

A SIMULATION STUDY ON BIOENERGY POTENTIAL WITH A GLOBAL LAND USE AND ENERGY MODEL

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ABSTRACT

Global bioenergy potential in the future is estimated using a multi-regional global land use and energy model (GLUE-11). The model consists of two sectors (a food sector and a forest sector) and describes land use competition among various uses for biomass applications such as paper, timber, food, feed, and energy. The model covers a wide range of biomass flow including food chains from feed to meat, paper recycling, and discharge of biomass residues. The model calculates the bioenergy potential from 1961 to 1990 based on the past records; and calculates that from 1990 to 2100 based on future biomass supply and demand scenarios.

Through a set of simulations, the following results were obtained. (1) There will be a potential of energy crop production from surplus arable land in North America, Western Europe, Oceania, Latin America, and Former USSR and Eastern Europe. However, the potential of energy will be strongly affected by food demand parameters in the future, such as animal food demand per capita. (2) Ultimate energy potential of biomass residues will increase from 85 EJ/year to 258 EJ/year in 2100 globally. The potential will be robust to food demand. There will be large energy potentials of biomass residues in North America, Centrally Planned Asia, Latin America, and South Asia that will be major biomass consumers or major biomass exporters. Wood harvesting residues, wood scrap, cereal harvesting residues, and animal dung will be the biomass residues with large energy potentials.

1. INTRODUCTION

Biomass is indispensable to human activity as food and material; moreover biomass is important as an energy resource. Bioenergy is expected to become one of the key energy resources for global sustainable development because bioenergy maintained adequately is renewable and free from net CO₂ emissions. However, bioenergy cannot be infinite, since land area available for biomass production is limited and a certain amount of biomass must be reserved for food and material. In addition, bioenergy is produced from not only energy crops but also biomass residues such as black liquor, cereal harvesting residues (e.g. cereal husks), and animal dung.

In order to evaluate such bioenergy resources comprehensively, we developed the global land use and energy model (GLUE) considering land use competition and overall biomass flow including those of biomass residues. We reported analyses using the model in the references of [1], [2], [3], [4], and [5].

In 1997 we visited pulp-related factories in Hokkaido in Japan and investigated pulp-related biomass flow in Japan. The purposes of this study are (1) to revise wood biomass flow in the model based on the investigation and (2) to recalculate global bioenergy potential and land use changes using the model [1]. We also revise the multi-regional data sets for the new model using the relation between GDP_{PPP} (purchasing power parity) and biomass demands.

The following three chapters show an outline of GLUE-11, the data sets, and the results, respectively.

2. OUTLINE OF MULTI-REGIONAL GLOBAL LAND USE AND ENERGY MODEL (GLUE-11)

The structure of the multi-regional global land use and energy model (GLUE-11) follows that of the land use sub-model of GLUE (Figure 1). GLUE-11, which consists of two sectors (a food sector and a forest sector), describes land use competition among various uses for biomass applications such as paper, timber, food, feed, and

energy. The sub-model covers a wide range of land uses and biomass flow including food chains from feed to meat, paper recycling, and discharge of biomass residues (Figure 2) (Figure 3).

The authors modified the wood biomass flow (Figure 2). The modification is based on our investigation tour at pulp-related factories in Hokkaido in Japan in 1997. The main modifications of the wood biomass flow are as follows. (1) Most woodpulp is made from low quality wood such as low-quality roundwood, sawmill residues, and timber scrap. (2) Board, which consists of particleboard and fiberboard, as well as woodpulp is made from low quality wood.

The high quality wood is used for production of high quality and high price products such as timber, plywood, and veneer in the factories in Japan. The next grade wood (the low quality wood) is the material of woodpulp and board. The worst grade wood is used for fertilizer and fuelwood (excluding high quality charcoal use). We explain the related data in the section three.

The model calculates the bioenergy potential from 1961 to 1990 based on the past records and that from 1990 to 2100 based on the data sets (explained in the next section) with one-year time step. The model was written in FORTRAN. The eleven regions are shown in Table 1.

Forest area in the model is divided into two areas: mature forest area and growing forest area. We assumed that we would cut off trees from only the mature forest area considering sustainable forest management.

Next, we explain calculation procedures of production, import, and export of biomass. The procedures are divided into two groups: (1) for all kinds of wood and food biomass except cereals and energy crops, and (2) for cereals and energy crops.

(1) The calculation procedures for all kinds of biomass except cereals and energy crops:

(1-1) First, we assumed that net import ratios (regional net import per regional supply in weight) of net import regions would be constant at the ratios in 1990.

(1-2) On the other hand, we assumed that net export shares (regional net export per global net export in weight) of net export regions would be constant at the shares in 1990.

(1-3) The model equalizes the net imports and the net exports of the biomass globally, and calculates net imports and exports, biomass demands, and land use demands.

(2) The calculation procedures for cereals and energy crops:

(2-1) First, the total arable land area minus the land use demands for all the food biomass except cereals and energy crops is equal to the land area for cereals and energy crops.

(2-2) The production and the import and export of cereals and energy crops are based on the principle that food production takes priority over energy production. The priorities of land uses were set as follows.

(First priority) Cereal production for the own region;

(Second priority) Cereal production for the other regions;

(Last priority) Energy crop production for the own region.

In other words, energy crops are produced from surplus arable land. In addition, if cereal demand exceeds the cereal supply globally and food shortage occurs, the model will just calculate the gap between the supply and demand of cereals and will not simulate the social impacts such as depopulation. We also assumed that the energy crops would be consumed in the own region entirely.

Table 1 Regions in the model [a]

(1) North America (2) Western Europe (3) Japan (4) Oceania (5) Centrally Planned (6) Middle East and North Africa (7) Sub-Saharan Africa (8) Latin America (9) Former USSR and Eastern Europe (10) Southeast Asia (11) South Asia

[a] In this study, region (1) to (4) are defined as developed regions and the other regions are defined as developing regions.

3. DATA SETS OF THE MODEL

We analyzed data related to biomass supply and demand and GDPppp and prepared data sets of the model. In this section we explain the main data of the model.

3.1 Biomass Supply Data

3.1.1 Arable Land Area

Scenarios of arable land area are based on the reference [6] and [7]. In the developed regions it was assumed that fallow land (at 70 Mha in all the developed regions) would be changed to arable land. In the developing regions it was assumed that degraded land (at 550 Mha in all the developing regions) would be added to arable land.

3.1.2 Productivity of Biomass

Productivity of arable land is based on the reference [8]. The land productivity in 2100 will be between 0.99 times (in Japan) and 2.98 times (in South Asia) as much as those in 1990. We assumed the catches of fishery products would be constant at the level in 1990 [4]. Rates of biomass accumulation in growing forest range from 3.1 t-biomass/ha/year (in Former USSR and Eastern Europe) to 17 t-biomass/ha/year (in Southeast Asia and Latin America) [4]. In the developed regions, perfect reforestation is achieved already. In the developing regions, it was assumed perfect reforestation would be achieved in 2025 [1].

3.2 Biomass Demand Data

3.2.1 Population

According to the middle scenario of World Bank, the population will increase to 1.5 billion in all the developed regions and 10 billion in all the developing regions in 2100.

3.2.2 Biomass Consumption and GDPppp

In this study, we divided final biomass consumption into six categories: timber, board, paper, traditional fuelwood, vegetable food, and animal food. Then, we analyzed the relations between those kinds of biomass consumption per capita and GDPppp (purchase power parity) per capita (Figure 4 to 8) in order to make biomass demand scenarios. Figure 4, 5, and 6 show wood biomass such as timber (plus board), paper, and traditional fuelwood; Figure 7 and 8 show food biomass such as vegetable food and animal food. The data of GDPppp are based on those at World Bank [10].

In this study, we show the aggregated demand of timber and board in Figure 4. This is because (1) the board demand is about one-tenth as much as the timber demand, and (2) the former can be mostly substituted by the latter, and vice versa.

Figure 4 shows that the timber plus board consumption of North America is twice as much as the average of the other developed regions; Former USSR and Eastern Europe consume much timber compared to its GDPppp. Figure 5 shows that data are plotted near the curve with constant elasticity between paper consumption and GDPppp. However, the paper consumption of North America is 1.5 times larger than the average of the other developed regions. Figure 6 shows that the consumption of traditional fuelwood of Sub-Sahara Africa, Southeast Asia, and Latin America exceeds 400 kg-biomass per capita per annum. In addition, the consumption of North America, where huge forest resources are available, is 260 kg-biomass per capita per annum and is three times larger than the average of the other developed regions. Figure 7 shows that there is no large deference between the vegetable food consumption of the developed regions and that of the developing regions. However, the regions with lowest GDPppp such as Sub-Sahara Africa and South Asia do not consume enough vegetable food. Figure 8 shows there is a weak but defined correlation between animal food consumption and GDPppp. However, the points in the figure vary widely. For example, the animal food consumption of Southeast Asia, Middle East and North Africa, and Japan is small compared to their GDPppp. On the contrary, the animal food consumption of Centrally Planned Asia is large compared to its GDPppp. In particular, the GDPppp of Centrally Planned Asia is half as much as that of Southeast Asia; however, the animal food consumption of the former is 1.5 times as much as that of the latter.

3.2.3 Long Term Biomass Demand Scenario

Based on the analyses of the biomass consumption in the previous section, we made long term biomass demand scenarios for the model of GLUE-11. The procedures of the scenario building are as follows.

First, we assumed that all the biomass demands per capita in the developed regions would be constant at the level in 1990. Next, we assumed that the biomass demands per capita in the other regions would increase as GDPppp per capita increase; then the demands per capita would be constant after those reach their upper limits (shown in Table 2). Specifically we assumed the function as follows:

$$(\text{Biomass demand per capita}) = a * (\text{GDPppp per capita})^b;$$

and estimated the values of “a” and “b” using two data such as the point in 1990 and the upper limit shown in Table 2. We made a GDPppp scenario based on a GDP scenario of IS92a that is a reference scenario of IPCC [11].

The upper limits (Table 2) were set using the analyses in the previous section. For example, the upper limit of the wood biomass per capita is the average of that of the developed regions except North America.

Concerning timber and board, “a” and “b” in the above function are determined by the aggregated value of timber and board (Figure 4). However, using the estimated function and the each value of timber and board in 1990, we prepared each demand scenario of timber and board.

In addition, the long-term prospect of biomass contains substantial uncertainty. Hence, we prepared two scenarios (Scenario A as a reference scenario and Scenario B as an alternative scenario) in order to analyze the sensitivity of the simulation results between the two scenarios. There is particularly large uncertainty concerning animal food demand of Centrally Planned Asia (see Figure 8). Therefore, we assumed that the upper limit of the animal food demand per capita of Centrally Planned Asia in Scenario A would be that of Japan; on the other hand, that in Scenario B would be the average of those of the developed regions except Japan (Table 2).

Table 2 Upper Limits of Biomass Demand per Capita in Developing Regions [a]

<i>Categories</i>	<i>Upper Limits of Biomass Demand per Capita</i>
1. Timber plus board, paper, traditional fuelwood:	The average of the developed region except North America
2. Vegetable food:	The average of the developed region
3. Animal food:	
3-1 (Former USSR and Eastern Europe / Latin America):	The average of the developed region except Japan
3-2 (The other developing regions):	The value in Japan
3-3 (Centrally Planned Asia in Scenario A):	The value in Japan
3-4 (Centrally Planned Asia in Scenario B):	The average of the developed region except Japan

[a] Data for Scenario A (reference scenario) except 3-4.

4. SIMULATION RESULTS

4.1 Potential of Energy Crop Production

In the reference scenario (Scenario A), there will be a potential of energy crop production from surplus arable land in North America, Western Europe, Oceania, Latin America, and Former USSR and Eastern Europe. The area of the surplus arable land is 158 Mha and the energy potential is 47 EJ/year in 2100 globally (Figure 9). However, in Scenario B, food shortage will occur and there will be no potential of energy crop production in 2100 globally. From this, we conclude that the potential of energy crop production will be vulnerable to changes of food demand parameters.

4.2 Energy Potential of Biomass Residues

“Ultimate energy potential” of biomass residues is explained here. “Ultimate energy potential” of biomass residues is defined as heat values of all the discharged (minus recycled) biomass residues. Thus, “Ultimate energy potential” means a yardstick of amount of bioenergy resources [4].

Figure 9 shows that there will be the large energy potential of biomass residues in North America, Centrally Planned Asia, Latin America, and South Asia. These regions will be major biomass consumers or major biomass exporters. The global ultimate energy potential of biomass residues will increase from 85 EJ/year in 1990 to 258 EJ/year in Scenario A in 2100. Moreover, the potential will be robust to changes of food demand parameters. The potential in Scenario B in 2100 will be 280 EJ/year.

Figure 10 shows that there will be the large energy potential of wood harvesting residues, wood scrap, cereal harvesting residues, and animal dung. The energy potential of sawmill residues in this study is much smaller than that of the past study [1], because in this study we revised the wood biomass flow where most sawmill residues are for woodpulp

5. CONCLUSIONS

In this study, we evaluated bioenergy potential and land use changes regionally, using a multi-regional global land use and energy model (GLUE-11) including land use competitions and overall biomass flow.

Through a set of simulations, the following results were obtained. (1) Potential of energy crops produced from surplus arable lands will be strongly affected by food demand parameters in the future, such as animal food demand per capita. (2) Ultimate Bioenergy potential of biomass residues will be 258 EJ/year in 2100. The potential will be robust to food demand parameters; however the potential will be reduced by constraints of utilization technologies and their costs.

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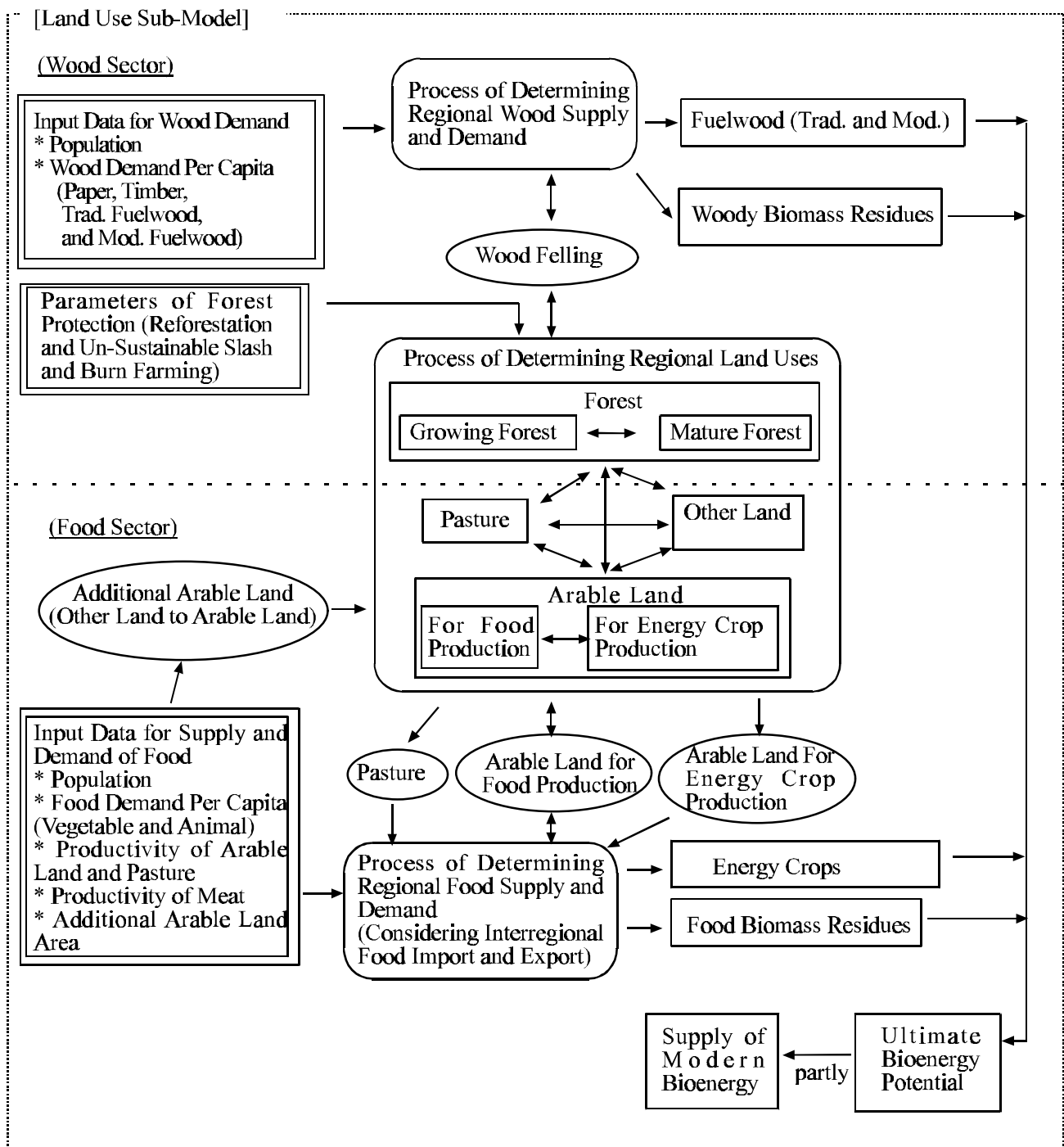


Figure 1 Outline of Structure of Global Land Use and Energy Model (GLUE-11)

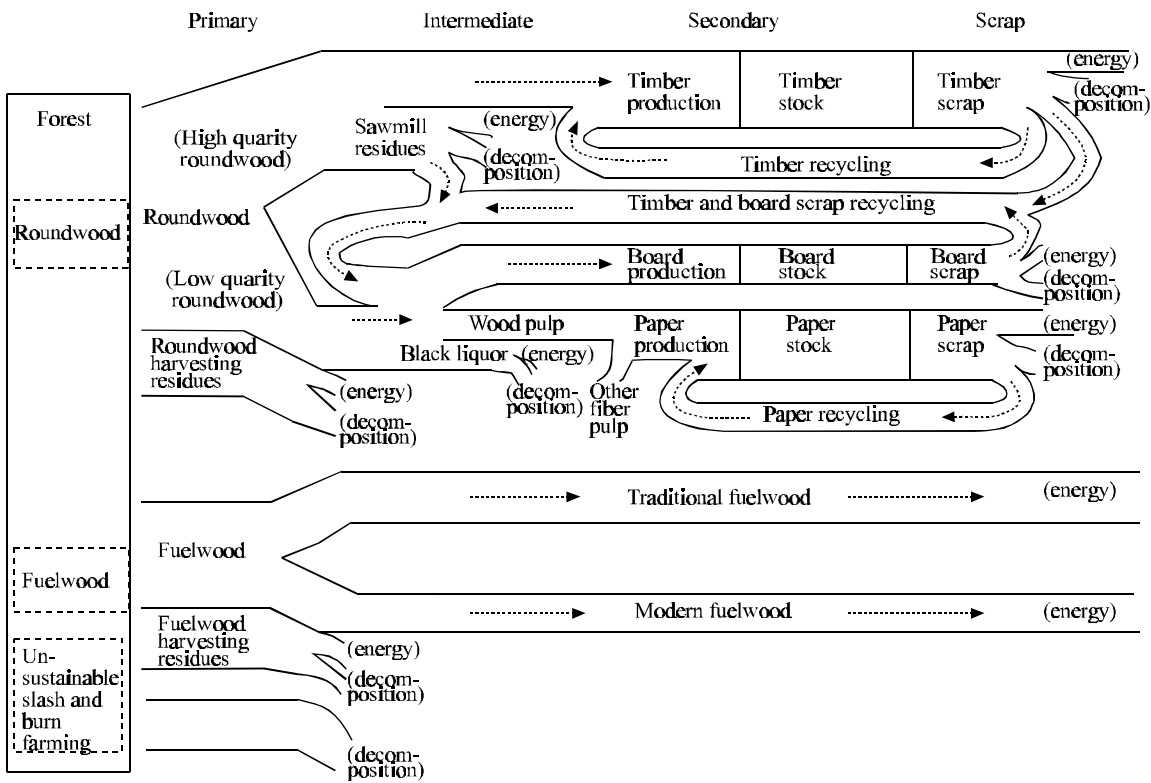


Figure 2 Flow of Wood Biomass (Modified)

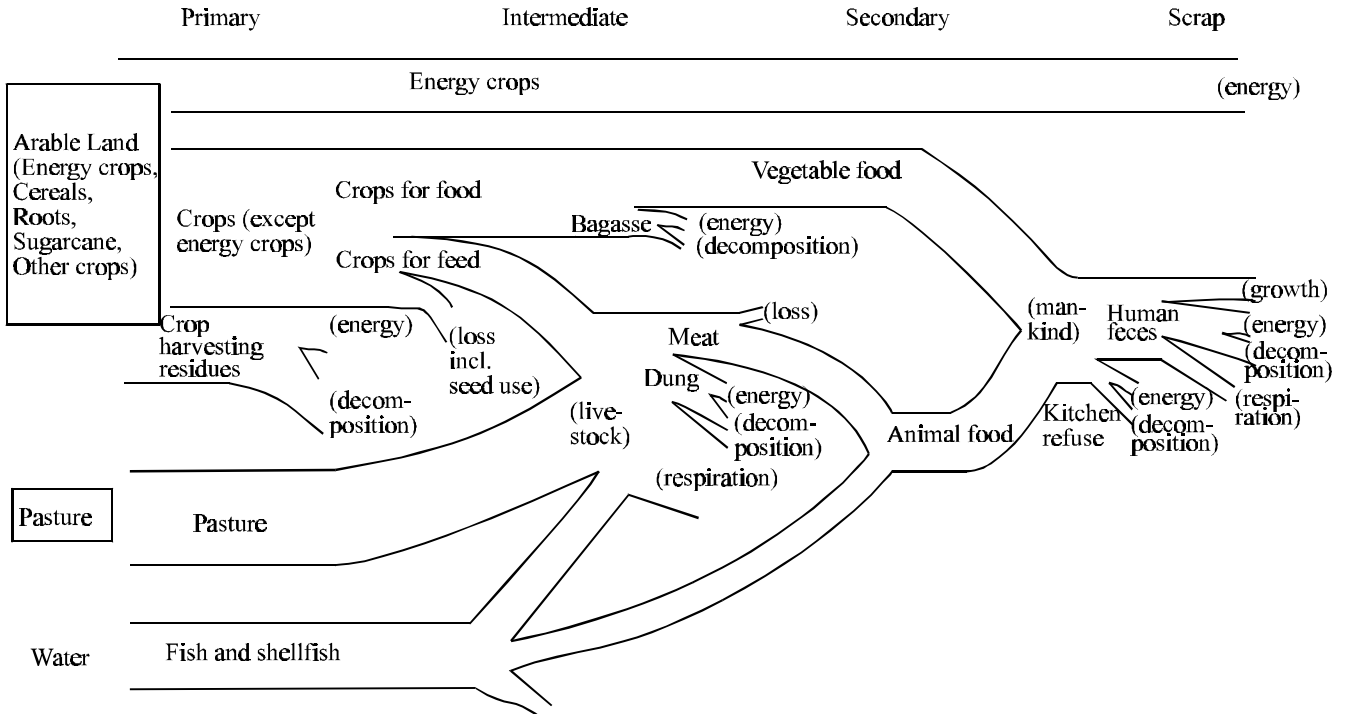


Figure 3 Flow of Food Biomass

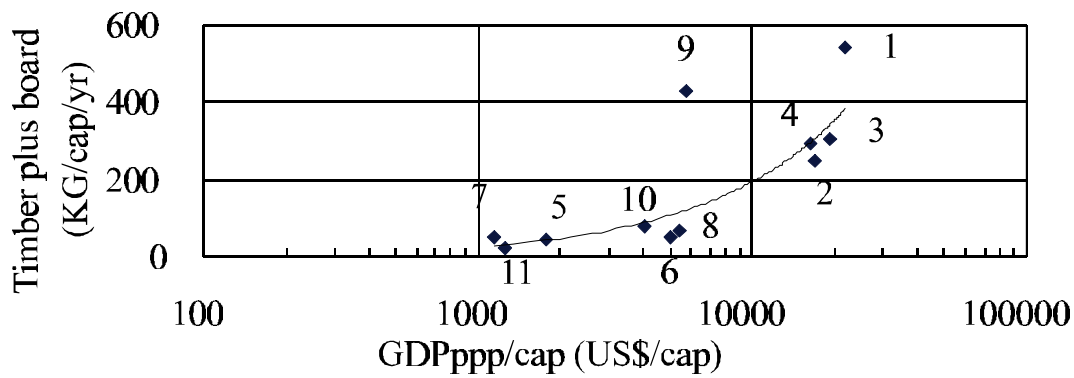


Figure 4 Timber plus Board Consumption and GDPppp (in 1990) [a]

[a] The numerals in the figure correspond to the regions in Table 1.

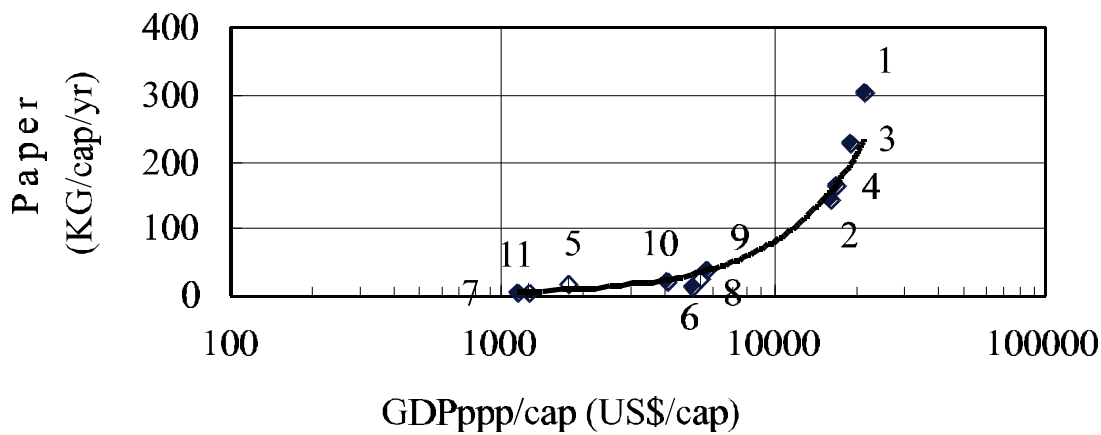


Figure 5 Paper Consumption and GDPppp (in 1990) [a]

[a] The numerals in the figure correspond to the regions in Table 1.

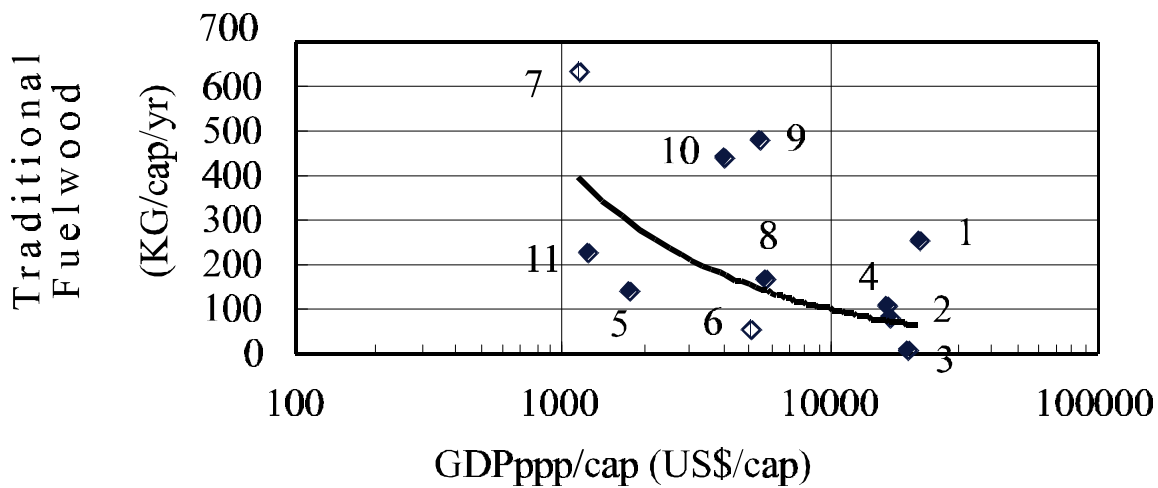


Figure 6 Traditional Fuelwood Consumption and GDPppp (in 1990) [a]

[a] The numerals in the figure correspond to the regions in Table 1.

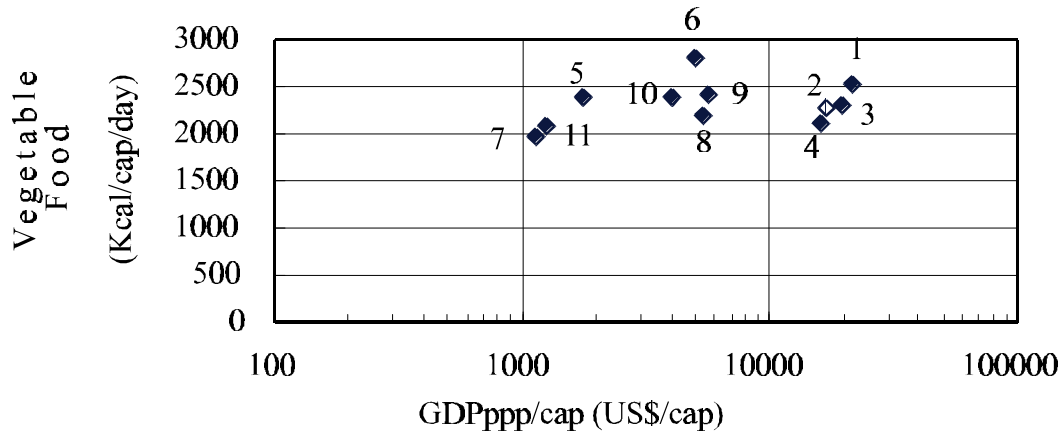


Figure 7 Vegetable Food Consumption and GDPppp (in 1990) [a]
 [a] The numerals in the figure correspond to the regions in Table 1.

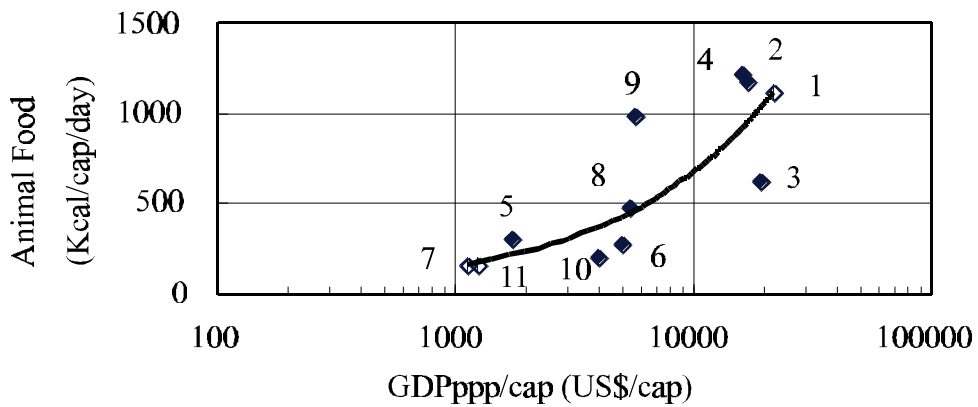


Figure 8 Animal Food Consumption and GDPppp (in 1990) [a]
 [a] The numerals in the figure correspond to the regions in Table 1.

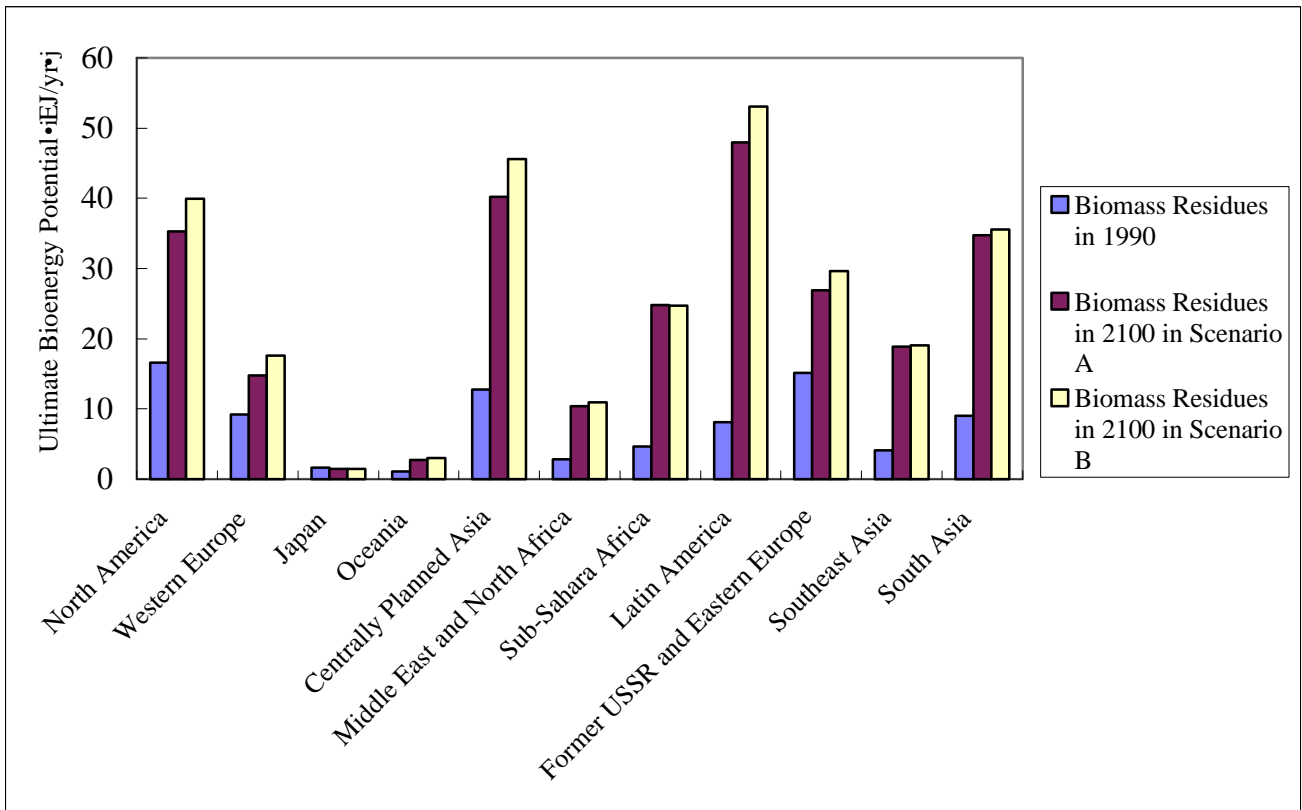


Figure 9 Ultimate Bioenergy Potential (in 2100, in Scenario A and Scenario B)

Figure 10 Ultimate Bioenergy Potential of Biomass Residues (in 2100, in Scenario A)

