「한국 시스템다이내믹스 연구」 제10권 제3호(2009.10): 105-124

Analysis of Global Food Market and Food-Energy Price Links: Based on System Dynamics Approach

김규림*
Kim, Gyu-Rim*

Abstract

The situation of the global food markets has been being rapidly restructured and entering on a new phase by new dynamic and driving forces. The factors such as economic growth and income increase, high energy price, globalization, urbanization, and global climate change are transforming patterns of food consumption, production, and markets. The prices and markets of world food and energy are getting increasingly linked each other. Food and fuel are the global dilemma issues associated with the risk of diverting farmland or of consuming cereals for biofuel production in detriment of the cereals supply to the global food markets. An estimated 100 million tons of grain per year are being redirected from food to fuel. Therefore, the objectives of this study are as follows: Firstly, the study examines situations of the world food and energy resources, analyzes the trends of prices of the crude oil and biofuel, and formulates the food-energy links mechanism. Secondly, the study builds a simulation model, based on system dynamics approach, for not only analyzing the global cereals market and energy market but also forecasting the global production, consumption, and stock of those markets by 2030 in the future. The model of this study consists of four sectors, i.e., world population dynamics sector, global food market dynamics sector, global energy market dynamics sector, scenario sector of world economic growth and oil price.

Keywords : food, cereals, crude oil, biofuel, food-energy link, system dynamics

* Hankuk Academy of Foreign Studies B-214 GMC, 232 Wangsan-ri Mohyeon-myeon Yongin-Gyeonggi-do, 449-854, KOREA (gyurim1245@hanmail.net)

Ⅰ. Introduction

1. Statement of the Problem

Recently, the situation of the global food markets has been being rapidly restructured and entering on a new phase by new dynamic and driving forces. The factors such as economic growth and income increase, high energy price, globalization, urbanization, and global climate change are transforming patterns of food consumption, production, and markets.

In addition, the prices and markets of world food and energy are getting increasingly linked each other. Since 2000, the prices of wheat and crude oil have almost tripled, while the prices of rice and corn have practically doubled. Food and fuel are the global dilemma issues associated with the risk of diverting farmland or of consuming cereals for biofuel production in detriment of the cereals supply to the global food markets. Biofuel production has been rapidly increasing in recent years. Therefore, this is an international issue on the global scale.

The impact of increase in food price index on food-insecure and poor households is already quite dramatic. For every 1% increase in the food price, expenditures for food consumption in developing countries decrease by 0.75%. Being faced with higher prices, the poor switch to foods that have lower nutritional value and lack important micro-nutrients.[1)]

Changes in food availability, rising cereals prices, and new producer-consumer linkages have crucial implications for the livelihoods of poor and food-insecure people. Analyzing and interpreting recent trends and emerging challenges in the world food situation is essential in order to provide policy-makers with the necessary information to mobilize adequate responses at the national, regional, and international levels.[2)]

2. Objective of the Study

The objectives of this study are as follows:

Firstly, the study examines situations of the world food and energy resources, analyzes the trends of prices of the crude oil and biofuel, and formulates the food-energy links mechanism.

---

1) Joachim von Braun, Dec. 2007, 『The World Food Situation: New Driving Forces and Required Actions』, Washington D.C.: International Food Policy Research Institute, p. 6.

2) Ibid. p. 1.

Secondly, the study builds a simulation model, based on system dynamics approach, for not only analyzing the global cereals market and energy market but also forecasting the global production, consumption, and stock of those markets by 2030 in the future.

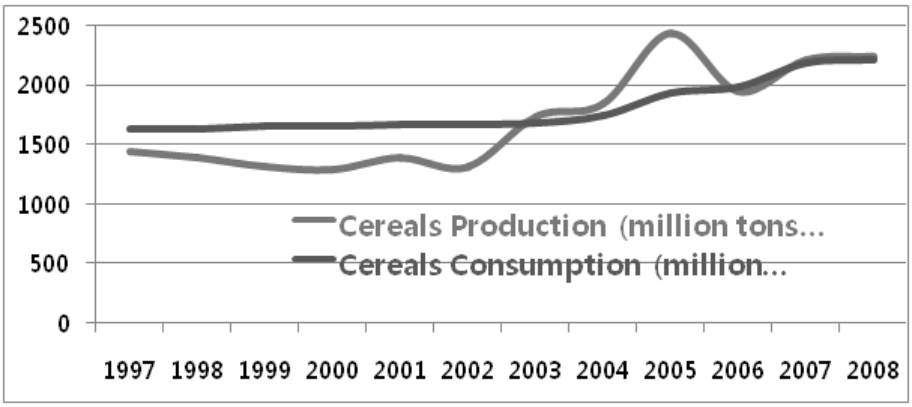
3. Methodology of the Study

This study applies not only the system dynamics approach to make a simulation model but also calculus-based method and statistical processing technique to analyze the markets of global food and energy mathematically and statistically. The study used Powersim as a system dynamics tool. For statistical analysis, one of the most famous and useful software, SPSS was used.

Ⅱ. Situations of the World Food and Energy Resources

1. The Cereals Production and Consumption

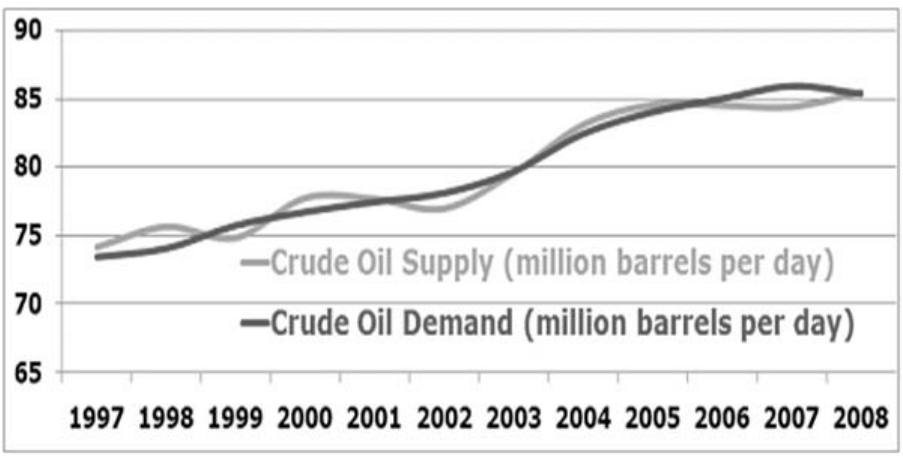
Total worldwide cereals production for 2008 was just over 2000 million tons. Among them, however, an estimated 100 million tons of cereals per year are being turned from food to biofuel. As farmers devoted larger parts of their cereals to biofuel production than in previous years, farmland and resources available for cereals production were reduced correspondingly. This has brought less food available for human consumption, especially in the developing countries, where a family's daily allowances for food purchases are extremely limited. The food crisis seems to have dichotomized rich and poor nations, since, for instance, filling a tank of a car with biofuel, amounts to as much cereals as a poor African person consumes in an entire year.



[Figure 1] Cereals production and consumption (1997~2008)

2. The Crude Oil Supply and Demand

The crude oil supply had risen by 11.3 million barrels per day (mb/d), on the average, during the past 11years from 1997 (74.2 mb/d) to 2008 (85.5 mb/d). An average increase of 1 mb/d annually is recorded. Similarly, the crude oil demand had increased by 11.9 mb/d from 1997 (73.4 mb/d) to 2008 (85.3 mb/d). The excess demand from 2006 to mid-2008 resulted in a sharp rise of the crude oil price. Most research reports expect that the crude oil demand will outstrip the crude oil supply and crude oil depletion will cause crude oil prices to go up over the next 20 years. In addition, the sharp rise of oil price will inflate cereals price worldwide.



[Figure 2] Crude oil supply and demand (1997~2008)

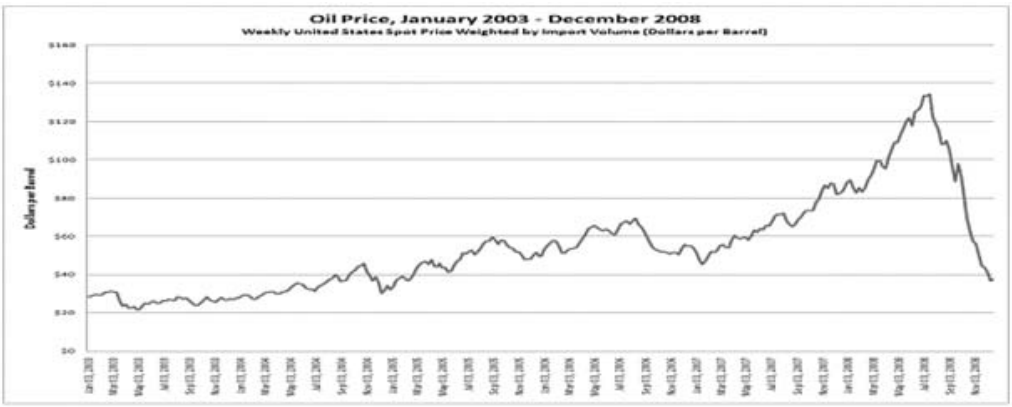
3. Trends of Crude Oil Price and Cereals Price

From the mid-1980s to September 2003, the inflation adjusted price of crude oil was generally under $25/barrel. Then the price rose above $30 in 2003, reached $60 by August, 2005, and peaked at $147 in July 2008. Commentators attributed the price increases of this period to a confluence of factors, including a decline in petroleum reserves, worries over peak oil, Middle East tension, and oil price speculation. For a time, certain geo-political events and natural disasters not directly related to the global crude oil market had strong short term effects on crude oil prices. By 2008, such pressures did not appear to have as much of a significant impact on crude oil prices, possibly because of a global recession. In December 2008, oil prices fell to below $40 per barrel.[3)]

Oil price increases since 2003 resulted in increased demand for biofuels. Transforming vegetable oil into biodiesel is not very hard or costly. So there is a profitable arbitrage situation if vegetable oil is much cheaper than diesel. Diesel is also made from crude oil. So vegetable oil prices are partially linked to crude oil prices. Farmers can switch to growing vegetable oil crops if those are more profitable than food crops. So, cereals prices are linked to vegetable oil prices, and in turn to crude oil prices.

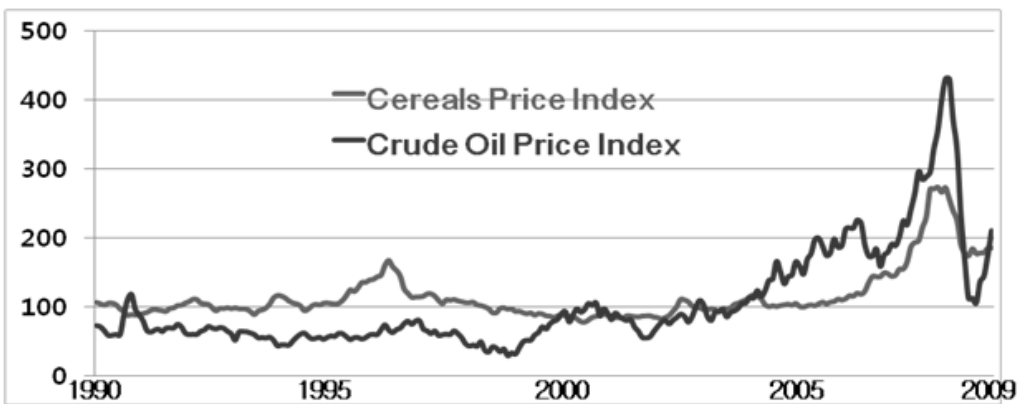
On the other hand, the world cereals price shot up dramatically during the years 2007 – 2008, bringing a state of global food crisis and causing economical and political instability. The main causes of the world-wide cereals price spikes result from unseasonable droughts in grain producing nations and a sudden rise of crude oil price. Other causes are said to be lower cereals reserves, the increasing production and usage of biofuels in developed countries, and the increasing demand for meats by the expanding middle-class populations of Asia. These factors have all contributed to the sharp world-wide rise in food prices, especially cereals price. The areas of farmland, technical progress and climate change are also the important causes in the long run. Since 2006, the average world price for rice has risen by 217 percent and wheat by 136 percent. In April 2008, rice prices hit 24 cents a pound, doubled the price that it had been seven months earlier.

3) http://en.wikipedia.org/wiki/2000s_energy_crisis [1. Feb. 2009]



[Figure 3] Oil price trend (2003~2008)

* Source: http://en.wikipedia.org/wiki/2000s_energy_crisis



[Figure 4] Trend comparison of oil price and cereals price index

Ⅲ. Price Links Mechanism of Global Food-Biofuel-Crude Oil Integrated Market

To analyze the mechanism of global food-energy price links before formulating the system dynamics model, it is important to acknowledge all the essential variables needed to form the causal-loop diagram, which are demands, supplies and prices of crude oil, biofuel and cereals, respectively and so on.

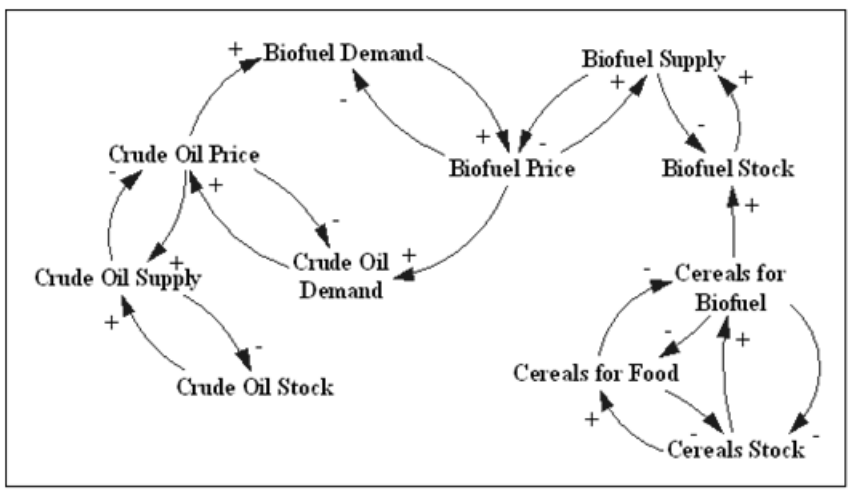
As illustrated in the [Figure 5], demand and supply of the crude oil determine the crude

oil price which, in effect, influences the biofuel demand by the relationship of substitutes. When the crude oil demand increases, the crude oil price increases, too, but when the crude oil price increases, the crude oil demand decreases. Also, as the crude oil supply increases, the crude oil price decreases, and as the crude oil price increases, the crude oil supply increases. The crude oil supply has the cause-and-effect relationship with the crude oil stock as well.

Furthermore, all these relationships among those variables resembles similarly with the relationships among the variables of the biofuel, as can be seen in the [Figure 5].

To focus more on the mechanism of food-energy price links, a causal link from the crude oil price to the biofuel demand is positive, meaning that an increase in the crude oil price results in an increase in the biofuel demand. There are several more positive links: a link from the biofuel demand to the biofuel price, a link from the biofuel price to the crude oil demand, and a link from the crude oil demand to the crude oil price. From these links, it may seem that only positive causal links exist, a situation which can lead to ever-increasing variables of the causal-loop.

However, there are lots of negative feedback links which prevent the variables from ever-increasing. The negative links are as follows: a link from the biofuel price to the biofuel demand, a link from the crude oil price to the crude oil demand, a link from biofuel supply to biofuel price, a link from crude oil supply to both crude oil price, and a link from biofuel supply to biofuel stock.



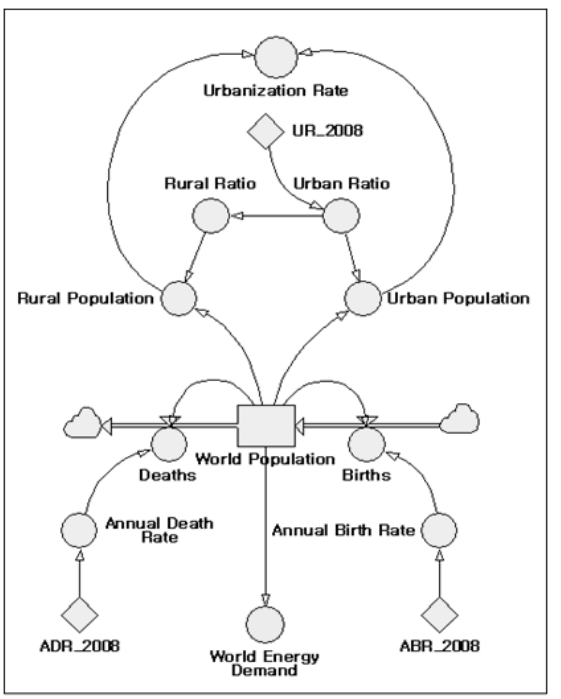
[Figure 5] Causal loop of food-biofuel-oil price links

Ⅳ. System Dynamics Model Formulation of Global Food Market and Food-Energy Price Links

The model of this study consists of four sectors, i.e., world population dynamics sector, global food market dynamics sector, global energy market dynamics sector, scenario sector of world economic growth and oil price.

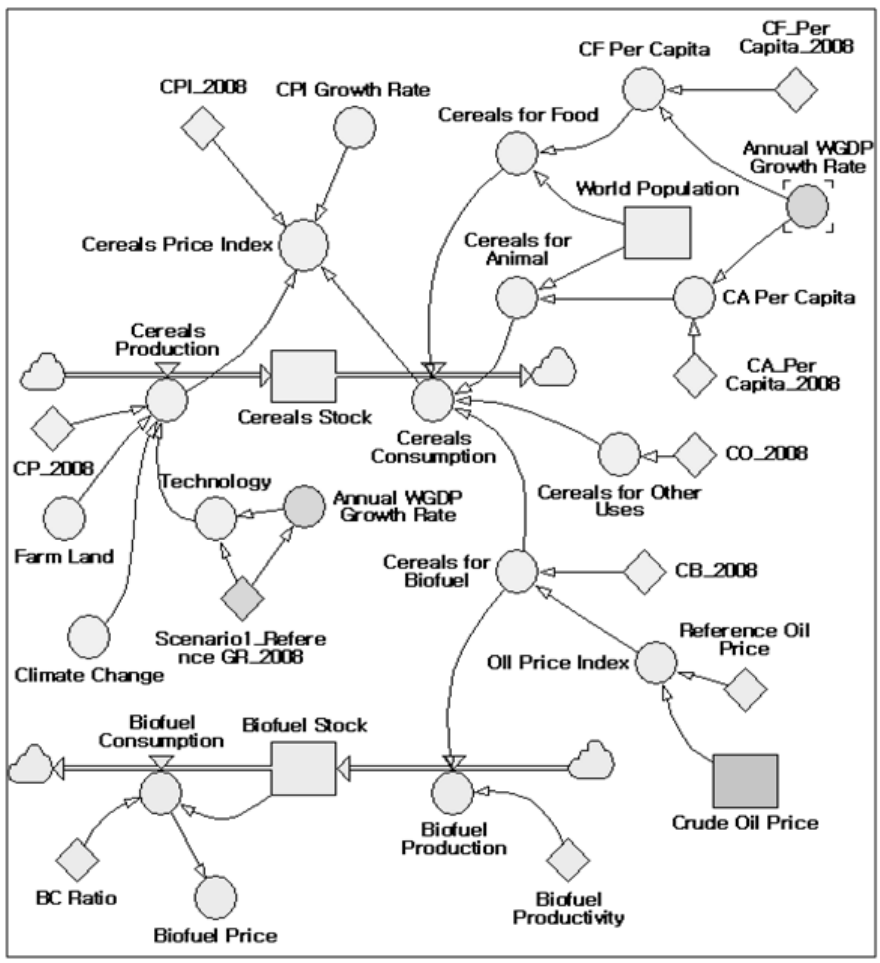
1. World Population Dynamics Sector

The following figure demonstrates a flow diagram of the world population dynamics made by Powersim. In the model, the level of world population is influenced by several variables such as births and deaths through linked arrows. Those two determining factors of population come from the results of their annual growth rate multiplied by the last year population. While the world population is simulated through such decisive factors, the model divides population into two groups to calculate urbanization rate: rural population and urban population.



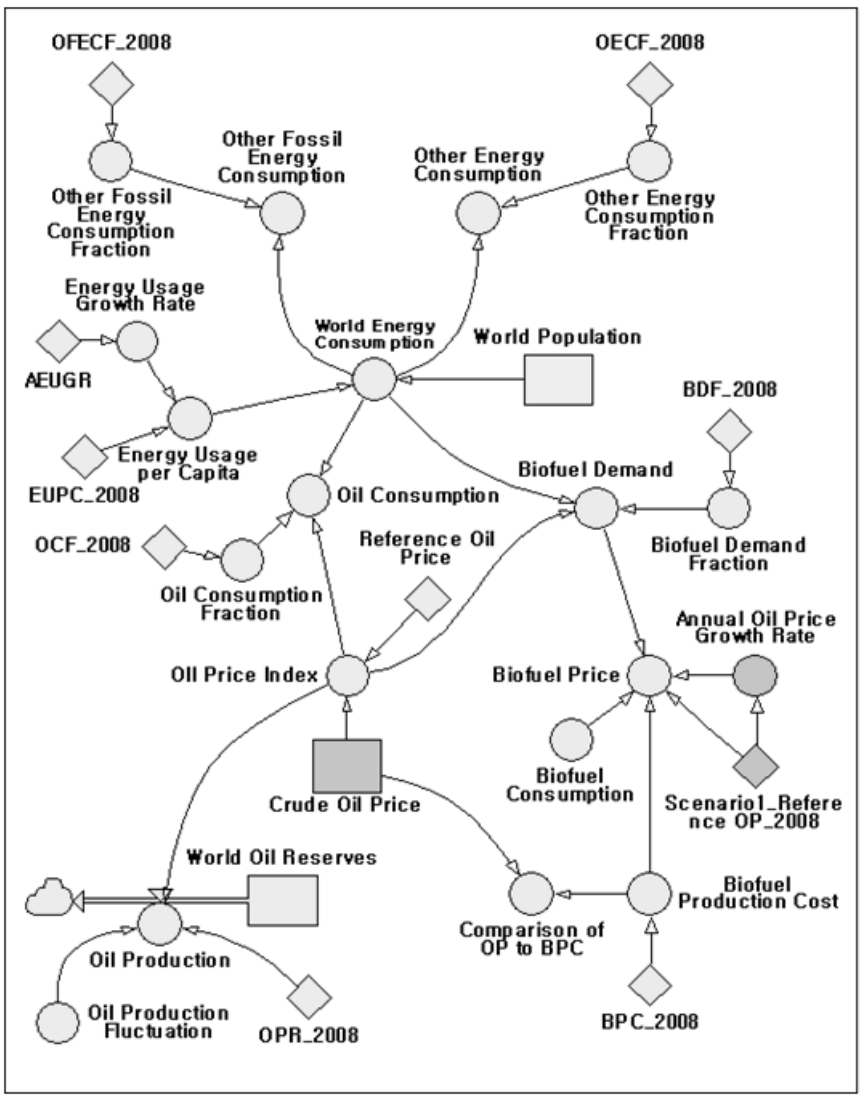
2. Global Food Market Dynamics Sector

As illustrated in the figure below, the global food market dynamics is closely related with both world population and biofuel market. Cereals stock is heavily affected by both cereals consumption and production. While the cereals production comes from combining factors of technology, farm land, and climate change, the cereals consumption are mainly used for four purposes: food for people, feed or forage for animals, biofuel and other usages. Uses for people and animals will be decided with diverse variables such as world population and annual world gross domestic product (WGDP) growth rate. On the other hand, cereals used for biofuel production will not only be greatly influenced by crude oil price, but also increase biofuel production, affecting the biofuel market as a whole.



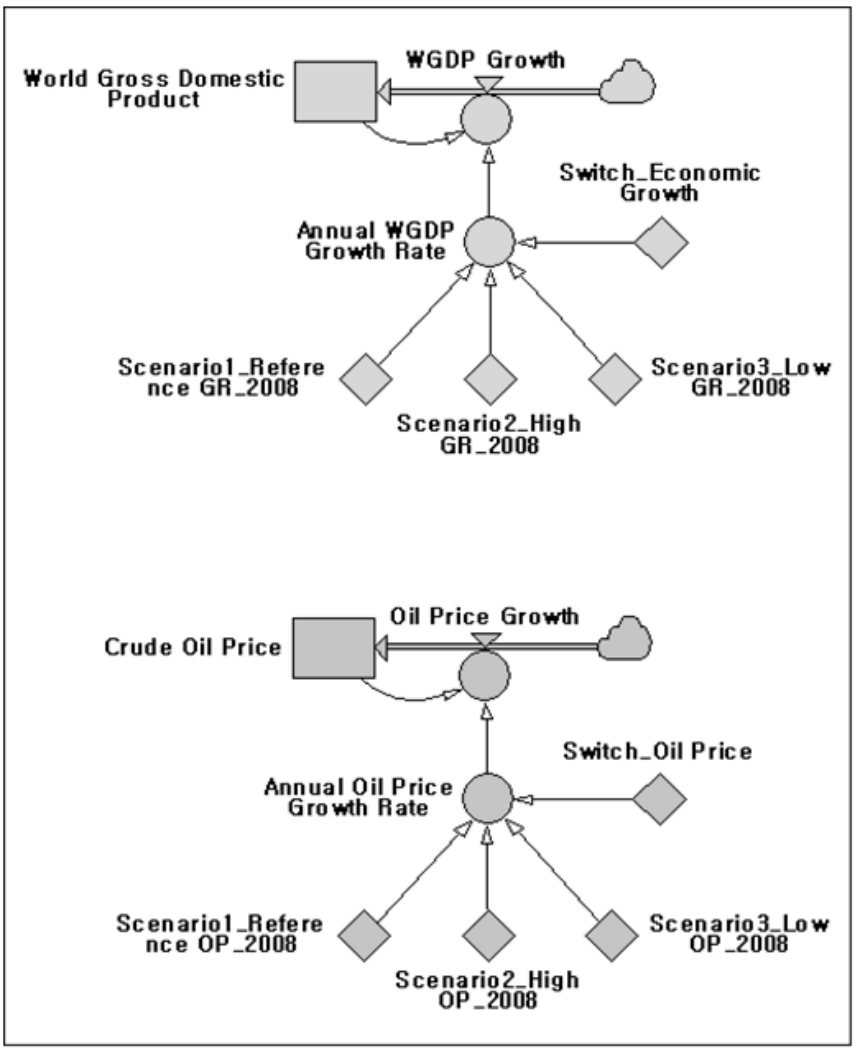
3. Global Energy Market Dynamics Sector

The subsequent sector depicts global energy market dynamics including crude oil energy, other fossil fuel energy, biofuel energy, and other sources of energy. Such various forms of energy are closely linked through world energy consumption. As calculated in the former sectors, the crude oil price crucially affects the oil market as a whole since those variables determine the oil price index and the oil production. Through the oil price index, the model demonstrates the increase and decrease links between biofuel demand and oil consumption.



4. Scenario Sector of World Economic Growth and Oil Price

The last sub-model figure contains the sector of both world GDP (WGDP) growth and crude oil price change. The WGDP growth is measured through multiplying the last year's WGDP by the annual WGDP growth rate. For the annual growth rate, however, there are three scenarios to be considered in the model according to the 'International Energy Outlook 2009':the highg rowth rate (4.0%), the low growth rate (3.0%), and the reference(3.5%). Similar to the former case, the other sector of oil price growth also includes three scenarios for its growth rate which are the high($200in2030), the low($50), and the reference($130).



Ⅴ. Scenarios for Simulation and Analysis

To attain the simulation results from 2010 to 2030 through system dynamics model, we need to suppose and determine the alternatives of uncertainty in the projections: alternative economic growth cases and alternative world oil price cases.

As shown in the following table, for the uncertainties associated with economic growth trends, there are three cases to be considered and included which are the high economic growth case, the low economic growth case, and the reference. These economic growth cases use respectively different assumptions about future economic growth paths while maintaining the same relationships between changes in WGDP and changes in energy consumption that are used in the reference case.

The high economic growth rate, according to 'International Energy Outlook 2009', has approximately 4.0 percentage which is 0.5 percentage point more than the growth rate assumed for the reference case. For the low economic growth rate, the IEO 2009 assumes it to be 3.0 percentage which is 0.5 percentage point subtracted from the reference case growth rate.

Similar to the alternative economic growth cases, alternative world oil price cases are divided into three different presumptions: the high oil price case, the low oil price case, and the reference. Such division of cases in both economic growth and world oil price yields nine scenarios to be processed through the simulation model by multiplying 3 economic growth cases by 3 oil price cases.

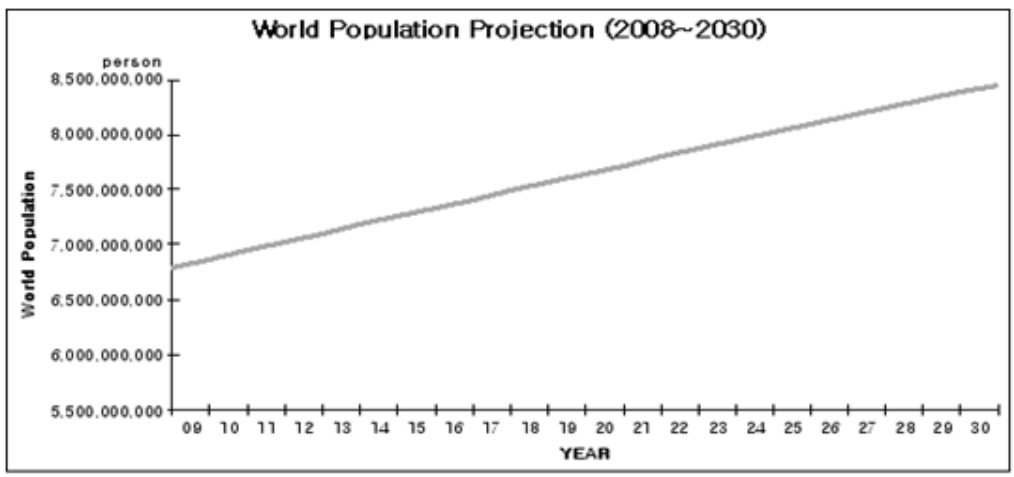
〈Table 1〉 Nine Scenarios: 3 Economic Growth Cases by 3 Oil Price Cases

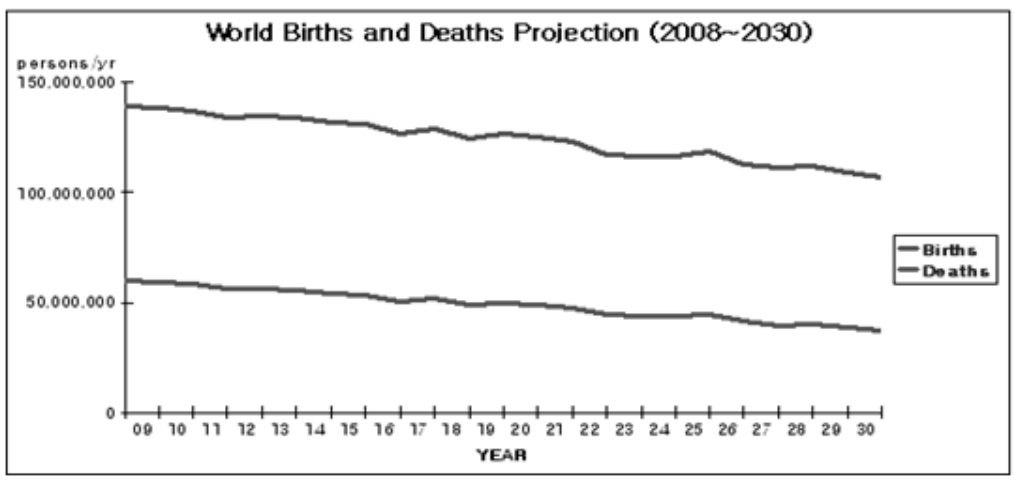
Economic Growth / Oil Price in 2030 (2008 Constant Price)	Reference (GR=3.5%)	High Economic Growth (GR=4.0%)	Low Economic Growth (GR=3.0%)
Reference ($130)	Scenario 1	Scenario 4	Scenario 7
High Oil Price ($200)	Scenario 2	Scenario 5	Scenario 8
Low Oil Price ($50)	Scenario 3	Scenario 6	Scenario 9

Ⅵ. Model Behaviors and Simulation Results

1 World Population Projection

From 2010 to 2030, the general trend of world population shows that the population tends to constantly increase in the following projection. According to the results of simulation, the population increases from 6,948 million to 8,451 million. Such an increase in overall population derives from the difference in births and deaths. Although the world births decrease from 137 million to 107 million by 2030, 107 million births still outnumber 38 million deaths in 2030.



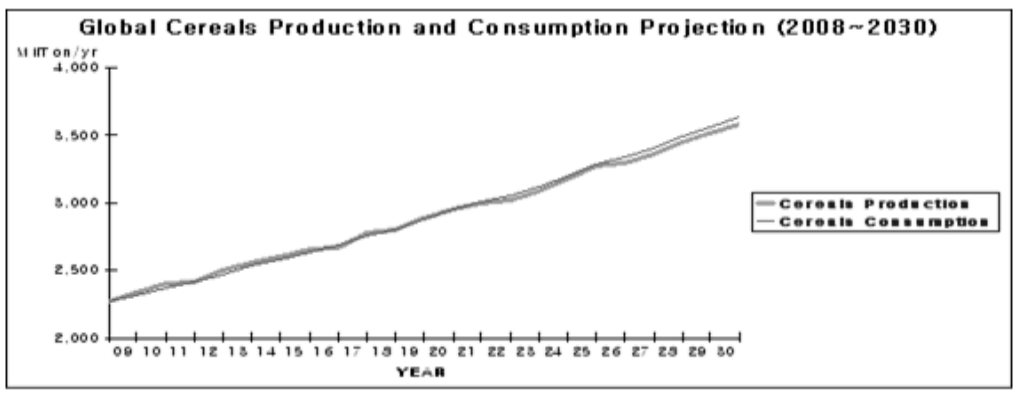


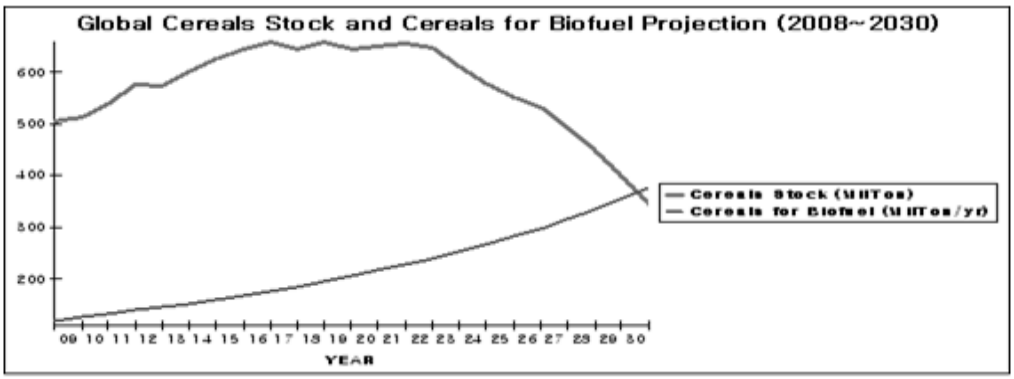
(Unit: Million)

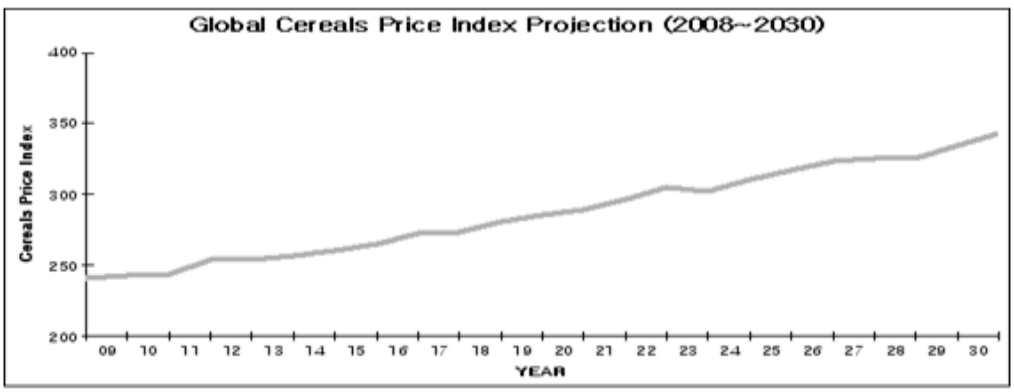
Year	Population	Births	Deaths
2010	6,948	137	58
2015	7,339	131	53
2020	7,722	125	49
2025	8,092	119	44
2030	8,451	107	38

2. Scenario 1: Reference Behavior

The following projections demonstrate the generally possible trends, i.e., the reference model behavior (Scenario 1), of global cereals production, consumption, stock, price index, and cereals used for biofuel. Although both cereals production and consumption have a tendency to increase continuously in the almost same amount from 2010 to 2030, cereals consumption (3,638 million tons) slightly outnumbers cereals production (3,575 million tons) by 63 million tons in 2030. As cereals consumption starts to outnumber production from 2020, the global cereals stock contains the greatest number of 651 million tons in 2020 and is prone to decrease afterwards to 346 million tons by 2030. While cereals used for biofuel production keep increasing from 132 million tons to 374 million tons, cereals price index also continues to increase from 245 to 342.



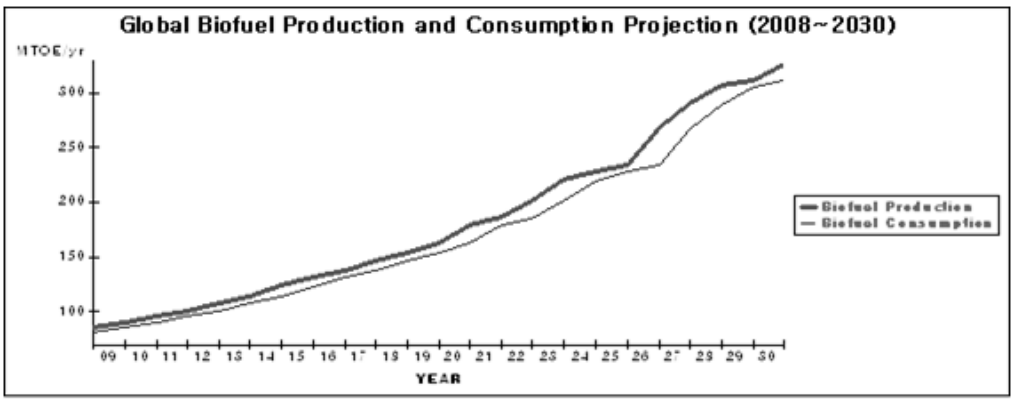


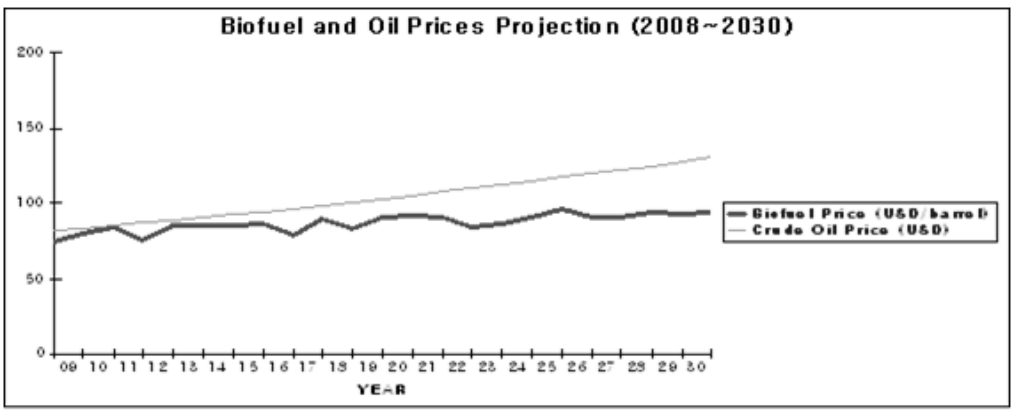


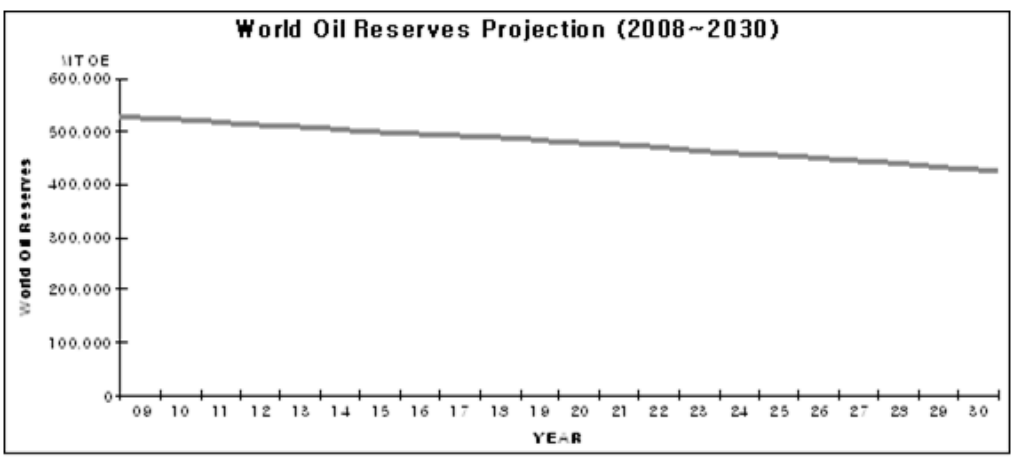
Year	Cereals Production (Mil Ton / yr)	Cereals Consumption (Mil Ton / yr)	Cereals Stock (Mil Ton)	Cereals for Biofuel (Mil Ton / yr)	Cereals Price Index (1998~2000 =100)
2010	2,402	2,364	538	132	245
2015	2,653	2,638	643	168	266
2020	2,947	2,944	651	216	289
2025	3,264	3,283	552	282	316
2030	3,575	3,638	346	374	342

In the below projections, the global biofuel production and consumption incline to increase consistently with a few fluctuations from 2010 to 2030. The biofuel production also continues to outnumber consumption by 15 million tons of oil equivalent (MTOE) in 2030. For the comparison of biofuel and crude oil price, the second projection illustrates that oil price increases more than the biofuel price does. While the biofuel price increases only from $84/barrel to $94/barrel on the basis of 2008 constant price, the oil price rises from

$85/barrel to $130/barrel by 2030. However, the world oil reserves maintains to decrease slowly from 519 billion tons of oil equivalent (BTOE) to 426BTOE.







Year	Biofuel Production (MTOE/yr)	Biofuel Consumption (MTOE/yr)	Biofuel Price ($/barrel)	Crude Oil Price ($/barrel)	World Oil Reserves (BTOE)
2010	96	90	84	85	519
2015	131	123	86	95	498
2020	179	163	92	106	476
2025	234	228	96	117	452
2030	325	310	94	130	426

3. Scenario 5: High Economic Growth and High Oil Price

To compare and contrast differences among model behaviors and simulation results of the several meaningful scenarios, we supposed three assumptions for both future economic growth rate and oil price growth rate respectively.

For example, in the case of Scenario 5 in which both growth rates are high, the simulation results are altered from the results of Scenario 1 where the reference applies. Since the economic growth is presumed to be more rapidly increasing in Scenario 5, cereals consumption and cereals for biofuel rise in numbers more greatly in Scenario 5 when compared with those of Scenario 1. In the case of cereals used for biofuel production, they increase from 142 million tons in 2010 to 794 million tons in 2030, which is approximately double the increase in Scenario 1. As cereals for biofuel grow fast, the biofuel production is also predicted to double its amount to 716 million tons by 2030. Furthermore, with the high crude oil price growth rate, the biofuel price of Scenario 5 increases higher than that of Scenario 1.

Year	Cereals Production (Mil Ton / yr)	Cereals Consumption (Mil Ton / yr)	Cereals Stock (Mil Ton)	Cereals for Biofuel (Mil Ton / yr)	Cereals Price Index
2010	2,492	2,462	480	142	238
2015	2,754	2,743	575	208	262
2020	3,059	3,098	498	327	294
2025	3,387	3,451	258	551	337
2030	3,711	3,805	-155	794	499

Year	Biofuel Production (MTOE/yr)	Biofuel Consumption (MTOE/yr)	Biofuel Price ($/barrel)	Crude Oil Price ($/barrel)	World Oil Reserves (BTOE)
2010	103	94	88	90	519
2015	169	148	101	110	495
2020	271	236	122	135	465
2025	458	420	143	164	425
2030	716	655	169	200	367

4. Scenario 9: Low Economic Growth and Low Oil Price

On the other hand, for example, both economic growth rate and oil price growth rate are assumed to be low as in Scenario 9. Thus, the simulation results are opposite to those of Scenario 5. Although cereals consumption increases constantly from 2010 to 2030, the amount of increase in consumption is even lower than that of production, resulting in expanding cereals stock from 553 million tons to 798 million tons in 2030. In addition, there is relatively a few increase in the use of cereals for biofuel. For the crude oil price, by the assumption, it rather decreases from $75/barrel to $50/barrel by 2030.

Year	Cereals Production (Mil Ton / yr)	Cereals Consumption (Mil Ton / yr)	Cereals Stock (Mil Ton)	Cereals for Biofuel (Mil Ton / yr)	Cereals Price Index
2010	2,354	2,339	553	115	251
2015	2,571	2,560	611	124	268
2020	2,792	2,780	670	135	286
2025	3,065	3,051	735	147	305
2030	3,303	3,290	798	159	322

Year	Biofuel Production (MTOE/yr)	Biofuel Consumption (MTOE/yr)	Biofuel Price ($/barrel)	Crude Oil Price ($/barrel)	World Oil Reserves (BTOE)
2010	83	82	70	75	520
2015	91	88	65	68	503
2020	101	99	60	62	489
2025	113	110	58	56	478
2030	124	120	53	50	469

Ⅶ. Conclusions

There are 854 million hungry people in the world and 4 million more join their ranks every year. We are facing the tightest food supplies in the recent history. For the world's most vulnerable, food is simply being priced out of their reach.

Many experts describe various scenarios for the precarious food supply balance in coming years. An optimistic version would see markets automatically readjust to shortages, as higher prices make it more profitable once again to grow crops for people rather than cars.

There are hopes that new crop varieties and technologies will help crops adapt to capricious climactic conditions. And if people move on to a path of eating less meat, more land can be freed up for human food rather than animal feed.

【Reference】

Averill M. Law and W. David Kelton, 1982, *Simulation Modelling and Analysis*, New York: McGraw-Hill

Energy Information Administration (EIA), May 2009, *International Energy Outlook 2009*.

FAO(Food and Agriculture Organization), November 2007, *Food Outlook: Global Market Analysis*.

____, November 2008, *Food Outlook: Global Market Analysis*.

Geoffrey Gordon, 1978, *System Simulation*, New Jersey: Prentice-Hall

George P. Richardson and Alexander L. Pugh, 1981, *Introduction to System Dynamics Modeling with Dynamo*, Cambridge: Wright-Allen Press

Goettemoeller Jeffrey, Adrian Goettemoeller, 2007, *Sustainable Ethanol: Biofuels, Biorefineries, Cellulosic Biomass, Flex-Fuel Vehicles, and Sustainable Farming for Energy Independence*, Missouri: Praire Oak Publishing.

Jaesook Yoo, 1985, *A Simulation Model for Socio-economic Changes of a Satellite City(Anyang) Lying in the Suburbs of Seoul, Korea*, Bangkok: Asian Institute of Technology

Jay W. Forrester, 1971, *World Dynamics*, Cambridge: Wright-Allen Press

Joachim von Braun, Dec. 2007, *The World Food Situation: New Driving Forces and Required Actions*, Washington D.C.: International Food Policy Research Institute

N. Gregory Mankiw, 2007, *Principles of Economic*(4th ed.), Mason: Thomson South-Western

Nicholas Stern, 2006, *The Economics of Climate Change*, Cambridge: Cambridge University Press

OPEC(Organization of Petroleum Exporting Countries), 2008, *Annual Statistical Bulletin 2007*.

_____, 2008, *World Oil Outlook 2008*.

The Worldwatch Institute, 2007, *Biofuels for Transport: Global Potential and Implications for Energy and Agriculture*, London: Earthscan Publications Ltd.

http://en.wikipedia.org/wiki/Food_vs._fuel, [27 Dec. 2008]

http://en.wikipedia.org/wiki/2000s_energy_crisis [1. Feb. 2009]

논문접수일: 10. 14 / 심사완료일: 10. 23