SUSTAINABLE ENERGY PATH*

by

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The uses of fossil fuels cause not only the resources exhaustion but also the environmental problems such as global warming. The purposes of this study are to evaluate paths toward sustainable energy systems and roles of each renewable. In order to realize the purposes, the authors developed the global land use and energy model that figured the global energy supply systems in the future considering the cost minimization.
Using the model, the authors conducted a simulation in C30R scenario, which is a kind of strict CO_2 emission limit scenarios and reduced CO_2 emissions by 30% compared with Kyoto protocol forever scenario, and obtained the following results. In C30R scenario bioenergy will supply 33% of all the primary energy consumption. However, wind and photovoltaic will supply 1.8% and 1.4% of all the primary energy consumption, respectively, because of the limits of power grid stability. The results imply that the strict limits of CO_2 emissions are not sufficient to achieve the complete renewable energy systems. In order to use wind and photovoltaic as major energy resources, we need not only to reduce the plant costs but also to develop unconventional renewable technologies.

Key words: *sustainable energy sistem, global energy sistem, bioenergy, land use competition, renewabbe energy*

Introduction

The uses of fossil fuels cause not only the resources exhaustion but also environmental problems such as global warming. Before the fossil fuels are exhausted or the CO_2 emissions of the fossil fuels cause the catastrophic climate change, we need to develop the new energy systems that are fossil-fuel-free. In this study, the authors evaluate the path toward the sustainable energy systems.

In the past researches, renewable energy scenarios were published [1-3]. However, any researches that considered systematic analysis of land use competitions and bioenergy supply potential and constraint of power grid stability concerning intermittent

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renewables such as photovoltaic and wind power and that evaluated the path toward sustainable energy systems using an optimization model are not known.

In order to discover the path toward the sustainable energy systems, the authors developed the global land use and energy model (GLUE) [4, 5]. The model figures the global energy supply systems including overall energy resources including fossil fuels and renewables and overall energy conversion technologies, and minimizes the energy system costs in the world.

In this study, the authors conducted a simulation using the model of GLUE and calculated a renewable-intensive scenario. Then, the authors discussed the role and the limit of the current renewable technologies and how to solve the limit in order to realize the complete renewable energy systems.

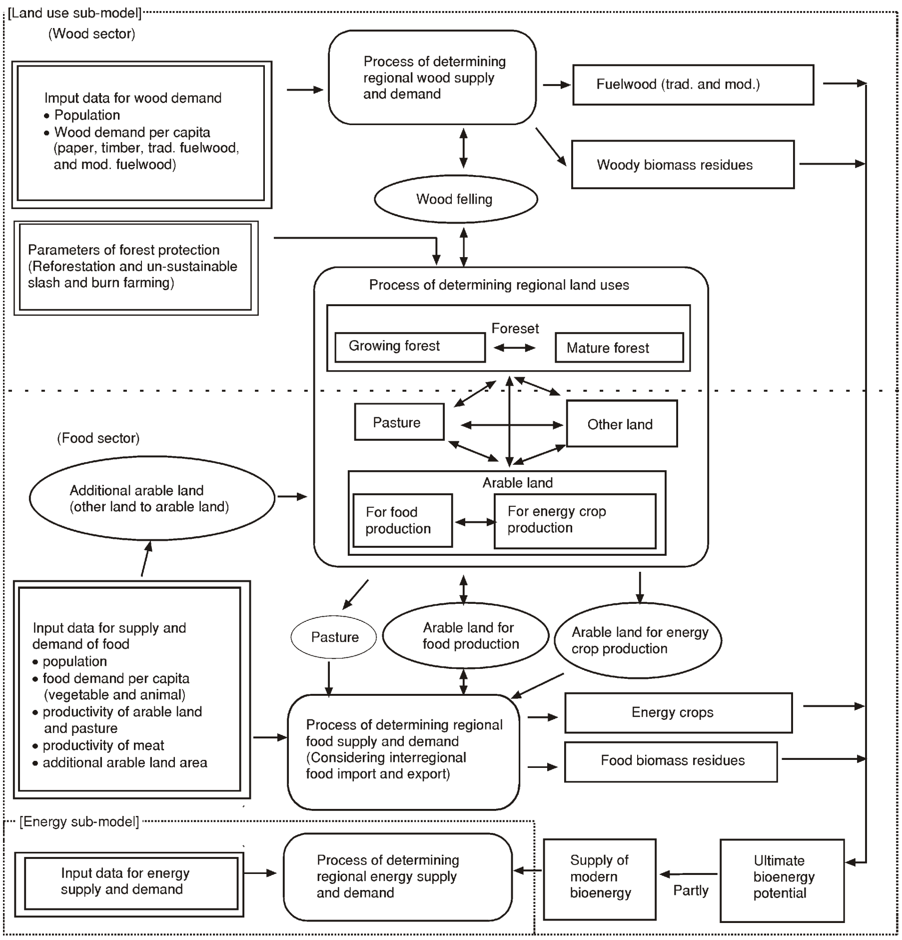

Figure 1. Structure of the model

Outline of the model

The world is divided into 11 regions (tab. 1). The model calculates the optimal energy systems including bioenergy systems from 2000 to 2050 at every ten year using Linear Programming (LP) technique. The objective function of the model is the summation of the energy system costs.

The model consists of two parts: an energy systems part and a land use part. The energy systems part is based on a global energy systems model named New Earth 21 (NE21) [6] and the land use part is base on a global land use and energy model (GLUE-11) (fig. 1) [4]. The land use part covers a wide range of land uses and biomass flow including food chains, material recycling, and discharge of biomass residues. Those two parts are connected through common variables concerning bioenergy supply potential. The number of constrains is about 4,300 in the energy systems part and is 2,100 in the land use part.

Table 1. Regions in the model

No.	Regions
1	North America
2	Western Europe
3	Japan
4	Oceania
5	Centrally Planned Asia
6	Middle East and North Africa
7	Sub-Sahara Africa
8	Latin America
9	Former USSR & Eastern Europe
10	Southeast Asia
11	South Asia

The authors prepared data for GLUE using publications of FAO [7], IPCC [8], World Bank [9], DOE [10], and so on. For example, the authors calculated the data of power generation costs of photovoltaic and wind power based on the literature [10] (fig. 2). The details of the data set are explained in the reference [4, 5].

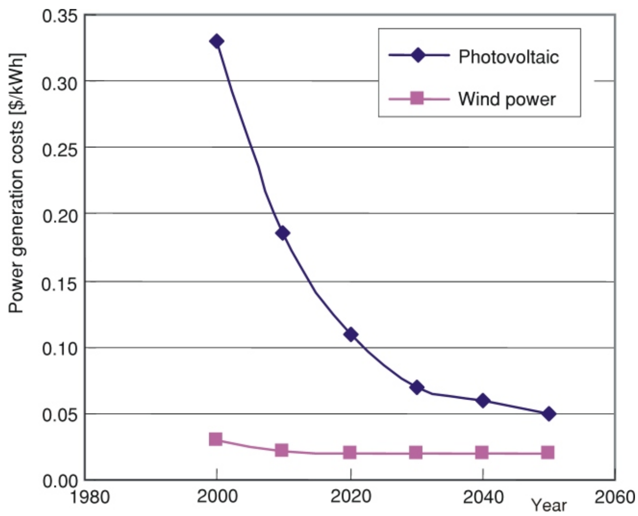

Figure 2. The assumption of power generation costs of photovoltaic and wind power
The authors calculated the data of power generation costs of photo voltaic and wind power based on the literature [10]. The costs of photovoltaic are the costs in the United State (where the incident light was assumed at 1,800 kWh/m^2/year). The costs of wind power are the reference costs (where the average wind speed was assumed at 5.8 m/s) and were assumed to increase following degradation in the average wind speed [5]

CO_2 emission scenario

It was assumed that the final energy demand would increase following IPCC SRES-B2 scenario [8]. In order to satisfy the demand, the model selects primary energy resources and energy conversion technologies.

The authors assumed a CO_2 emission scenario named C30R that is a kind of scenarios that will impose the severe constraints of CO_2 emissions in and after 2020 (fig. 3). In C30R, the authors assumed that the CO_2 emissions in and after 2020 would be by 30% less than those in 1990 in the developed regions, and those in and after 2020 would be by 30% less than those in the same point of time in a case without CO_2 emission constraint in the developing regions. The authors assumed that the trade of CO_2 emission rights would be allowed among all the regions in the world.

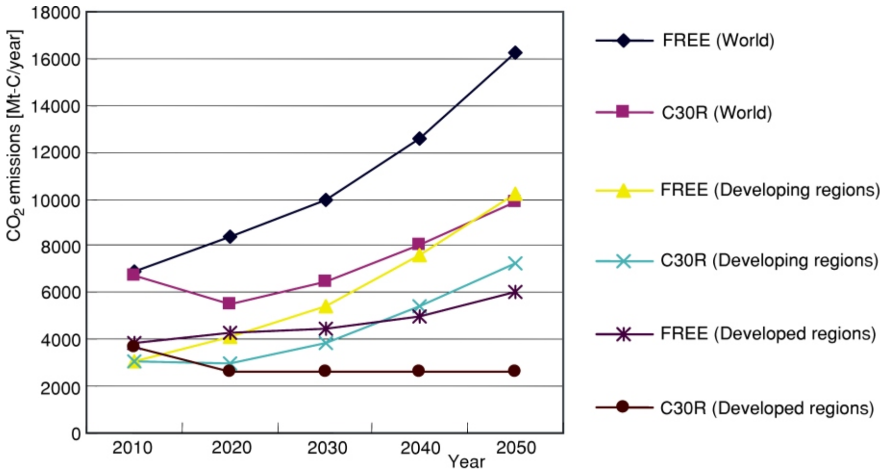

Figure 3. CO_2 emission scenarios in FREE and C30R
FREE means no CO_2 emission constraint scenario. In C30R, the CO_2 emissions in and after 2020 will be by 30% less than those in 1990 in the developed regions, and those in and after 2020 will be by 30% less than those in the same point of time in a case without CO_2 emission constraint in the developing regions

Simulation results

Using the model of GLUE and the CO_2 emission scenario of C30R, the authors conducted a simulation and obtained the following results.

In C30R scenario, bioenergy resources will be used on a large scale by 2050 (figs. 4 and 5). Most of practical supply potential of biomass residues will be used by

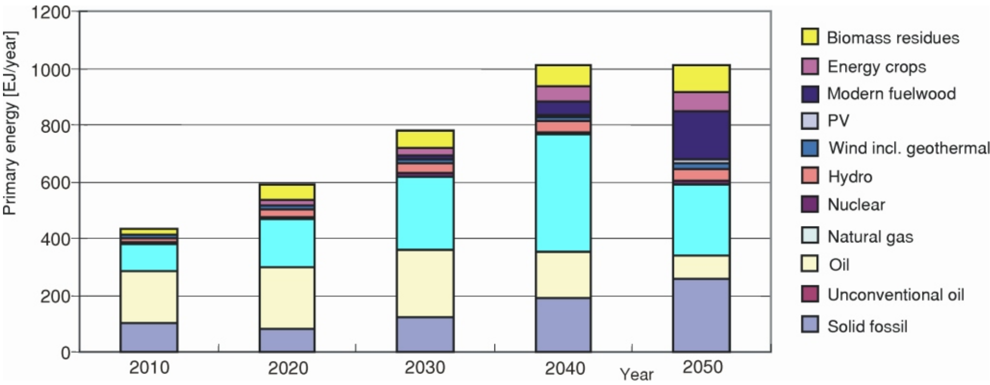

Figure 4. Primary energy consumption in the world in C30R scenario (in EJ/year)

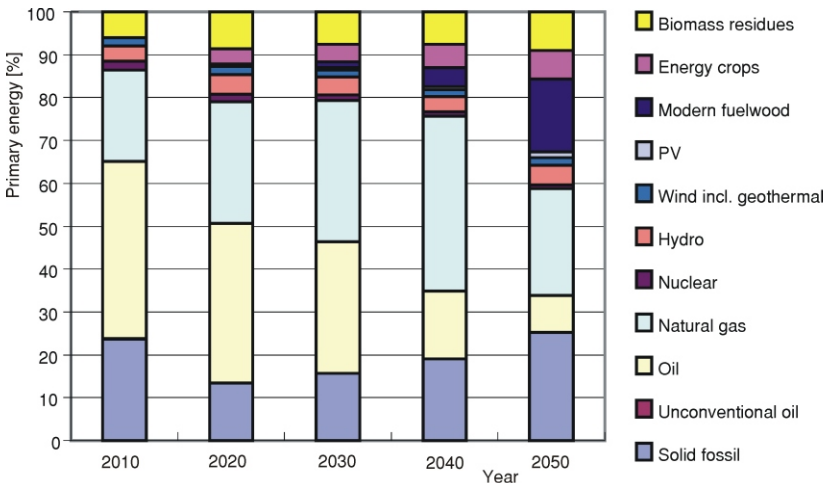

Figure 5. Primary energy consumption in the world in C30R scenario (in percent)

2050; all the supply potential of energy crops produced on surplus arable lands will be used by 2050; two-thirds of all forest resources in the world will be used to supply material wood and fuelwood by 2050. It means that two-thirds of the forest will be converted into the management forest where the forest may lose bio-diversity. For reference, the natural forest area is at around 9/10 of all the forest and the management forest is at around 1/10 in the world currently.

Using those bioenergy resources including bioenergy residues, energy crops, and fuelwood, bioenergy will become at 33% of all the primary energy consumption in the world in 2050. However the consumption of wind and photovoltaic will be at 1.8%

and 1.4% of all the primary energy consumption in 2050, respectively (figs. 4 and 5). Thought bioenergy is stock energy and can supply energy following energy demands, wind and photovoltaic are intermittent and the installed capacities of them are limited due to keep the stability of the electricity power grids. The upper limit of the installed capacity of the sum of wind and photovoltaic was assumed at 5% of the whole power demand in the daytime; the upper limit of the installed capacity of wind was assumed at 5% of the whole power demand at night [11]. On the other hand, the consumption of fossil fuels will decrease between 2040 and 2050, since the costs of fossil fuels become disadvantageous relatively compared with renewables due to an increase in mining costs of fossils and a decrease in renewable costs.

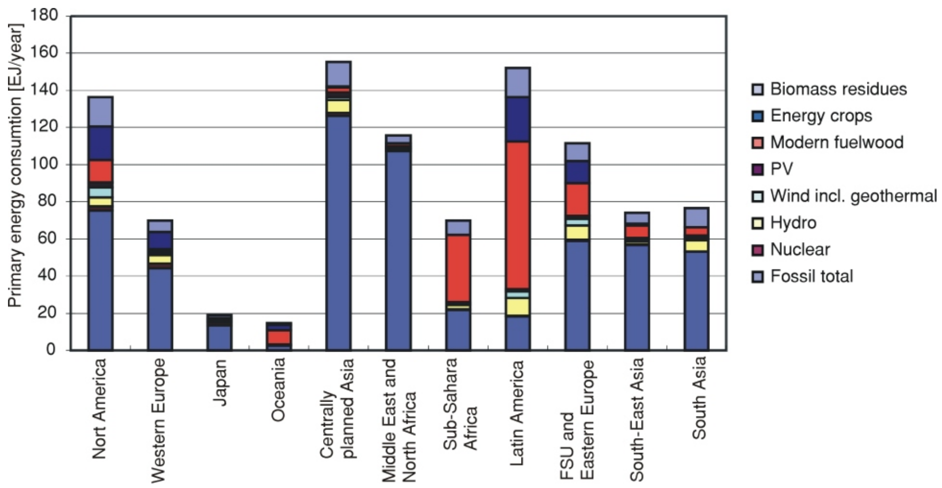

Figure 6. Primary energy consumption in each region in C30R scenario (in EJ/year)

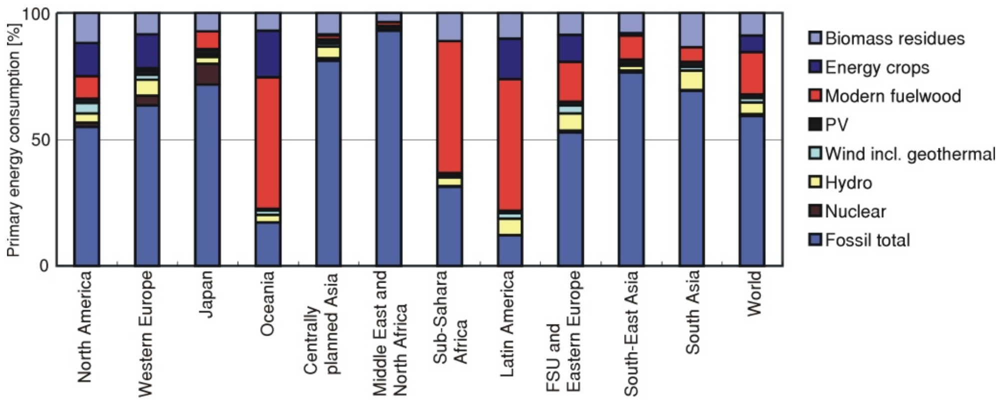

Figure 7. Primary energy consumption in each region in C30R scenario (in percent)

Concerning the regional results, Oceania, Sub-Sahara Africa, and Latin America, where the population densities are low and the bioenergy resources are plenty, will consume renewables over two-thirds of all the primary energy consumption (figs. 6 and 7).

Conclusions

The uses of fossil fuels cause not only the resources exhaustion but also the environmental problems such as global warming. Therefore, the world looks for the paths toward the sustainable energy systems based on renewable energy. However, renewables are limited by the supply potentials and the unstable outputs of photovoltaic and wind.

The purposes of this study are to evaluate paths toward sustainable energy systems and roles of each renewable. In order to realize the purposes, the authors developed the global land use and energy model (GLUE) that figured the global energy supply systems in the future considering the cost minimization. The model includes overall energy resources including fossil fuels and renewables and overall energy conversion technologies including power generation, gasifier, and liquefaction.

Using the model, the authors conducted a simulation in C30R scenario, which is a kind of strict CO_2 emission limit scenarios and reduced CO_2 emissions by 30% compared with Kyoto protocol forever scenario, and obtained the following results.

In C30R scenario bioenergy will supply 33% of all the primary energy consumption. However, wind and photovoltaic will supply 1.8% and 1.4% of all the primary energy consumption, respectively, because of the limits of power grid stability.

Oceania, Sub-Sahara Africa, and Latin America, where the population densities will be low and the bioenergy resources will be plenty, will consume renewables over two-thirds of all the primary energy consumption in 2050. Bioenergy resources will be one of the most important renewables especially in Oceania, Sub-Sahara Africa, and Latin America, but bioenergy resources will reach the upper limits of the supply potential.

The results imply that the strict limits of CO_2 emissions are not sufficient to achieve the complete renewable energy systems. In order to use wind and photovoltaic as major energy resources, we need not only to reduce the plant costs but also to develop unconventional technologies such as photovoltaic system directly connected with battery or electrolysis systems that can avoid the problem of the power grid stability.

The authors plan to evaluate the perfect renewable energy systems in the world considering the unconventional renewable energy systems.

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