0.41762
2027	0.0068	0.0092	0.0000	0.0073	0.0059	0.0000	0.0013	0.0317	0.0244	0.0483	0.0119	0.0301	0.4182
2037	0.0055	0.0093	0.0000	0.0114	0.0049	0.0000	0.0023	0.0301	0.0257	0.0627	0.0122	0.0318	0.45264
2047	0.0105	0.0158	0.0000	0.0074	0.0100	0.0000	0.0020	0.0349	0.0301	0.0749	0.0238	0.0661	0.59853

Table 3 continued

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	Total
CN_j: trade-adjusted accounting													
1997	0.0087	0.0082	0.0000	0.0006	0.0054	0.0000	0.0010	0.0184	0.0094	0.0124	0.0160	0.0047	0.24472
2007	0.0310	0.0109	0.0000	0.0016	0.0035	0.0000	0.0015	0.0212	0.0124	0.0244	0.0241	0.0065	0.3202
2017	0.0563	0.0344	0.0000	0.0051	0.0012	0.0000	0.0009	0.0642	0.0167	0.0403	0.0217	0.0094	0.48891
2027	0.0327	0.0145	0.0000	0.0072	0.0005	0.0000	0.0005	0.0539	0.0138	0.0525	0.0053	0.0074	0.42694
2037	0.0549	0.0247	0.0000	0.0104	0.0010	0.0000	0.0008	0.0428	0.0188	0.0639	0.0032	0.0081	0.48137
2047	0.0647	0.0303	0.0000	0.0082	0.0003	0.0000	0.0012	0.0515	0.0269	0.0706	0.0040	0.0145	0.58498
CM_j: demand-based accounting													
1997	0.0051	0.0052	0.0018	0.0035	0.0021	0.0042	0.0028	0.0036	0.0044	0.0020	0.0061	0.0014	0.24014
2007	0.0085	0.0048	0.0057	0.0092	0.0015	0.0162	0.0046	0.0058	0.0056	0.0030	0.0128	0.0023	0.32333
2017	0.0087	0.0068	0.0140	0.0300	0.0016	0.0424	0.0031	0.0076	0.0092	0.0044	0.0089	0.0112	0.56368
2027	0.0035	0.0038	0.0120	0.0184	0.0008	0.0375	0.0013	0.0043	0.0073	0.0036	0.0059	0.0086	0.44144
2037	0.0028	0.0049	0.0144	0.0310	0.0007	0.0474	0.0022	0.0046	0.0078	0.0042	0.0068	0.0110	0.51894
2047	0.0023	0.0063	0.0195	0.0226	0.0013	0.0566	0.0020	0.0052	0.0087	0.0049	0.0091	0.0165	0.59564

"Total" column represents the total emission of industry sectors and those of theenergy and the final demand sectors

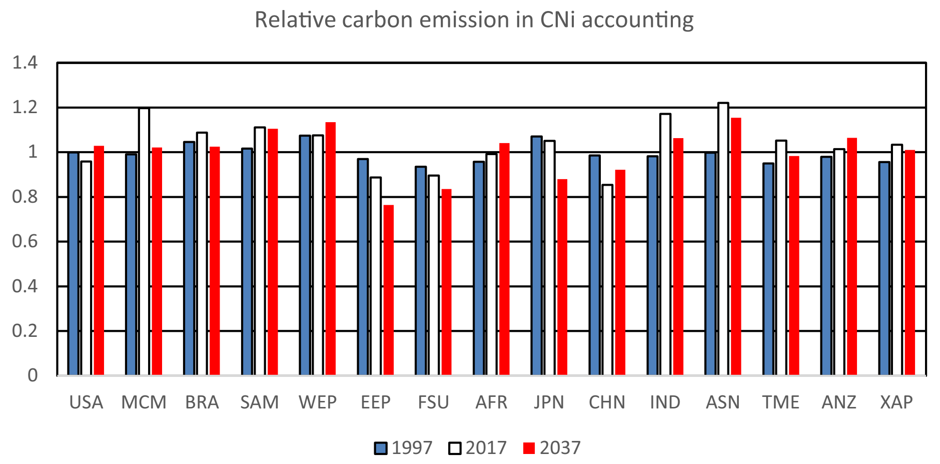


Fig. 3 Relative emission of CN_i (trade-adjusted accounting) to C_i (production-based accounting)

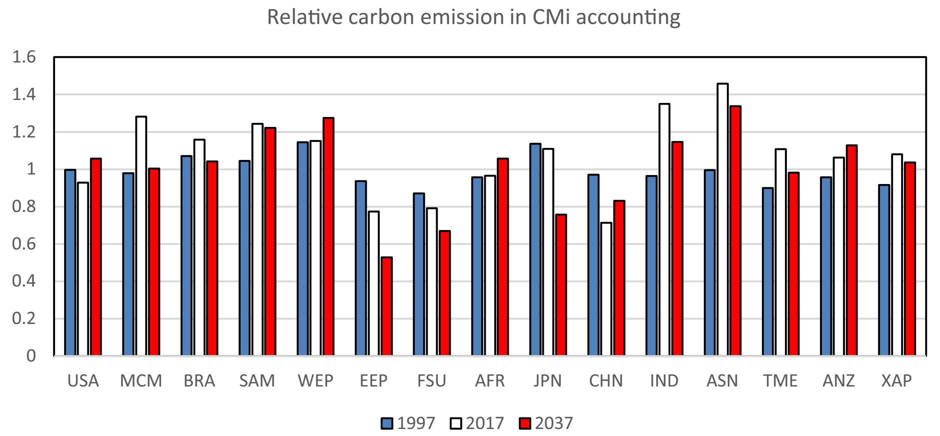


Fig. 4 Relative emission of CM_i (commodity-embodied accounting) to C_i (production-based accounting)

observation appears more clearly when carbon emission is accounted by CM_i in Fig. 4. Japan and China also show similar tendency. On the other hand, MCM, IND and ASN regions show more than 1.0 results in both Figs. 3 and 4. These observations suggest EEP, FSU, JPN and CHN are energy-intensive products exporters.

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. Since W-85 and W-70 exclude the participation of energy conversion sector, these scenarios do not correspond to the conventional market equilibrium cases. Global and all market player participation case corresponding to the equilibrium case is described in our previous paper (Mori et al. 2011).

> *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. These scenarios do not imply the market equilibrium but seem to be realistic. This study does not touch upon the outcome of carbon tax, a possible alternative policy instrument for carbon control. This topic will be dealt with in the another paper.

> *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 accounting (C_i).*
>
> *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 accounting (CN_i).*
>
> *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 accounting (CM_i).*

where nine regions of world 15 regions given in Table 4 participate in the emission control agreement.

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

Scenario B shows how the increase in participation of regions affects the emissions and economies. Here, it is assumed that MCM, SAM and IND join the emission control agreement. Thus, 12 regions of world 15 regions participate in emission control.

Scenario C evaluates how the participation of energy sector contributes. Here, power generation industry joins in addition to the scenario A.

Figures 5 and 6 show the comparison of the global CO2 reduction and the global GDP losses and from BAU. It should be noted that the GDP losses tend to be decline after 2027. It is because that some periods are needed to replace the older plants by new ones, since THERESIA incorporates the energy technology replacement dynamics similar to the existing bottom-up technology models. These figures suggest that the replacement of new technologies can substantially mitigate the economic loss of carbon emission constraints but it takes time. However, it is also expected the economic loss will increase

Table 4 Regional partial participation cases in scenario A

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

1, participate; 0, not participate

Fig. 5 Comparison of global CO2 reductions and GDP losses in 15 % reduction cases. **a** CO2 emission reduction from BAU: comparison of 15 % reduction cases. **b** GDP loss from BAU: comparison of 15 % reduction cases

under the more stringent carbon emission policy such as 2.0 or 1.5 °C atmospheric temperature rise target.

It should also be noted that since energy conversion sectors do not participate in emission agreement in W-85 and W-70 cases, total global carbon emission reductions do not reach the target. These figures show some remarkable observations: First, even if participation of regions is within developed countries, global carbon emission reduction is almost same, especially in C_i (producer-based accounting) constraint. Second, Fig. 5 suggests that both economic loss and carbon emission reduction are negligible small when carbon emission accounting policy employs CN_i (trade-adjusted accounting) or CM_i (commodity-embodied accounting) if carbon reduction policy is not stringent. Third, Fig. 6 shows the differences in accounting policy tend to decrease as carbon emission target becomes stringent. Fourth, partial participation substantially weaken the carbon emission policy.

Figure 7 shows the comparison of 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 CN_i (trade-adjusted accounting) case is apparently smaller than A1 and A3. It is also shown that carbon emission of INS sector substantially declines when all industries and regions participate in carbon emission policy.

Figure 8 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

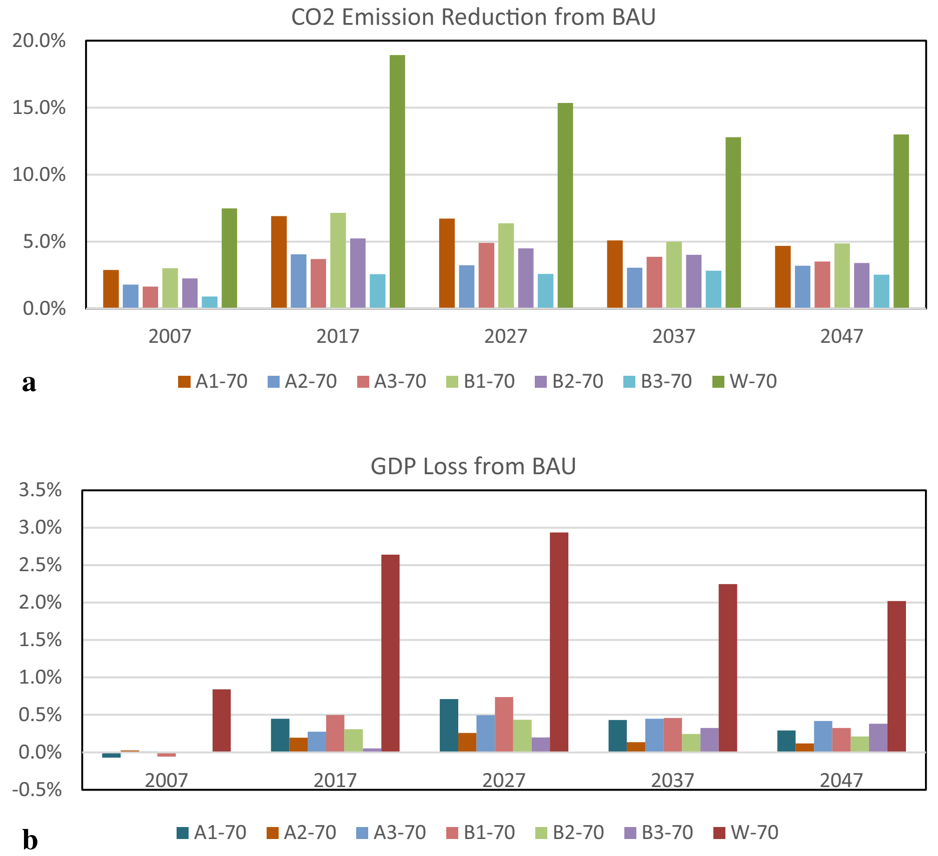


Fig. 6 Comparison of global CO2 reductions and GDP losses in 30 % reduction cases. **a** CO2 emission reduction from BAU: comparison of 30 % reduction cases. **b** GDP loss from BAU: comparison of 30 % reduction cases

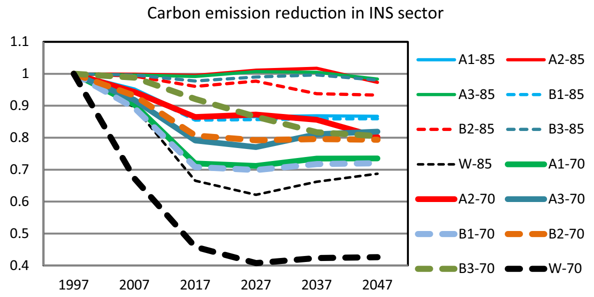


Fig. 7 Relative carbon emission reductions to BAU in INS (iron and steel industry) sector

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.

Finally, I compare the carbon emissions of INS (iron and steel industry) sector among scenarios in Tables 5 and 6 to see how the "carbon leakage" differently appears depending

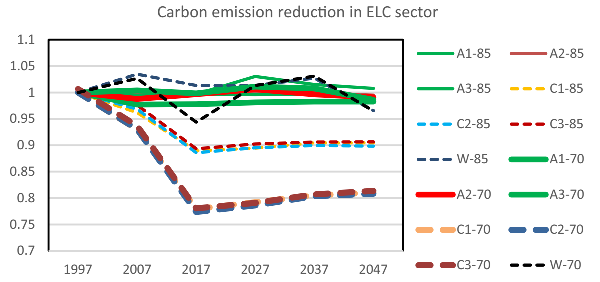


Fig. 8 Relative carbon emission reductions to BAU in power generation sector

on the accounting method. Table 7 shows the world carbon emissions in three accounting method in scenario A.

These tables show some interesting findings: First, when one compares the A1-85 scenario, where only Group A regions participate in the carbon emission reduction policy to 85 % of BAU based on the A1 (producer-based accounting), world carbon emission exceeds 85 %. This suggests the occurrence of "carbon leakage." Second, when Group A regions agree with the same carbon emission policy based on A2 (trade-adjusted accounting), both the in-group and the global carbon emissions hardly decrease while CN_i meets the carbon emission target. In this case, export of carbon-intensive products compensates the domestic carbon emission reduction. Thus, one can observe that the accounting policy on "producer based" could cause "carbon import" and that, on the contrary, carbon control on "trade-adjusted" or "demand-based" emission accounting may cause larger "carbon export" effects which can harm the global carbon emission

Table 5 Carbon emissions of INS (iron and steel industry) sector in Group A regions (in billion tons of carbon)

	C_i_GroupA	CN_i_GroupA	C_i_GroupA (%)	CN_i_GroupA (%)	C_i_GroupA (%)	CN_i_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 6 Carbon emissions of INS (iron and steel industry) sector in world total (in billion tons of carbon)

	BAU (Gt-C)		A1-85		A2-85	
	C_i_World	CN_i_World	C_i_World (%)	CN_i_World (%)	C_i_World (%)	CN_i_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 Global carbon emission in total in billion tons of carbon (left three columns) and ratio to BAU in % (right two columns)

	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*

control target. It should be noted that the above two "leakage" patterns disappear when carbon emission target is agreed by all countries. 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 between energy conversion sector and consumers is 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 in emission allocation options affects the industry and technology allocation by the carbon emission control policy.

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