

GISELA – GIS-based Evaluation of Land-use and Agriculture Market Analysis and the Effects of Income Distribution

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Abstract

One of the important future issues is how agriculture production can meet the future demand increase due to the population and the income growth. Global warming would give both positive and negative impacts on them. Agriculture is often expected to supply biofuels to meet the growing transportation energy demand and the warming control policy. GISELA – GIS based Evaluation for Land use and Agriculture production model - is developed to evaluate the current and the potential cropland for rice, wheat, maize and soy-beans production under climate changes. We also assess the food and the feed demand based on the historical regional statistics for world into 18 regions. Finally, we assess the future food market integrating the above supply and demand conditions developing a dynamic optimization model, GISELA. Current GISELA findings are as follows: (1) potential cropland in south America will be extensively cultivated, (2) market price of wheat and soy will gradually go up while that of maize is almost stable in medium yield case, and (3) in the low-yield case, all crop prices hike rapidly in the mid of this century.

We then approach the hunger issue focusing on the income distribution. Applying Gamma distribution to the income quintile statistics of World Bank, we estimate how the income distribution pattern shifts along with the economic growth. As a preliminary results, although the population in absolute poverty would decrease, there still remain people who would not access the food market in some regions especially in case of low-yield scenario.

Keywords: Global Warming, GIS, Land use, Food market model

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Introduction

Recently, biofuel is expected to play a major role in both energy security and global warming mitigation issues. In 2007, United States promoted maize-based bio ethanol production to mitigate the high oil price as well as to support the agriculture industry. The international crop prices then went up rapidly.

The existing studies on the food supply security issue have mainly focused on whether the future potential food production can meet the increasing demand under the population and the economic growth in developing regions. Dietary pattern changes according to the income growth should then be taken into account for assessing the demand-supply conditions in the international crop market.

Although the food supply per capita has been improved in average which could support all population in the world, however, there exist eight hundred million people suffering from hunger. It is pointed out that the global warming would cause water resource shortage and extreme climate events which affect the future food production.

The above points suggest that the food supply and demand issues should be discussed comprehensively from multiple points of views.

In this paper, we talk about two topics: firstly, we describe the overview of an optimization model to assess the long term food production potentials based on detailed production conditions using Geographical Information Systems (GIS). The impacts of climate changes are also taken into account. Second, in order to assess the effects of crop market on poor class, we focus on the changes of income distributions applying the Gamma distribution function to the Income Quintile Statistics of World Bank.

1. Background of this Study

The possibility of food production which meets the food demand under the population and the economic growth has been a central policy issue. We can list up a number of debates between the pessimistic and the optimistic views since the historical Malthus argument. While Lester Brown [Brown(1995,2005)] proposed a typical pessimistic view, IFPRI emphasizes a possibility to overcome the hunger in 2020 VISION [IFPRI, 2008] stressing an importance of world corporation and action. Mitchel [Mitchel, 1997] points out the production growth of the former central economy countries and concludes that the world will feed the doubling population in the next two decades. Kawashima [Kawashima, 2008] also concludes that the food supply shortage is unlikely to occur because of the food demand saturation, the assessments of potential cropland including fallow land.

The assessment of the impacts of global warming is still controversial due to the uncertainties in both the spatial distribution of climate change and the possibility of adaptability. The Fourth Assessment Report of Intergovernmental Panel of Climate Change [IPCC, 2007] points out the decrease of yields in the 1-2 Celsius degree atmospheric temperature rise in the low latitude area while 1-3 Celsius degree atmospheric temperature rise in the middle latitude area may both increase and decrease them. Higher temperature rise would mostly decrease the yields.

Besides the above middle-to-long term food potential production issues, recent market price fluctuation is also worried about. Figure 1 and Figure 2 exhibit the international prices of major crops and the trends in the world crop supply and demand [MAFF, 2008], respectively. The world crop production has mostly followed the world demand while the market prices have heavily fluctuated. Needless to say, such vulnerability of the world crop market affects the daily life of poor people seriously.

The above suggests that the projection on the distribution of income and the assessment of future market possibilities are essential as well as the crop supply and demand possibility when we talk about the poverty and the hunger issue.

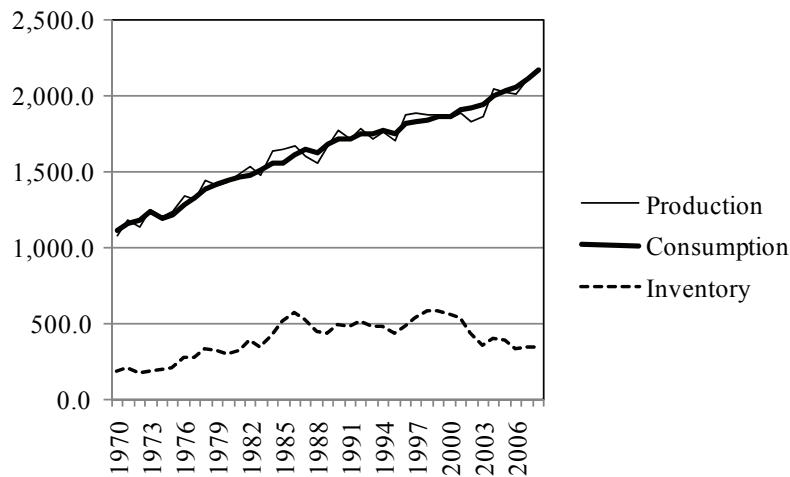


Figure 1 World crop production, demand and inventory in million ton [MAFF, 2008]

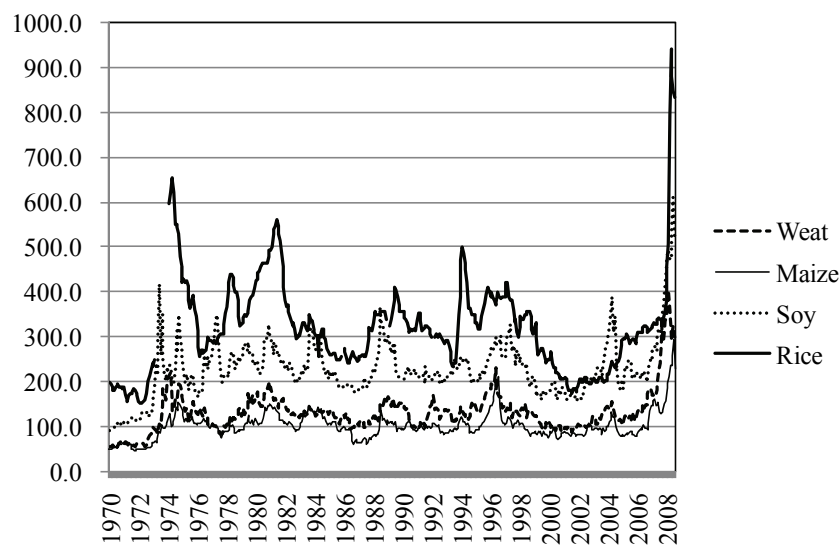


Figure 2 Trends in world crop prices in US dollars per ton [MAFF,2008]

The second and the third issues are related with each other. The investment for the expansion of cropland under the market uncertainty would decrease while the marginal productivity of additional cropland would be decreasing. Such lowered investment will make the agriculture system more vulnerable by the insufficient irrigation, fertilizer, storage system, etc. On the contrary, the augmented management and production capability given by the technological progress will strengthen the market robustness which provides stable agriculture policy. Biofuel will widely be utilized under the stable crop market.

When we discuss the food demand-supply issue, it is needed to assess not only the potential supply capability but also the market conditions, especially the market pressure to raise the price.

In this study, we develop a model to assess the crop production and demand potentials under the market behavior model. This model provides a basis to assess the food distribution and biofuel potentials.

2. Outline of this study

Many of existing studies on potential cropland have focused on the certain regions based on detailed data. The long term assessment on the potential global food production under climate changes are provided by IIASA[IIASA,2003], RITE[Akimoto, 2006] where maximum potential cropland is focused on. IMAGE-2[Strengers, 2001] provides the dynamic changes of crop land under climate changes where the market behavior is not formulated. Global food market has been analyzed by equilibrium models. IFPSIM developed by Ohga [Ohga,1998] is widely used to assess the food market, while the assessments of potential cropland and land use change are not

explicitly formulated.

We develop a long term food supply and demand model considering the long term climate change. In this paper, the short term price fluctuations affected by financial market and other speculative dealings are not described. The market vulnerability will be suggested by the equilibrium price changes and the required development of potential cropland.

In this paper, we consider four major crops, i.e., maize, rice, soy and wheat. We apply Geographical Information System (GIS) to analyze the relationship between climate changes and the potential production by crop. Potential cropland by crop is estimated based on the detailed land use data given by USGS[USGS,2006], soil map given by FAO[FAO,2004], growing conditions on temperature and water availability. Reflecting the uncertainties of climate models, we compare the six Atmosphere-Ocean General Circulation Model (AOGCM) studies and estimate the pessimistic yield case and optimistic yield case besides the base case. The potential cropland area generated by the above gives the upper limit of the cultivation. We then develop a dynamic optimization model to see the market behavior. Under the given world population and economic growth scenario, the model generates equilibrium market prices and demand by crop by maximizing the summation of discounted consumer's surplus. Feed demand is given exogenously.

The outline of this study is shown in Figure 3. The boxes with bold line and italic characters are the exogenous data and the boxes connected with the market equilibrium model by both-side arrow represent endogenous variables. Other boxes are the estimated parameters. Land use data and climate change simulations provide potential cropland by crop and region. The demand functions of crops by region are given based on the Business-as-Usual (BAU) GDP and population scenario and statistically estimated parameters. We employed the IPCC-SRES-B2 scenario [IPCC,2000] for the reference GDP and population scenario. The model is named GISELA – GIS-based Evaluation of Land use and Agriculture market.

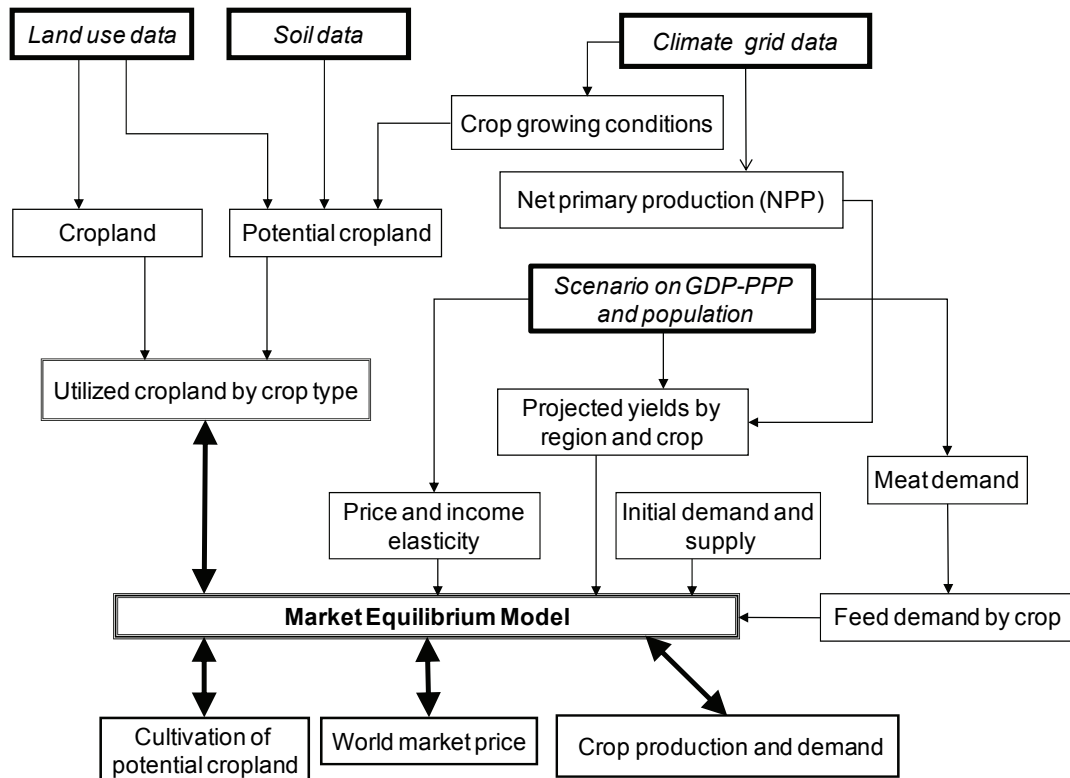


Figure 3 Outline of GISELA model

We then focus on the modeling of the income distribution to see the food and poverty issue more quantitatively. Gamma distribution is employed to represent the income distribution based on the income quintile data.

3. Structure of GISELA model

3.1 Definition of region group

The market equilibrium model block of GISELA aggregates the world into eighteen regions shown in Table 1 while it deals with USGS 1km grid data to assess the potential cropland. We assume the reference population and GDP scenario according to the IPCC-SRES-B2 scenario.

Table 1 Eighteen regions of GISELA market model

Code	Region	Code	Region
USA	USA	CAF	Central Africa
CAN	Canada	SAF	Southern Africa
MCM	Central America	JPN	Japan
BRA	Brazil	CHN	China, Hong-Kong, Taipei
SAM	South America	SEA	South-East Asia
WEP	Western Europa	IND	India
EEP	Eastern Europa	TME	Middle-East
FSU	Former USSR	OCE	Australia, NewZealand
NAF	Northern Africa	XAP	Rest of the world

3.2 Estimation procedure of potential cropland

Potential crop production is a product of the potential cropland and the yield. The estimation procedure of the former is as follows: the current land use data is provided by USGS GLCC-Version2. We extracted the number of grids classified as maize, rice, soy and wheat production area. We calculate the ratio of number of grids to the FAO cropland statistics in 2000 as conversion coefficient. Next, we extract the pasture/grassland area, the tropical forest area and other forest area. According to Tivy [Tivy, 1990] and FAO Soil Map [FAO, 2004], we select the possible soil grid for cropland conversion. We then extract the potential grid based on the climate conditions. We assume the cumulative temperature and the cumulative precipitation shown in Table 2 following to Seino [Seino, 2006] as growing condition.

Table 2 Climate conditions for crop growing

crop	Cumulative temperature in Celsius degree	Cumulative precipitation in mm
Maize	1500-3000	500-700
Rice	2500-3800	600-
Soy	2000-3200	450-750
Wheat	1300-2500	100-1500

We employ the long term climate scenario according to the six AOGCM simulation results shown in Table 3 provided by IPCC data distribution center [IPCC, 2008]. Since the simulation results for SRES-B2 are not provided, we employ the case of SRES-A1B which represents similar GHG emission in 2100. The atmospheric temperature rise in 2090-2099 from the average value between 1980-1999 of SRES-B2 is 1.4-3.8 Celsius degree while that of SRES-A1B is 1.7-4.4 Celsius degree [IPCC, 2007b]. Therefore we assume slightly higher climate changes.

Table 3 Six AOGCM simulations [IPCC, 2008]

Name	Organization	Spatial resolution (degree)
CNRM-CM3	Centre National de Recheres Meteorologiques	2.8
MIROC3.2(HI)	National Institute for Environmental Studies	1.1
MIROC3.3(ME)	National Institute for Environmental Studies	2.8
MPI-ECHAM5	Max-Plank-Institut for Meteorology	1.9
MRI-CGCM2.3.2	Metorological Research Institute	2.8
NCAR-CCSM3.0	National Centre for Atmospheric Research	1.4

We employ the MIROC3.2(HI) simulation results as the reference case because of the highest spatial resolution of this model. Based on the above land use, soil and the climate data, we can estimate the potential cropland by crop and region. Table 4 shows the potential cropland in 2050 according to the MIROC3.2(HI) results where the cropland in 2000 is also shown. It should be noted that the summation of potential cropland by crop is not the potential cropland since there are some grids which are suitable for cultivation for plural crops. IIASA [IIASA,2003] estimates the potential cropland to be 2,718 million ha and Crosson et.al. [Crosson, 1992] report 1,392 million ha as potential cropland in developing region while Table 4 indicates that the total potential cropland is 1,591 million ha. Therefore our estimation is compatible with existing studies. Although the potential cropland seems abundant, the conversion to cropland will be constrained since most of them are in forest area and we do not consider the condition of slope ground.

3.3 Estimation of yields

In this study, we define the yields as the product of photo-synthesis efficiency and the progress of agricultural technology since other factors such as the CO₂ fertilization effect [Allen,L.H. et.al. 2006] and the high temperature damage [Abrol,P. et.al., 1996] are controversial. The former reports 10% increase of yields in doubled CO₂ concentration while the latter indicates 10% decrease of yields by 1.0 Celsius degree temperature rise. However, it is also pointed out that these numbers depend on the crop type, agriculture method, etc. [IPCC, 2007c]

We employ the Chikugo model [Seino et.al., 1992] to assess the Net Primary Productivity (NPP) as the index of the photosynthesis efficiency based on the climate data shown in Table 2. We calculate the NPP values for the six AOGCM results in 2050 and 2099 shown in Table 3 and then extract the lowest and the highest NPP values which represent the range of uncertainties of yield by crop. These two cases, i.e., low-yield case and high-yield case, and the mid-yield case by MIROC3.2(HI) as reference results are compared. We estimate the NPP changes interpolating the 2050 and 2099 values.

It is often pointed out the technological progress in agriculture is a function of per capita GDP [Kawashima, 2008]. We estimate the relationship between historical per capita GDP and yields aggregating the regions into some groups. The estimated parameters are shown in Table 5.

Table 4 Estimation of potential cropland and current cropland in 2000 in million ha

Maize					
	Forest	Pasture	Tropical forest	total	2000
Africa	71.5	27.2	5.2	103.9	25.6
Oceania	22.6	0.3	4.7	27.7	0.1
North America	4.9	0.4	0.0	5.3	39.6
South America	16.6	3.4	39.4	59.4	17.5
Eurasia	21.1	0.9	4.9	26.9	55.3
World	136.6	32.3	54.2	223.2	138.1

Rice

	Forest	Pasture	Tropical forest	total	2000
Africa	48.1	25.4	0.3	73.8	7.6
Oceania	24.8	0.3	4.5	29.6	0.1
North America	6.5	0.2	0.0	6.7	2.0
South America	22.5	3.3	28.0	53.8	5.6
Eurasia	11.8	1.3	1.7	14.8	138.5
World	113.7	30.5	34.5	178.7	153.8

Soy

	Forest	Pasture	Tropical forest	total	2000
Africa	189.7	34.5	35.9	260.0	1.0
Oceania	14.9	1.1	2.7	18.7	0.1
North America	14.2	1.3	0.0	15.5	30.4
South America	32.2	2.3	250.2	284.7	24.1
Eurasia	14.7	0.7	2.9	18.3	18.8
World	265.6	39.9	291.6	597.1	74.4

Wheat

	Forest	Pasture	Tropical forest	total	2000
Africa	187.5	94.1	13.6	295.2	8.1
Oceania	38.0	2.6	2.0	42.6	12.2
North America	120.8	8.6	0.0	129.4	33.1
South America	47.3	11.5	71.0	129.7	8.5
Eurasia	233.2	39.1	1.1	273.4	150.3
World	626.8	155.9	87.7	870.4	212.1

Total potential cropland

	Forest	Pasture	Tropical forest	total
Africa	393.9	136.2	49.5	579.6
Oceania	82.0	3.9	9.9	95.9
North America	132.2	9.3	0.0	141.5
South America	88.2	13.5	350.8	452.5
Eurasia	271.0	40.8	9.6	321.3
World	967.2	203.8	419.8	1,590.8

Table 5 Region grouping and the estimated parameters of yields

$$\text{Yield} = A \ln(\text{GDP-PPP/Cap}) + B$$

Crop	Region group	A	B	R ²
Maize	USA, CAN, SAM, WEP, FSU, NAF, OCE	2.0 (24.8)	-12.8 (17.8)	0.76
	BRA, CAF, SAF, JPN, IND, SEA	0.37 (18.4)	-1.20 (7.3)	0.62
	EEP, CHN	0.35 (3.4)	1.31 (1.7)	0.19
Rice	SAM, OCE	2.76 (17.6)	-18.4 (13.0)	0.81
	USA, EEP, WEP, CAF, JPN, IND, SEA	1.25 (43.8)	-6.48 (27.2)	0.88
	NAF, CHN	1.46 (11.4)	-11.8 (4.9)	0.71
	SAF	--	2.31	--
Soy	USA, CAN, BRA, SAM, CHN, OCE	0.296 (14.9)	-0.62 (3.6)	0.52
	WEP	1.43 (16.8)	-1.09 (14.9)	0.82
	EEP, FSU, CAF, SAF, JPN, IND, SEA	0.27 (15.4)	-1.04 (7.49)	0.55
	NAF	0.86 (3.12)	-6.61 (1.09)	0.6
Wheat	SAM, WEP	2.17 (33.5)	-1.60 (27.7)	0.97
	CAF, IND	0.74 (16.6)	-3.32 (10.9)	0.78
	EEP, CHN	0.64 (11.6)	-1.51 (3.54)	0.64
	USA, CAN, BRA, FSU, SAM, SEA, OCE	0.55 (15.4)	-3.24 (9.31)	0.61
	NAF, JPN	0.94 (27.2)	-5.90 (19.8)	0.91

(*) Values in the parenthesis represent t-statistics.

Based on the growth rates on NPP and yields, we develop the scenario on yields. In Figure 4, we compare our results in 2030 with the production estimates given by FAO[FAO, 2003] in 2030 where our estimates are mostly compatible with those of FAO.

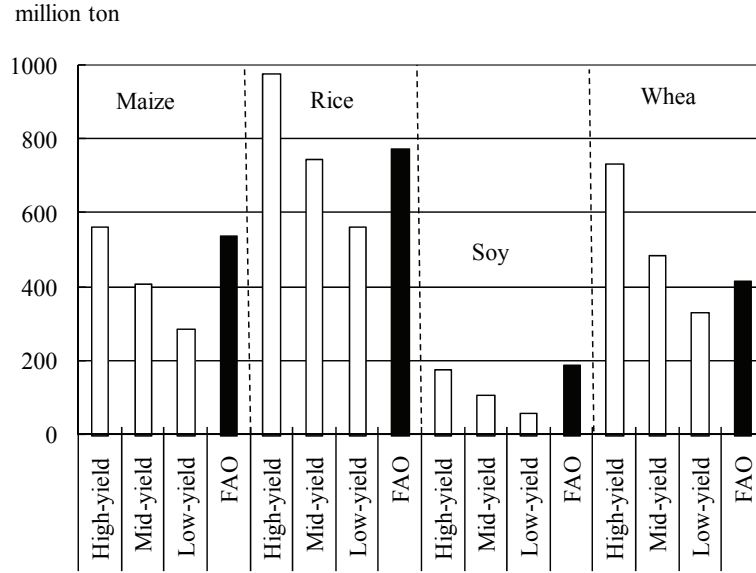


Figure 4 Comparison of potential crop production

Other adaptation options will be applicable under the climate change. However, due to the lack of information, we have not included such possibilities at the moment.

3.4 Crop demand functions

In our model, demand for crop consists of food demand and the feed demand which is given exogenously extrapolating the historical trends. We assume the food demand functions as follows: hereafter, suffix t , h and i represent period, region and crop type, respectively. The demand for crop i , $D_h(t, i)$ is represented by

$$D_h(t, i) = A_{h,i} \cdot L_h(t) \cdot (Y_h(t)/L_h(t))^{\theta_{h,i}} MDP_h(t, i)^{-\beta_{h,i}} \quad (1)$$

where MDP , Y and L denote domestic market price of crop i , GDP and population respectively. Similar to the case of yield in the previous section, we aggregate the regions into some groups and estimate the parameters using regression analysis. The results are summarized in Table 6 where one can see that the statistically significant parameters are limited. However, since we employ the consumer's surplus as objective function and zero price elasticity seems to be unrealistic, we impose the lower bound of price elasticity to be 0.15 uniformly.

Table 6 Region grouping and the estimated parameters of crop demand

$$D_h(t, i) = A_{h,i} \cdot L_h(t) \cdot (Y_h(t) / L_h(t))^{\theta_{h,i}} MDP_h(t, i)^{-\beta_{h,i}}$$

Crop	Region group	θ	β	R^2
Maize	(all regions)	--	--	--
	USA, CAN, WEP, EEP, FSU, OCE	-0.55 (4.16)	0.34 (2.22)	0.19
	MCM, SAM, SAF, TME	0.68 (2.92)	--	0.15
Rice	BRA, NAF, CAF	0.50 (12.0)	--	0.81
	JPN	--	--	--
	CHN, IND, XAP	--	--	--
	SEA	0.26 (2.89)	--	0.39
	USA, MCM, XAP	0.83 (6.15)	--	0.59
Soy	CAN, WEP, JPN, CHN, IND, SEA	0.62 (13.4)	0.24 (3.03)	0.7
	EEP, FSU, NAF, CAF, SAF, TME, OCE	0.63 (8.21)	0.81 (6.51)	0.38
	SAM	--	--	--
	BRA	--	--	--
	CAN WEP OCE SAM	0.56 (6.92)	0.59 (2.93)	0.38
Wheat	USA, BRA, MCM, SAF, CAF, SEA	0.50 (10.3)	0.11 (0.68)	0.56
	EEP, FSU, NAF, TME	0.76 (3.94)	--	0.19
	CHN, IND, JPN, XAP	-0.11 (2.23)	--	--

(*) Values in the parenthesis represent t-statistics.

4. Formulation of market equilibrium model

GISELA market equilibrium model maximizes the discount sum of the consumer's and the producer's surplus under the supply-demand balance and market price conditions as well as the constraints on potential cropland developments. GISELA market model distinguishes the market price as five categories by crop and region according to FAO statistics [FAO, 2006], i.e., A:domestic production price(DP), B:export price (P_{ex}), C:import price (P_{im}), D:domestic market price (MDP) and E:international market price (DIP). DIP is the weighted mean value of export price of each region and MDP is the weighted mean value of the supply of domestic products and import products. Tax and subsidy are imposed between DP and P_{ex} and between DIP and P_{im} . The share of each region in the international market is formulated as a decreasing function of the ratio of P_{ex} to DIP. The relationships among the above five prices are shown in Figure 5.

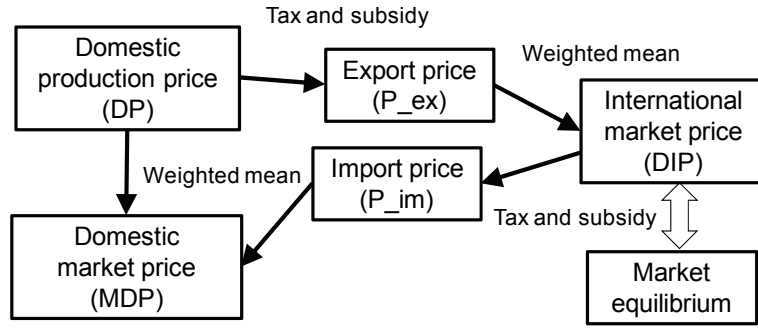


Figure 5 Relationships among price categories

The cropland for crop i production at t in region h , $C_h(t,i)$, is represented by the newly cultivated potential cropland of category k (k =forest, tropical forest and pasture), $N_h(t,k,i)$, and rotated cropland from crop j to crop i , $R_h(t,j,i)$,

$$C_h(t,i) = C_h(t-1,i) + \sum_k N_h(t,k,i) + \sum_j R_h(t,j,i) - R_h(t,i,j) \quad \sum_i N_h(t,k,i) \leq N^*(t,k) \quad (2)$$

where $N^*(t,k)$ represents the total potential cropland by region and period as is shown in the fifth block of Table 4. $C_h(t,i)$ and yield $Yld_h(t,i)$, described in section 3.3, give the supply balance equation among domestic production, trade $Trd_h(t,i)$ and domestic supply $S_h(t,i)$ distributed to the food and the feed demand, i.e. $D_h(t,i)$ and $NF_h(t,i)$, respectively.

$$S_h(t,i) = C_h(t,i) \times Yld_h(t,i) + Trd_h(t,i) \quad (3)$$

$$S_h(t,i) = D_h(t,i) + NF_h(t,i) \quad (4)$$

$$\sum_h Trd_h(t,i) = 0 \quad (5)$$

The cost of the development of new cropland is one of the most uncertain factor in the land use investigations. In this study, we assume a simple supply function. Let $C_h(t,i)$ and $\Psi_h(t, C_h(t,i), i)$ denote the cropland area and the marginal production price of crop i in region h at period t , respectively. We assume that the $\Psi_h(t, C_h(t,i), i)$ increases as the new cropland is developed. That is,

$$\Psi_h(t, C_h(t,i), i) = \Psi_h(0, C_h(0,i), i) + f_{h,i}(C_h(t,i) - C_h(0,i)) \quad (6)$$

where $f(x)$ represent the additional marginal cost according to the conversion of land use. We simply assume that $f(x)$ increases towards 150% of the initial cost as $C_h(t,i)$ approaches the upper limit. This assumption is similar to the assumption with supply price elasticity model employed in IFPSIM. The formulation and estimation problem in the land use change are the remaining issue.

Based on the demand and the supply functions one can calculate the equilibrium by maximizing the discount sum of the producer and the consumer surplus. Let $\Phi_h(t, D_h(t,i), i)$ denote the inverse function of equation (1).

$$MDP_h(t,i) = \Phi_h(t, D_h(t,i), i) \quad (7)$$

Then the equilibrium is obtained by

$$\max. \quad \sum_t (1-r)^t \sum_h \sum_i \left\{ \int_0^{D_h(t,i)} \Phi_h(t, \omega, i) d\omega - \int_0^{C_h(t,i)} \Psi_h(t, \mu, i) d\mu \right\} \quad (8)$$

where exogenous feed demand is excluded.

When the supply fails to meet the demand, a price premium $P^*(t,i)$ is imposed on the international market price to

give the market equilibrium as

$$DIP^*(t,i) = DIP(t,i) + P^*(t,i) \quad (9)$$

5. Simulation results

5.1 Crop production and price changes

In this section, we show some simulation results on GISELA model. Figure 6 and Figure 7 show the world production profile of maize and rice in mid-yield case. Production increases accordingly to the demand change. International market prices in the mid-yield case and the low-yield case are exhibited in Figure 8 and Figure 9. In mid-yield case, the prices rise gradually. On the other hand, the market prices rise rapidly in the mid of this century. The premium price in Equation (9) is introduced in this case. The world food market will be vulnerable and affect the poor people. The distribution issue will appear seriously.

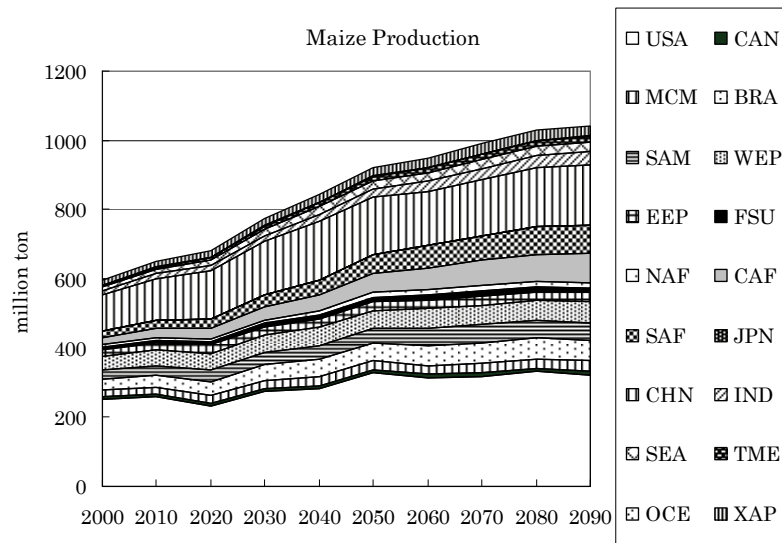


Figure 6 Maize production profile in mid-yield case

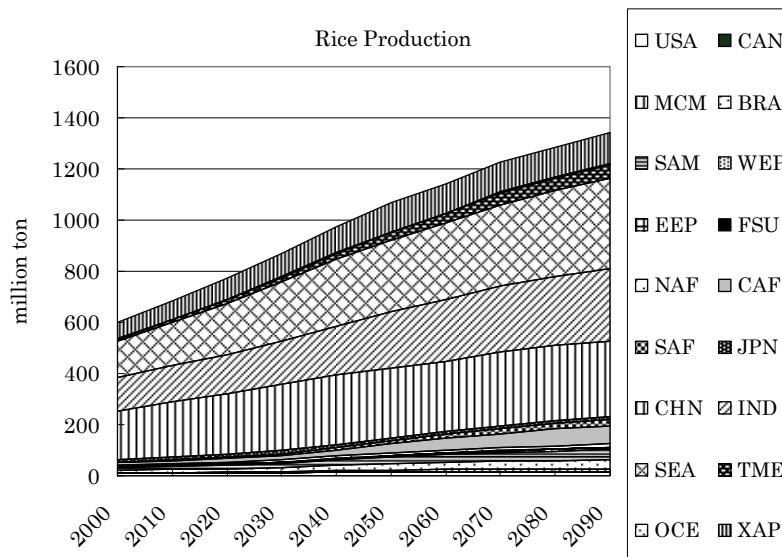


Figure 7 Rice production profile in mid-yield case

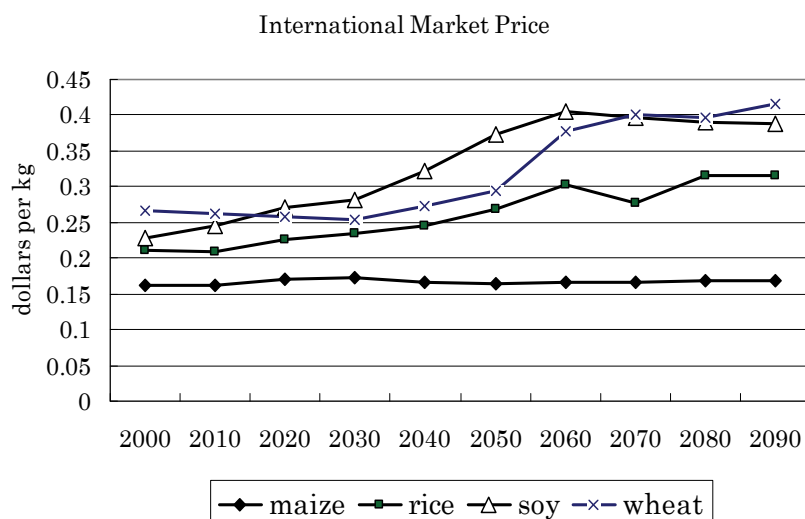


Figure 8 International market prices in mid-yield case in US dollars per kg

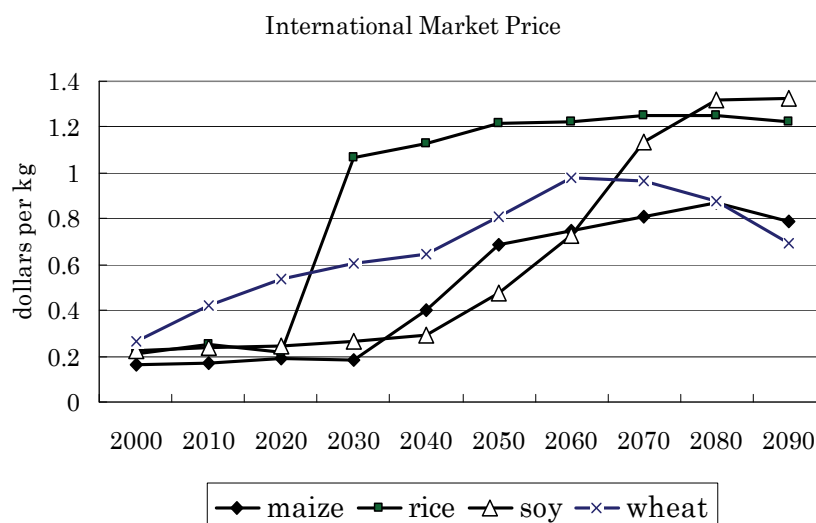


Figure 9 International market prices in low-yield case in US dollars per kg

5.2 Conversion of potential cropland

Table 7 compares the ratio of converted area to the potential cropland by yield case. In the low-yield case, potential cropland is developed extensively as crop prices rise. It should be noted that potential cropland is converted rapidly in South America. In Middle Africa and other region (XAP), the demand for the cropland conversion changes among cases due to the uncertainties in climate change. It is suggested that the food supply policy should be set up carefully especially in these developing regions. China shows high development rates in all cases. It is because that the potential cropland in China is not so large.

Table 7 Simulation results on the ratio of converted area to the potential cropland

		USA	CAN	MCM	BRA	SAM	WEP
Mid-yield case	2050	0.0%	0.0%	0.0%	30.7%	33.7%	0.0%
	2090	0.0%	0.0%	3.5%	55.3%	56.3%	0.0%
		EEP	FSU	NAF	CAF	SAF	JPN
	2050	0.0%	0.0%	0.0%	0.0%	2.7%	0.0%
	2090	35.5%	0.0%	0.0%	26.1%	13.5%	0.0%
		CHN	IND	SEA	TME	OCE	XAP
	2050	11.6%	0.0%	0.4%	0.0%	0.0%	0.0%
	2090	81.0%	67.8%	53.1%	0.0%	2.3%	17.1%
		USA	CAN	MCM	BRA	SAM	WEP
	2050	0.0%	0.0%	0.0%	18.5%	0.0%	0.0%
Low-yield case	2090	0.0%	0.0%	14.0%	55.3%	56.3%	0.0%
		EEP	FSU	NAF	CAF	SAF	JPN
	2050	0.0%	0.0%	0.0%	2.0%	2.7%	0.0%
	2090	72.1%	0.0%	0.0%	68.3%	62.3%	0.0%
		CHN	IND	SEA	TME	OCE	XAP
	2050	12.7%	0.0%	1.9%	0.0%	0.0%	0.0%
	2090	79.1%	67.8%	74.1%	0.0%	3.7%	75.0%
		USA	CAN	MCM	BRA	SAM	WEP
	2050	0.0%	0.0%	0.0%	38.9%	56.3%	0.0%
	2090	0.0%	0.0%	0.0%	55.3%	56.3%	0.0%
High-yield case		EEP	FSU	NAF	CAF	SAF	JPN
	2050	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%
	2090	0.0%	0.0%	0.0%	2.5%	1.9%	0.0%
		CHN	IND	SEA	TME	OCE	XAP
	2050	11.6%	0.0%	0.0%	0.0%	0.0%	0.0%
	2090	81.0%	0.0%	8.4%	0.0%	2.1%	8.1%

6. Modeling of the income distribution

6.1 The modeling of income distribution

As is well known, the global warming would cause serious damages especially on the poor people who would have less adaptive options than middle to high income ones. The high crop price will also affect them even if the total crop supply could meet the total food demand. The assessments of income distribution are therefore needed to see how the future global warming influence the society through the food market changes.

Gini coefficient is widely used to represent the level of economic equity. However, since it fails to deal with the income level explicitly, it is not suitable to assess the number of people who cannot access the food market.

On the other hand, World Bank[World Bank, 2005] provides the income distribution in absolute value as Income Quintile for around 200 countries. We apply the Gamma distribution to this quintile data and then find the relationship between the average income and the parameter of Gamma distribution. Extrapolating the parameters based on the SRES scenario, we can estimate the future income distribution by region. Comparing the possible future crop prices given by GISELA with the income distribution and population projection, we can assess the fraction of people who are excluded from the food market.

6.2 Gamma distribution

To begin with, we have to choose the distribution type. Since the data number is limited, distribution function with one or two parameters is needed. Second, income distribution may not be symmetric. We employ the Gamma distribution which meets these two requirements as follows:

$$f(x, \alpha, \beta) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \quad (10)$$

where the products of two parameters, $\alpha\beta$, represents the mean value and $\alpha\beta^2$ does the variance. As is observed in the Figure 10, this function with different parameter draws completely different shape with same mean value.

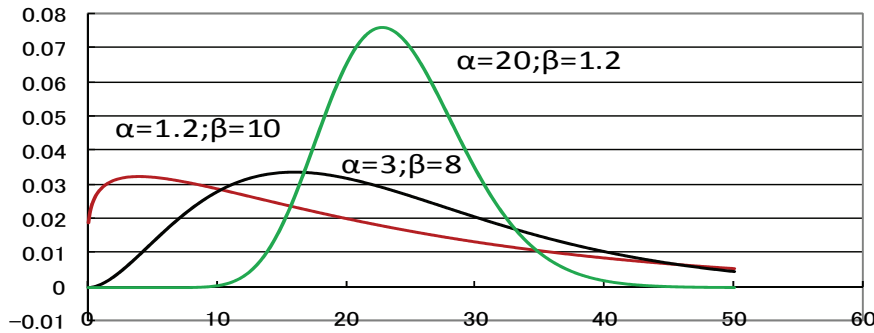


Figure 10 Example of Gamma distribution function shapes with same mean values

Based on the income quintile statistics by World Bank, we can obtain the parameters by country. Tables 8 represents the estimated parameters as well as the mean income, R2 and Gini coefficients for selected countries.

Table 8 Estimated parameters of Gamma distribution, mean income, R2 and Gini coefficients

Country	α	β	Ave.Income	R2	Gini coeff.	Year	Country	α	β	Ave.Income	R2	Gini coeff.	Year
Albania	3.74	3.84	14.36	0.976	28.2	2002	India	2.22	2.05	4.55	0.919	32.5	1999-00
Denmark	4.14	78.02	323.00	0.956	24.7	1997	Spain	2.69	49.91	134.09	0.969	32.5	1990
Japan	4.57	75.92	346.95	0.941	24.9	1993	Tajikistan	2.61	0.93	2.43	0.962	32.6	2003
Belgium	3.63	75.17	272.80	0.978	25.0	1996	Canada	2.75	85.99	236.21	0.911	32.6	2000
Sweden	3.94	70.32	276.93	0.979	25.0	2000	France	2.68	97.80	262.58	0.926	32.7	1995
Czech Republic	4.29	14.06	60.28	0.957	25.4	1996	Mongolia	2.73	1.86	5.08	0.935	32.8	2002
Slovak Republic	4.59	8.67	39.77	0.978	25.8	1996	Pakistan	2.22	2.47	5.48	0.906	33.0	1998-99
Norway	3.65	102.58	374.91	0.939	25.8	2000	Belgium	2.28	99.60	227.54	0.980	33.0	2000
Bosnia and Herzegovina	4.38	2.85	12.47	0.976	26.2	2001	Canada	2.66	76.98	204.72	0.978	33.1	1998
Uzbekistan	4.08	1.37	5.57	0.972	26.8	2000	Switzerland	2.65	132.61	350.78	0.974	33.1	1992
Hungary	4.03	16.27	65.48	0.965	26.9	2002	Sri Lanka	2.26	3.95	8.93	0.925	33.2	1999-00
Finland	3.94	59.72	235.45	0.945	26.9	2000	Bangladesh	2.23	1.69	3.76	0.974	33.2	2005
Belarus	3.85	8.00	30.84	0.918	28.0	2005	Burundi	1.39	1.00	1.39	0.934	33.3	1998
Ukraine	3.68	4.98	18.36	0.913	28.2	2005	Yemen, Rep.	2.50	1.48	3.69	0.966	33.4	1998
Germany	3.78	61.14	230.86	0.956	28.3	2000	Latvia	2.47	11.29	27.86	0.962	33.6	1998
Slovenia	4.30	25.64	110.27	0.979	28.4	1998-99	Tajikistan	2.38	1.35	3.21	0.966	33.6	2004
Rwanda	3.23	0.95	3.08	0.946	28.9	1983-85	Switzerland	2.49	138.01	344.08	0.930	33.7	2000
Croatia	2.94	15.01	44.19	0.967	29.0	2001	Armenia	2.07	4.45	9.23	0.963	33.8	2003
Ukraine	3.47	1.85	6.40	0.967	29.0	1999	Poland	2.35	22.00	51.69	0.957	34.1	2002
Croatia	3.47	24.39	84.58	0.954	29.0	2005	Indonesia	2.10	4.29	9.00	0.925	34.3	2002
Austria	3.46	69.07	238.97	0.902	29.1	2000	Greece	2.38	48.52	115.69	0.963	34.3	2000
Bulgaria	3.29	7.75	25.48	0.939	29.2	2003	Ireland	2.28	111.06	253.15	0.953	34.3	2000
Austria	3.22	80.22	258.08	0.977	30.0	1997	Egypt, Arab Rep.	1.99	7.55	14.99	0.902	34.4	1999-00
Ethiopia	2.90	0.39	1.13	0.984	30.0	1999-00	Egypt, Arab Rep.	2.36	5.71	13.48	0.944	34.4	2004-5
Hungary	3.12	32.40	101.04	0.942	30.1	2004	Lao PDR	2.08	1.63	3.39	0.961	34.6	2002
Mongolia	1.09	4.22	4.59	0.906	30.3	1998	Spain	2.32	62.30	144.34	0.965	34.7	2000
Romania	2.53	8.27	20.90	0.955	30.3	2002	Kyrgyz Republic	2.14	1.48	3.18	0.945	34.8	2002
Kyrgyz Republic	3.04	1.24	3.77	0.945	30.3	2003	Poland	2.23	35.72	79.57	0.951	34.9	2005
Belarus	3.08	3.36	10.36	0.967	30.4	2000	Australia	2.41	82.86	199.39	0.000	35.2	1994
Netherlands	3.20	81.28	259.85	0.946	30.9	1999	Algeria	2.23	6.67	14.88	0.950	35.3	1995
Slovenia	2.92	56.98	166.39	0.949	30.9	2004	Greece	2.00	62.84	125.40	0.948	35.4	1998
Russian Federation	3.06	7.73	23.66	0.935	31.0	2002	Israel	2.06	92.25	189.63	0.966	35.5	1997
Albania	2.94	7.92	23.29	0.968	31.1	2004	Bosnia and Herzegovina	2.12	12.94	27.49	0.943	35.8	2005
Pakistan	2.60	3.10	8.07	0.953	31.2	2005	Latvia	2.13	27.85	59.38	0.929	35.8	2004
Romania	2.76	16.56	45.73	0.957	31.5	2005	Lithuania	2.13	30.74	65.43	0.961	35.8	2004
Bangladesh	2.50	1.30	3.26	0.928	31.8	2000	Ireland	2.12	95.90	203.60	0.960	35.9	1996
Bulgaria	2.97	5.76	17.11	0.986	31.9	2001	Estonia	2.09	42.30	88.28	0.963	36.0	2004
Lithuania	2.81	11.63	32.63	0.967	31.9	2000	United Kingdom	1.93	130.58	251.59	0.950	36.0	1999
Kazakhstan	2.81	7.31	20.55	0.967	32.3	2003	Italy	2.26	84.22	190.40	0.906	36.0	2000

Country	α	β	Ave.Income	R2	Gini coeff	Year	Country	α	β	Ave.Income	R2	Gini coeff	Year
New Zealand	2.01	88.96	179.16	0.941	36.2	1997	Thailand	1.35	15.27	20.57	0.956	42.0	2002
Jordan	1.86	8.59	15.96	0.924	36.4	1997	Kenya	1.31	3.45	4.51	0.950	42.5	1997
Azerbaijan	1.87	3.72	6.96	0.969	36.5	2001	Singapore	1.34	160.68	215.89	0.963	42.5	1998
Nepal	1.84	1.25	2.30	0.930	36.7	1995-96	Iran, Islamic Rep.	1.27	12.69	16.14	0.953	43.0	1998
Uzbekistan	1.86	2.12	3.93	0.956	36.8	2003	Uganda	1.23	2.04	2.51	0.921	43.0	1999
India	1.71	4.17	7.13	0.961	36.8	2004-05	Nicaragua	1.30	6.13	7.96	0.990	43.1	2001
Georgia	2.02	3.41	6.91	0.967	36.9	2001	Thailand	1.28	15.75	20.23	0.943	43.2	2000
Lao PDR	1.76	2.02	3.56	0.916	37.0	1997	Hong Kong, China	1.19	211.19	252.14	0.971	43.4	1996
Vietnam	1.79	2.40	4.31	0.937	37.0	2002	Turkey	1.26	26.71	33.69	0.935	43.6	2003
Vietnam	1.89	2.89	5.45	0.967	37.0	2004	Ecuador	0.77	25.15	19.41	0.937	43.7	1998
Estonia	1.95	21.07	41.12	0.960	37.2	2000	Nigeria	1.32	3.81	5.02	0.893	43.7	2003
Yemen, Rep.	1.70	4.68	7.97	0.954	37.7	2005	Philippines	1.23	7.99	9.81	0.938	44.5	2003
Armenia	1.80	3.37	6.07	0.947	37.9	1998	Uruguay e	1.27	47.66	60.53	0.960	44.6	2000
Jamaica	1.70	17.99	30.50	0.948	37.9	2000	Cameroon	1.16	5.09	5.93	0.922	44.6	2001
Iran, Islamic Rep.	1.78	15.51	27.66	0.922	38.4	2005	Côte d'Ivoire	1.23	5.27	6.50	0.933	44.6	2002
Portugal	1.72	64.74	111.06	0.942	38.5	1997	Bolivia	1.35	7.52	10.17	0.977	44.7	1999
Guinea	1.67	2.51	4.18	0.947	38.6	2003	China	1.28	8.15	10.47	0.966	44.7	2001
Jordan	1.66	11.79	19.58	0.938	38.8	2002-03	Uruguay e	1.24	27.24	33.69	0.973	44.9	2003
Mauritania	1.75	2.40	4.19	0.951	39.0	2000	Jamaica	1.12	29.52	33.12	0.972	45.5	2004
Malawi	1.56	1.39	2.16	0.963	39.0	2004-05	Uganda	1.03	2.23	2.29	0.942	45.7	2002
Israel	1.81	105.68	191.43	0.949	39.2	2001	Philippines	1.09	9.17	9.97	0.939	46.1	2000
Indonesia	1.50	8.41	12.65	0.902	39.4	2005	Mexico	0.90	73.81	66.10	0.963	46.1	2004
Burkina Faso	1.51	2.16	3.26	0.957	39.5	2003	Costa Rica	1.15	35.26	40.59	0.961	46.5	2000
Morocco	1.61	8.58	13.79	0.940	39.5	1998-99	Rwanda	0.99	2.16	2.14	0.952	46.8	2000
Mozambique	1.56	1.45	2.26	0.929	39.6	1996-97	China	1.14	13.28	15.12	0.922	46.9	2004
Tunisia	1.53	13.34	20.35	0.972	39.8	2000	Guinea-Bissau	0.93	2.27	2.12	0.983	47.0	1993
Turkey	1.61	18.14	29.26	0.955	40.0	2000	Nepal	0.88	3.44	3.01	0.903	47.2	2003-04
Sierra Leone	1.56	1.77	2.77	0.923	40.0	2003	Mozambique	0.93	2.55	2.38	0.981	47.3	2002-03
Mali	1.63	1.79	2.92	0.923	40.1	2001	Dominican Republic	0.99	24.33	24.13	0.929	47.4	1998
Sri Lanka	1.45	6.24	9.06	0.966	40.2	2002	Gambia, The	1.04	2.46	2.56	0.960	47.4	2003-04
Guinea	1.50	3.22	4.85	0.935	40.3	1994	Gambia, The	1.02	3.18	3.26	0.945	47.5	1998
Trinidad and Tobago	1.67	22.09	36.81	0.951	40.3	1992	Madagascar	1.04	2.62	2.72	0.931	47.5	2001
Cambodia	1.38	2.08	2.87	0.898	40.4	1997	Burkina Faso	0.63	3.98	2.50	0.909	48.2	1998
Georgia	1.60	8.99	14.35	0.942	40.8	2005	Costa Rica	1.03	42.55	43.72	0.938	48.2	2004
Turkmenistan	1.50	4.33	6.52	0.966	40.8	1998	Venezuela, RB	1.10	29.41	32.38	0.936	48.2	2003
Ghana	1.63	2.46	4.01	0.972	40.8	1998-99	Venezuela, RB	1.03	37.96	38.95	0.967	49.1	1998
United States	1.68	203.64	342.80	0.948	40.8	2000	Malaysia	0.94	50.87	48.01	0.967	49.2	1997
Senegal	1.37	3.93	5.38	0.920	41.3	1995	Guatemala	0.95	20.23	19.31	0.975	49.4	2004
Senegal	1.38	3.34	4.60	0.916	41.3	2001	Peru	0.99	20.99	20.78	0.954	49.8	2000

Country	α	β	Ave.Income	R2	Gini coeff	Year
Dominican Republic	0.90	39.17	35.42	0.971	49.9	2005
Malawi	0.79	2.82	2.23	0.900	50.3	1997
Swaziland	0.84	14.04	11.73	0.925	50.4	2000-01
Mali	0.85	2.89	2.45	0.932	50.5	1994
Niger	1.04	1.74	1.80	0.970	50.5	1995
Nigeria	0.84	3.51	2.94	0.921	50.6	1996-97
Zambia	0.90	5.34	4.83	0.918	50.8	2004
Papua New Guinea	0.84	12.71	10.65	0.981	50.9	1996
Argentina	0.91	43.66	39.91	0.968	51.3	2004
Peru	0.81	28.28	23.03	0.940	52.0	2003
Argentina	0.87	82.72	72.12	0.965	52.2	2001
El Salvador	0.88	25.38	22.40	0.909	52.4	2002
Zambia	0.81	4.01	3.24	0.938	52.6	1998
El Salvador	0.81	26.15	21.20	0.951	53.2	2000
Honduras	0.75	16.67	12.53	0.939	53.8	2003
Mexico	0.72	80.97	58.29	0.940	54.6	2000
Chile	0.66	69.78	46.39	0.975	54.9	2003
Honduras	0.74	14.43	10.66	0.952	55.0	1999
Panama	0.71	58.76	41.46	0.923	56.1	2003
Colombia	0.65	33.95	22.13	0.963	56.2	2004
Panama	0.69	56.85	39.39	0.955	56.4	2000
Brazil	0.65	72.29	47.21	0.963	56.6	2005
Zimbabwe	0.85	7.09	6.06	0.963	56.8	1995
Chile	0.60	81.69	48.79	0.927	57.1	2000
Colombia	0.61	34.65	21.03	0.932	57.6	1999
Paraguay	0.63	14.45	9.13	0.942	57.8	2002
South Africa	0.65	45.15	29.27	0.958	57.8	2000
Paraguay	0.61	15.92	9.77	0.954	58.4	2003
Brazil	0.59	53.44	31.36	0.944	59.3	2001
Guatemala	0.55	27.66	15.31	0.938	59.9	2000
Bolivia	0.58	15.80	9.13	0.898	60.1	2002
Swaziland	0.52	23.62	12.18	0.920	60.9	1994
Central African Republic	0.55	7.15	3.96	0.943	61.3	1993
Sierra Leone	0.62	5.31	3.27	0.986	62.9	1989
Botswana	0.39	64.29	25.28	0.987	63.0	1993
Lesotho	0.53	10.22	5.41	0.978	63.2	1995
Namibia	0.29	62.71	18.19	0.964	70.7	1993

Figure 11-Figure 14 exhibit the applied Gamma distribution in the cases of Lithuania, Peru, Thailand and Zambia. These figures show the variety of income distribution and the effectiveness of Gamma distribution.

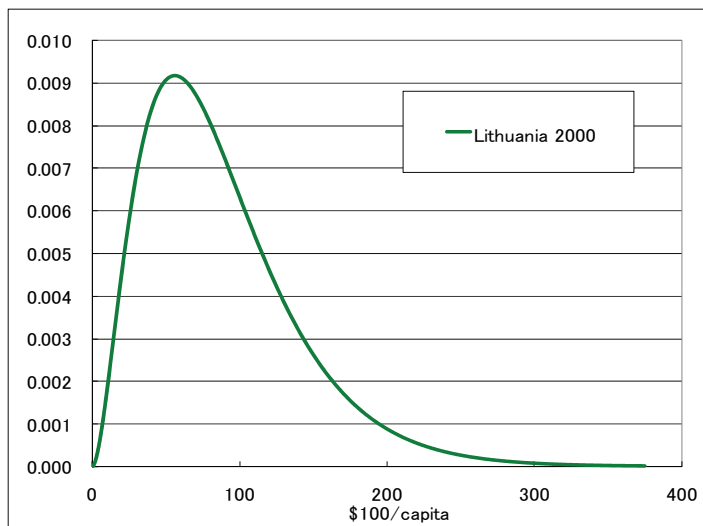


Figure 11 Example of the Gamma distribution (Lithuania,2000) α :2.8 β :11.6 R^2 :0.97 Gini coeff. 31.9

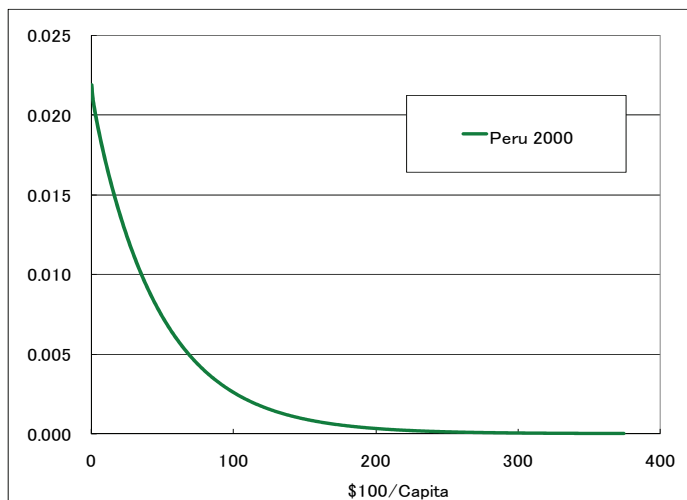


Figure 12 Example of the Gamma distribution (Peru 2000) α :0.98 β :21.0 R^2 :0.95 Gini coeff. 49.8

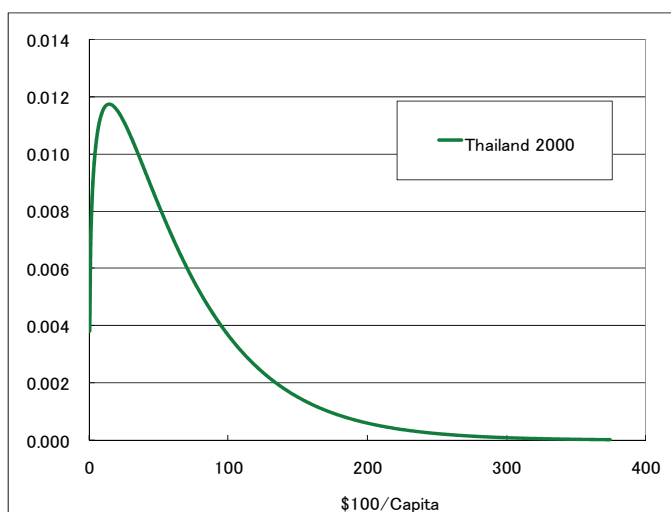


Figure 13 Example of the Gamma distribution (Thailand 2000) α :1.28 β :15.75 R^2 :0.94 Gini Coeff. 34.7

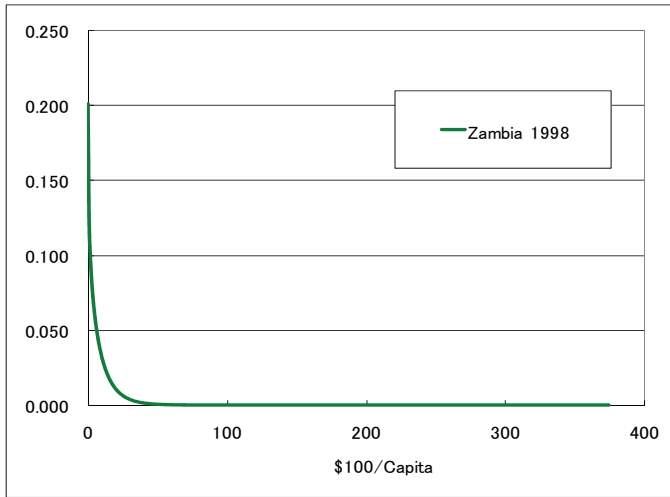


Figure 14 Example of the Gamma distribution (Zambia 1998) α :0.81 β :4.01 R^2 :0.93 Gini Coeff. 52.6

The countries are aggregated into 18 regions like the GISELA aggregations in the previous chapter. The Gamma parameters are calculated based on the aggregated mean and variance.

6.3 Projection of Gamma parameters

We are interested in how the income distribution pattern changes with the economic growth. Figure 15 exhibit the relationship between per capita income in PPP and the Gamma parameter β . Aggregating 18 regions into two groups, we obtain the following regression results in Table 9.

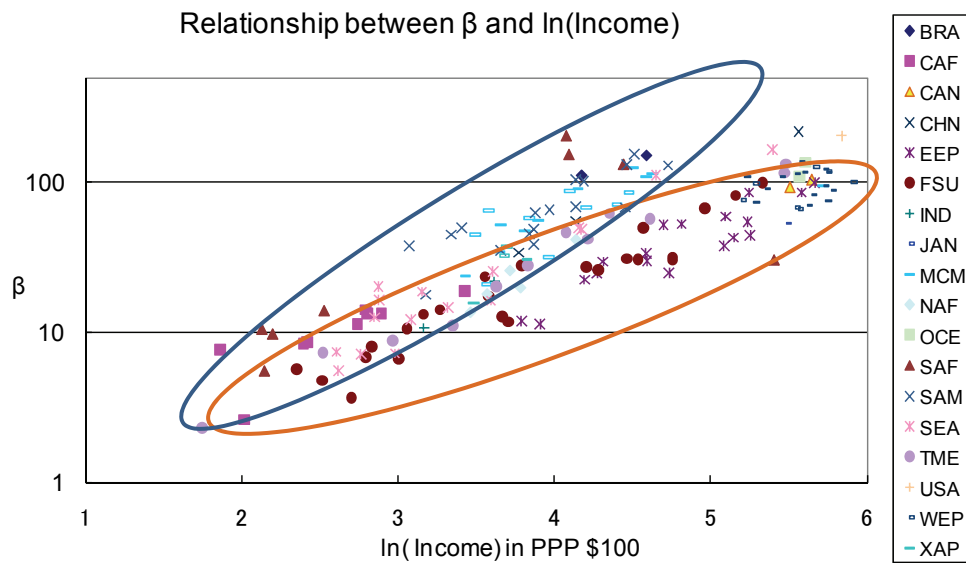


Figure 15 Relationship between β and per capita income in PPP

Table 9 Estimated parameters of β $\ln \beta = B + A \times \ln(Y)$

	Group-1 (in blue circle)	Group-2 (in orange circle)
B	-0.049 (0.153)	-0.264 (1.856)
A	0.982 (12.1)	0.865 (27.5)
R ²	0.668	0.891
regions	BRA,CHN,MCM,NAF,SAF,SAM,SEA,XAP	CAF,CAN,EEP,FSU,IND,JPN,OCE,TME,USA,WEP

Values in the parenthesis represent t-statistics.

The A values in Table 9 suggest that α in Group-1 does not change as the per capita income increases while that in Group-2 does. This point represents the characteristics of the historical economic growth. On the contrary, no significant relationship were found on α . However, given the mean per capita income Y , the definition $\alpha = Y/\beta$ can be applied.

6.4 Projection on income distribution

Based on the future scenario of GDP and population, we can give the income distribution parameters. Figure 16 shows the changes in absolute poor population whose annual income is less than \$365. Reflecting the global economic growth, number of absolute poor people decreases. However, the fraction of those people shown in Figure 17 suggests that the decreasing patterns are different among regions.

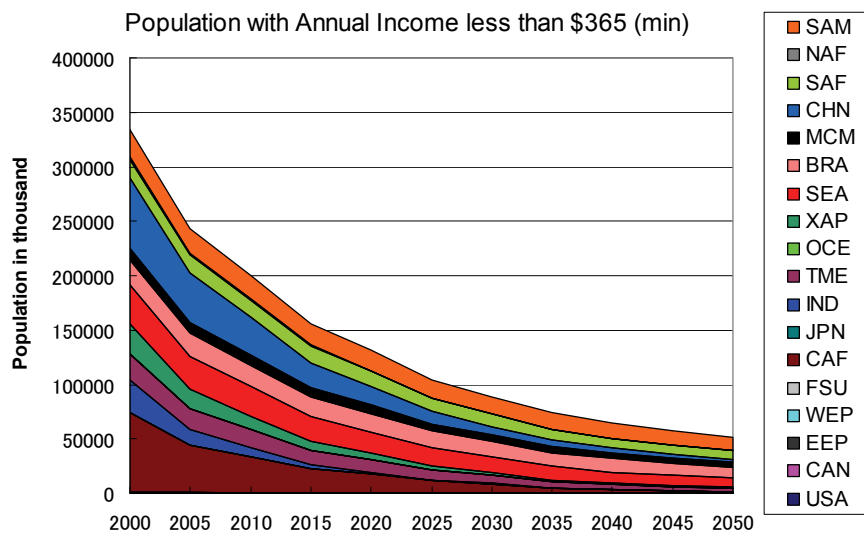


Figure 16 Profile on the absolute poor population (annual income less than \$365)

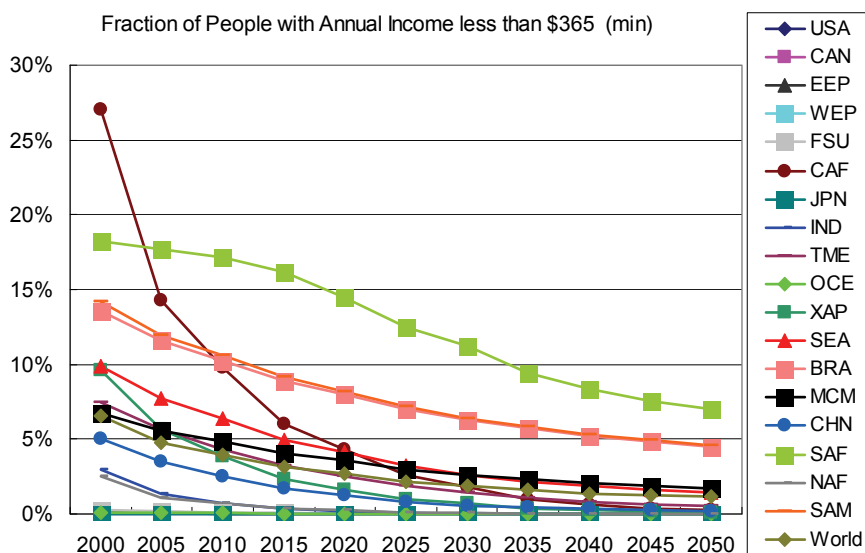


Figure 17 Fraction of the absolute poor population by region (annual income less than \$365)

6.5 Assessment of food accessibility - a preliminarily study

GISELA generates domestic market prices of crops. Assuming the minimum food requirement of crop to be 2800kcal/day, we can calculate the minimum expenditure for food. Needless to say, since this value does not cover the need for protein and other nutrition, it is no more than a preliminarily index. However, it will still suggest how

the population which is hard to access the food market changes according to the economic growth. While this expenditure is less than 5% of the average income even in the lowest income region and in the minimum yields case, there are still poor people whose income is less than the above minimum expenditure. Figure 18 and Figure 19 show the profiles of population of those who cannot afford the minimum crop requirement and the fraction of these people by region in the minimum yield case of wheat, respectively. Figure 20 and Figure 21 are those in average yield case.

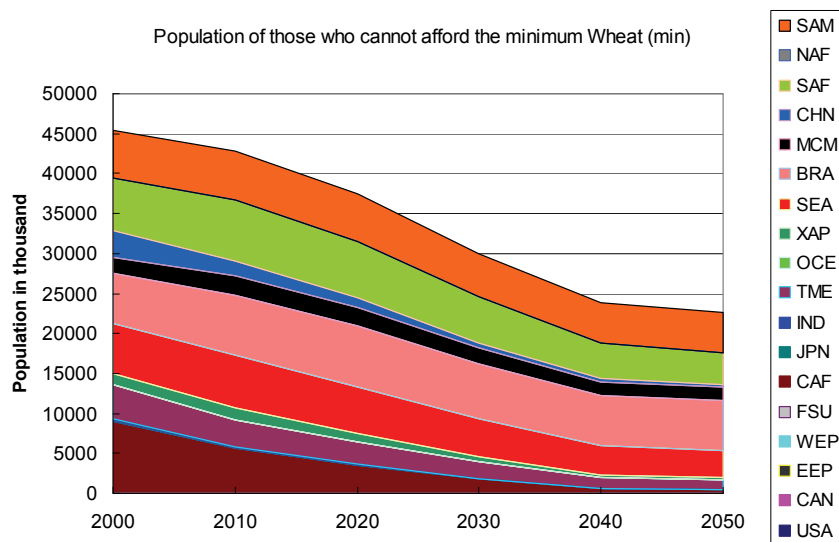


Figure 18 Population of those who cannot afford the minimum wheat requirement in minimum yield case

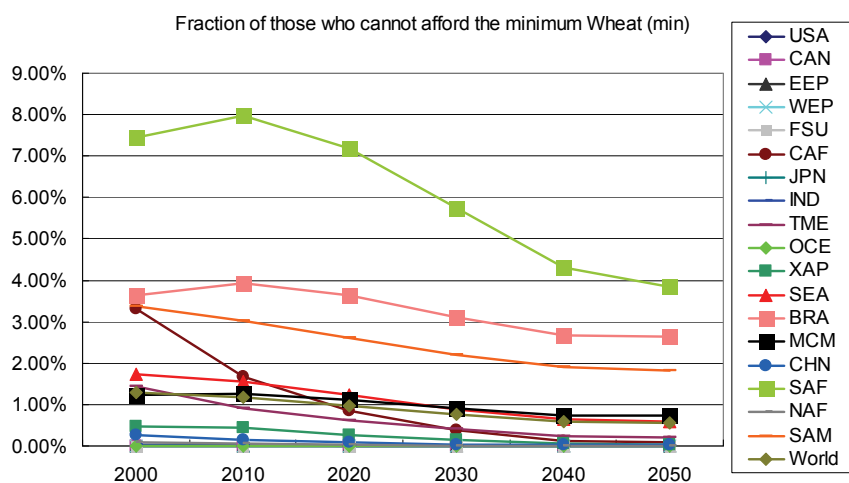


Figure 19 Fraction of those who cannot afford the minimum wheat requirement in minimum yield case

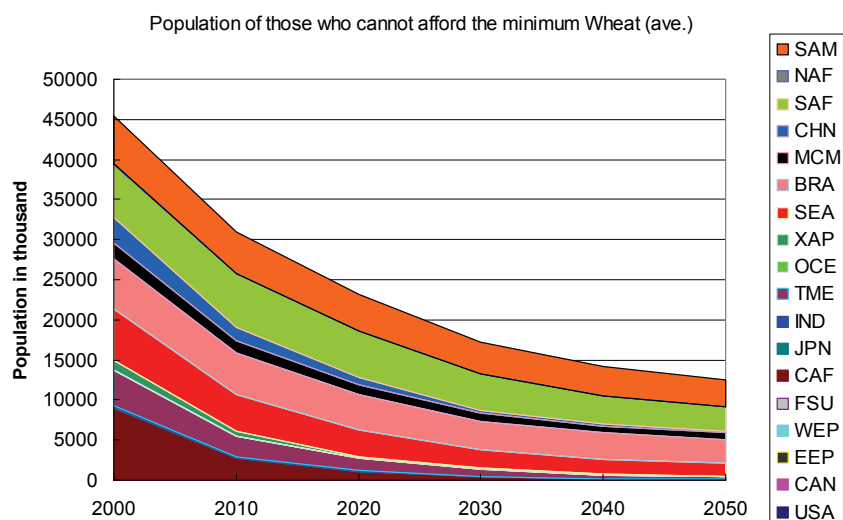


Figure 20 Population of those who cannot afford the minimum wheat requirement in average yield case

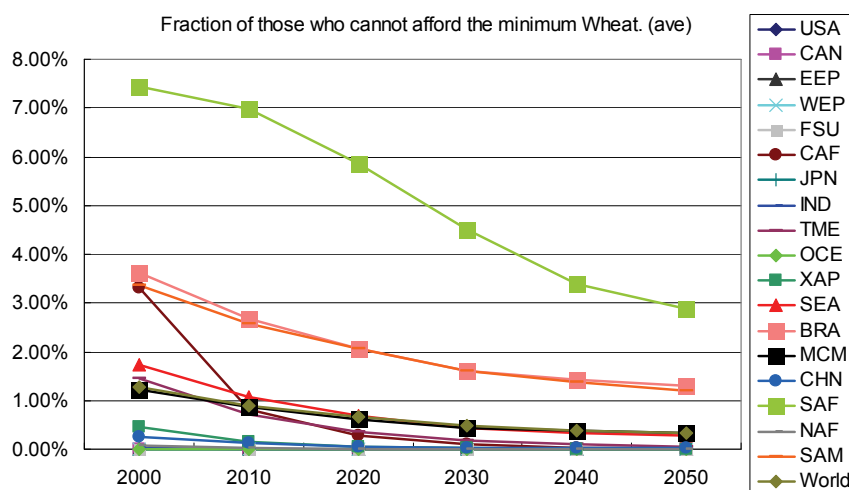


Figure 21 Fraction of those who cannot afford the minimum wheat requirement in average yield case

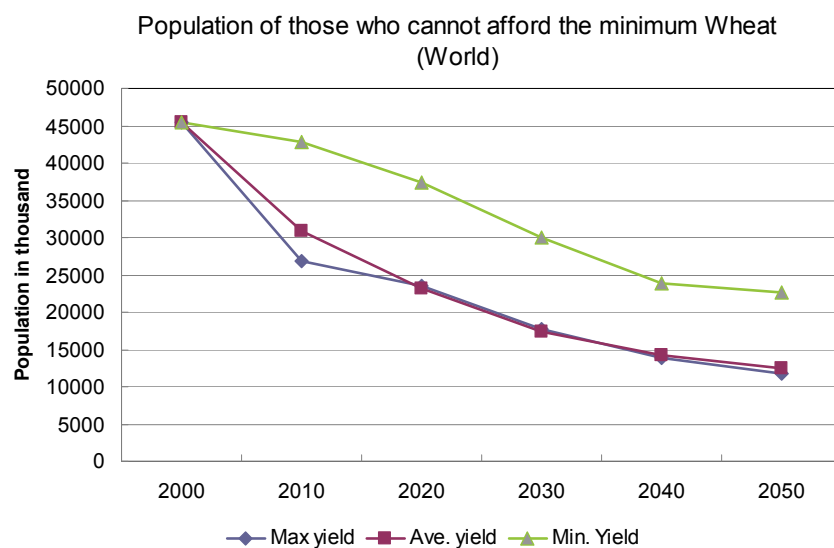


Figure 22 Comparison of population of those who cannot afford the minimum wheat requirement

These figures suggest that although the number of poor people who are hard to afford the minimum requirement food is decreasing, its declining ratio may not be so large and remaining population is far from negligible small even in the middle of this century.

7. Conclusion

We describe the development of GISELA model which integrates the potential supply and the market behavior and its simulation results. In all cases, the potential cropland is converted in South America region. In mid-yield case, crop prices hike gradually and thus the food market will relatively stable. On the contrary, however, in the low-yield case, potential cropland has to be rapidly converted in South-east Asia, Africa and others. International market crop prices rise rapidly in the mid of this century. Price premium is introduced in the second half of this century. This suggests that the food market becomes more vulnerable and poor people would suffer from the high price.

Income distribution is modeled based on the quintile statistics provided by World Bank applying Gamma distribution. The estimation results represent the variety of distribution patterns and enable us to assess the future distribution. We then estimate the number of absolute poor people and assess the food market accessibility. Although this procedure is no more than a preliminary study, it still suggests that the poverty and hunger problem may still remain in the middle of this century even if total crop production would meet the world food demand.

Poverty and hunger are the central issues in the societal sustainability. It is concluded that this study provides an evaluation system to discuss them quantitatively. The assessment of the impact of bio fuel production and the adaptation possibility is the future subject of this study.

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