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Development of Land Use Model for IPCC New Emission Scenarios (SRES)

Toshihiko MASUI[1], Yuzuru MATSUOKA[2], Tsuneyuki MORITA[1],
Mikiko KAINUMA[1] and Kiyoshi TAKAHASHI[1]

[1]*Social and Environmental Systems Division, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-0053, Japan*
[2]*Graduate School of Engineering, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan*

Abstract—In order to support a special project for developing a new set of long-term GHGs emission scenarios in IPCC, the new general equilibrium model, which can analyze the land use change, has been developed. According to the long-term land use scenario projected by the model, greenhouse gas (CO_2, NO_x, SO_x, CH_4, CO, and N_2O) emissions from land use were calculated. Based on the simulations, the forest area will increase after the beginning of the 21st century in all scenarios, especially the B1 and B2 scenarios in which societies consider not only economic development but also environmental preservation. The forest area in Asia will be recovered faster than that of the global one.

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) published a special report on a new set of long-term greenhouse gases emission scenarios (IPCC, 2000), which was called SRES (Special Report on Emission Scenarios). Figure 1 shows the four different narrative storylines developed to consistently describe the relationships between emission driving forces and their evolution and provide context for the scenario quantification. Each storyline represents different demographic, social, economic, technological, and environmental developments. The A1 storyline describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. The A2 storyline describes a very heterogeneous world, which preserves local identities in the future. The A2 Population growth is higher than in the other storylines. Per capita economic growth and technological change are more fragmented and slower than in the other storylines. The B1 storyline describes a convergence world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy. The B2 storyline describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with moderate population growth, and intermediate levels of economy development.

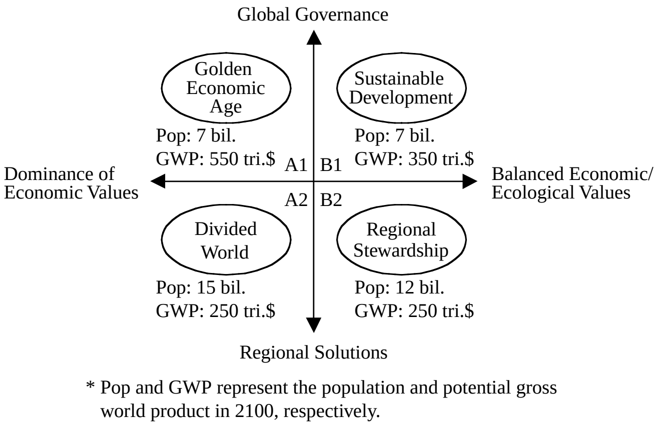


Fig. 1. Characteristics of four different narrative storylines of IPCC new emission scenarios.

The National Institute for Environmental Studies has participated in the project for developing the new scenarios since 1996. In the process of this scenario development, the land use changes in the future must be taken into account in order to estimate the amount of greenhouse gases which originate from land use type and land use change. With this background, we developed a land use model which is based on a time-recursive dynamic general equilibrium model, and has estimated future land use changes and GHG emissions under the storylines of the new IPCC scenarios.

STRUCTURE OF LAND USE MODEL

The land use model is based on the Global Trade and Analysis (GTAP) model (Hertel, 1997) and its database (McDougall *et al*., 1998) developed at Purdue University. In analyzing the equilibrium of land use, it was assumed that land is distributed among sectors for the maximization of profits in each period similar to capital and labor, although land use does not change as quickly.

In this model, we used 10 economic sectors and divided the world into 17 countries and regions, as shown in Table 1. Land use was divided into five categories: cropland for agriculture, pasture for livestock, forests, biomass fields, and other land uses. Except for the biomass fields, these categories are based on the categories of the Food and Agriculture Organization (FAO, 1997).

Figure 2 shows an outline of this model. Based on the SRES basic scenarios, potential future economic activities were assumed. Using this land use model, equilibrium solutions were then found. The inputs used for the production were capital, labor, land, and other intermediate inputs.

The basic production structure of this model is shown in Fig. 3. Three elementary factors, land, capital, and labor are mixed-up and build the value-added input factor. The value-added factor and intermediate inputs, which

Table 1. Regions and production sectors of the model.

Country classifications*		Sector classifications**	
ANZ	Australia and New Zealand	AGR	Agricultural goods
JPN	Japan	LVS	Livestock
KOR	Korea	FRS	Forestry
IDN	Indonesia	FSH	Fisheries
MYS	Malaysia	MIN	Minerals
THA	Thailand	DAR	Dairy products
CHN	China	FOD	Processed foods
IDI	India	MAN	Manufacturing
RAS	Rest of Southeast Asia	SER	Services and utilities
CAN	Canada	BIO	Biomass energy
USA	USA		
LAM	Latin America	*	Original GTAP database contains 45 regions.
EUR	Western Europe		
FSU	Former Soviet Union and Eastern Europe		
MEA	Middle East Asia	**	Original GTAP database contains 50 goods and service sectors.
AFR	Africa		
ROW	Rest of the World		

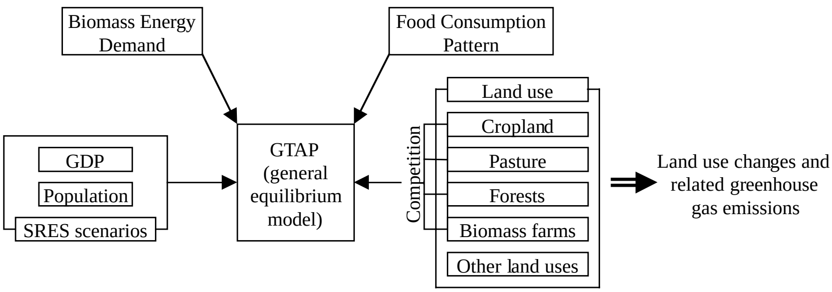
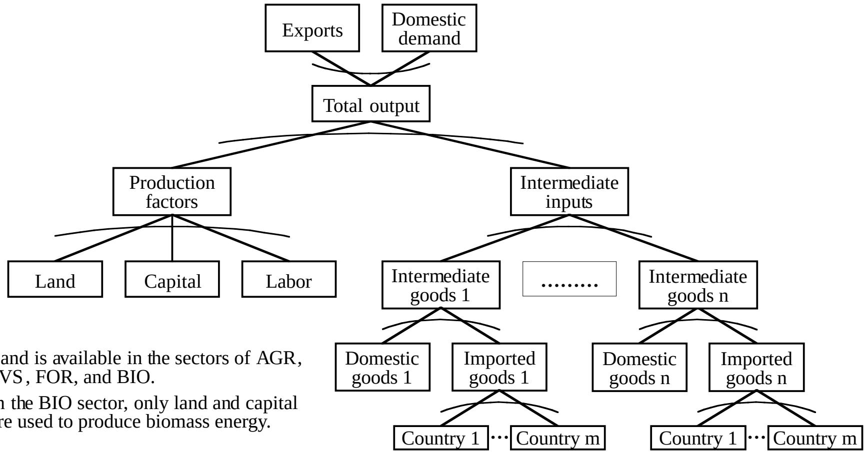


Fig. 2. Outline of this work.

consisted of domestic and imported goods, are mixed-up and build the final output. In this model, we introduced the minimum biomass energy requirements from the AIM energy model simulations. Through the general equilibrium process, land will be assigned for use as cropland, pasture, forests, and biomass farms. These land uses as well as land use changes will generate greenhouse gas emissions.

Targeted gases

Emissions of the following greenhouse gases and related gases were calculated: carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), methane (CH_4), carbon monoxide (CO), and nitrous oxide (N_2O). The emissions



Land is available in the sectors of AGR, LVS, FOR, and BIO.
In the BIO sector, only land and capital are used to produce biomass energy.

Fig. 3. Production structure of this model.

of each gas were simply calculated from the land use or land use change as well as the relevant emission factor. For example, the emission of carbon due to deforestation was calculated from the area of deforestation multiplied by the carbon emission factor from deforestation. Table 2 shows an inventory of the targeted gases and their sources, and Table 3 shows the methods used to calculate the greenhouse gas emissions from the land use changes. The emission factors are calculated from the emission data in 1990 prepared by Olivier *et al.* (1996) and ICF (1998), and the land use pattern in 1990 from FAO (1997).

Flow of simulation

The original GTAP model is a static model, and some modifications were made in order to evaluate the dynamic process of land use changes. That is, certain parts of the original GTAP model were modified in succession to provide the dynamic general equilibrium model. Prior to simulation, based on the SRES scenarios, the minimum requirement of the biomass energy from the AIM energy model was set as the constraint by region. From the biomass energy demand constraint, the global biomass field was maintained. It was assumed that the productivity of biomass plants is 0.40 EJ/million ha, and that its growth rate in the A1 scenario is assumed to be 0.5%/year as shown in Table 4. In order to provide energy from the biomass, it was also assumed that additional capital would be needed. This capital cost for biomass energy production was assumed to be $27.9 billion/EJ (Sakai, 1998).

In this model, the only economic sectors that utilize land are the AGR (agricultural goods), LVS (livestock), FRS (forestry), and BIO (biomass energy) sectors. The reasons why other land uses were excluded in the simulation were as follows. The other land consists of built-up areas and barren areas, and these

Table 2. Inventory of the targeted gases and their sources.

Gas	Sources	Emissions in 1990		Total Emissions in 1990*	
CO2	Deforestation	0.88	GtC		
	Total	0.88	GtC	6.99	GtC
CH4	Cultivation	59.76	MtCH4		
	Savanna burning	8.87	MtCH4		
	Enteric ferment	80.30	MtCH4		
	Biomass burning	15.15	MtCH4		
	Agricultural waste burning	14.26	MtCH4		
	Biofuel resident	6.97	MtCH4		
	Total	185.31	MtCH4	337.37	MtCH4
NOx	Deforestation	4.94	MtN		
	Savanna burning	1.73	MtN		
	Agricultural waste burning	1.35	MtN		
	Biofuel resident	2.27	MtN		
	Total	10.29	MtN	33.32	MtN
CO	Deforestation	378.75	MtCO		
	Savanna burning	221.67	MtCO		
	Agricultural waste burning	51.94	MtCO		
	Biofuel resident	174.37	MtCO		
	Total	826.73	MtCO	1089.26	MtCO
N2O	Savanna burning	0.11	MtN2O-N		
	Manure management	4.32	MtN2O-N		
	Agricultural waste burning	0.09	MtN2O-N		
	Post-burn effects deforestation	1.06	MtN2O-N		
	Biofuel resident	0.14	MtN2O-N		
	Total	5.72	MtN2O-N	6.95	MtN2O-N
SOx	Deforestation	1.30	MtS		
	Savanna burning	0.76	MtS		
	Agricultural waste burning	0.18	MtS		
	Biofuel resident	0.60	MtS		
	Total	2.84	MtS	70.60	MtS

* "Total Emissions in 1990" includesgas emissions from fuel combustion and industrial processes.

barren areas such as deserts cannot be evaluated under a general equilibrium situation. Concerning the built-up area, there are no precise relationships between land use and production activities. The productivity of land areas used for other than biomass fields in the A1 scenario was assumed to be 1.5%/year for cropland and pasture, and 0.5%/year for forests, also based on the figures of Edmonds *et al.* (1996).

In this model, it is regarded that the land belongs to the household sector, and when the economic sectors use the land, they must pay the rent of these land areas to the household sector. This interpretation is the same as the relationship between the capital use and its rent. The other land use area was calculated from total land area minus the croplands, pasture, forests, and biomass fields in each region.

Table 3. Calculation method to estimate greenhouse gas emissions from land use changes.

Gas	Sources	Calculation method
CO2	Deforestation	[Net deforestation area]*[Emission factor]
CH4	Cultivation	[Arable land area]*[Emission factor]
	Enteric ferment	[Pasture area]*[Emission factor]
	Biomass burning	[Deforestation area]*[Emission factor]
	Agricultural waste burning	[Arable land area]*[Emission factor]
	Biofuel resident	[Arable land area]*[Emission factor]
NOx	Deforestation	[Deforestation area]*[Emission factor]
	Agricultural waste burning	[Arable land area]*[Emission factor]
	Biofuel resident	[Arable land area]*[Emission factor]
CO	Deforestation	[Deforestation area]*[Emission factor]
	Agricultural waste burning	[Arable land area]*[Emission factor]
	Biofuel resident	[Arable land area]*[Emission factor]
N2O	Arable land	[Arable land area]*[Emission factor]
	Manure management	[Arable land area]*[Emission factor]
	Agricultural waste burning	[Arable land area]*[Emission factor]
	Post-burn effects deforestation	[Deforestation area]*[Emission factor]
	Biofuel resident	[Arable land area]*[Emission factor]
SOx	Deforestation	[Deforestation area]*[Emission factor]
	Agricultural waste burning	[Arable land area]*[Emission factor]
	Biofuel resident	[Arable land area]*[Emission factor]

Table 4. Assumption on land productivity improvement (%/year).

		A1B	A2	B1	B2
Production from cropland	Developed countries	1.5	1.5	2.0	1.0
	Developping countries	1.5	1.0	2.0	1.0
Production from pasture	Developed countries	1.5	1.5	2.0	1.0
	Developping countries	1.5	1.0	2.0	1.0
Production from forest	Developed countries	0.5	0.5	1.0	0.5
	Developping countries	0.5	0.3	1.0	0.5
Production from biomass farm	Developed countries	0.5	0.5	1.0	0.5
	Developping countries	0.5	0.3	1.0	0.5

SIMULATION OUTPUT

After preparation of the above parameters, the simulations were performed. The land use supply was determined to meet the demands of agricultural, livestock, forest, and biomass energy products. The simulation outputs based on the A1 scenario are shown in Fig. 4. Figure 4 shows the land use changes in the developing Asian region and the world. Figure 5 shows the CO_2 emission from land use changes. Biomass fields will expand most rapidly after 2020. Up to 2100, pasture for livestock will also increase due to the growth in the demand for meat accompanying economic progress. Though the food demand will increase,

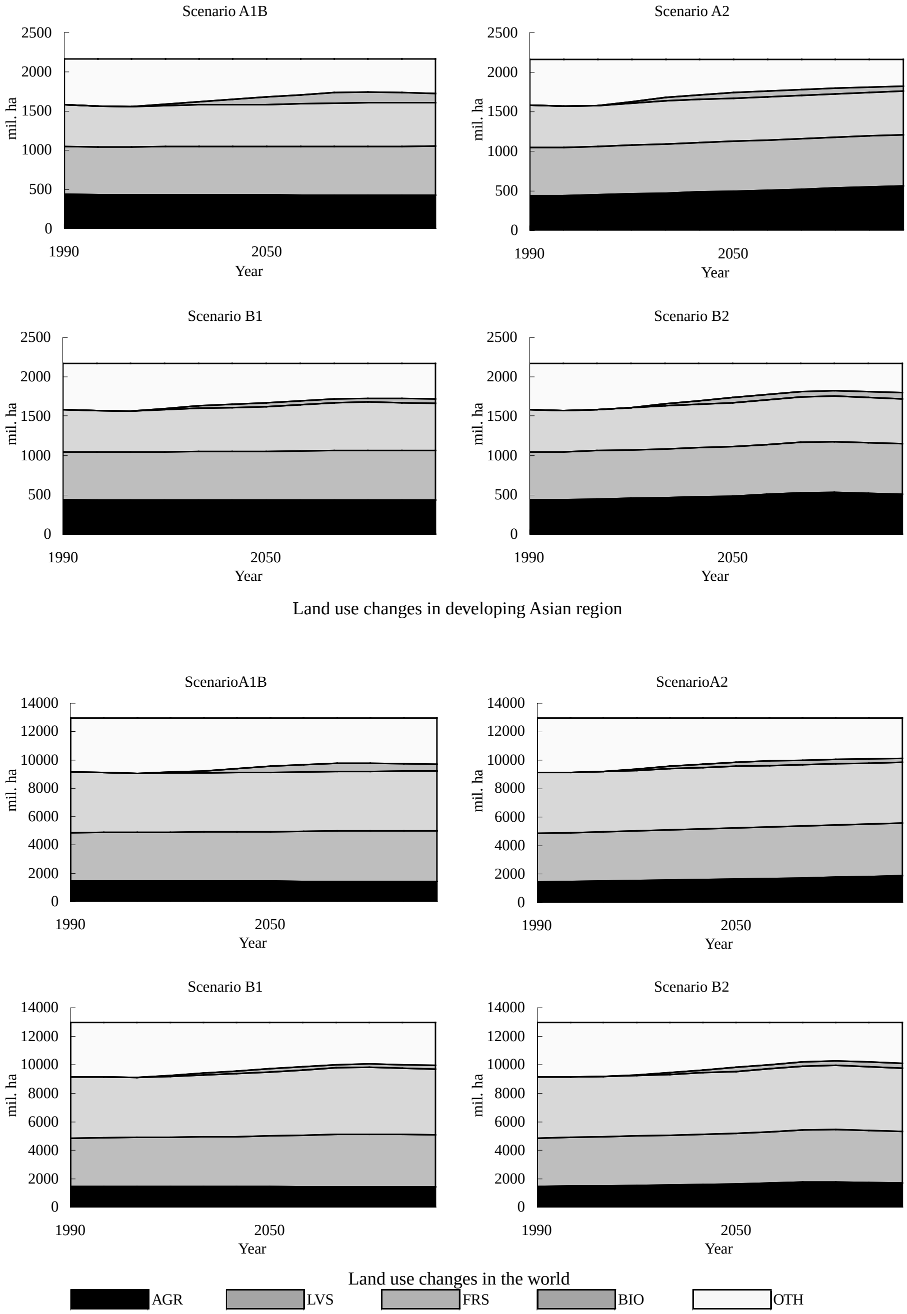


Fig. 4. Land use change under the four different scenarios (Upper: Asia, Lower: World).

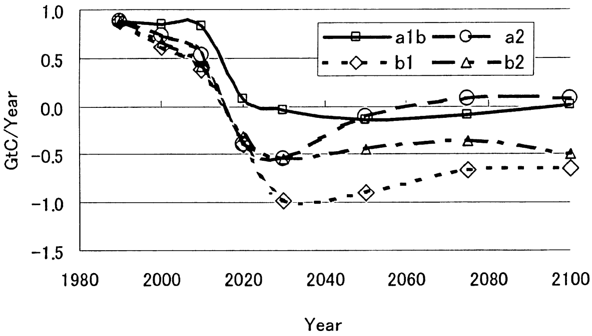


Fig. 5. CO_2 emission caused by land use change (World).

agricultural croplands will slightly decrease during the 21st century. The reasons for this are that the productivity of land will be promoted during the next century and a food demand shift will occur. On the other hand, the forest area will decrease until 2030, and then it will increase. Under the scenarios with simultaneous objectives of both environmental preservation and economic development, namely B1 and B2, the rate of reforestation and the amount of CO_2 removed from the atmosphere because of land use changes will be more than the other scenarios. According to the results in Asia, it is found that the reduced forest area will be maintained faster in Asia than in the rest of the world.

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T. Masui (e-mail: masui@nies.go.jp), Y. Matsuoka, T. Morita, M. Kainuma and K. Takahashi