Evaluation of Global Warming Mitigation Policies with a Dynamic World Energy-economic Model Considering Changes in Industrial Structures by IT Penetration

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Abstract

This study aims to reveal their impacts of changes in the industrial structures and the rapid IT (Information Technology) penetration on economic activities and energy systems under CO2 emission constraints by using a dynamic world energy-economic model, namely, DEARS (Dynamic Energy-economic model with multi-Regions and multi-Sectors). This model deals with 18 divided regions and 18 non-energy sectors by integrating top-down economy and bottom-up energy system modules to assess global warming mitigation policies. The energy module of DEARS comprises seven types of primary energy sources and four types of secondary energy with the consideration of CCS (Carbon dioxide Capture and Storage). Simulation studies, combining the carbon emission policies with the input-output coefficient scenarios, are conducted: the climate policies consist of the non-climate policy case and the two constraint cases meeting the IPCC-S550 or -S450 ppmv stabilizations, and the input-output scenarios consist of the fixed coefficient case and the two variable coefficients cases with consideration of changes in industrial structures and rapid IT (information technology) penetration. The results suggest that the carbon stabilization policies and the evolutions of industrial structures and IT lead not only to changes in energy systems but also the shift to lower carbon and energy intensity, and higher value-added industry. This indicates that the post-heavy industrial structures by the IT penetration will leads to sustainable economic developments.

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1.Introduction

The purpose of this study is to reveal their impacts of changes in industrial structures and rapid IT (Information Technologies) penetration on economic activities and energy systems under CO2 emission constraints. A dynamic world energy-economic model, namely, DEARS (Dynamic Energy-economic model with multi-Regions and multi-Sectors) is utilized in this study (Homma *et el*. 2005a, 2005b). The DEARS focuses on the middle-term assessment of the impacts of these policies on energy and economy for a comprehensive assessment of climate change mitigation policies.

The importance of assessing the mitigation impacts is increasing in light of the international arguments on the framework of emission reduction after 2013 and the realization of a sustainable economic society. An analysis of climate policies should be undertaken by incorporating economy, energy, and technological issues. Many believe that the development pathways of economy will lead to the dynamic changes in industrial structures. Others assert that the latter will result in the former. Under these arguments, recently, the rapid IT penetration also causes the development of economy including the changes in the allocation of industries and consumption patterns of commodities, and will affect the energy consumptions and carbon emissions. It is widely recognized that the rapid IT penetration can affect not only economic activities but also global warming issues (J.A.Laitner et al., 2000). Thus, the relationship between rapid IT penetration and changes in energy systems including energy demand and carbon emissions are important for the assessments of global warming mitigation policies. The discussions on the effects of these structural changes on global warming mitigation policies need the consistent analysis of the impacts on both economic activity and energy system with the consideration of differences in sectors and regions.

The previous studies for energy systems under the changes in industrial structures in the rapid IT penetration have mainly dealt with short-term impacts of IT on energy consumptions for the specific regions, mainly focused on U.S.A and Japan, around the year

2010 (Takase and Murota, 2004; J.A.Laitner et al., 2000). Although the regional or global possibilities of future structural changes through the rapid IT penetration are widely discussed in the literature, these have not been well researched in the global warming issues on the consideration of differences in the region and sectors based on global comprehensive solutions. Assessments of global warming mitigation policies including energy resources and technologies on IT penetration also have not been sufficiently discussed in the existing literature. Furthermore, it is also important to assess the regional and sectoral differences under the climate policies. It is necessary to evaluate the global issue of carbon emission reduction potential by using a dynamic energy-economic model incorporating the dynamic changes in the industrial structure for multi-regions and multi-sectors.

The structure of the paper is as follows. Section 2 outlines the model structure of DEARS; Section 3 presents the assumptions on input-output coefficients; and Section 4 describes the computational results and discussions in a simulation study. Finally, Section 5 presents the summary of this research.

2.Model Structure

2.1 Basic Framework of DEARS

DEARS is formulated as a multi-regional dynamic model, in which the entire world is geographically divided into 18 regions, as shown in Table 1. It is also formulated as a multi-sectoral optimization model, in which the whole macro sector—excluding the energy sectors—is economically divided into 18 non-energy sectors. The sectoral economic data are also based on the GTAP5 database. Dealing with the detailed regional and sectoral division enables the observation of the sectoral differences in both economic and energy systems and the identification of regional characteristics for comprehensive and consistent assessments.

INSERT Table 1

The model has the following characteristic features: (1) integration of a top-down economic model—such as the GTAP model (Hertel 1997)—and a bottom-up energy technology assessment model—such as DNE21 (Fujii and Yamaji 1998) and LDNE21 (Yamaji *et al*. 2000) and (2) formulation as an intertemporal optimization model with multi-sectors. DEARS is an intertemporal multi-regional and multi-sectoral model developed for the analysis of the pathways of world economic growth under a climate change policy. The time horizon of DEARS is from 1997 to 2047, and it has time intervals of 10 years. As part of its dynamic framework, this model determines sectoral production, the final consumption, investment, and international trade as the maximization of the whole consumption utilities. The capital stock in time $t+1$ is determined by the depletion of the capital stock plus the investments in the immediate predecessor time t.

In this model, the Cobb-Douglas production functions are applied to the description of the total production and the final consumption of the non-energy sectors by region. Figure 1 provides a detailed structure of the economic and energy flows in the model. The model consists of 18 regions and the economic and energy systems in these regions are linked by the international trade of non-energy industrial commodities and fossil fuels.

<u>INSERT Figure 1</u>

DEARS is an intertemporal non-linear optimization model, in which the cumulative consumption utility is maximized to represent the optimal energy and economic system. The model is built on a comprehensive and consistent economy and energy dataset. The model deals with the choice of energy technology, sectoral energy consumption, and economic growth by region for the middle term. DEARS comprises an energy systems module—having seven types of primary energy and four types of secondary energy—and an economic module having 18 economic sectors.

Figure 2 represents the assumed energy flow of the specific region in the model. The primary energies taken into account are coal (COL), crude oil (CRU), natural gas (GAS), nuclear (NUC), biomass (BIO), wind (WIN), and hydro (HYD). The secondary energies taken into account are solid fuel (SLD), liquid fuel (OIL), gaseous fuel (GDT), and electricity (ELE). Both energy and monetary flow systems modules are consistent with each other with regard to the market price. In the energy module, the supply side is formulated by the bottom-up process, while the demand side is formulated by the top-down process. The energy systems module covers various energy conversion processes such as electricity generation including CCS (carbon dioxide capture and storage), as shown in Figure 2. These regional energy flows are interlinked by interregional trade items: coal, crude oil, and natural gas. The energy commodities are traded by their common international prices. The domestic production prices are defined as cost-supply functions, while the international prices are determined by the method of weighted mean of the regional domestic production prices. The regional market prices are determined by the method of weighted mean of the regional domestic production and international trade prices.

The energy balances in the assumed conversion processes of crude oil to liquid fuel (petroleum), coal to solid fuel, natural gas to gaseous fuels, and various fuels to electricity are described using conversion efficiency scenarios. The model also deals with the conversion process in power generation, including transmission loss.

<u>INSERT Figure 2</u>

Figure 3 describes the model structure for the variables through the input-output and energy flow tables in this model. Due to the above-mentioned structure, the model can evaluate the costs and energy technologies required to reduce CO2 emission for 18 regions under CO2 emission regulations. A remarkable feature of the model is that it enables the sectoral assessment of CO2 emission for the world and detailed regions. Thus, it provides useful information about the quantitative and comprehensive assessments for the climate change mitigation policies.

In order to integrate a bottom-up energy systems module and a top-down economic systems module, the input-output structure and energy supply-demand balances are determined as the relational equations in the model. In this model, the supply curve of primary energy is characterized by the parameter related to the supply curve of the primary energy. We utilize the approximate linear function of the cost supply curve of such exhaustive resources as crude oil, coal, and natural gas, which is explained by the respective amounts of their cumulative productions. The value-added of the electricity sector equals the total facility costs of various power generation processes. On the energy demand side, the final energy consumption is determined by the growth of per capita GDP and income elasticity.

INSERT Figure 4

2.2 Model assumptions

The assumed potentials of fossil fuel resources are derived from WEC (2000) and USGS (2000). The regional potentials of fossil fuels are shown in Figure 4. The growth rates of the conversion efficiencies of fossil fuels are assumed by region. The production costs of coal, crude oil, and natural gas are 0.9, 1.5, and 1.1 $/GJ, respectively. The future production costs of the fossil fuels are expressed as linearlized cost-supply functions based on Rogner (1997). The facility costs of power generation by coal, oil, and natural gas are 24.0, 7.2, and 6.7 $/MWh, respectively. These related input data of the current model are derived mainly from an energy systems model, namely, DNE21. The assumed costs and time-series potentials of biomass fuels are derived from Yamamoto *et al.* (2001). The regional potentials of biomass energy are shown in Figure 4. The facility cost of power generation by biomass energy is 48.1 $/MWh. The resource cost of biomass energy is 0–20 $/GJ; this is determined by the time-series linearlized cost-supply function with the cost spread of the accumulated consumptions. The potentials and costs of hydropower and wind power are derived from WEC (2000) and Akimoto *et al.* (2004). The costs of hydropower and wind power are 30–180 and 56–118 \$/MWh, respectively. The annual cost reduction of wind power is assumed to be 1.0%.

The model also considers the CO2 geological storage for CCS technology. It can assess the future economical potentials by region. The operational cost by using the CCS technology is derived from Rubin *et al.* (2004). The assumed costs for transport and geological storage are 3.2 and 5.0 \$/tCO2, respectively. The operational cost for the CCS technology is added to the fuel cost in the monetary flow as the input for power generation with CCS. The facility plant cost of a power plant with CCS by coal and the other fossil fuels is assumed to be 1.75 and 2.12 times higher than that without CCS, respectively. The regional CO2 storage potential into an aquifer is derived from Akimoto *et al*. (2004).

<u>INSERT Figure 4</u>

The AEEI (Autonomous Energy Efficiency Improvement) parameters—the reducing growth rates of the time evolution of technological changes in energy demands for non-energy sectors—are estimated by logistic regression analysis. The model includes energy saving not only for AEEI but also for the increase in induced price. The coefficients for the energy inputs to non-energy and energy sectors, excluding the electricity sectors, are fixed in terms of the monetary unit instead of the physical unit. Consequently, we assume the Leontief-type of production function for the energy consumption in sectors. These approaches imply that the price elasticity for the energy demand in the non-energy industry is equal to one. In this manner, the model represents energy saving by the induced price increase under the carbon reduction polices.

Table 2 shows the assumed regional trade scenarios. They are based on those in Crowther's international balance of payments development stages theory (Crowther 1957; METI 2002). The theory focuses on the time-series changes and structures in a country's balance of payments in the course of economic development. The trade scenario in a country is categorized into six stages of balance of payments development: immature debtor nation, mature debtor nation, debt repayment nation, immature creditor nation, mature creditor nation, and credit disposition nation. This theory is applied to the regions excluding developed regions, e.g., USA, WEP, and JPN. This model utilizes the assumptions that the assigned balance of payments development stage, estimated by its volume in the base year, is characterized as the regional ratio of net total export volume relative to GDP.

INSERT Table 2

3. Scenario generation of intermediate input-output coefficient

3.1 Constant technical structures scenario

We assumed the fixed technical structures scenario, where the input-output coefficients, which represent the sectoral technical structures, are constant at the level of the benchmark year from the beginning to the end of the time horizon. This scenario implies the middle-term stability of the technical structures in production, where there are no changes in technical structures by technical innovations, relative prices, and product mix. The effect of relative prices should be neglected because the DEARS deals with only real prices of commodities. The results by using the DEARS in this scenario for the technical structures lead to the economic development paths harmonized with the SRES-B2 GDP profiles for the four SRES regions.

3.2 Technical structures changes scenario with the consideration of Rostow's theory

Technical structures changes scenario is based on the assumptions of the future changes in technical structures as the input-output coefficients scenarios. Although the previous results by using DEARS consider the changes in industrial structures under the assumptions of the fixed input-output coefficients, the possible changes in the technical structures have not been sufficiently discussed.

The regional input-output coefficients scenarios including the future changes in the technical structures are generated by the econometric method, namely, the EU estimation method. It is widely recognized that the EU method is the popular estimation method of input-output coefficients, especially utilized for the EU countries (Yoshinaga 1997). The procedures of this method consist of the following seven steps:

(1) Estimations of world and regional GDP based on the possible path of economic development,

(2) Estimations of sectoral world domestic outputs consistent with world GDP generated in step (1),

(3) Generations of regional and sectoral domestic outputs by convergence method with the use of assumptions of steps (1) and (2),

(4) Estimations of regional and sectoral value-added,

(5) Estimations of regional final demand based on assumptions of step (4),

(6) Estimations of regional input-output coefficients by EU method based the results of steps (4) and (5),

(7) Incorporation of estimations generated in step (6) into the DEARS as future input-output coefficients.

In the above process, the utilization of the EU method requires the assumptions of the possible path of economic development, e.g., regional and sectoral domestic outputs, value-added, and final demands. In this study, the assumptions are based on the economic theories that economic structures in the global and regional economy consist of (a) effects of developments with changes in economic developments and technological innovations, e.g., the trend towards the service economy with economic developments, and (b) effects of comparative advantage with global allocations of industry, e.g., the continual and significant share of the middle east regions in the world production of crude oil up to the middle of this century. The two effects are considered as the main factor in industrial structures for the future scenarios.

We also consider the changes in economic structures based on Rostow's theory (Rostow 1960). This theory, applied widely for economic analysis in the field of development economics (Parr 1998), implies a national economy and society passing through the sequence of the following five stages: traditional society; preconditions for take-off; take-off to sustained growth; drive to maturity; and age of high mass consumption.

The assumptions about the elasticity of the sectoral domestic outputs and the regional growths in GDP between the year 2017 and 2027 in utilizing the EU estimation method with the consideration of Rostow's theory are given in Tables 3 and 4, respectively. This method of estimations of the input-output coefficients has the following characteristic features: (1) incorporating easily the changes in industrial structures into the DEARS because of mere reflection of the estimated input-output coefficients to the model; (2) enabling consideration of the possible impacts of industrial structures across the many fields corresponding the 18 non-energy sectors; and (3) simple calculation process in generating estimations of input-output coefficients.

3.3 Greater IT penetration scenario

The assumptions about the elasticities of the sectoral domestic outputs and the regional growths in GDP between the year 2017 and 2027 with the consideration of IT penetration in utilizing the EU estimation method are shown in Tables 3 and 4, respectively. We consider the greater IT penetration scenario incorporating the above-mentioned technical structures changes scenario with consideration of Rostow's theory.

The assumptions about the elasticities of the sectoral domestic outputs and the regional growths in GDP between the year 2017 and 2027 in utilizing the EU estimation method with the greeter IT penetration are given in Tables 3 and 4, respectively. The input-output scenario for the greater IT penetration is generated by using the aforementioned EU method based on the following regional and sectoral economic impacts. The scenario is based on the assumptions that by greater IT penetration, U.S.A., Japan, Asian NIES, and BRICs regions—e.g., Brazil, Former USSR, India, and China—have an important advantage of economic development, e.g., increment in GDP; China and India regions, in particular, have higher growth rates of GDP than other regions because of outsourcing and offshoring. As to industrial difference in development, the other machinery and business service sectors increase their growths of demand and supply relatively to those in the industrial structures changes scenario, while the non-ferrous and agriculture sectors decrease their growths.

4. Simulation study

4.1 Data assumptions and simulation cases

A simulation study was applied to DEARS by employing the expanded data obtained by combined IEA data (IEA 2002a, 2002b) and the aggregated GTAP-EG (Rutherford 2000) database, which is based on the production statistics in the year 1997. A case study was carried out on the assumption under the reference case—as the No-CO2 regulation case—up to the middle of this century. We conducted the case study in regions where the population scenario was identical to the SRES-B2 corresponding the United Nations middle population growth scenario; further, CO2 emissions and GDP trajectories, which were determined endogenously in the model, were harmonized with the SRES-B2 marker scenario by adjusting parameters such as the regional annual rate of technical progress. The population of the 18 regions was the aggregated country-level population and downscaled projections for the SRES B2 Scenario 1990–2100 by CIESIN (2005); the historical regional population in the year 1997 was adjusted by the WDI (World Bank 2002). The regional rate of technical progress was basically adjusted in accordance with the annual growth rate of the per capita GDP of the IPCC-SRES-B2 scenario.

We assumed that the parameters of both the annual discount and depreciation rates are 5% in all the regions; they are the same as those assumed in Manne *et al.* (1995). It should be noted that the lifespan of power plants and other plants was not explicitly considered. The optimization software GAMS/CONOPT3 was utilized for the simulation study. It is important to mention here that in order to avoid the "end effect," which influences the computational results around the end of time horizon, we argue the solutions only until 2027, although we solve our dynamic model through the time horizon until 2047.

The simulation cases in this study are conducted under the nine cases combining the following three carbon emissions polices and three input-output coefficients scenarios. Three carbon emissions policies consist of (1) the reference case (CO2-REF case) under no carbon emission control, (2) the IPCC-S550 stabilization case (CO2-S550 case), and (3) the IPCC-S450 stabilization case (CO2-S450 case). Under the latter two cases, the global CO2 emissions are constrained such that they do not exceed their IPCC WGI stabilization profiles with emission trading. Three technical structure scenarios consist of (a) the fixed technical structure scenario (Aij-FIX scenario), in which all the input-output coefficients until 2047, excluding those of sectors with AEEI, are constant at the levels in the benchmark year, (b) the technical structure changes scenario (Aij-TS scenario), where the input-output coefficients until 2047 are variable parameters under the industrial structure changes scenario, and (c) the IT scenario (Aij-IT scenario), where the input-output coefficients until 2047 are variable parameters with the consideration of the technical structures by the greater IT penetration scenario.

4.2 Computational results and discussions

Table 6 shows the computational results of the factor analysis of world CO2 emissions between the years 1997 and 2027. Net carbon emissions, *CO2 net*, can be expressed in the following product form [Kaya identity, Kaya (1990)]:

$$
\begin{aligned}
&CO2\ net \\
&= \frac{CO2\ net}{CO2\ gross} \cdot \frac{CO2\ gross}{GDP} \cdot \frac{GDP}{POP} \cdot POP \\
&= \frac{CO2\ net}{CO2\ gross} \cdot \frac{CO2\ gross}{PE} \cdot \frac{PE}{Q} \cdot \frac{Q}{GDP} \cdot \frac{GDP}{POP} \cdot POP,
\end{aligned} \tag{1}
$$

where *CO2 gross*, *PE*, *Q*, *GDP*, and *POP* are gross carbon emissions, primary energy consumptions, domestic outputs including intermediate inputs and value-added, total value-added, and population, respectively. The first term on the right-hand side of Eq. (1) explains the ratio of captured carbon emission by the CCS technologies in the total carbon emission. The second term denotes the carbon intensity. The third term is defined as the extended energy intensity in this study, although the original energy intensity is expressed as the primary energy consumption per GDP. The growth rate of the original energy intensity is obtained by that of the energy intensity plus that of the output per GDP. The fourth term stands for the rate of domestic output in GDP, that is, the inverse value of the ratio of the value-added in the total domestic output. The fifth and final terms represent the per capita GDP and population, respectively.

The extended energy intensity is dependent not only on the change in the energy systems but also on that in the industrial structures. The decrement in the extended energy intensity is caused by the reduction in primary energy consumption for energy saving in energy systems, the post-heavy industrial structures, or trends toward the service economy. The domestic outputs per GDP are also influenced by the shifts in industrial structures. The domestic output per GDP is decreased by reducing the ratio of intermediate inputs in domestic outputs.

The carbon intensity, energy intensity, and the population in all the CO2-Ref cases between the years 1997 and 2027 are lower than those between 1990 and 2000, while the per capita GDP in this period is higher. This result indicates that the positive growth of carbon emission continues because of the increasing economic growth, while the contribution of the decrements in the carbon intensity and the energy intensity to the reduction of carbon emission can be expected to continue up to the year 2027.

In the CO2-Ref case, the carbon emission per GDP in the fixed technical structure scenario (-1.49%/Yr) is larger than that in other scenarios. The carbon emissions per GDP between the Aij-TS and -IT scenarios are approximately –0.39 and –0.40 percentage points relative to that in the Aij-FIX scenario, respectively. The lower stabilization case, however, causes the lesser differences between Aij-FIX and other scenarios. Their differences in the carbon emission per GDP between in the Aij-FIX, and -TS and -IT in the CO2-S450 case are –0.20 and –0.18 percentage points, respectively.

For the carbon stabilization, the level of importance to reduce carbon emissions increase in the following order: carbon intensity, energy intensity, per-capita GDP, and output per GDP. In particular, the reductions of the carbon and energy intensity is very important key contribution to reducing carbon emissions.

As for the economic growth, for example, in the CO2-S550 case, the annual growth rate of per-capita GDP under the Aij-FIX, -TS, and -IT scenarios between the years 2017 and 2027 are –0.05, –0.09, and –0.06 percentage points relative to those in the CO2-Ref case respectively. This indicate that the possibility in the Aij-FIX scenario is larger than that in other technical structure scenarios because of the most backward evolution of the economic structure in the in the Aij-FIX scenario. The results in the CO2-S450 case also show much the same pattern of the above-mentioned economic growth as shown in Table 3.

In the CO2-Ref case, the growth rate of the output per GDP (0.02%/Yr) in the Aij-TS scenarios is smaller than that (0.09%/Yr) in the Aij-FIX scenario. This indicates that the improvement of technical structures lead to the shift to the higher value-added industry than that in the fixed technical structure case. Furthermore, under the CO2-Ref case, the growth rate of the output per GDP (0.00%/Yr) in the Aij-IT case is the smaller than that in the Aij-TS case.

Based on these findings, the greater IT penetration result in the shift to the highest added-added industry under all the CO2-Ref case. Because lesser value of output per GDP leads to decrease in the carbon emissions from Eq. (1), changes in technical structures and the greater IT penetration play a role of reduction in carbon emissions under the CO2-Ref case. This implies that the changes in industrial structures and the rapid IT penetration are one of the effective mitigation options of global warming.

The growth rates of per-capita GDP in the Aij-TS and -IT cases are larger than that in the Aij-FIX case under the CO2-Ref cases, as shown in Table 3. Because population is an exogenous variable in this model, the differences in the growth rate of the per-capita GDP are dependent on the GDP, which is endogenously calculated in the model. Based on these findings, the changes in technical structures and the rapid IT penetrations contribute to both economic developments and reduction in carbon emissions on the assumptions in this study.

Under the CO2 stabilization cases, it is also observed that the growth rates of per-capita GDP in the Aij-TS and -IT cases are larger than that in the Aij-FIX case, as shown in Table 3. However, the losses of economic developments are observed in the stabilization cases relative to that in the CO2-Ref cases.

INSERT Table 6

Figure 5 visually describes the simulation result for the sectoral value-added in the world. This figure suggests some prospects for global industrial structure in the future. The obtained economic growth in the world shows a continual, gradual increases from the beginning to the end of the time horizon. The total value-added of the world observed in the year 2027 is 2.4 times larger than that of the year 1997. From the base year onwards, the share of the service sectors including BSR and SSR (see Table 1) is constantly higher than that of the other sectors.

INSERT Figure 5

Figures 6-8 visually describe the differences in the world macro balances in the year 2027 in the CO2-S550 & Aij-FIX, -IS, and -IT cases relative to those in the CO2-Ref & Aij-FIX, -IS, and -IT cases, respectively. These figures define I_S, CRP, NFM, NMM, and P_P as the "energy-intensive sector"; CNS as the "construction sector"; T_T and ATP as the "transportation sector"; BSR and SSR as the "service sector"; and TRN, OME, OMN, FPR, LUM, TWL, OMF, and AGR as the "other sectors."

INSERT Figures 6, 7, and 8

Figures 9-11 represent the world macro balances in the year 2027 in the CO2-S550 & Aij-FIX, -TS, and -IT cases, relative to those in the CO2-Ref case & Aij-FIX, -TS, and -IT cases, respectively. These macro balances consist of (1) domestic output, (2) intermediate input demand, (3) final consumption including private and public sector, (4) investment, and (5) net export. The domestic outputs Q are measured by the following identical equation:

$$Q = ID + C + I + (Ex - Im), \qquad (2)$$

where ID, C, I, Ex, and Im are intermediate input demands, final consumptions, investments, exports, and imports, respectively. Because the world imports are equal to the world exports, we can neglect the final term (Ex-Im) in Eq. (2), namely the world net exports.

INSERT Figures 9,10, and 11

The carbon emission reduction policy has more critical economic impacts on the energy-intensive and construction sectors with more energy requirements than the service sectors. For example, under the Aij-FIX scenario, the loss of the world value-added of the sector total in the year 2027 in the CO2-S550 is 1.5% decrease over that in the CO2-Ref case, as shown in Figure 6. From the point of view of world economic macro balances, the change in the investment is larger than other demand in the sector total as shown in Figure 9, because it directly influences total capital stocks in decreasing the growth of economy development. Since the model structure through investments is explicitly formulated in DEARS, their strict constraint cause dramatically decrease in investments.

The carbon emission reduction policy has less critical economic impacts on the service sector with less energy requirements than the energy-intensive and construction sectors. The change in the domestic outputs of service sectors sector, which has a largest share in total production and consumption, are almost larger than those of other sectors. For example, the change in that in the CO2-S550 & Aij-FIX in the year 2027 are -0.9% relative to that of the CO2-Ref & Aij-FIX case. This is because (1) the service sector has lower energy intensity; (2) the service sector plays an important role in the provision of consumption commodities not investment commodities. This indicates that the implementation cost for CO2 mitigation options will be effectively reduced by post-heavy industrial structures in the changes in industrial structures and the greater IT penetration.

5. Conclusion

This study evaluated the impact of climate change policies and changes in industrial structures by the rapid IT penetration on economic activities. Nine simulation cases, combining three carbon emission policies with the input-output coefficient cases, are conducted: as to carbon emission policies, the reference case (non-climate policy case) and the two emission constraint case meeting the IPCC-S550 and -S450 ppmv stabilizations; as to input-output coefficients, the fixed scenario and the two variable scenarios under the technical structure changes and greater IT penetration cases. The evolutions in industrial structures by IT toward the post-heavy industry in the stabilization cases leads to increases in economic development and decreases in carbon emissions. This indicates that the shift to a lower energy and carbon intensity, and higher value-added industry observed in the technical structure changes and greater IT penetration scenarios result in lower carbon emissions. This indicates that the implementation cost for CO2 mitigation options will be effectively reduced by post-heavy industrial structures in the trends toward the service economy with changes in technical structures and IT penetration.

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Table 1: Regions and non-energy sectors in DEARS

No.	Region Code	Description
1	USA	U.S.A
2	CAN	Canada
3	MCM	Central America
4	BRA	Brazil
5	SAM	South America
6	WEP	Western Europe
7	EEP	Eastern Europe
8	FSU	Fomer USSR
9	NAF	Nothern Africa
10	CAF	Central Africa
11	SAF	Southern Africa
12	JPN	Japan
13	CHN	China
14	IND	India
15	ASN	Asian NIES
16	TME	Middle East
17	ANZ	Oceania
18	XAP	Rest of the world

No.	Sector Code	Description
1	I_S	Iron and steel
2	CRP	Chemical products
3	NFM	Non-ferrous metals
4	NMM	Non-metalic metals
5	TRN	Transport equipments
6	OME	Other machinery
7	OMN	Other mining activities
8	FPR	Food products
9	PPP	Paper, pulp, and printings
10	LUM	Wood and wood products
11	CNS	Construction
12	TWL	Textiles
13	OMF	Other manufacturing
14	AGR	Agriculture
15	T_T	Transportation
16	ATP	Aviation
17	BSR	Bussiness service
18	SSR	Social service

Table 2: Assumed balance of payments development stage

	USA	CAN	MCM	BRA	SAM	WEP	EEP	FSU	NAF	CAF	SAF	JPN	CHN	IND	ASN	TME	ANZ	XAP
1997	VI	IV	I	I	I	IV	I	II	I	I	IV	IV	IV	II	III	I	II	I
2007	-	IV	I	I	I	-	I	II	I	I	IV	-	IV	II	III	I	II	I
2017	-	V	II	II	II	-	II	III	II	II	V	-	V	III	IV	II	III	II
2027	-	V	II	II	II	-	II	III	II	II	V	-	V	III	IV	II	III	II
2037	-	VI	III	III	III	-	III	IV	III	III	VI	-	VI	IV	V	III	IV	III
2047	-	VI	III	III	III	-	III	IV	III	III	VI	-	VI	IV	V	III	IV	III

Note: This table defines I as immature debtor nations, II as mature debtor nations, III as debt repayment nations, IV as immature creditor nations, V as mature creditor nations, and VI as credit disposition nations. The ranges of the regional ratio of the net total exports relative to GDP after the base year are constrainted as follows: I (between –2% and –1%); II (between –1% and 0%); III (between 0% and +1%); IV (between +1% and +2%); V (between +2% and +1%); VI (between +1% and 0%).

Table 3: Assumed elasticities of the sectoral domestic outputs between the year 2017 and 2027

Sector	Rostow's theory	Greater IT penetration
LS	0.37	0.55
CRP	0.89	0.89
NFM	0.64	0.60
NMM	0.48	0.48
TRN	1.08	1.08
OME	1.49	1.65
OMN	0.28	0.28
FPR	0.28	0.28
PPP	0.50	0.50
LUM	0.24	0.20
CNS	0.63	0.63
TWL	0.19	0.19
OMF	0.48	0.48
AGR	0.27	0.23
T_T	0.68	0.68
ATP	0.89	0.89
BSR	1.24	1.50
SSR	1.01	1.01

Table 4: Assumed growth rates of GDP between the year 2017 and 2027

Region	Rostow's theory	Greater IT penetration
USA	1.19	1.49
CAN	1.41	1.41
MCM	3.60	3.60
BRA	3.15	3.65
SAM	2.71	2.71
WEP	1.47	1.47
EEP	3.38	3.38
FSU	4.25	4.45
NAF	4.98	4.98
CAF	4.44	4.44
SAF	5.65	5.65
JPN	1.58	1.78
CHN	6.30	7.20
IND	6.31	7.81
ASN	3.87	4.37
TME	3.31	3.31
ANZ	1.34	1.34
XAP	6.78	6.78

Table 5: Sectoreal response and effect ratio in the year 2027

Sector	Response Ratio			Effect Ratio		
	(1) Fixed	(2) Rostow	(3) IT	(1) Fixed	(2) Rostow	(3) IT
I_S	1.26	*0.94*	*0.95*	1.32	*1.26*	*1.26*
CRP	2.13	**2.32**	*2.07*	1.25	*1.20*	*1.18*
NFM	0.91	*0.71*	*0.69*	1.37	*1.23*	*1.19*
NMM	0.87	*0.74*	*0.76*	1.17	**1.23**	**1.26**
TRN	0.91	**1.23**	**1.19**	1.28	**1.34**	**1.32**
OME	2.41	**4.03**	**4.21**	1.28	**1.32**	**1.34**
OMN	1.19	*0.68*	*0.76*	1.15	**1.39**	**1.34**
FPR	0.73	*0.56*	*0.56*	1.07	*0.91*	*0.92*
PPP	0.92	*0.79*	*0.78*	1.13	*1.07*	*1.06*
LUM	0.61	*0.56*	*0.56*	1.18	**1.20**	**1.18**
CNS	0.50	**0.55**	**0.55**	1.22	**1.31**	**1.34**
TWL	1.31	*0.77*	*0.76*	1.20	*1.19*	**1.24**
OMF	0.76	*0.65*	*0.64*	1.11	**1.17**	**1.24**
AGR	1.28	*0.65*	*0.68*	0.83	**0.84**	*0.83*
T_T	1.43	**1.48**	**1.43**	0.97	**1.08**	**1.10**
ATP	0.50	**0.55**	**0.54**	1.08	**1.16**	**1.17**
BSR	2.40	**4.04**	**4.16**	0.83	**0.87**	**0.88**
SSR	0.84	**1.08**	**1.03**	0.87	**0.91**	**0.92**

Note: **Bold** and *Italic* indidcate the increases and decreases in the ratio under the technical structure change and greater IT penetration scenarios ralative to that under the fixed input-output case, respectively.

Table 6: World average annual growth rate between the years 1997 and 2027 (%/year)

CO2 Emission Path	Technical Structure	CO2 net	CO2 net /CO2 gross	GC2 gross/GDP				GDP/POP	POP
					CO2 gross /PE	PE/Output	Output /GDP		
Historical Trend (1990-2000)		1.24	0.00	-1.31	-0.21	–1.10*		1.13	1.41
CO2-Ref	Aij-FIX	1.39	0.00	-1.49	-0.31	-1.27	0.09	1.75	1.13
	Aij-TS	1.26	0.00	-1.88	-0.38	-1.52	0.02	2.01	1.13
	Aij-IT	1.21	0.00	-1.89	-0.36	-1.53	0.00	1.97	1.13
CO2-S550	Aij-FIX	0.76	-0.31	-1.76	-0.50	-1.34	0.08	1.70	1.13
	Aij-TS	0.76	-0.25	-2.03	-0.51	-1.53	0.01	1.92	1.13
	Aij-IT	0.76	-0.25	-2.03	-0.47	-1.54	-0.02	1.91	1.13
CO2-S450	Aij-FIX	0.28	-0.28	-2.20	-0.77	-1.48	0.06	1.63	1.13
	Aij-TS	0.28	-0.28	-2.40	-0.74	-1.64	-0.02	1.83	1.13
	Aij-IT	0.28	-0.29	-2.38	-0.69	-1.65	-0.04	1.82	1.13

* We consider the growth rate of *PE/GDP* between the years 1990–2000 instead of *PE/Q* and *Q/GDP* because it is difficult to obtain the domestic output *Q* between the years 1990 and 2000 in terms of corresponding 18 divided sectors in this study.

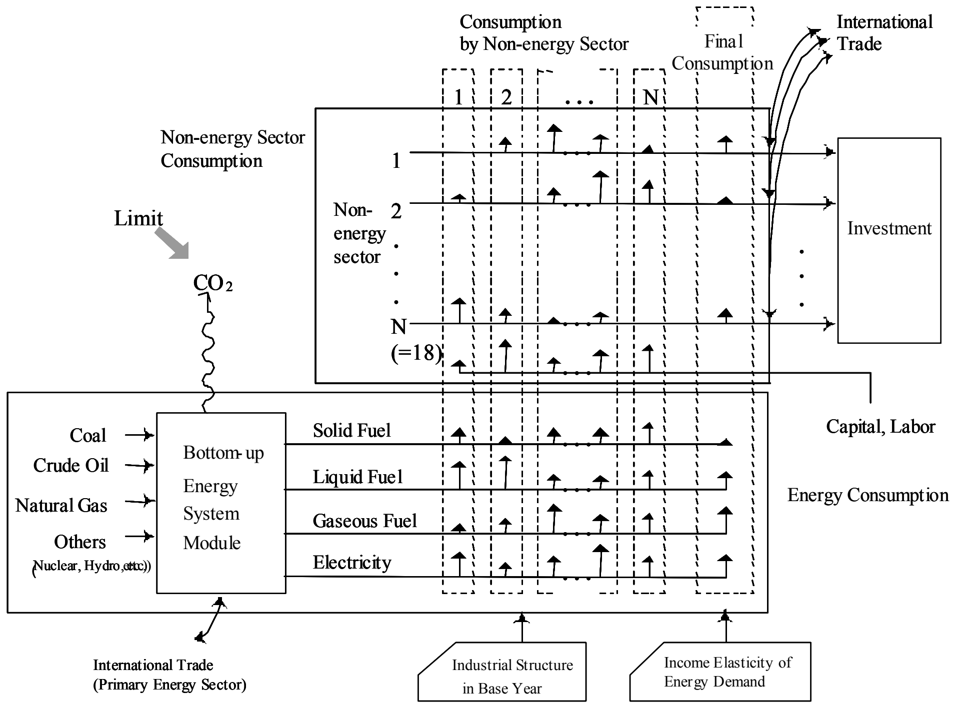

Figure 1: Integration of non-energy sectors and energy technologies in DEARS

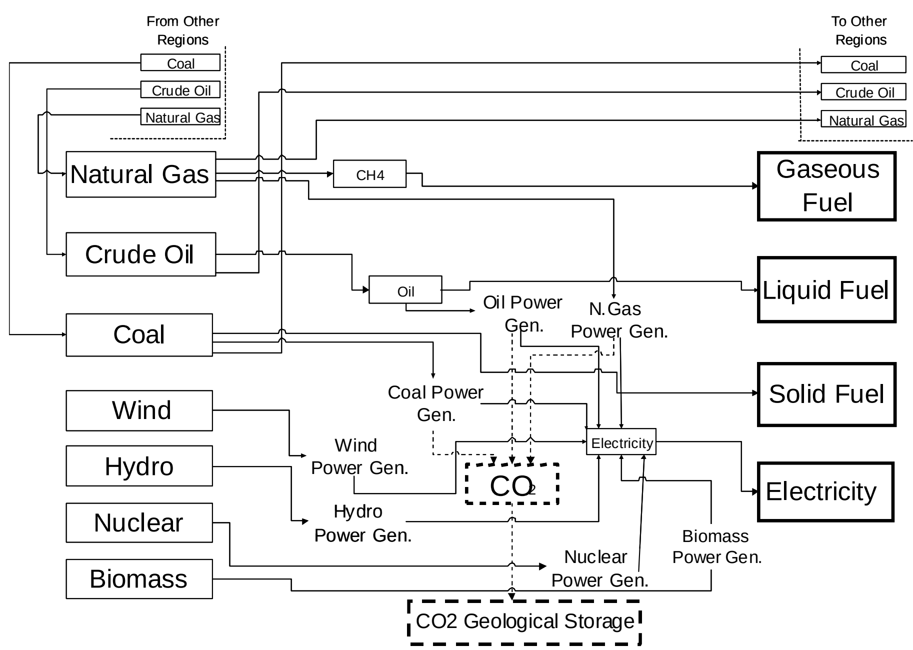

Figure 2: Assumed energy flow in DEARS for one region

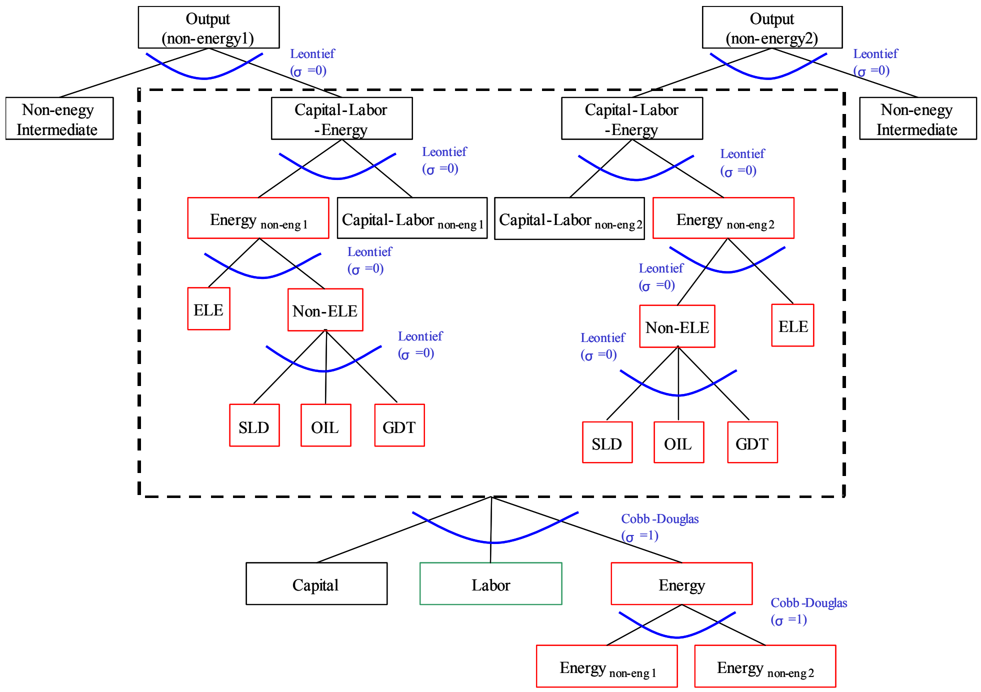

Figure 3: Nesting structure of the non-energy and energy sectors

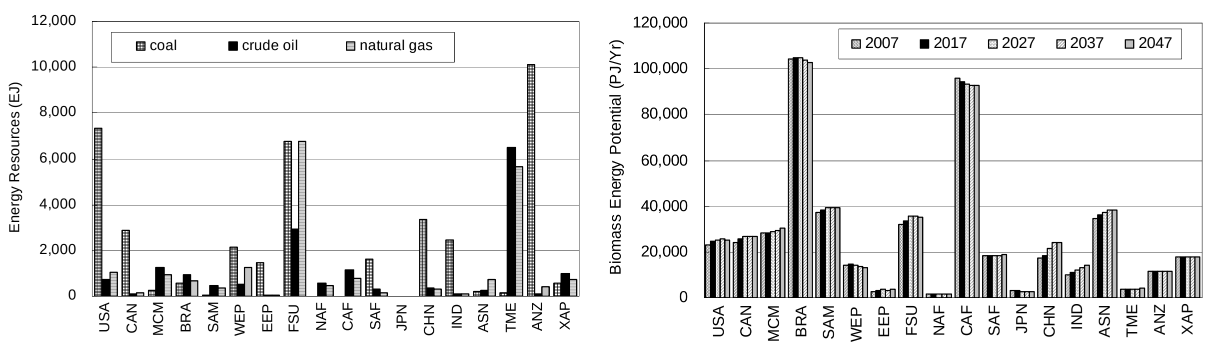

Figure 4: Assumed potentials of fossil fuels and biomass fuels

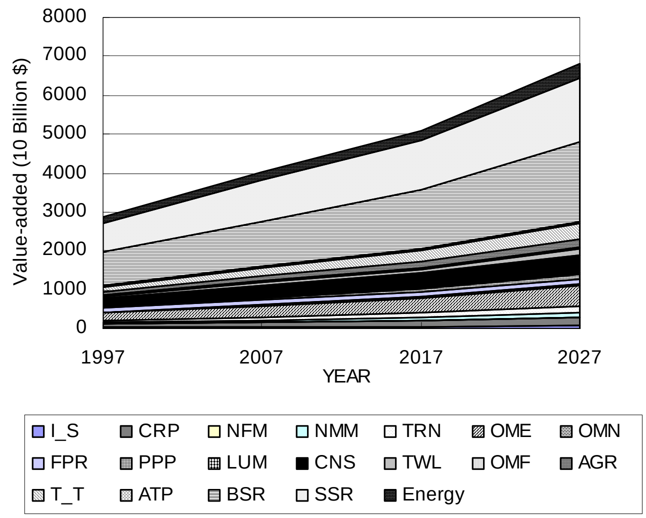

Figure 5: World value-added in the CO2-Ref & Aij-FIX case

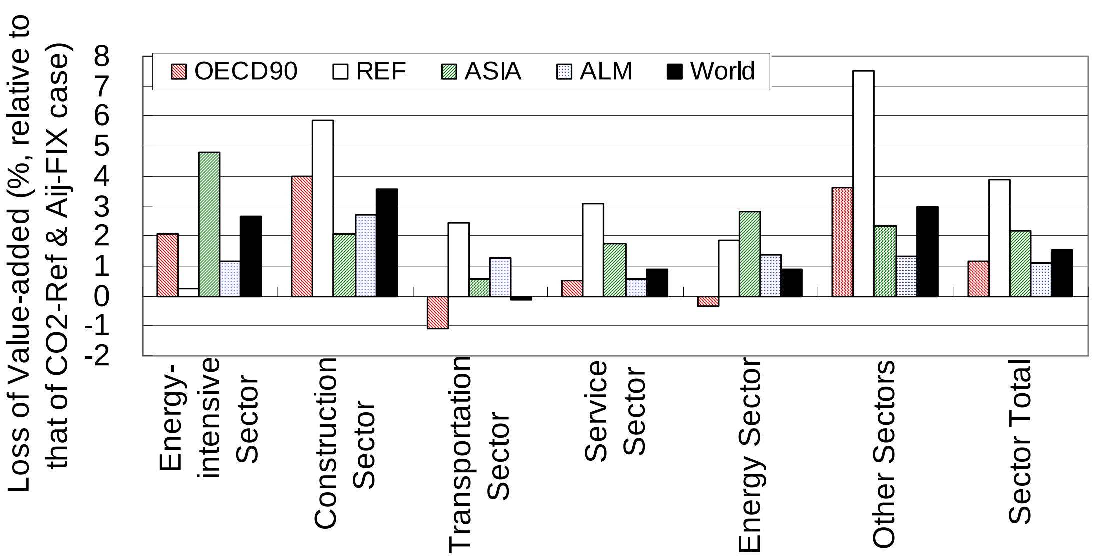

Figure 6: Loss of value-added in the year 2027 in the CO2-S550 & Aij-FIX case (10 billion $)

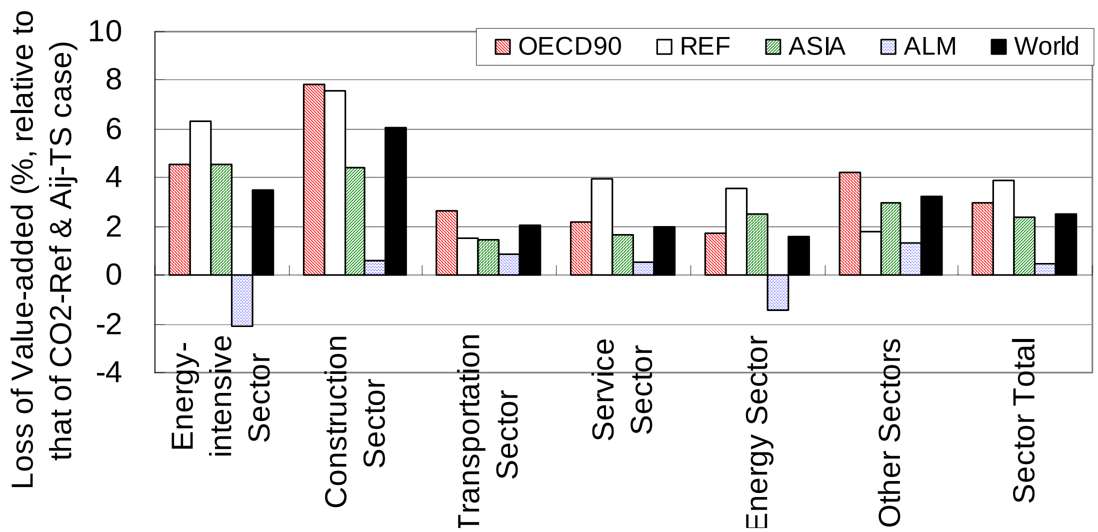

Figure 7: Loss of value-added in the year 2027 in the CO2-S550 & Aij-TS case (10 billion $)

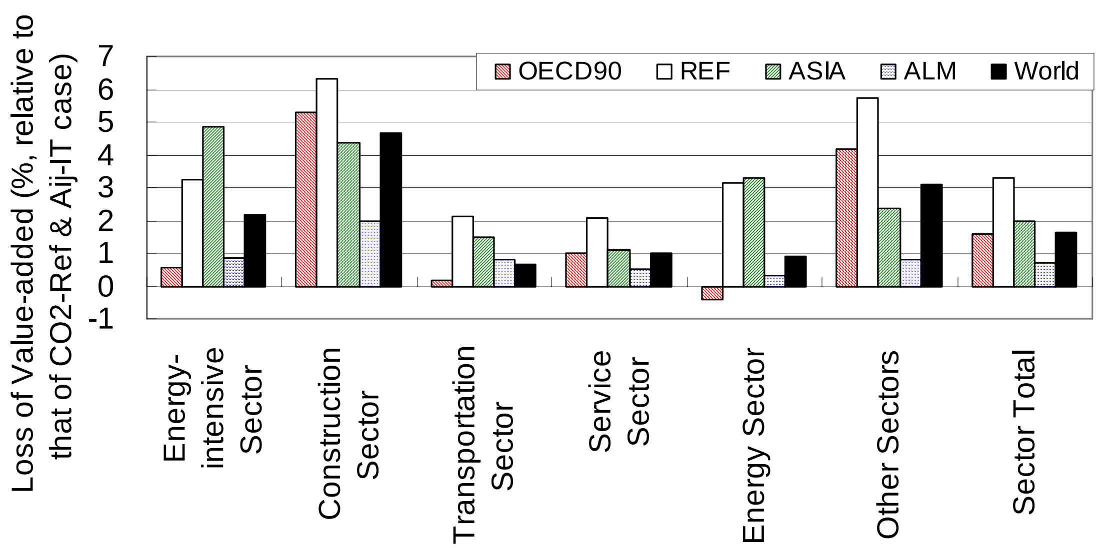

Figure 8: Loss of value-added in the year 2027 in the CO2-S550 & Aij-IT case (10 billion $)

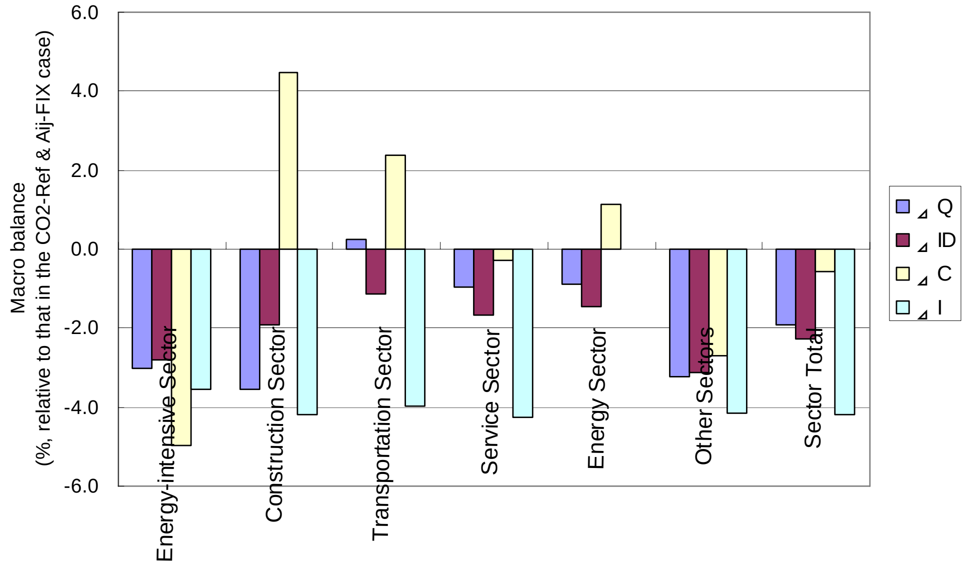

Figure 9: Differences of macro balance in the year 2027 between the CO2-REF and -S550 cases in the Aij-FIX case (10 billion $)

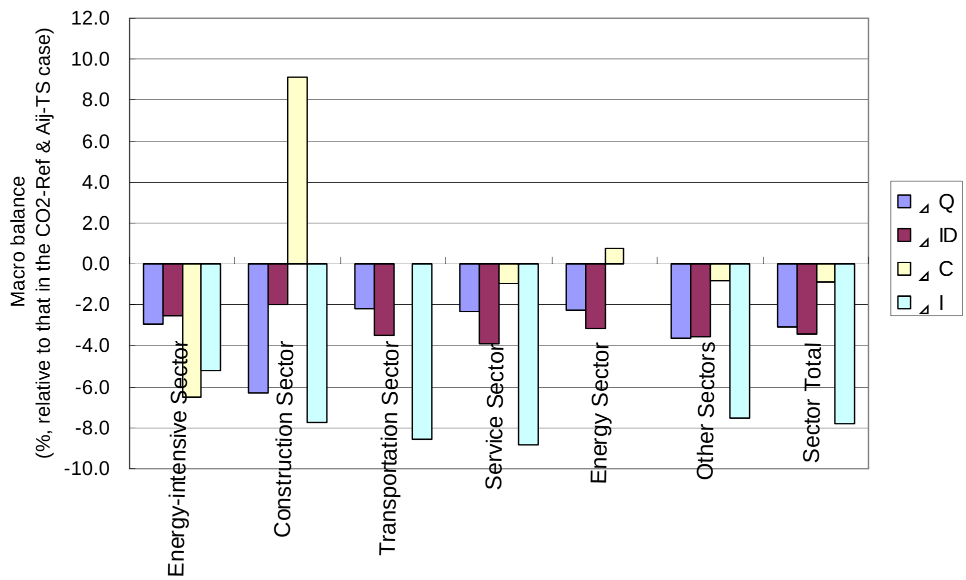

Figure 10: Differences of macro balance in the year between the CO2-REF and -S550 cases in the Aij-TS case (10 billion $)

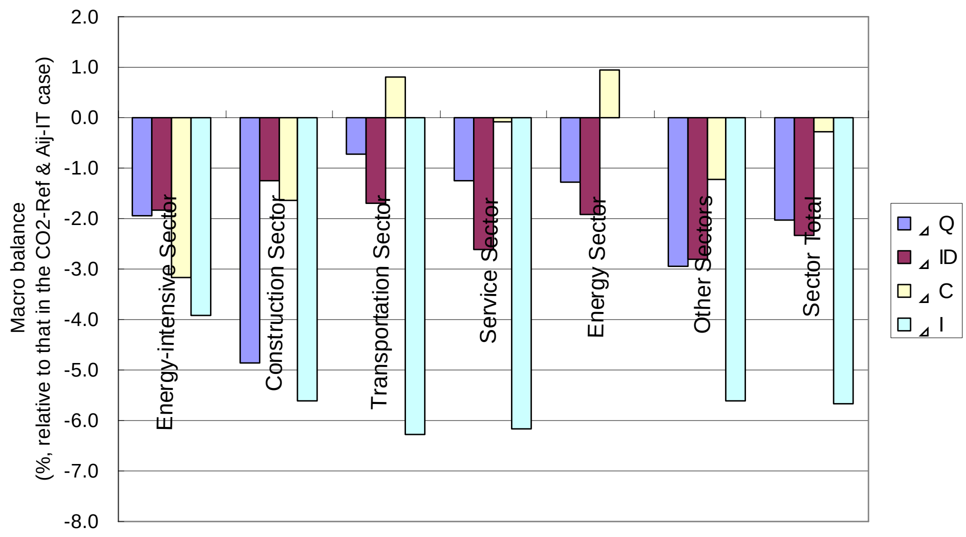

Figure 11: Differences of macro balance in the year 2027 between the CO2-REF and -S550 cases in the Aij-IT case (10 billion $)