MODELING OF HUMAN INDUCED CO2 EMISSION BY ASSIMILATING GIS AND SOCIO-ECONIMICAL DATA TO SYSTEM DYNAMICS MODEL FOR OECD AND NON-OECD COUNTRIES

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ABSTRACT:

Using GIS and socio-economical data the relationship between human activities and global environmental change is Analysed from the view point of food productivity and CO2 emission. Under the assumption that the population problem, the food problem and global warming due to energy consumption can be stabilized through managing land use, impacts of human activities such as consumption of food, energy and timber on global environment changes, and global population capacity are Analysed using developed system dynamics model in the research. In the model the world is divided into two groups: OECD countries and the others. Used global land use data set is land cover map derived from satellite data, and potential distribution of arable land is estimated by the method of Cramer and Solomon which takes into consideration spatial distribution of climate data such as precipitation and evapotranspiration. In addition, impacts of CO2 emission from human activities on food production through global warming are included in the model as a feedback.

The results of the analysis for BaU scenario and Toronto Conference scenario are similar to the results of existing models. From the result of this study, the human habitability in 2020 is 8 billion people, and CO2 emission in 2020 based on BaU Scenario and on Toronto Scenario is 1.7 and 1.2 times more than the 1986's respectively. Improving spatial resolution of the model by using global data to distribute the environmental variables and sauce-economical indices is left for further studies.

1. INTRODUCTION

A research concerning the earth's environment and its various problems such as global warming, acid rain, the deforestation tropical rainforest and desertification is performed. These environmental problems are mutually related to each other. For instance, forests are deforested to obtain lands for cultivation to maintain an adequate supply of food. Hence, the CO2 density in the atmosphere increases by decreasing the CO2 fixation area , which in turn contributes to global warming. The influence by human activities such as food consumption and energy consumption greatly contribute to many of these problems.

To provide insight into relative importance of different linkages in the Society - biosphere - climate, IMAGE2[1] was developed. But this can't explain the relationship between human activities and global environmental change.

Goto[2] estimated the population that can be accommodated with the potential arable land (using NDVI from NOAA-AVHRR) which can be potentially cultivated is used for grain production. considering the amount of meat production. And he estimated the CO2 emission from the human activities when the population is maximum of the capacity by using Edmond-Raily Model explicitly.

Yamamoto[3] evaluated the overall CO2 exhaust due to the improvement of land use, population increase, living standard improvement, forest destruction and so forth and obtained the amount for which the biomes can be used. In this model, the CO2 exhaust due to two energy sectors were evaluated: energy consumption sector and the sector in which the area of forests is decreased due to logging and due to slash-and-burn agriculture to clear away plots of land for farming. But the population is inputted.

Past Researches mentioned above can not explain the balance between human activities and LUC.

This study aims to make a model by which the influence of human activities such as food consumption, energy consumption, etc. on the earth's environment is evaluated and to evaluate the size of the influence from 1986 to 2020 for OECD and Non-OECD region.

2. METHODOLOGY

2.1 Research Flow

In this research, there are five major sections in the model shown in Fig. These are feed back by the amount of the CO2 exhaust, CO2 exhaust due to wood consumption, CO2 exhaust due to food consumption, CO2 exhaust due to population and CO2 exhaust due to energy consumption. These are modeled using system dynamic model. Moreover, two cases concerning the forecast of the future amount of fossil fuel-use and the ratio of fossil fuel-use will be established. The amount of CO2 exhaust for each case in the future and the population capacity are evaluated.

2.2 Definition of Variables
Each variable used by this research is as follows:

t : Time
dt : Time period
POP : Population
BIRTH : Number of births
DEATH : Number of the deaths
F_CNS : Amount of food consumption
F_CNS_CAP : Amount of food consumption per capita
F_EXP, F_IMP : Amount of food import and export
PRD_HA : Amount of food production per 1ha cultivated land
ARB_NPP : Net primary productivity per 1ha cultivated land
F_CO2 : Amount of CO2 exhaust due to food consumption
E_CNS : Amount of energy consumption
E_CNS_CAP : Amount of energy consumption per capita
COAL_CNS : Amount of coal consumption
OIL_CNS : Amount of oil consumption
GAS_CNS : Amount of natural gas consumption
α, β, γ : CO2 exhaust coefficient according to each source of energy
E_CO2 : Amount of CO2 exhaust due to energy consumption
FW_CNS : Amount of wood-use for fuel
RW_PRD : Amount of log production
FW_CNS_CAP : Amount of wood-use for fuel per capita
RW_PRD_CAP : Amount of log production per capita
WD_VLM : Number of trees that can be used per 1ha of forest
WD_NPP : Net primary productivity per 1ha of forest
FW_CO2 : Amount of CO2 exhaust due to use of wood for fuel
LU_CO2 : Amount of CO2 exhaust due to land-use chang

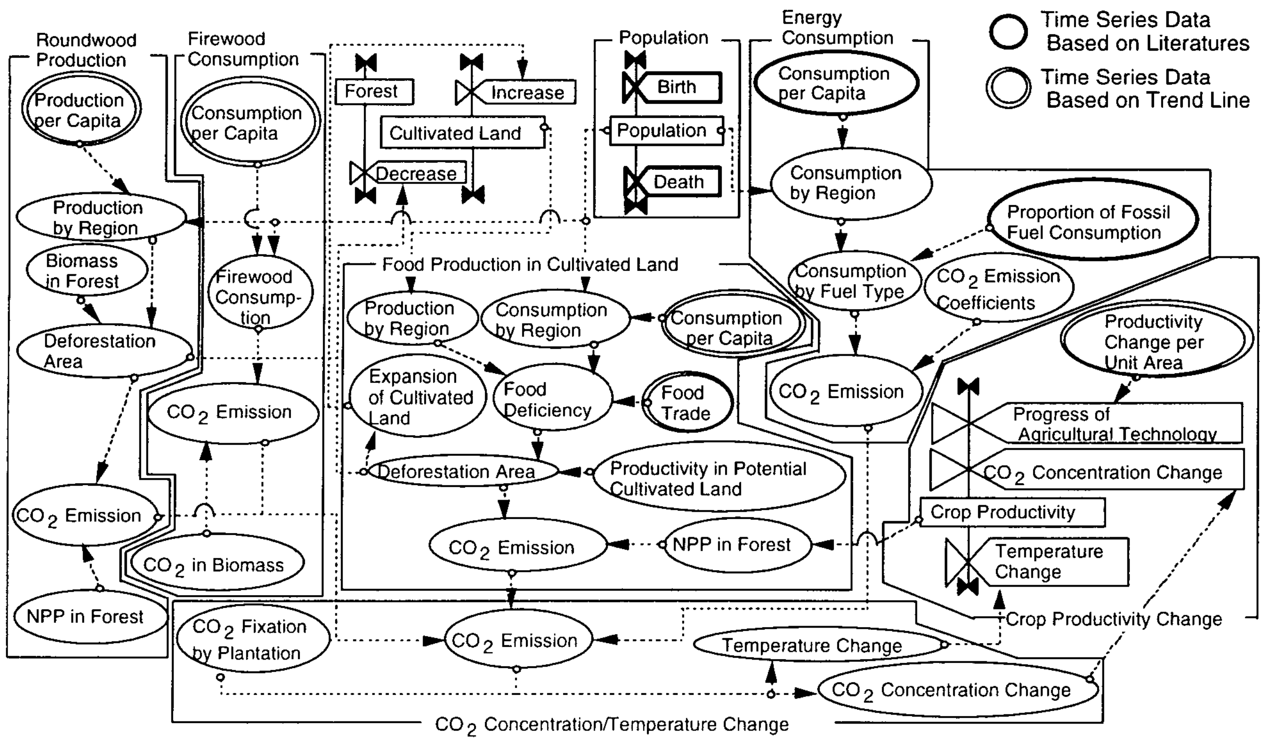


Fig.1. Assessment Model for Human Impact on Global Environmental Change

2.3 Prediction of Population

The population is obtained from equation (1) by using the number of births[4] and the numbers of the deaths[4].

$$POP(t)=POP(t-dt)+BIRTH(t)-DEATH(t)$$ □ □ □ (1)

2.4 Prediction of the Amount of CO2 Exhaust

The focus of this research is the CO2 exhaust due to energy consumption, food consumption and wood consumption.

(1) Prediction of the Amount of CO2 Exhaust Due to Energy Consumption

The targeted source of energy is oil, coal and natural gas. When these fossil fuels are used, the CO2 exhaust is assumed to be the amount of the CO2 exhaust due to energy consumption.

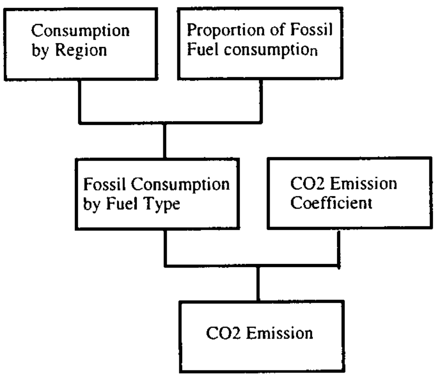


Fig.2. Method of predicting the amount of CO2 exhaust due to energy consumption

1) Amount of Energy Consumption

The amount of energy consumption is obtained from the population and the amount of energy consumption per capita.

$$E\_CNS(t)=POP(t)\times E\_CNS\_CAP(t)$$ □ □ □ (2)

2) Amount of CO2 Exhaust Due to Energy Consumption

The different amount of the CO2 exhaust for each source of energy is obtained by taking the ratio of the consumption of each source of energy to the total amount of energy consumption and using different CO2 exhaust coefficient[5] for each source of energy.

$$E\_CO2(t)=\alpha\, COAL\_CNS(t) + \beta\, OIL\_CNS(t)+\gamma\, GAS\_CNS(t)$$ □ □ □ (3)

(2) Prediction of the Amount of CO2 Exhaust Due to Food Consumption

At times when the amount of food consumption exceeds the present amount of food production, in other words, when the amount of food becomes insufficient, the forest where cultivation is possible is deforested to clear a plot of land for farming. In doing so, the amount of food production is increased and food-insufficiency is supplemented. In this case, the amount of CO2 exhaust due to deforestation can be thought of as the amount of CO2 exhaust due to food consumption or consumption of primary produces.

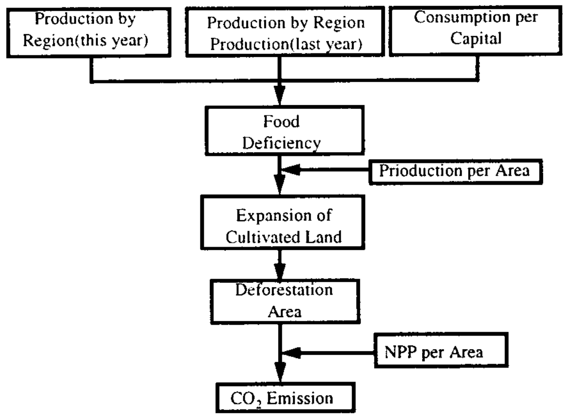


Fig.3. Method of predicting the amount of CO2 exhaust due to food consumption

1) Amount of Food Consumption

The amount of food consumption is obtained from the population and the amount of food consumption per capita.

$$F\_CNS(t)=POP(t)\times F\_CNS\_CAP(t)$$ □ □ □ (4)

2) Amount of Food Production

The method of predicting the present amount of food production uses the method which is proposed by Goto[6]. The subjects are amount of 4 types of meat production and the amount of the main 12 grains. Man does not consume all the grains produced in various places as food; livestock consume some percentage of these grains. In turn, meats are obtained from these livestock. The current amount of food production is obtained from the amount of grain production and the amount of meat production. Moreover, the present amount of food production is obtained from the amount of food produced from 1ha of cultivated land.

3) Amount of Potential Food Production

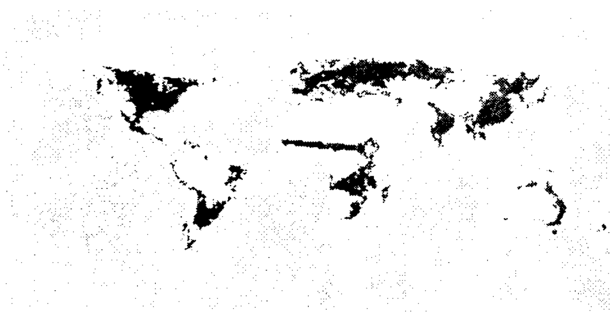
First of all, it is necessary to obtain the area of the region where cultivation is possible to obtain the amount of the potential food production. Using Cramer's method[7], the possible area of the land than can be cultivated is obtained. Cramer points at the region, in which the following three conditions applies, as a suitable region where land cultivation is possible.

i) Region of 2,000℃ or more in total temperature for a period it takes for plants to grow.

ii) The ratio of the soil moisture actually used in evapotranspiration and the needed moisture of the region is 0.45 or more.

iii) Exclude the region where the average monthly lowest temperature is 15.5℃ or more and the ratio in condition 2 in 1 year is 0.70 or more.

Fig.4 show the potential arable land distribution applied to these conditions.



World : 39.2 ×10⁴ha
OECD : 11.3 ×10⁴ha
Non-OECD: 27.8 ×10⁴ha

Fig.4 Potential Arable land Distribution Including Arable land

4) NPP/ha in Potential Arable Land

The net primary productivity that can be obtained from clearing 1ha of forest for potential cultivation is obtained by using the NOAA's NDVI data obtained through Box[8]'s method. The method for obtaining it is shown below.

Scaled NDVI = 240- (NDVI+0.05) × 350 □ □ □ (5)
NPP=-1467.82527 × log(1-2.5 × Scaled NDVI) □ □ □ (6)

Scaled NDVI : NDVI measured with NOAA (0 ~ 255)
NDVI : normalized vegetation index
NPP : Net primary productivity

From this result and from the area of land that can be potentially cultivated, the amount of primary production for each 1ha of land that can be cultivated potentially is obtained.

5) Amount of CO2 Exhaust Due to Food Consumption

The difference between the current food consumption and the preceding year's food consumption is the value by which the amount of food import and export is determined. The amount of the CO2 exhaust due to food consumption is obtained from the area of deforestation necessary to supplement the lack of food.

F_CO2(t)=ARB_NPP × (F_CNS(t)-F_CNS(t-dt) +F_EXP(t)-F_IMP(t))/PRD_HA □ □ □ (7)

(3) Amount of CO2 Exhaust Due to Wood Consumption

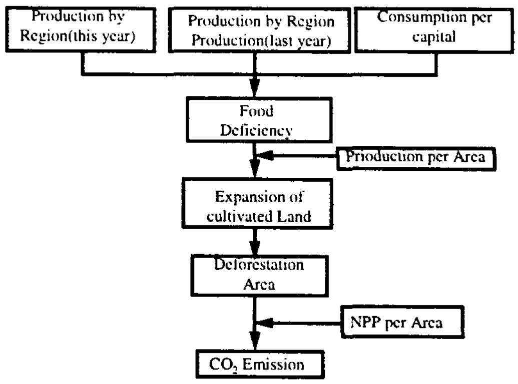


Fig.5. Method of predicting the amount of CO2 exhaust with wood

CO2 exhaust from wood is assumed to be generated when wood is burned for fuel and when forests are logged to secure logs for fuel-use and industrial-use.

1) Amount of Wood used for Fuel and Amount of Log Production for Fuel

The amount of the used of wood and the amount of log production are obtained by using the amount of wood-use for fuel and the amount of log production per capita and for the entire population.

FW_CNS(t)=POP(t) × FW_CNS_CAP(t) □ □ □ (8)

RW_PRD(t)=POP(t) × RW_PRD_CAP(t) □ □ □ (9)

2) Amount of CO2 Exhaust Due to using Wood for Fuel

When wood is burnt for fuel, the CO2 inside the tree is released. Because according to Llieth[9], the CO2 inside a tree is about 45% of its weight, the expression below was obtained.

FW_CO2(t)=0.45 × FW_CNS(t) □ □ □ (10)

3) Amount of CO2 Exhaust Due to Land-use Change

The area of deforestation is obtained from the amount of trees that can be used from 1ha of deforested land[9] to secure wood for fuel-use and to secure log for industrial-use. Using the same method in section 5.2.4 to obtain the net primary productivity per 1ha of deforested land, the amount of CO2 exhaust due to logging forests is obtained.

LU_CO2(t)=WD_NPP × RW_PRD(t)/WD_VLM □ □ □ (11)

2.5 CO2 Absorption by Afforestation

About 11,000,000ha[10] of land has been afforested in 1980, and in the future, it is assumed that about 11,000,000ha[10] of land will be afforested every year. Because the capacity of CO2 fixation is different depending on the fertility degree of the soil in the region, and the different growth rate depending on the kind of trees planted, the capacity of CO2 fixation of 9.6(highest value), 2.8(lowest value)-tC/ha and a simple average of 6.2tC/ha that was obtained by Brown[11] is used. According to the above value, capacity of CO2 fixation every year due to afforestation is 6.89×10^7(tC). Actually, the capacity of CO2 fixation along with the growth of the tree is saturated. In this research, the replanted trees and their carbon fixation is assumed not to change and is set to be constant.

2.6 Change in Amount of Grain Production

The change in the amount of grain production which depends on the advancement of agricultural technology and the CO2 exhaust is related to the amount of food production as a coefficient.

(1) Effect of Feedback of CO2 Density Increase

The effect of feedback of CO2 density increase was obtained based on the presumption of UNEP[12] that about 30% of the amount of grain production increased when the CO2 density doubled. It was assumed that there was a linear relation between the CO2 density at this time and the amount of the grain production.

(2) Effect of Feedback of Temperature Rise

Based on the research done by the CIA[13] on the effect of the change of temperature and rainfall in forecasting the amount of grain production, the effect of feedback of the temperature rise is obtained. However, because of the change in rainfall pattern brought on by global warming is not fully known yet, the influence of the amount of rainfall was disregarded in this research.

(3) Advancement of Agricultural Technology

The change in the amount of food production for each 1ha of cultivated land from 1985 to 1992 is assumed as follows as the advancement of an agricultural technology. From 1985 to 1992 and thereafter, the food production per 1ha of cultivated land for OECD, along with Non-OECD region will change in expanding rate.

3. SIMULATION RESULT

The result of two kinds of scenarios of the GREEN model[14] developed in OECD (economic cooperation development mechanism) secretariat was used and simulated concerning the forecast of future energy consumption in Tab.1.

The simulation result of two kinds of the following scenarios is used in this study.

1) Bau scenario: Current maintenance (BaU) scenario by which policy of regulating CO2 exhaust increase is not adopted at all

2) Toronto scenario: Toronto agreement type scenario by which different load is imposed on OECD region and Non-OECD region with respect to carbon restriction

To verify the validity of the result obtained from this research, the amounts of CO2 emission due to human activity are compared to the research result of IPCC[15]. The result is shown in Fig.6. This shows the human induced CO2 emission of two scenario used in this study is in the intermediate between three IPCC scenarios. Fig.7 shows the population, estimated by UN., trend used in this study. Fig.8 shows the human induced the CO2 emission in two regions. CO2 emission by food consumption and wood consumption are depend on the human activities through LUC. And this Fig. shows CO2 emission through LUC in Nou-OECD country larger then OECD country. And Fig.8. shows CO2 emission through LUC in Non-OECD country larger then OECD country

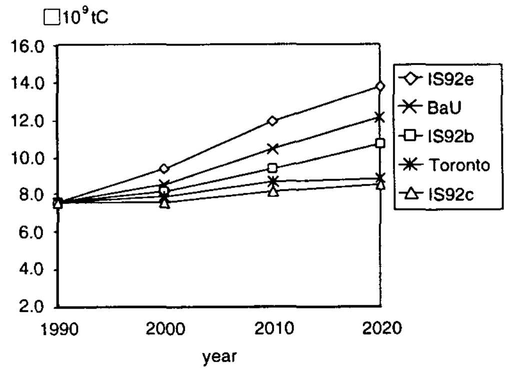


Fig.6. Estimated Human Induced CO2 emission vs. IPCC Estimation

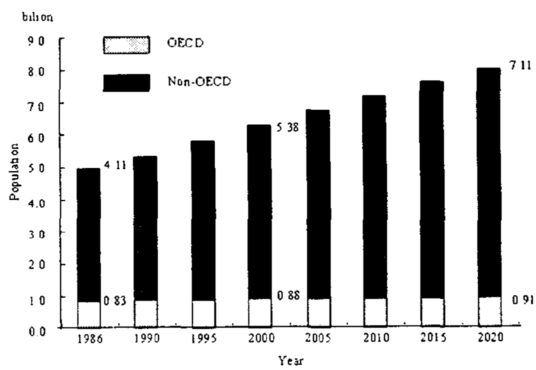
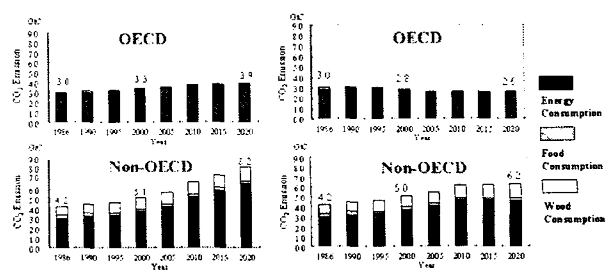


Fig.7. Population Trend



(BaU Scenario) (Tronto Scenario)

Fig.8 Estimated Human Induced CO_2 Emission

4. CONCLUSION

As a result of the research, the following items became clear:

□ The model to forecast the future amount of CO_2 exhaust due to energy consumption, land-use change and wood-use was made.

□ It is thought that the result that was obtained in this research was compared with the result of other researches, so there is validity in this model.

□ The amount's of CO_2 exhaust in two kinds of scenarios in the year 2020 will be about 1.6 times and 1.2 times the current amount respectively, and the energy consumption of the population is thought to be the main cause of the increase in the CO_2 exhaust.

□ It has been understood from the result of the simulation for the year 2020 that a population of 8,000,000,000 people or more can be supported.

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Tab.1 Assumpions of IPCC Scenarios

Scenario	Population	Economic Growth	Energy Supply
IS92b (**Middle** **CO_2 Emission)**	11.3 Billion by 2100 (World Bank, 1991)	1990-2025: 2.9% 1990-2100: 2.3%	Oil 12,000EJ Natural Gas 13,000EJ Solar Power Generation Cost Falls to $0.075/kWh 191EJ Biological Fuel is available with $70/barrel
IS92c (**Lower** **CO_2 Emission)**	6.4 Billion by 2100 (United Nations, Middle Prospect)	1990-2025: 2.0% 1990-2100: 1.2%	Oil 8,000EJ Natural Gas 7,300EJ Nuclear Power Generation Cost Reduces with 0.4%/year
IS92e (**Higher** **CO_2 Emission)**	11.3 Billion by 2100 (World Bank, 1991)	1990-2025: 3.5% 1990-2100: 3.0%	Oil 18,400EJ Natural Gas 13,000EJ Total Abolition of Nuclear Power Generation by 2075

Source: IPCC 1st W.G. and WMO/UNEP, Climate Change1992: IPCC Science Assessment Additional Report, A3, p.200

(EJ=10^{18}J, 1barrel=158.99liter)