Input - Output & Environment

International Input Output Meeting on Managing the Environment

SEVILLE (SPAIN)
July 9 - 11, 2008
http://www.upo.es/econ/IIOMME08

A Dynamic Multi-sectoral and Multi-regional Model towards a Middle-term Integrated Assessment: An Alternative of DEARS Mode

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Abstract

In this paper, the author describes an alternative model which is also formulated as a dynamic optimization model incorporating multi-regions, multi-sectors and energy technologies, named THERESIA - Toward Holistic Economy, Resource and Energy Structure for Integrated Assessment dealing with 15 world regions, 12 non-energy industry sectors and 7 energy sectors incorporating two labour categories, i.e., high-educated labour and general labour forces to evaluate how the substitutability between professional labour and capital, reflecting the expansion of such knowledge-based industries as information and business services, under the global warming mitigation measures. The simulation results show us that (1) the high labour-capital substitutability case gives higher economic growth than low substitutability case, (2) world GDP loss in 2037 is 1.88% (550ppmv stabilization scenario) and 3.36% (450ppmv stabilization scenario) in low labour-capital substitution while 3.50%(550ppmv stabilization scenario) and 5.63% (450ppmv stabilization scenario) in high labour-capital substitution case. (3) The economic loss in the construction sector is large as well as machinery sectors while damage in the service sectors is relatively small.

Keywords: multi-region, multi-sector, inter-temporal optimization, energy technologies

1. Introduction

Since 2005 when the Kyoto Protocol was taken into effect, the evaluation of global warming mitigation measures becomes one of the international policy issues. The Nobel Peace Prize 2007 for the IPCC activities seemed to recall the public concern. However, the situation towards the implementation of mitigation institutions is still far from the agreement since there lies a serious uncertainty in the long-term costs and benefits of global warming mitigation. With respect to the economic damages under the greenhouse gas control policies, the existing integrated assessment models collected in the IPCC-AR4-WG3 provide 0.2%-2.5% world GDP losses comparing with BAU in 2030 where the CO2 equivalent concentration stabilization level is set around 535-590 ppmv.

Although IPCC-AR4 as well as Stern Review in 2006 concludes the mitigation costs are small, it should be noted that the existing models do not always incorporate the dynamic industry structure changes which will play a key role in the next decades especially in the Asia region. In 2008, Japanese government proposed a new mitigation measure which focuses on the potential carbon emission mitigation by sector – i.e., “sectoral approach” as Post-Kyoto. Although it is not clear whether this approach is acceptable or not, the assessment of such new proposal requires disaggregated formulation of economic activities as well as the dynamics and the variety of energy technologies.

GTAP (Hertel(1997), GTAP(2008)) has often been employed to evaluate the trade and industry structure under the global warming mitigation policies. (NIES(2008), Paltsev et.al.(2005)) Iterative dynamic calculation procedure is basically employed to generate the dynamic economic activities. However, the dynamic interrelationships among energy technology options, industry structure and warming measures are not evaluated since the existing multi-sectoral models are basically formulated static.

A pioneering work to develop an inter-temporal optimization model with multi-sectors, multi-regions and energy technologies is provided by Homma, et.al. (2007), named DEARS (Dynamic Energy-economic model with multi-Regions and multi-Sectors) as a part of an integrated assessment project on global warming by RITE (Mori et.al.(2006)). DEARS proposed an ambitious formulation which incorporates such detailed energy-related technologies as the conventional and the advanced power generation options, biomass liquefication and other renewables as well as carbon sequestration options. Multi-regional Input-Output tables are included to evaluate the sectoral economic activities.

In this paper, the author describes an alternative model which is also formulated as a dynamic optimization model incorporating multi-regions, multi-sectors and energy technologies, named THERESIA - Toward Holistic Economy, Resource and Energy Structure for Integrated Assessment. The origin of THERESIA and the DEARS are same (developed by the author) but have been expanded toward different directions. DEARS is technology-rich but contains one macro production function for each region while THERESIA incorporates sectoral production functions with relatively simplified energy flows to DEARS. THERESIA deals with 15 world regions, 12 non-energy industry sectors and 7 energy sectors. THERESIA also incorporates two labour categories, i.e., professional labour and general labour forces. We employ the CES production function between capital and professional labour with low substitutability. Capital and professional labour CES function is connected with non-professional labour, secondary energy sources and other inputs in the Cobb=Douglas production function form.

2. Overview of Integrated Assessment Models

When the policy maker wants to build up policy measures taking into account the interactions among environmental impacts, economic cost and technological availability, quantitative evaluations of those factors are mostly needed and then he will explore the most preferable option mix based on the comprehensive information. Integrated assessment models (IAMs) have contributed to evaluate the policy measures under the complex interrelationships among environment, energy, economy, technology, resource and societal issues, especially in the global warming issues. Inter-governmental Panel on Climate Change (IPCC) eagerly employed IAM’s to provide the future socio-economic scenarios and evaluation of policy measures, e.g. carbon control cost under various warming mitigation policies and the role of carbon sequestration technologies (IPCC-SRES(2000), IPCC-TAR(2001), IPCC-AR4(2007)).

The integrated assessment models extensively developed in 1990s basically involve multi modules, i.e., climate changes, energy technologies, economic activities and environmental impacts on human activities such as agriculture, land use and human health. A pioneering work of IAM is DICE model developed by Nordhaus(1994) where global warming system, economic activities and warming damage functions are integrated in a compact non-linear optimization model. Although DICE did not include the energy technology flows, it has been expanded and used for the assessments of climate policies. MERGE developed by A. Manne and Richels (Manne(1993)) is an expansion of energy-economics model ETA=MACRO developed in 1970s (Manne (1981). MERGE involves the above four modules which are linked by data exchanges. IMAGE (Alcamo(1993)) and IMAGE 2.0(Alcamo(1994)) assessed the warming impacts on agriculture and biosphere using detailed land use data. In Japan, National Institute of Environmental Studies (NIES) has been developing AIM project including plural detailed model modules(NIES(2008). MARIA(Mori (2000)) expanded the DICE model to include detailed energy flow module, land use change module and food demand and production module dividing the world into eight regions. These models are still being expanded to assess the global warming policies reflecting new scientific findings and political situations.

Most of the IAMs developed in 1990’s mainly focused on the long-term assessments of global warming mitigation and energy technologies as well as fossil fuel resource issues through 21st century. Economic activities are mostly aggregated into one macro-sector. Thus, they fail to assess the dynamic structural changes in the international reallocation of industry sectors. For instance, decision maker will be interested in the impacts of carbon tax on the international allocation and the trade changes of iron and steel industry as the global warming mitigation is being in practice, e.g. in the “sectoral approach”. Schafer et.al.(2003) extensively mentions the need for the multi sector model for the IAM. The impacts of recent societal structural changes, e.g., the penetration of information and communication technologies (ICT), knowledge based industry and also aged society, on the energy and environmental issues have not been examined yet although they are the key factors in the near future.

On the other hand, there are some Computable General Equilibrium (CGE) models including multi-sector economic activities for multi regions. GTAP (Hertel (1997)) and G-CUBED (McKibbin (2000)), which are originally developed to analyze the international trade issues, have been extensively applied to the global warming issues. For instance, recent version of AIM (NIES (2008)) and MIT-EPPA (Schafer et.al.(2003), Paltsev et.al.(2005)) extensively combine GTAP and energy technology model to generate the dynamic sectoral impacts of global warming mitigation measures. However, the original CGE model is basically formulated as static and they do not include detailed energy technology flows like MERGE (Manne (1993)) or DNE-21 developed by Akimoto et.al. 2004) where technology choice is obtained by solving an optimization model under the physical constraints. Most of current studies involving CGE module require an iterative calculation procedure to generate dynamic scenarios exchanging intermediate data among model modules. However, when one is interested in the capital formation behaviour in manufacturing, government and energy sectors under carbon control policies, an inter-temporal optimization model is needed. The evaluation of dynamic trajectory of equilibrium price of commodities, especially the case of exhaustive resource under the technological progress scenarios, is also the case.

The DEARS model in the PHOENIX project as well as the model THERESIA described in this paper is developed to approach the above issues formulated as a dynamic multi-sectoral multi-regional energy-economic model

It should be also noted that existing IAMs are mainly utilized to assess the certain carbon control policy on the economic activities and energy technology strategies rather than to establish the cost and benefit analysis of global warming due to the lack of “economic damages caused by the expected global warming phenomena”. Thus, the potential problems of cost benefit analysis in the global warming issues are not clarified yet. Nonetheless, IAM is still the only tool to assess the policies quantitatively keeping the internal consistency of the assessments.

3. Model Formulation

3.1 Overview and the formulation of the model

Figure 1 shows the conceptual structure of THERESIA model which is similar to DEARS (Honma et.al.(2006)(2007)), where no difference from conventional input-output model is found except for the energy sectors. Both primary and secondary energy inputs are formulated in physical terms and consist of multiple energy conversion technology options exhibited in Figure 2 unlike the existing CGE models.

			Intermediate Inputs				Final demand			
			Non-energy sectors		Energy sectors		trade	Investments	Consumption	Output
			1	2	Primary	Secondary	m	I	C	Q
Int. Inputs	Non-energy Sectors	1	$X11=Q1\cdot a11$	$X12=Q2\cdot a12$			1	I1	C1	Q1
		2	$X21=Q1\cdot a21$	$X22=Q2\cdot a22$			2	I2	C2	Q2
	Energy Sectors	Primary				X_{pe}	p			EC_pre= PpS
		Secondary	$Xe1=PeE1$	$Xe2=PeE2$					Ce= PeEc	EC= PeE
Value Added		K	$Pk\cdot K1$	$Pk\cdot K2$	VA_pre	VA_E				
		L	$PL\cdot L1$	$PL\cdot L2$						Y
Output		Q	Q1	Q2	EC_pre= PpS	EC= PeE				Q

Figure 1 Conceptual framework of THERESIA and DEARS (simplified)[1]

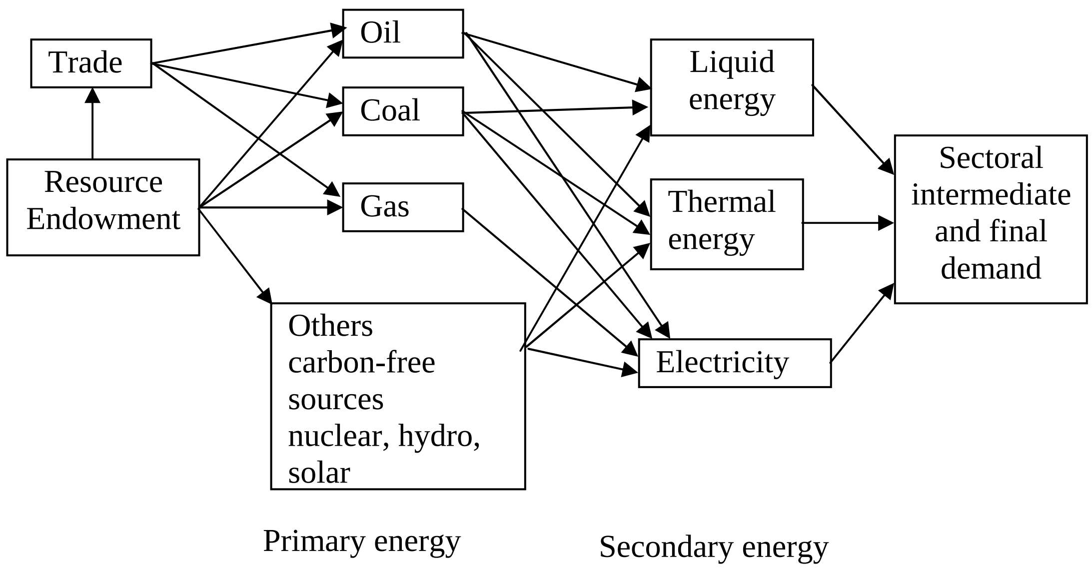


Figure 2 Concept of Energy Flows (simplified)

[1] For the sake of simplicity, intermediate inputs and labour costs for energy sectors are omitted in Figure 2. Needless to say, these numbers are not always 0 according to the statistics.

The frame of both DEARS and THERESIA is identical: developed by the author as a part of project PHOENIX (Mori et.al. 2006)) to see the middle-term dynamic behaviour of regional industry allocation under the carbon control policy. In the PHOENIX project, DEARS has been expanded to deal with the detailed energy technologies like DNE-21 (Akimoto et.al. (2004)) as well as carbon sequestration options while economic activity of the certain region is relatively simplified containing one macro production function with capital, labour and energy inputs. GDP is then distributed among sectors according to the domestic input-output constraints and the international trade balances.

Although the above formulation could avoid the complexity of numerical calculation successfully with 18 regions, 18 non-energy sectors and 11 energy sources with seven types of primary energy, i.e. coal, crude oil, natural gas, biomass, hydro power, wind power, and nuclear power, and four types of secondary powers, i.e. solid, liquid, gaseous fuels and electricity for eight periods, the behaviours of energy-capital-labour substitutability can not be differentiated among industry sectors.

THERESIA, instead, focuses on the sectoral activities in details: first, THERESIA can contain both sectoral production functions and aggregated one to deal with the trade-off between detailed outcome and numerical calculation difficulty. For instance, current THERESIA in this paper incorporates sectoral production functions for iron and steel industry sector, chemical products, paper, cement and glass industry sector and transportation machinery industry sector[2]. Second, labour sector is classified into two categories, i.e. professional labour and other non-professional group according to the GTAP data base. In THERESIA, two types of production function are formulated and compared: Cobb=Douglas type function of professional labour, other non-professional labour, capital and secondary energy inputs implying unity substitution elasticity among input factors and CES function with low substitutability between professional labour and capital implying that the role of education could be strongly embodied in the capital.

3.1.1 Formulation of energy flows

Energy flows from fossil fuels to electricity are further disaggregated into such power generation options as conventional fired plant, advanced combined cycle plant and fuel

[2] THERESIA still requires around two or three days for one calculation with 15 regions, 12 industry sectors and 7 energy categories for 7 periods by GAMS-CONOPT3 on 3.0GHz Core-DUO2 PC.

cell with different efficiency and capital cost represented by VA_E in Figure 1. Extraction and production cost of primary energy source is assumed to be a functions of cumulative production following to Rogner (1997). Total extraction and production cost during the period is represented by VA_pre in Figure 1. These are formulated as follows for the period t and region h.

$$S^h{}_{k,t} = \sum_j XE^h{}_{k,j,t} \quad \textbf{(1)}$$

$$S^h{}_{k,t} = SD^h{}_{k,t} + Sim^h{}_{k,t} \quad \textbf{(2)}$$

k: primary energy source, k=coal, oil, gas and others
j: secondary energy, j=liquid fuel, thermal energy and electricity
$S^h{}_{k,t}$: primary energy supply
$SD^h{}_{k,t}$: primary energy domestic production
$Sim^h{}_{k,t}$: primary energy net import
$XE^h{}_{k,j,t}$: energy flow from primary energy k to secondary energy j

$$XE^h{}_{k,j,t} = \sum_m XG^h{}_{k,j,m,t} \quad \textbf{(3)}$$

m: conversion technologies
$XG^h{}_{k,j,m,t}$: energy demand for conversion technology m of primary energy k for secondary energy j

$$E^h{}_{j,t} = \sum_m Eff^h{}_{k,j,m,t} XG^h{}_{k,j,m,t} + Eim^h{}_{j,t} \quad \textbf{(4)}$$

$E^h{}_{j,t}$: secondary energy supply
$Eim^h{}_{j,t}$: secondary energy net import (only for liquid fuel)
$Eff^h{}_{k,j,m,t}$: conversion efficiency of technology m

$$Scum^h{}_{k,t} = Scum^h{}_{k,t-1} + \frac{1}{2}\left(SD^h{}_{k,t-1} + SD^h{}_{k,t}\right) \times Yr \quad \textbf{(5)}$$

$$VA\_pre^h{}_{k,t} = SD^h{}_{k,t} \times f^h{}_k\left(Scum^h{}_{k,t}\right) \quad \textbf{(6)}$$

$Scum^h{}_{k,t}$: cumulative production of primary energy k
Yr: duration of one simulation period (10 years)
$f^h{}_k$ (x): extraction and production cost supply curve of fossil energy

$$VA\_E^h{}_{j,t} = \sum_k \sum_m XG^h{}_{k,j,m,t} \times FCe^h{}_{k,j,m,t} \quad \textbf{(7)}$$

$FCe^h{}_{k,j,m,t}$: capital cost of conversion technology m of primary energy k for secondary energy j

Wholesale prices of the primary and the secondary energy are defined by the total cost, i.e. capital costs + intermediate inputs + labour costs (if available), divided by total supply.

3.1.2 Formulation of labour supply

GTAP data base provides two labour supply categories, i.e. professional labour and other non-professional labour. It could be generally understood that the business service industry including information and communication sector and finance service sector are relatively low capital intensive to existing manufacturing industries and that the capital and equipments are embodied in the human resources as a basis of those knowledge-based businesses. The more the fraction of these industries in the world economy grows, the more the professional or high-educated labour would be the key driving force. It would be an interesting topic how the world industry structure would be influenced by the establishment of the education and professional training system. Furthermore, those structure changes would also affect the economic impacts of the global warming mitigation policies. On the other hand, unskilled labour would be more flexibly substituted by capital.

THERESIA model tries to assess how the international economy and energy structure are affected by the heterogeneity of the above labour categories. THERESIA incorporates two types of production function and compare how the difference of substitution elasticity affects:

(Cobb=Douglas type) $$YE^h{}_{i,t} = A^h{}_i \cdot K^h{}_{i,t}{}^{\alpha^h{}_i} \cdot LH^h{}_{i,t}{}^{\beta^h{}_i} \cdot LL^h{}_{i,t}{}^{\gamma^h{}_i} \times \left[\prod_j E^h{}_{i,j,t}{}^{\theta^h{}_{i,j}}\right]^{1-\beta_i}$$

(8)

(CES type) $$YE^h{}_{i,t} = B^h{}_i \cdot \left[\left\{\left(K^h{}_{i,t}{}^{-\mu^h{}_i} + C^h{}_i \cdot LH^h{}_{i,t}{}^{-\mu^h{}_i}\right)^{-\frac{1}{\mu^h{}_i}}\right\}^{\lambda^h{}_i} LL^h{}_{i,t}{}^{1-\lambda^h{}_i}\right]^{\beta^h{}_i} \times \left[\prod_j E^h{}_{i,j}{}^{\theta^h{}_{i,j}}\right]^{1-\beta^h{}_i} \quad \textbf{(9)}$$

where i, $YE^h{}_{i,t}$, $LH^h{}_{i,t}$, $LL^h{}_{i,t}$, $K^h{}_{i,t}$ and $E^h{}_{i,j,t}$ represent industry sector, value added plus energy expenditure, professional labour input, other non-professional labour input, capital stock and j-type secondary energy inputs, for i-th industry, the h-th region and at period t, respectively. $A^h{}_i,\ B^h{}_i, C^h{}_i,\ \alpha^h{}_i, \beta^h{}_i, \gamma^h{}_i,\ \mu^h{}_i,\ \lambda^h{}_i$ *and* $\theta^h{}_{i,j}$ are the parameters.

Labour supply constraints are as follows:

$$\sum_i LH^h{}_{i,t} \leq LHtotal^h{}_t \quad \textbf{(10)}$$

$$\sum_i LH^h{}_{i,t} + LL^h{}_{i,t} \leq Ltotal^h{}_t \quad \textbf{(11)}$$

where $LHtotal^h_t$ and $Ltotal^h_t$ represent exogenous supply of the professional labour and total labour force, respectively. Equation (11) implies professional workers can also work as an unskilled general labour.

3.1.3 Other Equations

Other model equations consists of row-wise balance representing the distribution of output commodity, column-wise balance corresponding to the financial balance and international trade balance which are basically similar to the existing CGE model. Intermediate inputs of each industry are defined according to the input-output coefficients and YE_i assuming the Leontief model.

Final demand vector $\mathbf{FD}^h_t$ consists of private sector investments $\mathbf{IP}^h_t$, governmental sector investments $\mathbf{IG}^h_t$, export $\mathbf{Tx}^h_t$, import $\mathbf{Tm}^h_t$, private sector consumption $\mathbf{CP}^h_t$ and governmental sector consumption $\mathbf{CG}^h_t$. Provided investment coeffcient matrix $\mathbf{CPF}^h_t$ and investment for sector i, $I^h_{i,t}$

$$\mathbf{IP}^h{}_t = \mathbf{CPF}^h{}_t \left[I^h{}_{1,t}, I^h{}_{2,t}, I^h{}_{3,t} \cdots I^h{}_{N,t} \right]^T \quad \textbf{(12)}$$

holds where N represents number of sectors.

Conventional capital formation relationship

$$K_{i,t} = (1-\delta)K_{i,t-1} + I_{i,t} \cdot Yr \quad \textbf{(13)}$$

where $I_{i,t}$ represents investment, is also included.

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

$$\max.\ \Phi = \sum_t (1-r)^t \sum_h w_h \sum_i L^h{}_t \ln\left(\Pi_i \left(CP^h{}_{i,t}\right)^{\mu^h{}_i} \Big/ L^h{}_t \right) \quad \textbf{(14)}$$

where w^h and μ_i represent the weights. We tentatively give w^h and $\mu^h{}_i$ the total consumption and the consumption fraction of commodity i in region h, respectively. It is also assumed that the consumption and the investment vectors in the governmental sector grow proportionally to GDP. According to GTAP, Armington model on the tradable goods is also imposed.

3.2 Data definition

THERESIA deals with 15 regions, 12 industry sectors, 4 primary energy sources and 3 secondary energy categories shown in Table 1 while DEARS (Honma (2006)) contains 18 regions, 18 industry sectors, 7 primary energy sources and 4 energy categories. Based on GTAP Ver.5, we aggregated the sectors and regions according to the Table.1 (a) and (b). We extract the energy production, conversion and consumption data from IEA Energy Balance Tables (IEA (2007)).

While wage expenditure by sector is provided in GTAP data, sectoral labour force in number by category is not available. Since the definition of GTAP labour category follows ILO, according to the ILO Labour Statistics (ILO 2007), we picked up the total labour force (Ltotal) and professional labour force (LHtotal) by region. We distributed the Ltotal and LHtotal among sectors proportionally to the wage expenditure assuming that the effective wage is identical among sectors.

Table 1 Definition of regions, industry sectors and energy

(a) Region

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

(b) Industry

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

(c) Energy

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

In THERESIA, total labour supply is given exogenously. We estimate the future labour supply in the following manner: first, future total labour supply of each region grows proportionally to the projected population given by UN (2006) by region. Second, we estimate the future trends of the share of professional labour extrapolating the historical trend assuming their upper limit to be 50%. Figure 3 exhibits the projection of the professional labour share.

The parameters on production functions are estimated based on GTAP ver 5 in 1997. We also assumed 5% discount rate. For CES production function (Equation (9)), substitution elasticity between capital stock and professional labour is needed. It is preferable to estimate them based on the historical data. At the moment, due to the lack of the data, we tentatively assumed 0.2 uniformly. Actual value would be between this low value and 1.0 (Cobb=Douglas case).

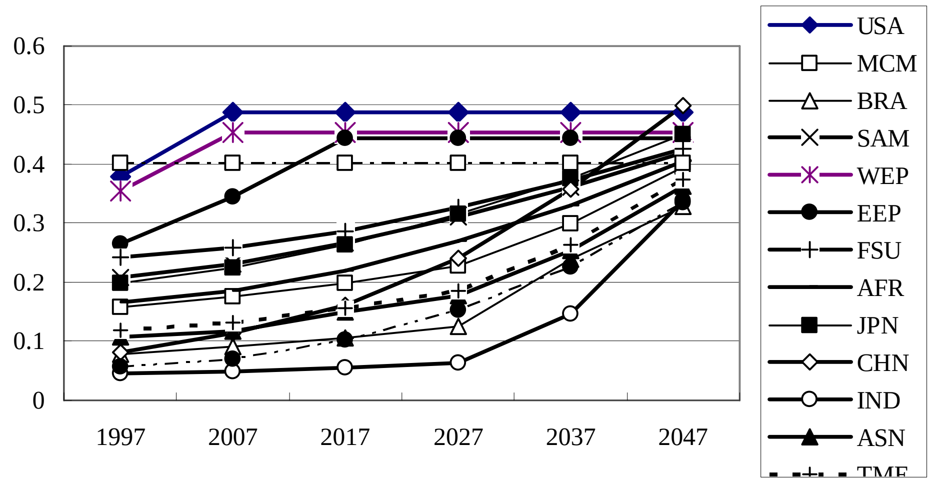


Figure 3 Assumption on future fraction of professional labour

4. Results

4.1 Simulation cases

Various simulation cases are available based on THERESIA model. In this paper, we present following 6 cases:

CES-BAU: low substitution elasticity between professional labour and capital
CES-550: CES-BAU+ 550ppmv concentration carbon control policy
CES-450: CES-BAU+ 450ppmv concentration carbon control policy
CDG-BAU: high substitution elasticity between professional labour and capital
CDG-550: CDG-BAU+ 550ppmv concentration carbon control policy
CDG-450: CDG-BAU+ 450ppmv concentration carbon control policy

In the carbon control policy cases, carbon emisiion trajectories are given by the WRE-550 and WRE-450 scenario in IPCC-TAR (2001). Figure 4 exhibits the carbon emission upper limit on WRE-550 and WRE-450. Carbon emission simulation results on CES-BAU and CDG-BAU are also exhibited.

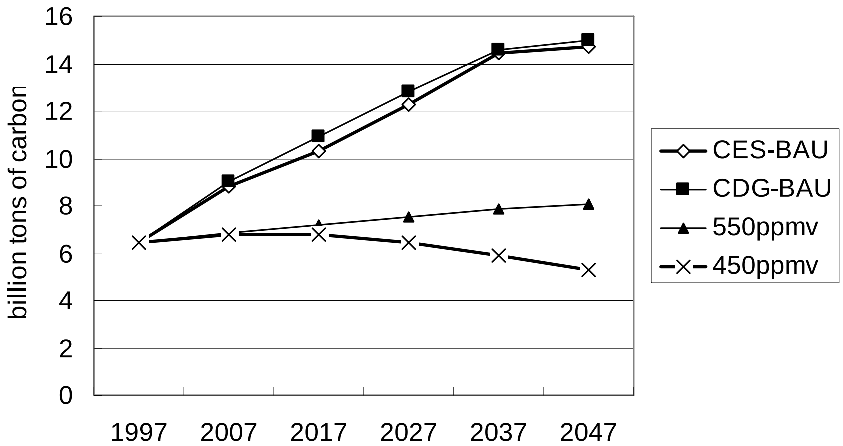


Figure 4 Carbon emission trajectories on WRE-550, WRE-450 and simulation results on CES-BAU and CDG-BAU

4.2 Results

Simulation results on CES-BAU are firstly exhibited as reference of simulations. Figure 5, Figure 6, Figure 7 and Figure 8 show the simulation results on world regional GDP, world sectoral GDP, and annual growth rates of the regional and the sectoral GDP, respectively. In CES-BAU, world annual GDP growth rate is 2.15% where those of developed regions are slightly moderate.

World sectoral labour supply profile is shown in Figure 9 where labour inputs in the service industries are increasing while those in manufacturing are decreasing. Figure 10, Figure 11 and Figure 12 are energy related figures: primary energy production, international primary energy production costs and the profile of world power generation technologies.

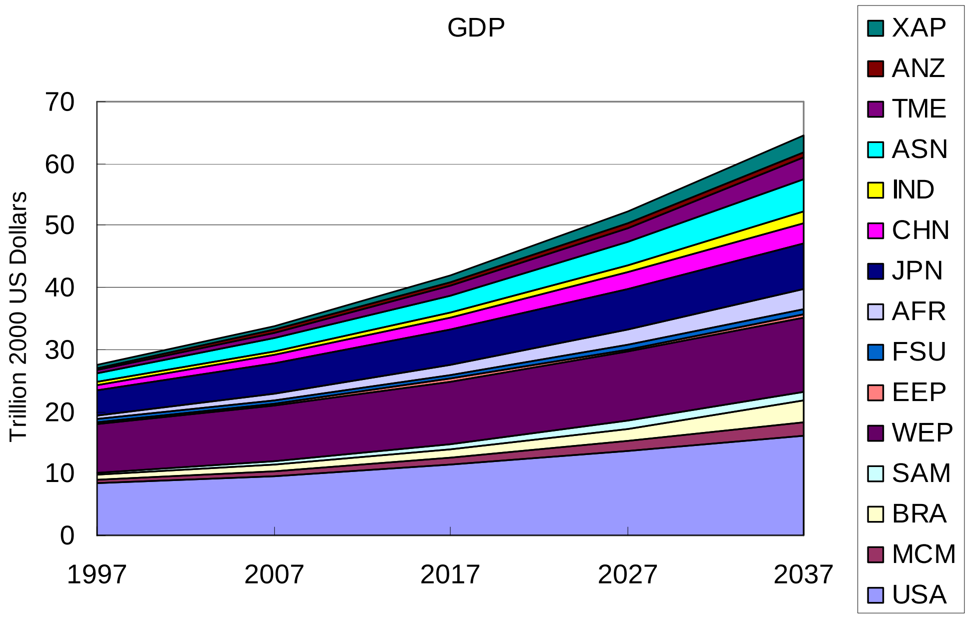


Figure 5 World regional GDP profile in trillion 2000 US dollars (CES-BAU)

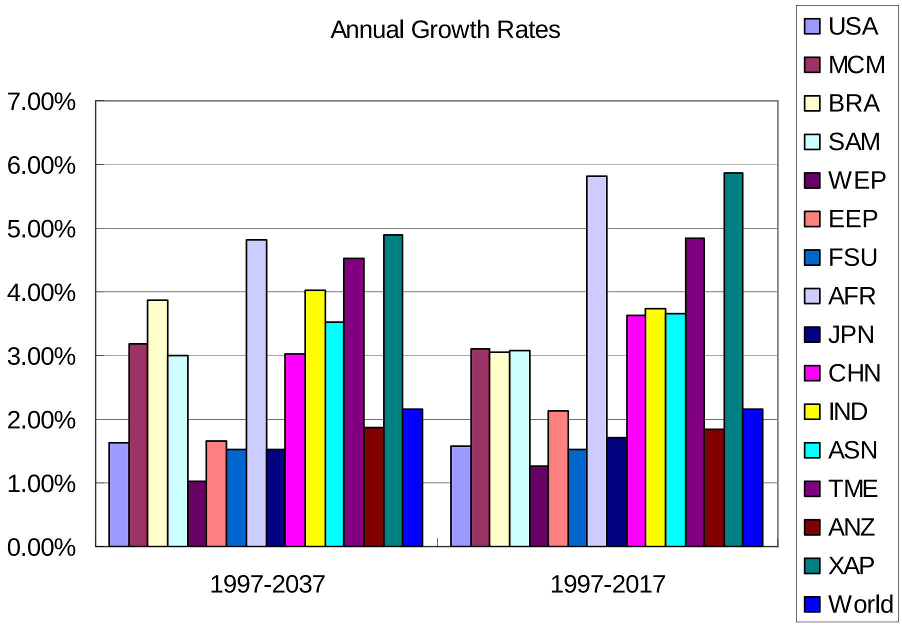


Figure 6 Annual growth rates of regional GDP during 1997-2037 and 1997-2017 (CES-BAU)

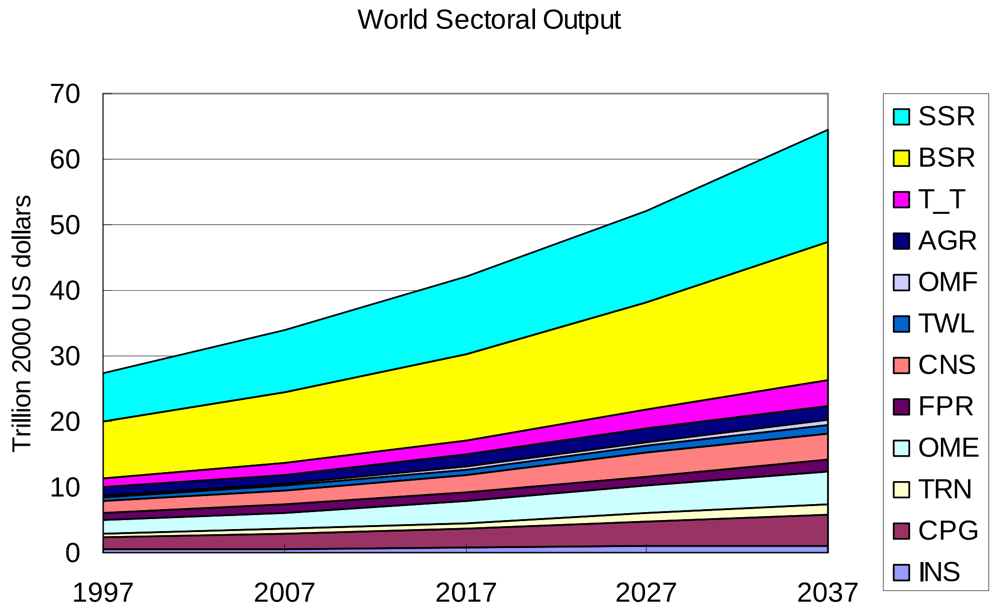


Figure 7 World sectoral GDP profile in trillion 2000 US dollars (CES-BAU)

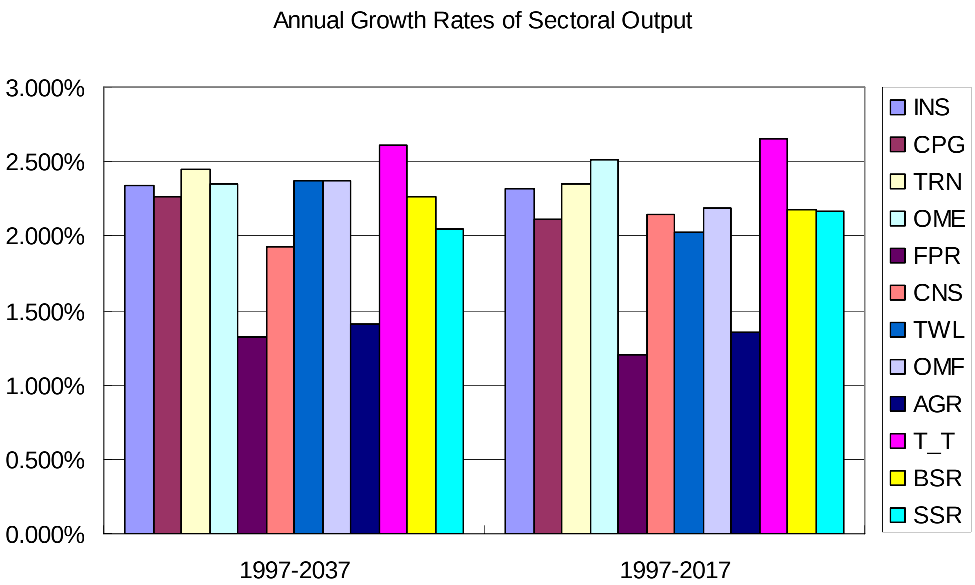


Figure 8 Annual growth rates of secctoral GDP during 1997-2037 and 1997-2017 (CES-BAU)

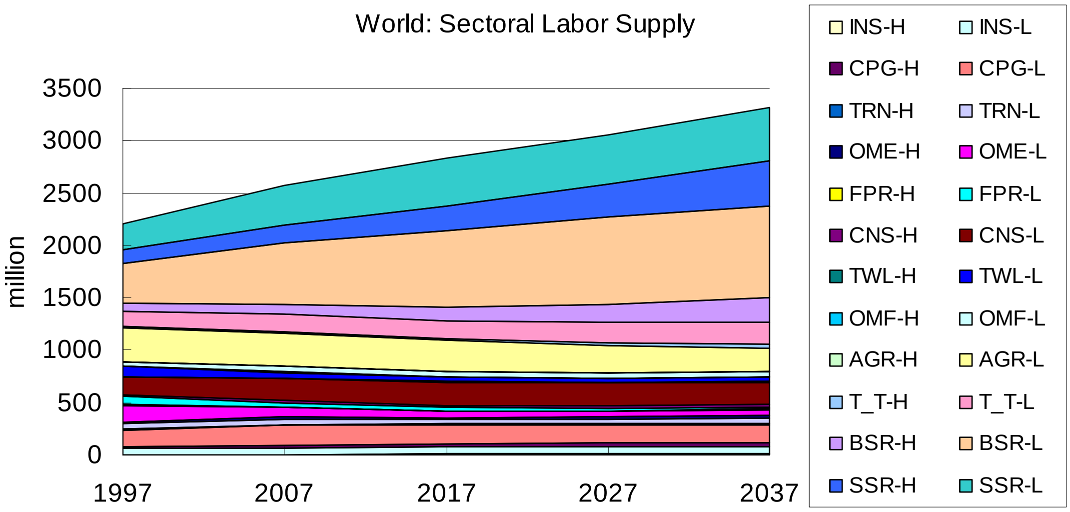


Figure 9 Profile of world sectoral labour supply (CES-BAU)

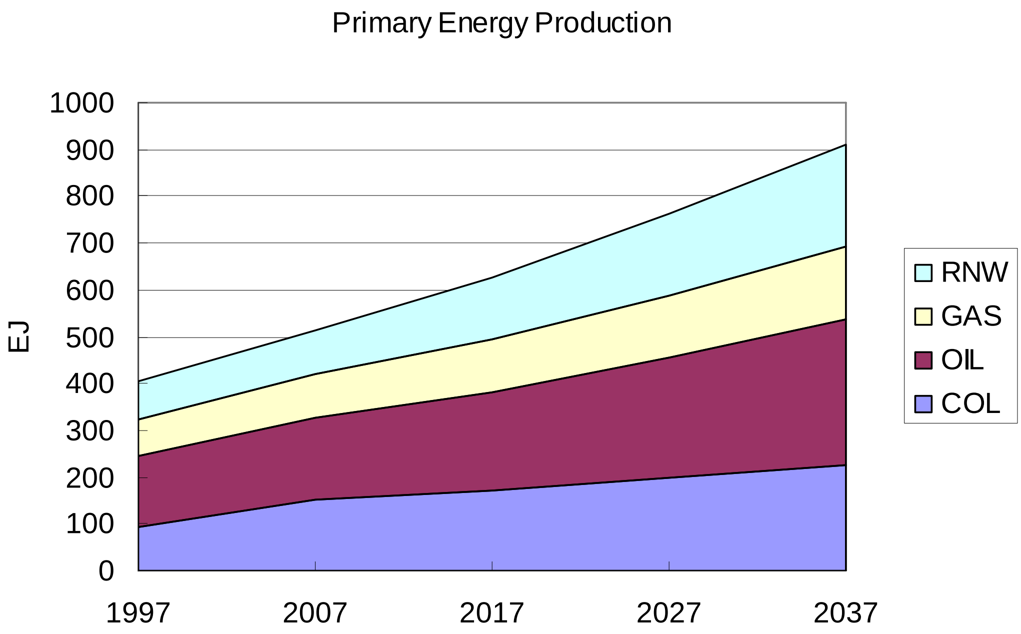


Figure 10 World primary energy production (CES-BAU)

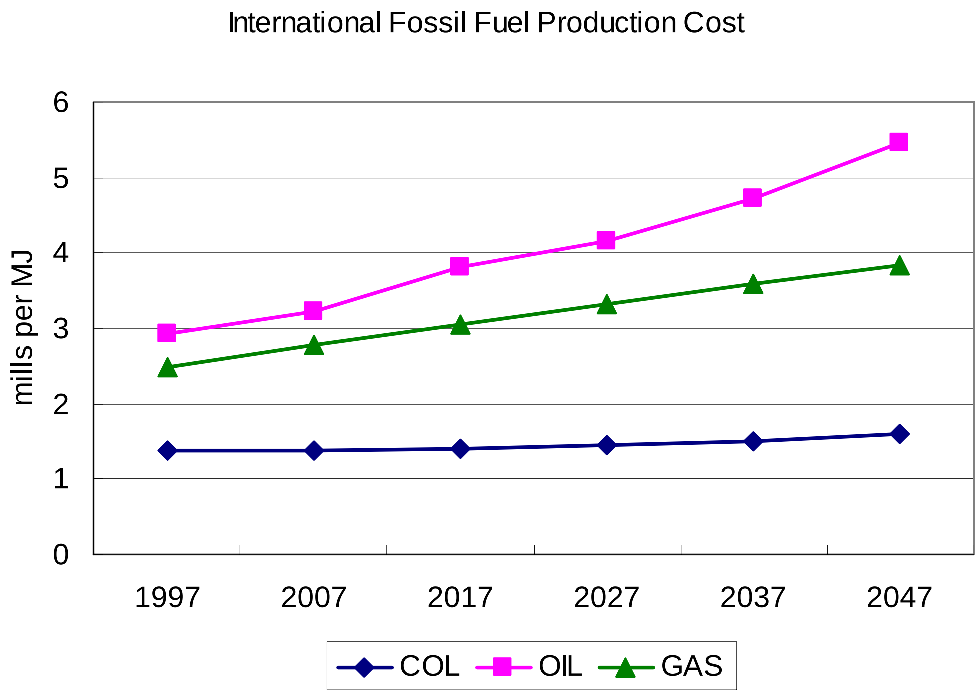


Figure 11 Trajectories of international fossil fuel production costs in mills per MJ

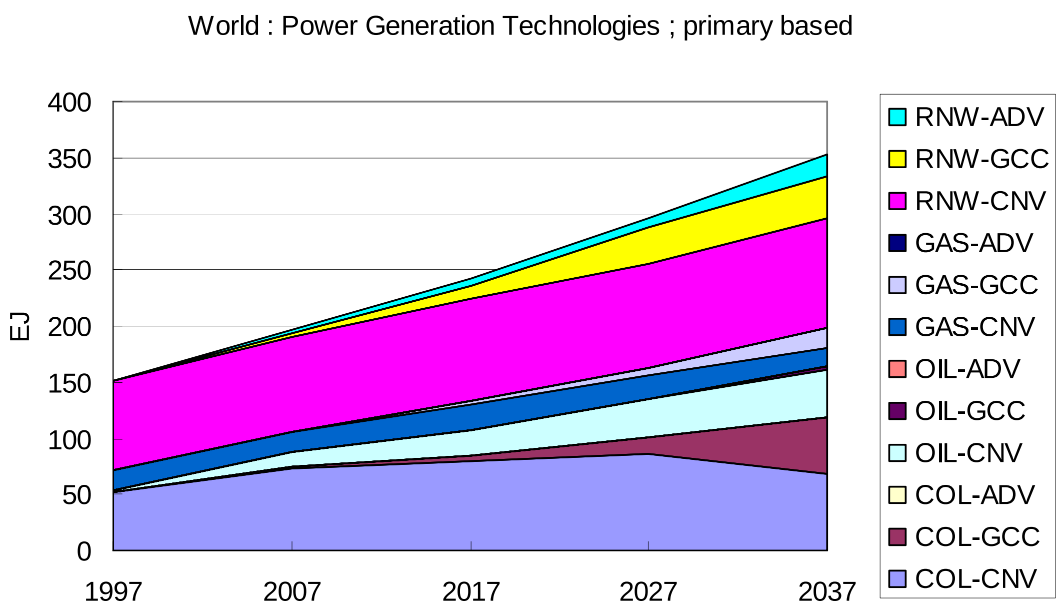


Figure 12 Profile of world power generation technologies in primary based (CES-BAU)

When carbon control policy is imposed, both economic activities and energy technologies are influenced to meet the carbon emission limit. In this paper, we focus on the global cooperation scenario. Emission trades under the differentiated emission rights and other new measures like sectoral approaches are not touched upon in this paper.

First, we show the primary energy production profile and world power generation scenarios in FIgure 13 and Figure 14, respectively. Renewable energy supply apparently increases and advanced technologies on renewables are largely implemented.

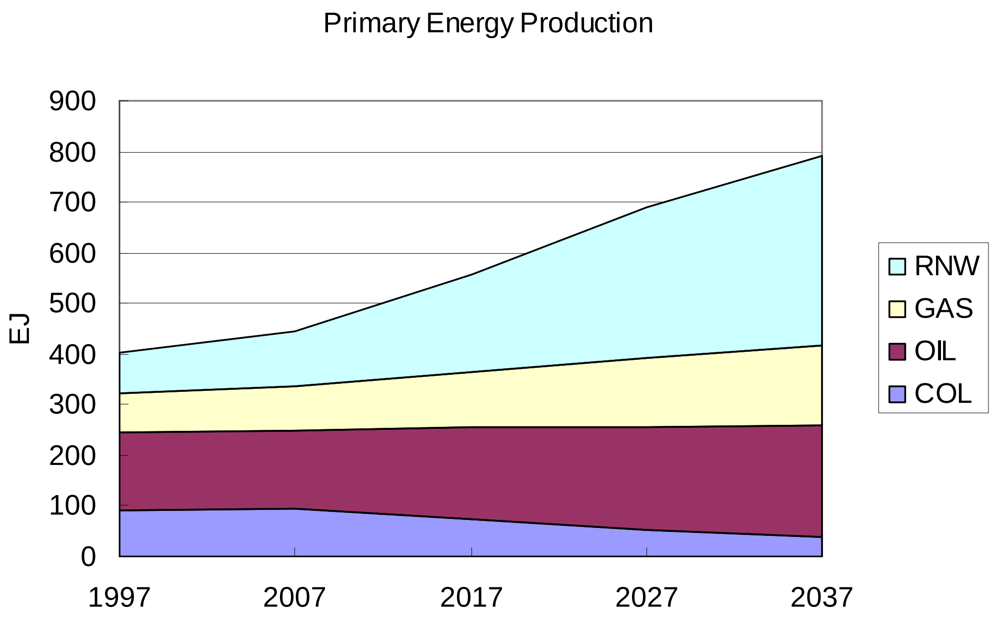


Figure 13 World primary energy production (CES-550)

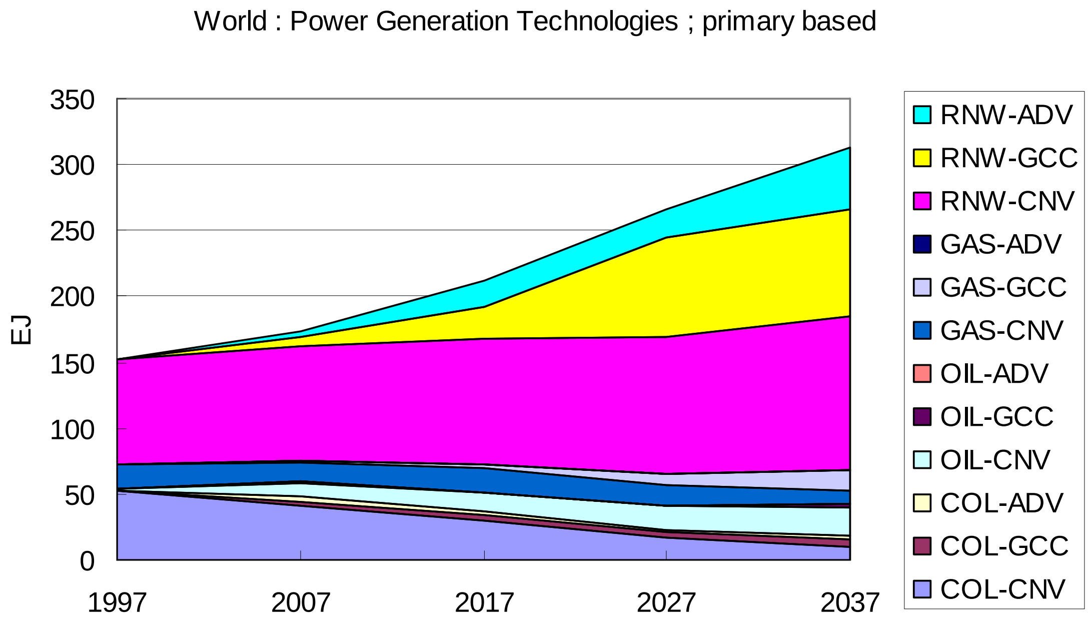


Figure 14 Profile of world power generation technologies in primary based (CES-550)

Figure 15 and Figure 16 exhibit the regional and the sectoral loss of GDP of CES-550 from CES-BAU in 2017 and 2037.

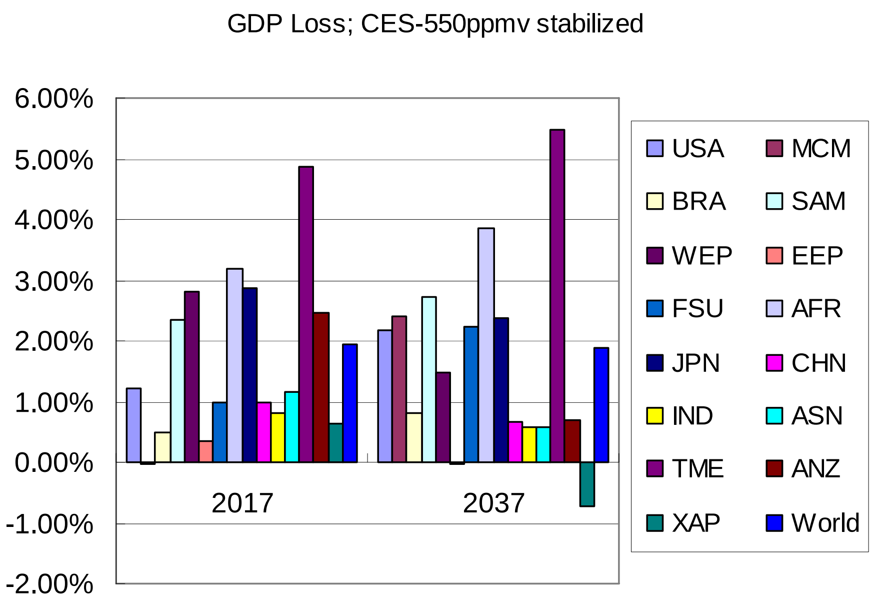


Figure 15 Regional GDP losses of CES-550 from CES-BAU in 2017 and 2037

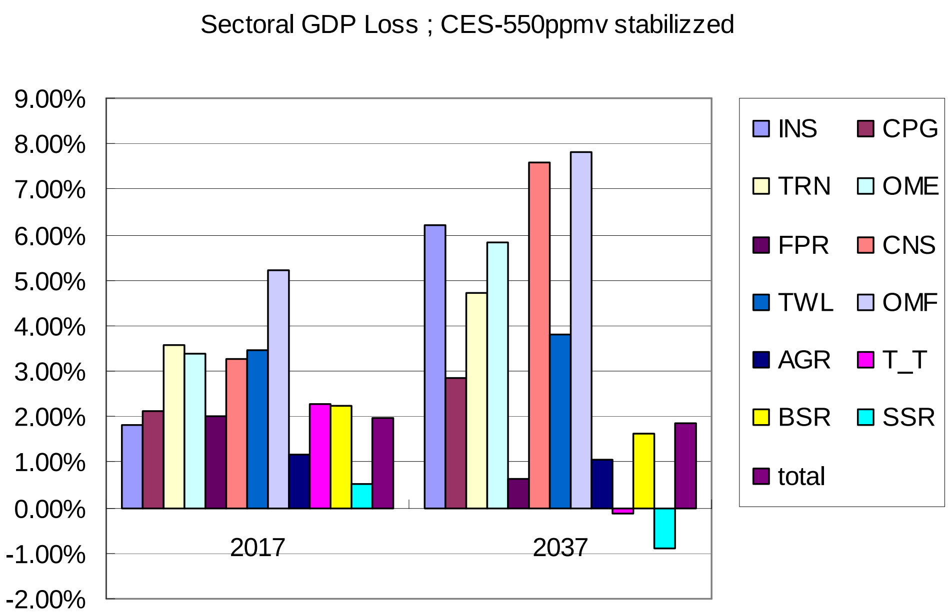


Figure 16 Sectoral GDP losses of CES-550 from CES-BAU in 2017 and 2037

One can observe that GDP loss appears relatively large in developed region in Figure 15 and that the losses of outputs in manufacturing industries and construction sector related to the capital formation are larger than service sectors. World GDP loss comes to 1.95% in 2017 and 1.88% in 2037, respectively.

The above tendency holds in more stringent carbon control case. Figure 17 and Figure 18 show the regional and the sectoral loss of GDP of CES-450 from CES-BAU in 2017 and 2037, where world GDP loss comes to 2.67% in 2017 and 3.36% in 2037, respectively.

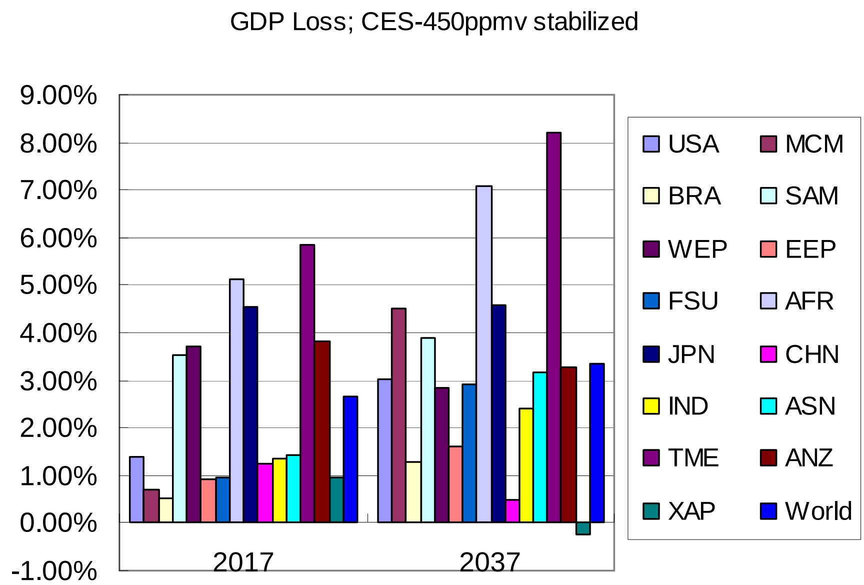


Figure 17 Regional GDP losses of CES-450 from CES-BAU in 2017 and 2037

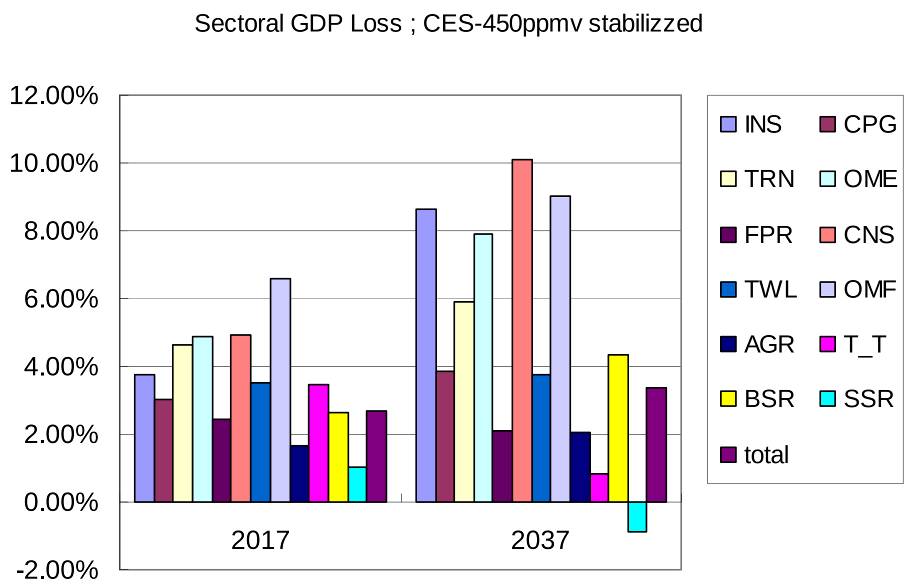


Figure 18 Sectoral GDP losses of CES-450 from CES-BAU in 2017 and 2037

When the substituion elasticity between professional labour and capital stock is high, the economic activities vary even if other conditions are identical. Figure 19 and Figure 20 show the growth rate of outputs based on low elasticity case (CES-BAU) to see how the regional and the sectoral outputs are influenced.

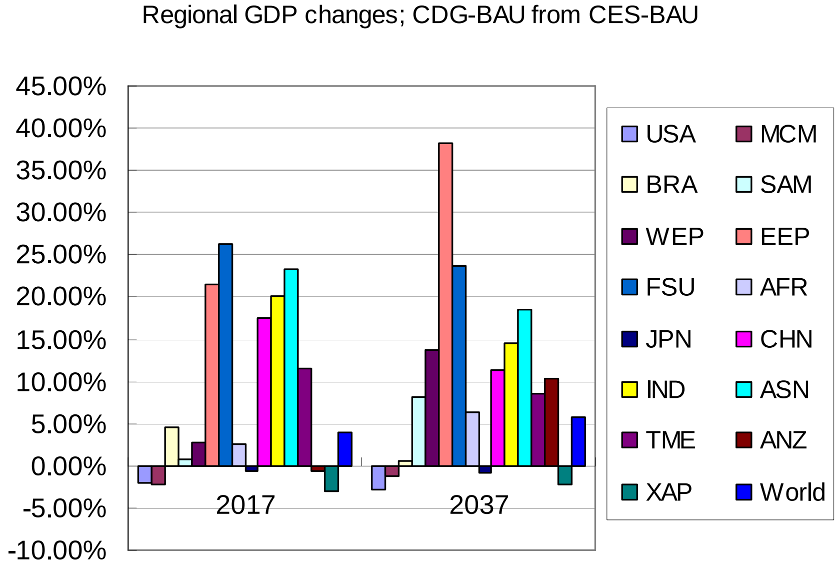


Figure 19 Regional GDP changes of CDG-BAU from CES-BAU in 2017 and 2037

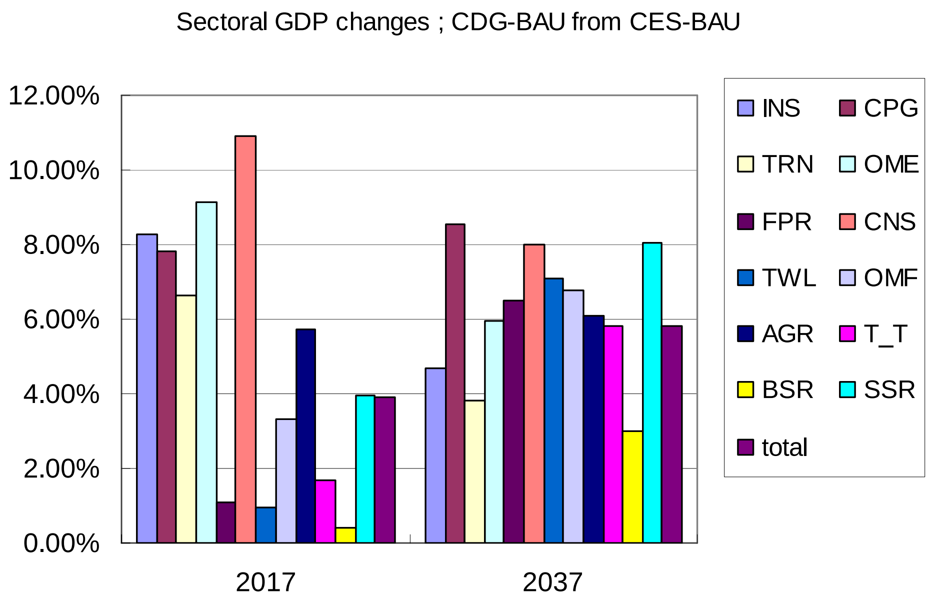


Figure 20 Sectoral GDP changes of CDG-BAU from CES-BAU in 2017 and 2037

Figure 19 suggests that GDP in such newly developed regions as EEP, FSU, CHN and ASN increases in CDG-BAU reflecting the flexibility of labour. One can observe that such capital related industries as material, machinery and construction sectors grow highly in high elasticity case especially in 2017 as shown in Figure 20 while the increased rates in 2037 are almost same. This suggests that CDG-BAU case stimulates the capital formation in the early stage. Thus, World GDP in CDG-BAU is larger than that of CES-BAU at 3.89% in 2017 and at 5.82% in 2037.

However, the loss of GDP in carbon control policy shows different picture. Figure 21 and Figure 22 show the regional and the sectoral loss of GDP of CDG-550 from CDG-BAU in 2017 and 2037, where world GDP loss comes to 4.07% in 2017 and 3.50% in 2037, respectively. It is shown that the GDP losses in TME, AFR, JPN and ANZ are especially larger than those in Figure 15. Reflecting the decrease of investment, construction sector suffers from large loss as shown in Figure 22. The above observation holds in CDG-450 where world GDP loss comes to 4.75% in 2017 and 5.63% in 2037.

The sectoral and regional GDP loss patterns in 2037. are summarized in Table 2. Comparing CES-450 values with those of CDG-450, one can observe how the assumption on professional labour substitutability affects the economic damage caused by thr carbon control policy.

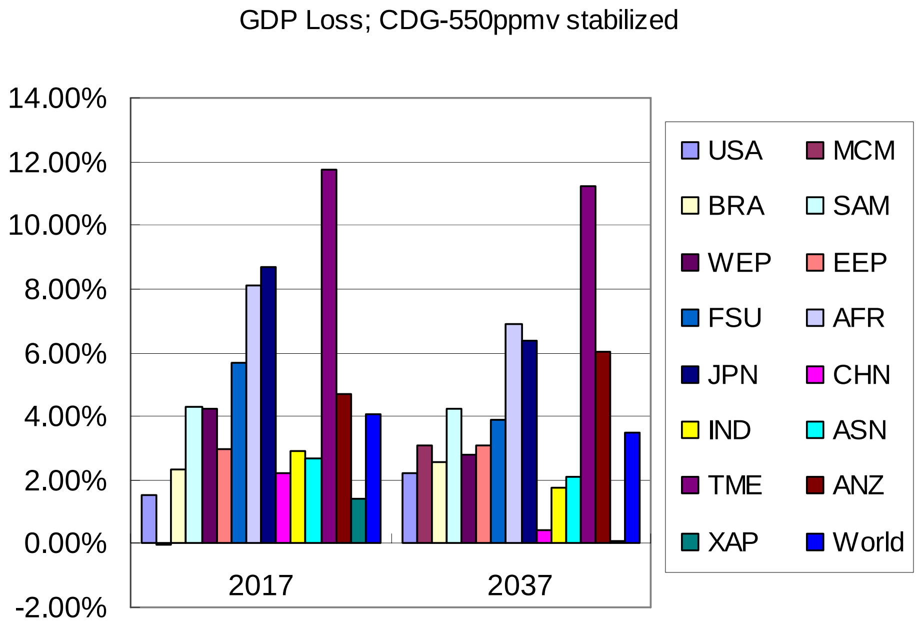


Figure 21 Regional GDP losses of CDG-550 from CDG-BAU in 2017 and 2037

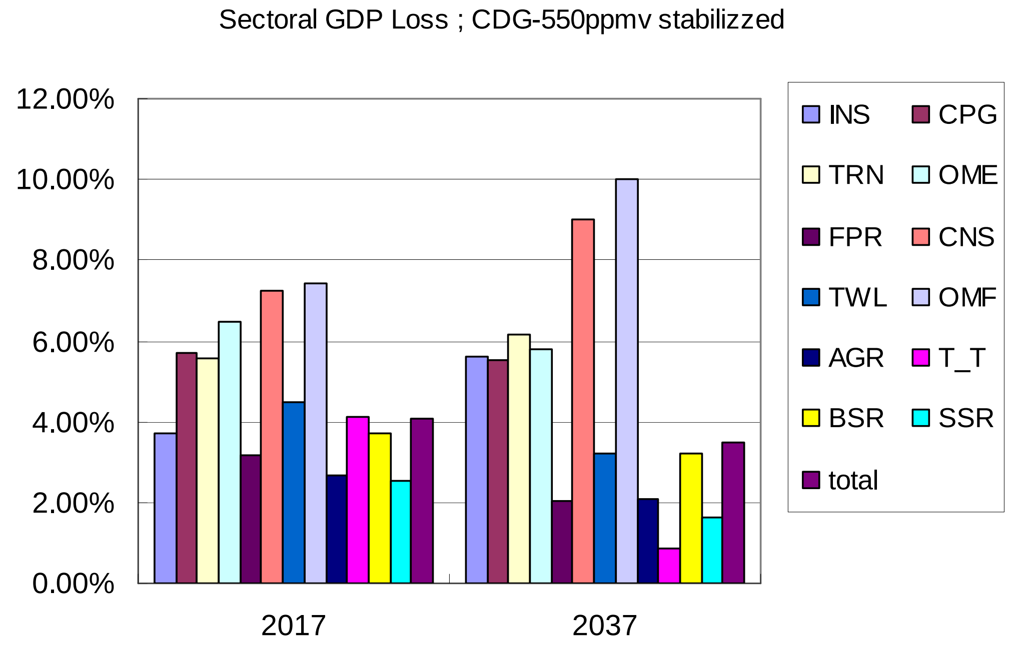


Figure 22 Sectoral GDP losses of CDG-550 from CDG-BAU in 2017 and 2037

First, GDP losses in CPG, FPR, T_T and SSR of CES cases are apparently lower than those of CDG cases while those in INS, TRN, OME and CNS related to the capital formation remain high. This point is remarkable. When professional labour force is strongly embodied in the capital stock, investment would be constrained by its supply capacity. In low substitution elasticity case, since the investment can not compensate for the labour supply constraints, the investment will decrease. This causes the lower demand for construction sector and other capital related sectors, i.e. iron and steel, machinery and etc. In other words, the lower elasticity between labour and capital would stimulate the shift from high capital intensive industry to lower ones, which also can be low energy intensive. This industry structure shift could have mitigated the economic damage caused by the carbon control policies.

Figure 23 shows the trends of world capital stock and the ratio capital to professional labour demand normalized at initial values to examine the above observation. Capital stock in low elasticity (K-CES) is lower than those in high elasticity case (K-CDG) while the difference of the ratio of capital stock to professional labour demand between these two cases is relatively small. Although the labour is fully employed in equation (11) in the equilibrium, some part of professional labour can be employed as general worker, even if in most regions professional labour is also fully employed as shown in Figure 24. These figures suggest that capital tends to substitute the professional labour in the high substitution elasticity case.

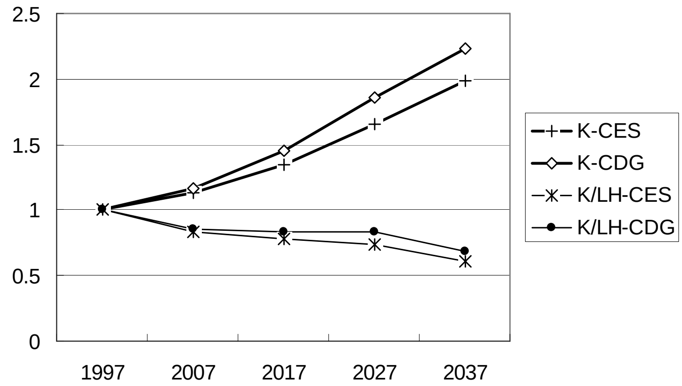
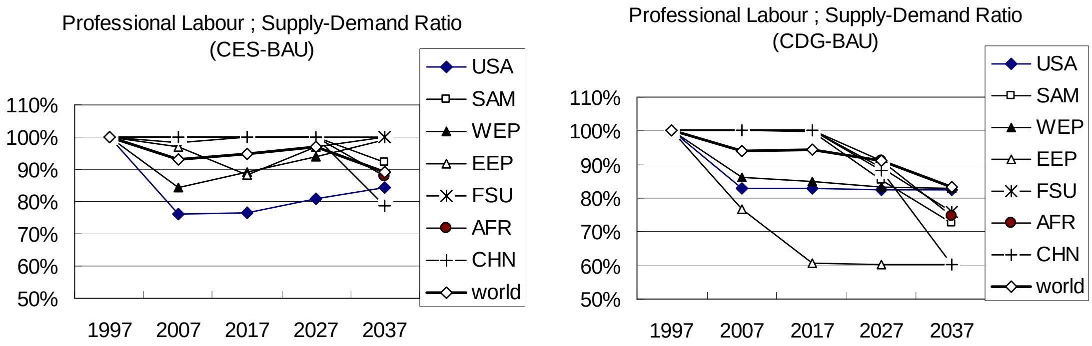


Figure 23 Trends of world capital stock and their ratio to professional labour demand



(a) low substitution elasticity case (b) high substitution elasticity case

Figure 24 Comparison of ratio of professional labour demand to potential supply

(*) In other regions, professional labour is fully employed through the period.

Second, directions of carbon control influence are basically same except for some cells: in JPN output of iron and steel industry (INS) decreases in CES-450 while it increases in CDG-450. Chemical products (CPG) in USA and ANS and food products in TME are also the case.

Third, GDP loss caused by the carbon control policy appears heavily in developed regions, however, which can be pointed out by the conventional IAMs with one macro economic activities.

Table 2 Summary of regional and sectoral GDP losses in 2037

CES-550

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	total
USA	-71.36%	-16.12%	5.28%	4.69%	4.58%	6.91%	5.63%	70.19%	1.53%	7.34%	2.03%	1.53%	2.18%
MCM	8.20%	16.83%	3.32%	4.54%	0.17%	9.85%	2.17%	6.29%	1.69%	3.63%	-4.54%	-0.04%	2.40%
BRA	43.43%	-13.58%	3.40%	4.62%	-27.87%	1.89%	94.97%	-12.55%	0.56%	-0.37%	-5.01%	0.56%	0.81%
SAM	19.71%	-48.03%	7.24%	5.25%	7.15%	6.98%	0.81%	-9.46%	1.91%	8.68%	9.10%	1.91%	2.71%
WEP	0.60%	-5.13%	5.16%	10.84%	2.43%	10.22%	5.21%	-24.90%	1.05%	-10.71%	-4.23%	1.05%	1.49%
EEP	8.11%	-14.25%	3.29%	4.53%	-2.60%	2.43%	5.66%	-24.98%	-0.02%	6.91%	-4.27%	2.87%	-0.02%
FSU	39.38%	-13.99%	5.83%	-180.82%	3.76%	9.24%	5.80%	47.66%	1.57%	17.92%	-9.84%	1.57%	2.23%
AFR	10.54%	-14.60%	4.24%	4.53%	0.20%	13.78%	5.71%	59.25%	2.71%	-0.15%	3.99%	-0.32%	3.85%
JPN	7.91%	-6.34%	4.21%	7.20%	2.12%	11.24%	3.65%	-25.00%	1.68%	-8.74%	6.66%	0.22%	2.39%
CHN	-4.99%	37.78%	1.02%	4.53%	-0.57%	2.21%	-3.56%	-31.09%	0.47%	-5.81%	-36.49%	2.11%	0.67%
IND	-14.76%	-14.40%	-7.29%	4.49%	0.21%	2.73%	-0.32%	-6.12%	0.40%	-4.15%	-0.39%	7.23%	0.57%
ASN	15.22%	7.00%	-0.48%	-51.63%	0.22%	2.41%	-86.87%	-77.43%	0.42%	-2.56%	8.78%	0.28%	0.59%
TME	40.24%	83.67%	2.99%	3.67%	-72.15%	23.97%	5.54%	39.04%	3.87%	11.35%	7.01%	-34.99%	5.48%
ANZ	7.90%	-14.74%	3.30%	-100.62%	0.19%	1.92%	5.69%	-5.89%	0.49%	12.09%	14.37%	-13.84%	0.70%
XAP	-13.13%	-8.39%	3.09%	4.61%	0.21%	-3.59%	25.30%	-6.60%	-0.51%	17.63%	-3.94%	1.29%	-0.73%
World	6.20%	2.85%	4.72%	5.83%	0.62%	7.58%	3.82%	7.80%	1.04%	-0.11%	1.65%	-0.91%	1.88%

CES-450

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	total
USA	-121.34%	-35.02%	6.10%	7.34%	6.45%	10.56%	5.38%	74.18%	2.13%	5.32%	5.84%	2.13%	3.03%
MCM	22.41%	42.87%	3.67%	9.16%	0.81%	14.87%	3.83%	14.68%	3.19%	2.49%	-18.61%	3.58%	4.52%
BRA	42.11%	-7.64%	3.53%	9.21%	-32.67%	2.84%	94.96%	0.00%	0.90%	4.39%	-4.95%	0.90%	1.28%
SAM	22.86%	-46.78%	44.17%	23.15%	7.24%	9.70%	1.23%	-12.76%	2.75%	6.43%	1.24%	2.75%	3.91%
WEP	-1.95%	-2.04%	4.30%	11.22%	2.28%	6.76%	4.35%	-8.17%	2.00%	-7.42%	2.01%	2.00%	2.85%
EEP	22.44%	-8.24%	3.46%	9.15%	-3.45%	4.06%	5.43%	-8.23%	1.12%	27.08%	1.97%	-6.08%	1.60%
FSU	59.84%	-1.49%	7.09%	-649.52%	0.88%	15.99%	5.49%	54.65%	2.05%	18.40%	-6.73%	2.05%	2.92%
AFR	17.46%	-8.39%	4.70%	9.25%	0.84%	22.55%	5.48%	52.55%	5.02%	-30.38%	12.67%	1.23%	7.09%
JPN	22.83%	-8.26%	6.56%	11.03%	5.03%	15.19%	4.78%	-298.18%	3.22%	19.31%	10.82%	-9.25%	4.57%
CHN	-22.87%	44.93%	0.13%	9.11%	0.50%	5.99%	3.80%	-8.19%	0.35%	-14.96%	-110.85%	18.73%	0.50%
IND	-9.64%	-8.40%	-32.98%	9.12%	0.84%	6.83%	3.53%	0.00%	1.70%	-1.72%	1.77%	6.51%	2.42%
ASN	30.15%	12.20%	2.03%	-30.01%	0.85%	5.66%	-86.61%	-64.11%	2.22%	-34.44%	17.30%	-3.71%	3.16%
TME	74.74%	92.85%	3.11%	8.23%	-51.35%	28.45%	5.30%	47.16%	5.83%	21.02%	12.22%	-46.12%	8.22%
ANZ	22.08%	-8.41%	3.46%	-98.70%	0.82%	4.41%	5.46%	2.11%	2.29%	-65.57%	23.47%	-6.45%	3.26%
XAP	-6.04%	-3.42%	3.41%	9.24%	-0.47%	-2.79%	22.28%	-1.15%	-0.17%	1.97%	0.59%	-3.06%	-0.24%
World	8.62%	3.85%	5.91%	7.88%	2.12%	10.07%	3.76%	9.03%	2.06%	0.83%	4.32%	-0.88%	3.36%

CDG-550

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	total
USA	-15.62%	28.18%	6.00%	-21.86%	-12.55%	8.85%	16.27%	52.04%	1.57%	5.63%	0.04%	1.57%	2.23%
MCM	13.83%	12.19%	5.29%	22.53%	4.44%	12.74%	6.34%	4.47%	2.18%	-0.55%	-3.99%	0.80%	3.10%
BRA	20.27%	5.48%	5.18%	22.49%	-25.09%	6.62%	16.29%	12.92%	1.80%	3.95%	2.05%	1.49%	2.56%
SAM	-7.38%	6.99%	17.90%	7.91%	4.50%	9.09%	4.79%	-12.18%	2.98%	7.00%	2.86%	2.98%	4.23%
WEP	1.94%	-20.71%	5.82%	18.04%	4.46%	1.25%	15.20%	16.91%	1.95%	-11.80%	3.34%	1.95%	2.78%
EEP	5.49%	-31.91%	5.18%	22.54%	-1.14%	0.52%	9.30%	-225.69%	2.16%	7.95%	9.46%	0.99%	3.07%
FSU	56.11%	-18.87%	-2.95%	-473.33%	4.47%	15.87%	16.32%	48.36%	2.76%	20.10%	0.66%	2.76%	3.92%
AFR	14.69%	-35.44%	3.54%	22.68%	4.46%	21.07%	16.32%	32.39%	4.87%	4.15%	4.76%	9.82%	6.88%
JPN	-70.11%	-9.88%	7.42%	19.06%	5.69%	19.81%	7.34%	-3.25%	4.52%	-3.45%	7.58%	5.53%	6.40%
CHN	-11.63%	45.02%	-18.59%	22.48%	2.62%	1.92%	-6.93%	-33.89%	0.30%	-7.28%	-53.00%	3.31%	0.43%
IND	21.57%	-54.18%	-23.96%	22.55%	4.47%	3.08%	5.74%	8.27%	1.21%	9.41%	-20.89%	3.46%	1.73%
ASN	9.79%	-53.76%	3.86%	-12.79%	8.83%	3.39%	-76.27%	-108.47%	1.47%	-5.15%	9.78%	4.23%	2.10%
TME	25.92%	68.95%	33.59%	22.27%	1.19%	27.73%	16.29%	27.34%	7.99%	7.76%	13.01%	-17.06%	11.22%
ANZ	11.06%	-13.82%	5.23%	-246.78%	4.44%	16.89%	16.30%	8.92%	4.25%	4.19%	15.39%	1.94%	6.01%
XAP	14.70%	15.81%	4.84%	22.53%	2.06%	-0.61%	-4.47%	-17.20%	0.06%	21.72%	1.19%	-12.26%	0.08%
World	5.61%	5.52%	6.17%	5.79%	2.05%	9.01%	3.20%	10.01%	2.09%	0.85%	3.20%	1.62%	3.50%

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	total
USA	-43.97%	20.44%	8.20%	-17.22%	-14.83%	11.38%	16.69%	74.92%	2.21%	3.58%	2.52%	2.21%	3.14%
MCM	30.46%	30.70%	7.38%	23.25%	6.79%	16.70%	7.91%	10.86%	3.46%	0.54%	-8.12%	0.25%	4.91%
BRA	39.00%	-4.15%	7.07%	23.22%	-27.03%	8.15%	16.72%	12.92%	2.63%	8.32%	3.25%	1.18%	3.74%
SAM	6.53%	-11.06%	21.63%	26.70%	6.85%	13.29%	5.05%	-9.50%	4.63%	9.45%	4.17%	4.63%	6.54%
WEP	10.51%	-15.96%	7.72%	21.76%	6.20%	6.83%	15.60%	18.31%	3.72%	-7.09%	4.62%	2.21%	5.27%
EEP	7.30%	-25.80%	7.06%	23.24%	-0.65%	4.15%	9.80%	-222.38%	3.47%	2.87%	23.59%	-12.34%	4.92%
FSU	69.39%	-30.18%	8.83%	-450.65%	6.83%	17.48%	16.74%	49.25%	4.95%	20.81%	3.69%	4.95%	6.99%
AFR	21.97%	-107.44%	5.56%	23.44%	6.82%	32.45%	16.75%	32.41%	8.45%	-32.81%	17.05%	9.66%	11.85%
JPN	-92.97%	-2.63%	9.60%	19.44%	8.16%	20.70%	8.12%	-19.47%	6.09%	44.98%	-9.57%	4.19%	8.59%
CHN	-14.58%	49.06%	-29.18%	23.19%	6.57%	5.33%	-2.57%	-57.50%	0.62%	-81.45%	-87.09%	20.13%	0.88%
IND	25.66%	-47.15%	-37.24%	23.30%	6.82%	8.00%	8.23%	11.36%	2.51%	10.45%	-11.71%	3.88%	3.57%
ASN	2.38%	-46.42%	4.04%	-25.51%	11.07%	8.50%	-75.30%	-102.13%	3.57%	-36.71%	18.36%	6.31%	5.05%
TME	70.21%	92.39%	-16.70%	22.78%	3.93%	35.42%	16.71%	28.43%	11.62%	19.54%	21.79%	-31.94%	16.17%
ANZ	30.63%	-27.98%	7.12%	-232.06%	6.79%	25.59%	16.73%	11.30%	6.64%	4.08%	20.25%	2.20%	9.34%
XAP	32.11%	11.48%	6.77%	23.25%	2.08%	1.27%	-12.47%	-14.12%	0.42%	5.54%	1.89%	-5.38%	0.61%
World	7.75%	7.76%	7.97%	8.98%	3.58%	12.97%	3.77%	14.31%	3.57%	3.62%	5.41%	2.93%	5.63%

5. Conclusion

In this paper, we described the outline and some simulation results of the dynamic multi-sectoral multi-regional integrated model THERESIA. Our current findings are as follows: first, the economic loss of carbon control policy appears relatively large in developed regions. Second, economic damage in such capital related industry as iron and steel, machinery and construction are relatively high while those in service industries are low. Third, if we assume that the professional labour is stronglu embodied in the capital, through the shift to the low capital intensive structure, economic dameges caused by the carbon control policy could be mitigated.

THERESIA currently leaves many assumptions caused by lack of information. For instance, the projection of input-output coefficients is needed and its procedure rewuires more sofisticated method. The estimation of capital coeffecient matrix and its projection are mostly needed. Other constraints or modifications of the euqtions would be considered to reflect the societal changes in reality.

Nonetheless, we would conclude that the model framework of THERESIA we proposed here provides useful insights of this field.

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