Interaction among Megatrends and the Paradigm of Low-Carbon Society

Eui Sun Yoo*

ABSTRACT

This paper investigates the interaction among the paradigm of Low-Carbon Society (LCS) and the megatrends in field of population, environment, geopolitics, and energy. The paradigm of LCS is regarded as a 'social will' trend, distinguished from other 'phenomenal' trends. The qualitative analysis shows that the megatrends and the LCS paradigm have positive/neutral/negative impacts on one another, while some impacts can be reversed to other types of impact with the conditions having ripened. In quantitative analysis, the correlation between the LCS paradigm and the economy is traced with our Integrated Assessment Model, looking into such response options as population control, increase in labor force participation, and productivity enhancement to maintain utility level despite the pursuit of LCS paradigm. The future challenges in national strategy and S&T policy are suggested, based on the interaction analyses.

KEYWORDS: megatrends, low-carbon paradigm, interactions, S&T policy challenges

1. INTRODUCTION

Changes in population structure, depletion of energy and resources, accelerating water shortage, decrease in bio-diversity, more frequent occurrence of natural disasters, shift of geopolitical power, intensified global financial crisis, threats of terror, and risks of new technology. All these are adding uncertainties to the future of mankind, making future study more and more important.

*Associate Research Fellow, Future S&T Strategy Center, Science and Technology Policy Institute; esyoo@stepi.re.kr

Especially now, coping with climate change has become a top priority for the global community. The ever accelerating climate change has brought about more frequent and more widely-affecting meteorological disasters. Even the issue of climate security has been raised on the global diplomatic stage, since there are possibilities of climate refugees and conflicts due to the cross-border migration of the refugees in the future.

Developed nations are pursuing Low-Carbon Society (LCS) to resolve climate change and energy issues and achieve sustainable development. The paradigm of LCS is expected to affect a wide range of areas such as energy/resources, environment/eco-system, economy, science and technology (S&T), and life quality.

In this context, this paper investigates the interactions among the future megatrends and the LCS paradigm. Based on the results of the interaction analyses, future challenges in national strategy and S&T policy are suggested. The time window of our analyses is set to 2040 or 2050, i.e. 30~40 years from now. The paradigm of LCS is regarded as a 'social will' trend, distinguished from other 'phenomenal' trends.

2. MEGATRENDS

2.1 Changes in Population Structure

The global population is expected to exceed 7.5 billion in 2020 and reach 9 billion in 2050 (UN, 2006). Population ageing will be further strengthened under the lead of developed countries. In the ageing society, health and welfare of the aged population will emerge as major issues.

On the other end of the spectrum, in developed countries whose population is on the decrease, a transition into a society with low birth will be accelerated further. The population decrease can even threaten the sustainability of a social system. The population gap in developed countries caused by population decrease will be filled with the immigrants from developing countries.

In addition, the concentration of the global population on urban areas will be intensified. The urbanization rate around the world is expected to exceed 60% in 2020, further being strengthened (Canton, 2007). The explosive concentration of population on cities may make acute the conflicts over such issues as employment, welfare, environment, energy, or safety.

2.2 Aggravation of Environmental Issues

If the current situation continues, the temperature of the earth is predicted to increase by 1.1~6.4℃ by 2100 (IPCC, 2007). Diverse disasters due to climate change are of concern. For example, if the globe temperature rises by more than 3℃ compared with that of the pre-industry age, various disasters may occur in the field of food, water resources, flood/waterlogging, and ecosystems (IPCC, 2007; Stern, 2006). The accelerated urbanization will intensify the heat island effect, which will further increase the local temperature. The positive feedback of climate change will amplify climate change itself and likely contribute to the acceleration of the degree of temperature increase.

The economic loss caused by climate change is analyzed to reach 5~10% of the global GDP in the year 2100 (Stern, 2006). The loss will be concentrated on Asia, where rapid population growth and urbanization are underway, and Africa, an agriculture-based society with poor social safety network (IPCC, 2007). In the case of India and countries in South East Asia, national GDP is forecasted to drop by 9~13% in 2100 (Stern, 2006). Since the damages from climate change are forecasted to be concentrated in the poorest countries whose greenhouse gas emission has been quite low, the issue of environmental justice has been raised.

In the future, water shortage will become more prevalent. The Royal Society (2004) of Britain forecasted that 3 billion people in 50 countries would suffer from water shortage in 2025 and almost of the entire world would be affected by water shortage in 2050. Especially, the southern Sahara Desert, East and South Asia, and Oceania are foreseen to suffer most. The current water shortage will be further aggravated by increased water consumption, water contamination and climate change. The climate change will also cause the bi-polarization of water resource, in that the water availability increases in tropical and high-latitude areas but decreases in semiarid and low/mid-latitude areas.

Other environmental issues such as decreasing bio-diversity, increasing toxic substances, and desertification are all becoming more serious. Although the efficiency of utilization of energy and resources has increased in developed countries, the coupling structure between economic growth and environmental load continues (RSBS, 2005).

2.3 Geopolitical Power Shift

The geopolitical power shift to the BRICs is being further accelerated. The growth of the BRICs is expected to drive the global economy by off-setting the economic downturn of developed countries caused by ageing and low growth. In terms of size, China will emerge as the world's number one economy in 2040 (Goldman Sachs, 2003).

The economic growth of China and Russia may bring fundamental changes to the political and diplomatic environment surrounding the Korean Peninsula. These changes may make possible the rapid opening of North Korea and early reunification of the Korean Peninsula. Like the case of East Germany, the collapse of the North Korean regime will be unstoppable once the exodus of North Koreans start to accelerate.

Besides the BRICs, other regional blocks and newly emerging markets are expected to prosper. The economic power of the South East Asian countries (e.g. Vietnam, Indonesia) will become bigger and they are anticipated to form an economic block. Africa also has potential to form regional blocks and achieve economic growth.

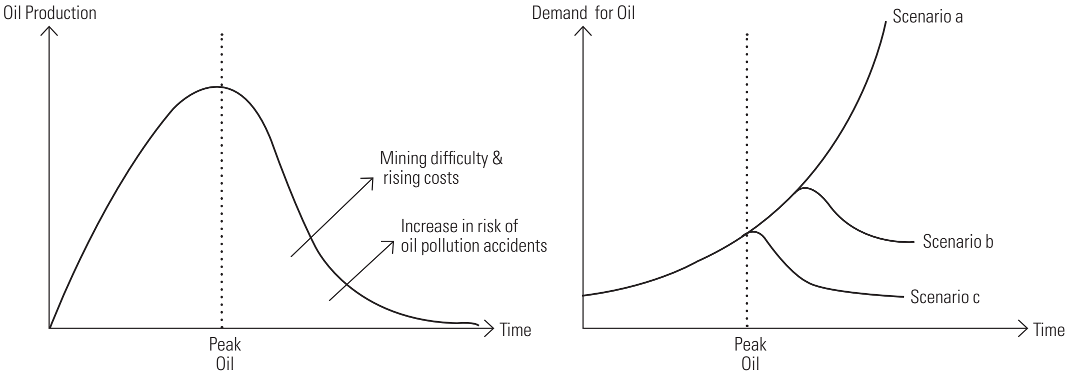
2.4 Era of High Energy Prices

The global energy demand will continue to rise. Over the next twenty years, the world's energy demand is predicted to grow by 50~100% (EIA, 2006/2004). However, the oil reserve is only enough to cover approximately 40 years of world's oil consumption (BP, 2005). The estimation of Peak Oil by many institutions or experts are centered around 2010~2030 (Wingert, 2005; DOE, 2004; Attali, 2009; CAT, 2010).

Oil prices will go up further after the Peak Oil, and the price increase may accelerate more if oil-producing countries become politically unstable. The peak of natural gas production is also foreseen to come in 2030 (Wingert, 2005).

After the Peak Oil, oil production is expected to follow either the path of rapid decrease or that of slow decrease (see FIGURE 1). If demand continues to increase after the Peak Oil (Scenario a), oil production is likely to decrease slowly. However, in case of reduction in demand after adjustment period (Scenario b), or in case of immediate reduction in demand without adjustment period (Scenario c), rapid decrease of production is most likely. In any of these scenarios, since oil production in deep sea or Polar Regions, where oil excavation is difficult, is expected to increase, the excavation cost and risks of pollution will increase. High oil prices will cause the prices of all other energy resources to hike up. As the Peak Oil nears, a momentum for industrial societies to escape from their heavy dependence on oil becomes more apparent.

FIGURE 1 Correlation Scenarios between Peak Oil and Demand for Oil



3. CHARACTERISTICS AND DRIVING FORCES OF THE PARADIGM OF LOW-CARBON SOCIETY

3.1 Characteristics of the Paradigm of Low-Carbon Society

The paradigm of LCS is different from that of High-Carbon Society (see TABLE 1; Yoo, 2008). The paradigm of LCS may be characterized by decoupling between economic growth and environmental load, increased use of knowledge, consideration of future generation, focus on demand management, increase of common use/occupancy, decentralized socioeconomic structure, and multilateral cooperation.

TABLE 1 Comparison of High-Carbon vs. Low-Carbon Society Paradigms

Classification	High-Carbon Society	Low-Carbon Society
Relations Between Economy and Environment	- Coupling: economic growth is coupled with increased load on environment - Trade-off	- Decoupling: economic growth is not coupled with increase in environmental load - Economy is operated within the scope of environmental capacity
Use of Resources vs. Knowledge	- High consumption of resources (Resource-intensive)	- High consumption of knowledge (Knowledge-intensive)
Goals of Environmental Management	- Environmental performance - Satisfying environmental criteria	- Environmental sustainability - Consideration of future generation - Social sustainability is also relevant
Focus of Management	- Supply-side	- Demand-side
Innovation System	- Innovation system focused on resource consuming materials - Innovation system based on catch-up mode	- Green innovation system focused on human and value - Creative innovation system

Classification	High-Carbon Society	Low-Carbon Society
Framework of Game	- Competition - Zero-Sum	- Mutual benefit - Win-win
Ownership Relations	- Ownership emphasized	- Sharing emphasized (e.g.: "Velib", a bike pool in Paris)
Development Index	- GDP	- Green GDP - Social/ecological/economic indices
Technology/Process/Product Competitiveness	- Price and quality	- Price and quality - Degree of Greening*
Energy Source	- Fossil fuel energy	- Renewable energy
Material Source	- Petrochemical-based material	- Bio-based material
Main Technology Level	- High-Tech	- High-Tech - Low-Tech
Key Industry	- Petrochemical-based industry - Manufacturing - IT - Finance	- Energy/environment - Energy/environment market + IT - Knowledge-based service industry
Market with Booming Market Opportunities	- Manufacturing market - IT and some new technology market - Financial market	- Carbon market - Energy/environment market (including water) - Markets where new technologies are related with energy/ environmental industries (e,g.: IT)
Socio-Economic Structure	- Centralization - Focus on central government	- Decentralization - Focus on local autonomy
International Relations	- Standing issues between South and North - International relations dominated by advanced countries	- Cooperation between developed and developing countries on global issues - Multilateral cooperation

** Low energy + low material + low pollution exhaustion + long life span + dematerialization.*

3.2 Dynamic Relations in the Paradigm Shift from High-Carbon to Low-Carbon Society

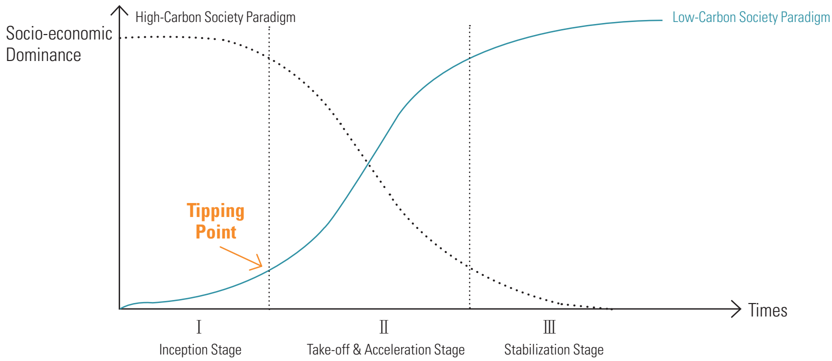
The paradigm of LCS has been created, as the existing paradigm of High-Carbon Society has many problems. The paradigm of LCS is rooted amidst the competition against the existing dominant paradigm of High-Carbon Society. During the early stage, the conflict between the two paradigms is especially intense(see FIGURE 2; Yoo, 2008).

During the inception phase of LCS paradigm, it is disadvantaged, as this new paradigm needs to root itself in the infrastructure and value chain of High-Carbon Society. Therefore, the following wedge factors are needed to overcome the disadvantages for the LCS paradigm: technological push, socio-economic pull, and civil society support. The time it takes to reach the 'Tipping Point' from inception phase is determined by two factors -- the gap in the socio-economic dominance between the old and new paradigms and the intensity of the wedge for the new paradigm.

Once the Tipping Point is reached, the LCS paradigm rapidly expands. During this take-off phase, market competitiveness is strengthened, more jobs are created, socio-cultural superstructure shifts including changes in consumption pattern. Policy support for low-carbon technologies that have already gained competitiveness can be reduced while policy support for less competitive low-carbon technologies increases.

During the stabilization phase, both economic substructure and socio-cultural superstructure are operated under the new LCS paradigm. Also the paradigm reproduction structure is solidified.

FIGURE 2 Dynamic Relations in the Paradigms Shift from High-Carbon to Low-Carbon Society



4. INTERACTION AMONG MEGATRENDS AND THE PARADIGM OF LOW-CARBON SOCIETY

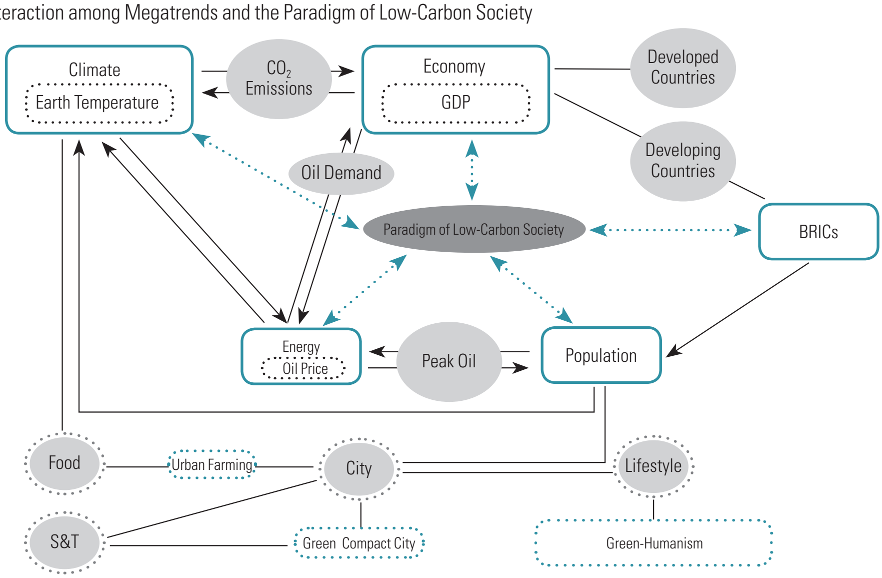
4.1 Qualitative Analysis of Interactions

4.1.1 Direction of Qualitative Analysis

The qualitative analysis looked into the multiple interactions among the megatrends in population, environment, geopolitics and energy, and the paradigm of LCS (see FIGURE 3).

We utilized a 5:5 matrix composed of four 'phenomenal' and one 'social will' megatrends to make the qualitative analysis on whether they have positive(+)/neutral(0)/negative(-) impacts on one another. The positive impacts are the impacts which stimulate the respective trends, while the negative impacts are those which reduce or curb the respective trends, and the neutral impacts are those which have no relation with the respective trends. Notable is that the impacts can be reversed to other types of impact after time passes or related thresholds are reached.

FIGURE 3 Interaction among Megatrends and the Paradigm of Low-Carbon Society



4.1.2 Impacts of Population Megatrend[1]

The megatrend of population increase has a positive impact on that in energy field (see TABLE 2). Population increase leads to higher energy demand, thereby stimulating the rise of energy prices.

The impact of population increase on the consumption amounts and prices of energy will be differentiated by the development stages of non-advanced countries that are mostly accountable for the population increase. The impact of population increase in developing or middle-income countries on energy fields will be significant, but that in the poor and poorest countries only slight.

TABLE 2 Interaction Matrix for the Qualitative Analysis

Megatrends by field		Population	Environment	Geopolitics	Energy	Social will
		Population increase & Change in population structure	Acceleration of climate change & Decrease in environmental capital	Growth of BRICs	Era of high energy prices	Paradigm of Low-Carbon Society
Population	Population increase & Change in population structure		⊕	⊕ / ⊙	⊕	⊖*
Environment	Acceleration of climate change & Decrease in environmental capital	⊖		⊖	⊕	⊕
Geopolitics	Growth of BRICs	⊕	⊕		⊕	⊖*
Energy	Era of high energy prices	⊖	⊖	⊖		⊕
Social will	Paradigm of Low-Carbon Society	⊖ / ⊙	⊖	⊖*	⊕	

Notes: ⊕ *Positive impacts: those to stimulate the respective trends.*
⊖ *Negative impacts: those to curb the respective trends.*
⊙ *Neutral impacts: those neutral or irrelevant to the respective trends.*
* *Impacts that can be reversed to other types of impact.*

The environmental impact of population increase is positive. The increase in consumption of energy and resources due to more population will further accelerate the climate change and the decrease in environmental capital. The impact difference between the developing vs. poorest countries will not be significant in the environment field, unlike that in the energy field, because poverty will lead to the exploitation of natural or environmental capital.

There are two aspects of the impact of population megatrends on the geopolitical shift. Changes in population structure have a positive impact on the growth of BRICs (first aspect). Population increase in the BRICs countries will support their labor-based economic growth.

[1] Only the impacts of population megatrend, energy megatrend, and the LCS paradigm were described here. Also those of environment and geopolitics megatrend may be depicted in the analogy (see TABLE 2).

Population ageing and decrease will weaken the competitiveness of developed countries, eventually bringing about the advantage of BRICs. However, the economic growth of developing nations that depend on the labor-based product exports will be limited in the long run and the nations will also enter an ageing society in near future. When this happens, the change in population structure will gradually have a neutral impact on the growth of BRICs (second aspect).

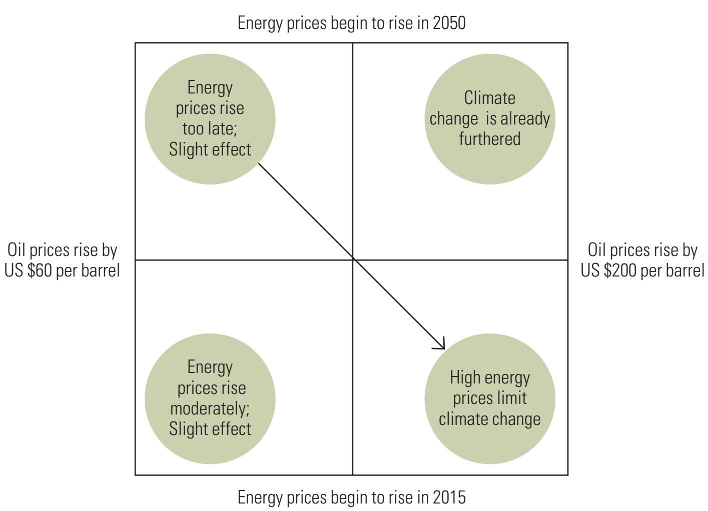
The megatrend in population has a negative impact on the paradigm of LCS. This is because the increase in carbon emissions, which are accompanied by population increase mainly in developing countries, is an obstacle to the transition into a LCS. However, in the mid-long term, the great increase in population may lead to the heightened interest in environment and energy issues and the greater demand for higher quality of life, gradually increasing the positive impact which solidifies the paradigm of LCS. Ageing can have a neutral or positive impact on the paradigm of LCS. Demands for higher quality of life in ageing societies will be in harmony with the paradigm of LCS, which lowers emissions of pollutants.

4.1.3 Impacts of Energy Megatrend

The megatrend in energy field has a negative impact on that in population field (see TABLE 2). The rising energy prices may weaken the trend of population increase in developing countries. However, the level of this impact may differ among developing countries, according to the economy level and the importance of energy in the economy. In developing countries where population is well managed, the limiting effect of energy prices on population increase will not be embossed. In most poor economies, where the population increase is distinctive, the limiting impact will be small, as oil is not significantly important in their economy.

The megatrend in energy field has a negative impact on the environment field. Particularly, rising energy prices will weaken the acceleration of climate change. However, the limit of the average rise of earth temperature to 2℃ by 2050 will depend on the level of energy prices and the time for the prices to rise substantially. The higher that energy prices become and the more rapidly the prices rise, the greater restraining effect on climate change will be (see FIGURE 4).

FIGURE 4 Limiting Effect of The Extent and Time of Rising Energy Prices on Climate Change



The megatrend in energy field has a negative impact on geopolitics. Rising energy prices will reduce the growth rate of BRICs. Large parts of the growth of BRICs are based on the move of labor-intensive and high-energy/pollutants accompanying industries from developed nations to BRICs.

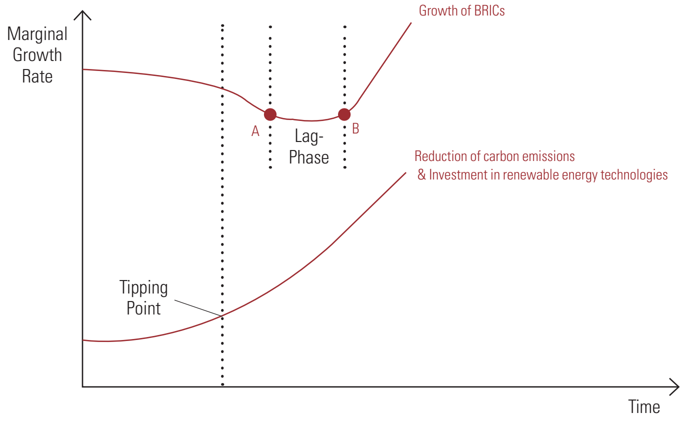
The megatrend in energy field has a positive impact on the paradigm of LCS. The era of high energy prices will encourage the paradigm of LCS. This is because energy saving and energy efficiency are economically beneficial to all individuals, enterprises, public sectors and countries due to high energy prices. The policy drive for high energy prices may directly lead to a swift transition into a LCS. Once external carbon costs become internalized according to international agreements, a comparative disadvantage, in terms of export prices among countries, may no longer be an issue

4.1.4 Impacts of the Paradigm of LCS

The paradigm of LCS has a neutral or negative impact on the megatrend in population field (see TABLE 2). In the case that the adoption and proliferation of the LCS paradigm is made at a low level, the impact on population field will be slight. Although the adoption and proliferation of the LCS paradigm is made at a high level, the impact on population field in the developed countries will be almost non-existent, since their population decreases or remains even. If the LCS paradigm is spread worldwide, the curbs on population increase in developing countries will be connected with the reduction of carbon emissions, probably boosting their birth control policies. This is a case where the paradigm of LCS has a negative impact on the megatrend in population field.

The paradigm of LCS has a negative impact on the megatrend in the environment field. It will limit the acceleration of climate change and the decrease in environmental capital. The paradigm of LCS has a negative impact on the megatrend in geopolitical field. The paradigm of LCS will act as a brake to the growth of BRICs. However, the impact of LCS paradigm on the geopolitical shift may turn into a positive (see FIGURE 5). The main question is when and to what extent each economy can transition from high-carbon to low-carbon, from resources-intensive to knowledge-intensive and from manufacturing-centered to services-centered structures. Another key is when and to what ex-

FIGURE 5 Impact of the Paradigm of Low-Carbon Society on the Growth of BRICs



Notes: A: Time point that the limiting effect of LCS paradigm on the growth of BRICs diminishes greatly.
B: Time point that the LCS paradigm begins to have a positive impact on the growth of BRICs.
AB: Transition time or lag-phase, in which the effect of the LCS paradigm that passed over Tipping Point is delivered on the growth of BRICs.

tent each economy can invest in low-carbon technologies. In the case that the LCS paradigm fails to proliferate broadly, its impact on the growth of BRICs will be only slight (neutral).

The paradigm of LCS has a positive impact on the megatrend in energy field. The paradigm of LCS will directly and indirectly strengthen the era of high energy prices. 'Carbon pricing' to realize the paradigm of LCS is expected to increases the prices of fossil fuels. Also, in the case that renewable energy begins to be introduced into the market on a full scale, it will hold the high prices of energy and power within the mid-term.

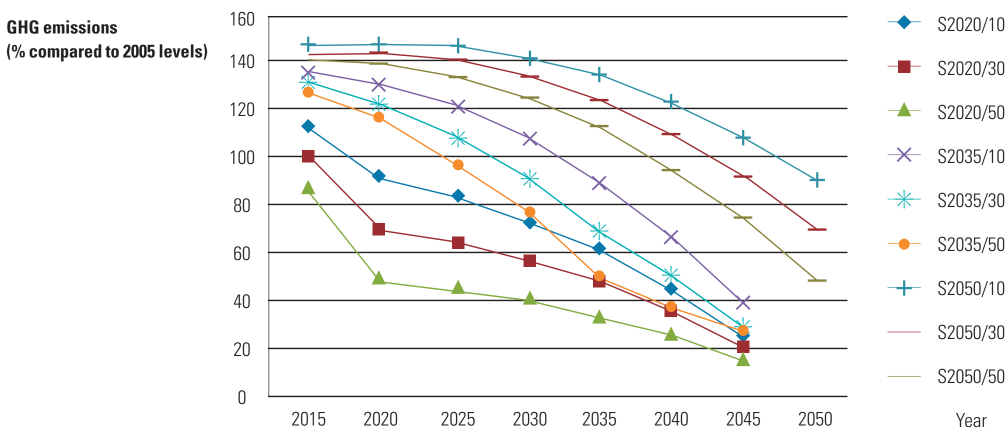
4.2 Quantitative Analysis of Interactions

4.2.1 Direction of Quantitative Analysis

The model applied to our quantitative analysis was the Integrated Assessment Model (IAM) (see Appendix II). This model analysis was focused on the interaction between the climate change and the economy. Time window was set to 2010~2050, while the comparisons were made with the levels of 2005. The entire world was regarded as one entity, so that no differentiation was made on a regional level. Items studied through this model were as following:

- Low-Carbon Societies in nine scenarios (see FIGURE 6) by differentiating the reduction of greenhouse gas (GHG) emissions by period (2020/2035/2050) and extent (10/30/50% compared to the levels of 2005)
- Feedback relations among production – greenhouse gases – capital - investment
- Response instruments to offset the decreased utility due to the reduction of GHG emissions: population control, increase in labor force participation, etc.
- Pessimistic and optimistic outlooks on the future by varying total population size, labor force participation rate, and total productivity

FIGURE 6 GHG Emission Trends by Scenarios: Compared to 2005 Level



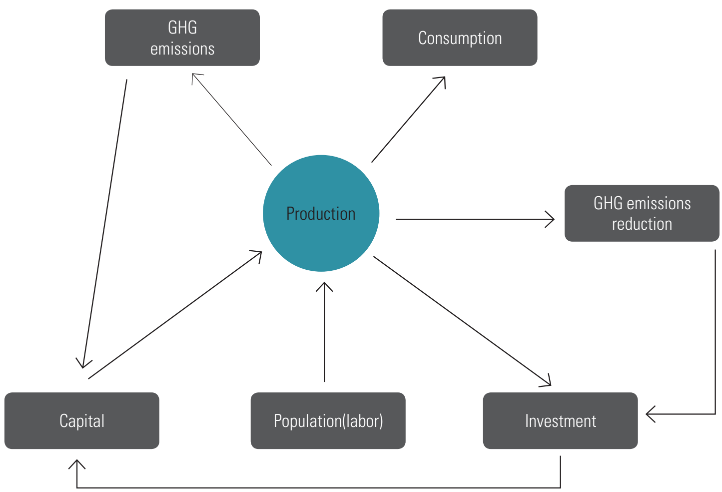
Notes: For example, S2020/10 indicates the scenario for the GHG reduction of 10% by 2020.

4.2.2 Model Structure and GHG Reduction Impacts

Our model was divided into economy and climate change parts (see FIGURE 7). It had higher simultaneous equations which used GAMS MINOS to maximize utility. The rate of capital decrease to be caused by the reduction of GHG emissions was determined by a linear equation.

① Production = f(Capital, Labor)
② Production = Consumption + Investment + Reduction of GHG emissions
③ Capital (T+1) = (1-Depreciation rate)*Capital(T)+Investment(T)
④ GHG emissions = f(Production)
⑤ Capital(T+1) = (1-Depreciation rate-Capital decrease rate(T))*Capital(T)+Investment(T)
⑥ Capital(T+1) = (1-Depreciation rate-Capital decrease rate(T))*Capital(T)+Investment(T) *(1-Investment decrease rate)
⑦ Utility per capita(T) = Consumption(T)/Total population(T)
⑧ Total utility = Sum of utility per capita

FIGURE 7 Correlation between the Reduction of GHG Emissions and the Economy in Our Model



Basic data applied to the model were like Appendix I. Population data were divided into those of the total population and the population with the age of 15~64. The labor force was assumed to be 60% of the population with the age of 15~64.

Baselines were needed to conduct the scenario comparison analysis. As to the BAU (Business As Usual) basis, which means that the current conditions continue without substantial efforts of GHG reduction, the following two baselines were applied:

- YI (Yes Impact) is the baseline where GHG emissions have an impact on capital (Capital decrease rate ≠ 0).
- NI (No Impact) is the baseline where GHG emissions presumably have no impact on capital (Capital decrease rate = 0).

The impacts of GHG reduction rates by scenario on the total production and utility levels were summarized as following (see TABLE 3, 4, 5; FIGURE 8)[2]:

- For identical reduction rates, the later the target years, the less the decrease ranges of total production, per capita utility, and total utility.
- For identical target years, the lower the reduction rates, the less the decrease ranges.
- For identical conditions, the decrease ranges to YI-basis were less than those to NI-basis.

TABLE 3 GHG Reduction Impact According to Scenario S2020/50 (%)

Comparison basis	Year / Factor	2015	2020	2025	2030	2035	2040	2045	2050
YI	Production amount	-0.289	-0.836	-1.465	-2.038	-2.591	-3.146	-3.719	-4.319
	Individual utility	-0.42	-1.032	-1.67	-2.253	-2.815	-3.379	-3.961	-4.57
	Total utility	**-2.23**							
NI	Production amount	-0.417	-1.008	-1.669	-2.268	-2.843	-3.416	-4.006	-4.621
	Individual utility	-0.548	-1.203	-1.873	-2.482	-3.066	-3.649	-4.248	-4.872
	Total utility	**-2.44**							

Notes: Data are the marginal increase/decrease rates compared with the YI- and NI-baseline.

TABLE 4 GHG Reduction Impact According to Scenario S2035/30 (%)

Comparison basis	Year / Factor	2015	2020	2025	2030	2035	2040	2045	2050
YI	Production amount	-0.142	-0.409	-0.772	-1.233	-1.797	-2.44	-3.136	-3.895
	Individual utility	-0.206	-0.506	-0.9	-1.393	-1.987	-2.652	-3.368	-4.147
	Total utility	**-1.678**							
NI	Production amount	-0.27	-0.582	-0.977	-1.465	-2.051	-2.713	-3.425	-4.198
	Individual utility	-0.334	-0.678	-1.105	-1.624	-2.24	-2.923	-3.656	-4.45
	Total utility	**-1.888**							

Notes: Data are the marginal increase/decrease rates compared with the YI- and NI-baseline.

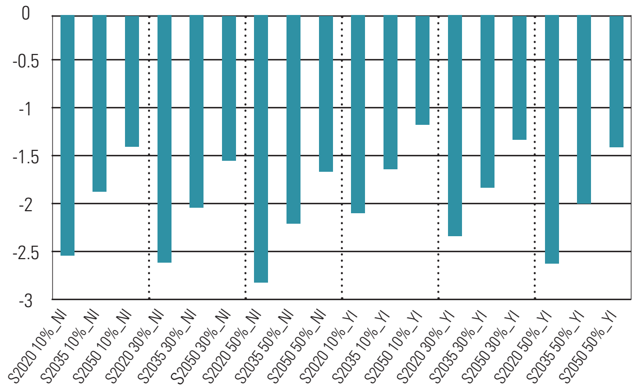
TABLE 5 GHG Reduction Impact According to Scenario S2050/10 (%)

Comparison basis	Year / Factor	2015	2020	2025	2030	2035	2040	2045	2050
YI	Production amount	-0.094	-0.272	-0.512	-0.818	-1.191	-1.635	-2.151	-2.741
	Individual utility	-0.137	-0.336	-0.597	-0.924	-1.318	-1.782	-2.318	-2.929
	Total utility	**-1.141**							
NI	Production amount	-0.222	-0.444	-0.718	-1.05	-1.447	-1.909	-2.443	-3.048
	Individual utility	-0.265	-0.508	-0.803	-1.156	-1.573	-2.056	-2.61	-3.235
	Total utility	**-1.353**							

Notes: Data are the marginal increase/decrease rates compared with the YI- and NI-baseline.

[2]Only the tightest, the moderate, and the loosest scenario (three ones of the nine scenarios) are shown in TABLE 3, 4, and 5.

FIGURE 8 Changes in Production Amount for 2035 by 9 Scenarios: NI and YI Basis (%)



4.2.3 Simulation of the Impact of Population Ageing under the GHG Reduction

The economic aspect concerned about population ageing is the increase of dependent population. In order to examine the impact of ageing on the economy, the simulation was so designed that the total population increased with no change in labor force size but with increase in productivity.

The simulation result in TABLE 6 shows that if the size of labor force participation remains unchanged but the dependent population rises by 5% due to the ageing, the GHG reduction (S2035/30) will decrease the total utility, unless the productivity increases by more than 4%. It seems almost impossible that the world economy continue to improve the total productivity by 4% every year under the current S&T levels. This means that the impact of ageing on the economy will be enormous.

TABLE 6 Total Utility Levels According to Improved Productivity : 5% Increase of Total Population Accompanied by Ageing; the Size of Labor Force Participation Fixed

(Unit: %)

Productivity: rate of change	Total utility: rate of change	Utility per capita : rate of change	Total production amount: rate of change	Note
0	-3.934	-4.762	0	Only population increase assumed
3.5	-0.408	-0.327	4.657	
3.6	-0.306	-0.199	4.791	
3.7	-0.205	-0.072	4.925	
3.8	-0.104	0.056	5.058	
3.9	-0.002	0.183	5.192	
4.0	0.099	0.311	5.326	

Notes: Data are the results of comparison with the case that both rates of population growth and productivity are zero. Time points for the change rates of utility per capita and total production amount are 2035.

4.2.4 Outlook on Response Levels under the GHG Reduction

Mankind will try to prevent the fall in utility due to GHG reduction. In order to keep utility levels steady, in spite of the GHG reduction, one of the following methods may be utilized.

• Decrease of total population: transition towards a low-birth society in the long run
• Higher labor force participation

In this context, we made simulations for two response options where the scenario S2020/30 was the object of comparison, and the comparison time of utilities was 2030, ten years from 2020. The first simulation showed that as a result of GHG reduction, the utility per capita decreased to US$9,416 from US$ 9,607 (see TABLE 7). The size of total population required to keep the utility per capita (i.e. US$ 9,607) despite the GHG reduction was 8,143 million persons. This means that the size of population decrease required amounted to approx. 165 million persons, which was nearly equal to 2% of the total population at that time.

The second simulation result was that in order to maintain the utility levels identical to those prior to the 30% GHG reduction by 2020, the global participation rate of labor force in 2030 had to increase by 2.2%, meaning that approximately 72 million persons had to be additionally employed (see TABLE 8).

TABLE 7 Estimation of Population Control Size under the GHG Reduction(S2020/30): Size of Excess Population in 2030

Category	Before reduction of GHG emissions (YI)	After reduction of GHG emissions	Unit
Utility per capita	9607	9416	US$
Total population	8308.895		Million persons
Size of population that can keep the untility level	-	8143	
Size of population decrease required to keep the utility level	-	165	

TABLE 8 Estimation of the Additional Size of Labor Force Required under the GHG Reduction: based on S2020/30

Item	Result
Rate of additional labor force participation required	2.2%
Size of additional labor force participation required	72million persons

Notes: Labor force size in 2030 is 3,273 million persons.

4.2.5 Outlook on Optimistic and Pessimistic Scenario

In order to have outlooks on optimistic and pessimistic futures, we varied the population size, labor force size, and productivity in comparison with those of neutral scenario (see TABLE 9). However, the rate of GHG emission reduction was kept fixed as S2035/30.

In the optimistic scenario of 2035, the total utility, per capita utility, and total production amount increased according to the decrease in population, increase in labor force participation, and enhancement of productivity.

In the pessimistic scenario of 2035, the total utility, per capita utility and total output decreased according to the increase in population, decrease in labor force participation and reduction of productivity.

TABLE 9 Total Utility, Per Capita Utility, World Production Amount According to Optimistic and Pessimistic Scenarios

Scenario	Description	Total utility	Utility per capita	Total production amount
Optimistic	-GHG reduction by 30% in 2035 -Compared to neutral scenario • total population: 95% • labor force: 105% • productivity: 100.5%	464.397 (8.796%)	$11,139 (10.858%)	$121.159tn (5.315%)
Neutral (Basic)	-GHG reduction by 30% in 2035	426.853	$10,048	$115.044tn
Pessimistic	-GHG reduction by 30% in 2035 -Compared to neutral scenario • total population: 105% • labor force: 95% • productivity: 99.5%	393.010 (-7.928%)	$8,558 (-9.779%)	$108.984tn (-5.268%)

Notes: Data in brackets are increase/decrease rates compared with the data of the neutral scenario.

4.2.6 Limits of Our Model and Research Challenges

This analysis regarded the entire world as one unity. Though, separate analyses on developing nations, developed nations, and BRICs may provide more locally relevant information in understanding the future society.

In the model, it is desirable to consider not only costs but also benefits by GHG reduction, which also helps to determine the time, method, and size of the GHG reduction. Benefits will be diverse in terms of economy, environment, society, and health.

The outlook on the future society by variation of the price of fossil fuels (the main cause of GHG emissions) will be also meaningful in the economic context. Into our model, we have yet to incorporate the change in globe temperature and the various results of climate change. The impact of the 'acceleration' of climate change should also be considered in the model.

5. CHALLENGES IN SCIENCE & TECHNOLOGY IN THE FUTURE SOCIETY

5.1 Challenges in National Strategy and S&T Policy to Respond to the Megatrend in Population

To effectively respond to the megatrend in population, it is necessary to strengthen health and welfare service of the aged society and diffuse S&T (e.g. age-mix technology) that supports aged population (see TABLE 10). As the immigrants from developing countries increase, technologies for cultural/socio-mix are also important.

From long-term perspective, a scenario should be developed to prepare for the transition into a society with low birth. The scenario should touch on such issues as the development of ways to maintain labor force, and the development of measures to tackle economic, welfare, and social problems including pension and insurance. Policies to reduce burdens on the young generation during the transition period should be developed.

At the same time, a mechanism should be developed, in cooperation with developed nations, which supports the policies and S&T that limit population growth in developing nations. It is also needed to diffuse S&T that can minimize the consumption of energy and resources accompanied by population growth.

TABLE 10 Summary of Korea's strategies in Response to Megatrends

Field	Megatrends	Core causes/ phenomena/results	Response strategies
Population	Population Increase & Change in Population Structure	• Population increase in developing countries • Ageing and Population decrease in developed countries	• Support policies and S&T to limit population increase in developing countries • Proliferation of S&T to minimize the energy and resources consumption according to population increase (high-efficiency technology, etc.) • Strengthening of health and welfare services in the ageing society, and development and diffusion of S&T which supports aged people • Policy-making to maintain migration from developing countries to desirable levels and strengthening of social-mix technology based on multi-culture • Development of a 'Low-Birth Society Scenario' in preparation for the future transition to a low-birth society
Environment	Acceleration of Climate Change & Decrease in Environmental Capital	• Rise of the globe temperature due to emission increase and absorption decrease in greenhouse gas • Decrease in biodiversity and water shortage	• International cooperation to maintain the global temperature rise to 2℃ in 2050 • Establish emergency plans for the case of global temperature rise beyond 2℃ in 2050 (food, water resources, flood, ecosystem, climate refugees & conflict) • Introduction & spread of environmental taxes to lower environment capital reduction • Stimulation of Ecosystem Preservation Trust and creation of eco-friendly city structures • Proliferation of policies and S&T to facilitate water demand management and water recycling • Development of international mechanisms to stimulate transition away from an economy based on disruption of environment resources in developing countries (CDM-like application)
Geopolitics	Rise of BRICs	• Heightening economic, political and diplomatic positions of BRICs	• Establishment of plans to address oil price hike, resources depletion (esp. rare minerals) and environment capital reduction strengthened by growth of BRICs • Stronger East Asia cooperation and R&D to respond to trans-border pollutions in the region • Establish scenarios for the reunification of Korea connected with the growth of China and Russia: including possibility of large population migration
Energy	Era of High Energy Prices	• Demand increase (by growth of BRICs etc.) and Nearing of Peak Oil	• Establish a contingency plan for high oil prices ($100/$200 per barrel): including the response to energy poverty • Set up a strategy to transition to knowledge-intensive industries/services : low energy/resources-based • Pursue carbon pricing & incentive policies for energy conservation & efficiency • Policy for desorption from high-carbon path-dependency : e.g. making the public buildings carbon-neutral • Stronger R&D of new combinations of 'sources + carriers' of future energy • Establishment of "Long-term national strategy to improve built environment": introduce quotas on self-produced renewable energy from new buildings, and develop 'Zero-Carbon Special Zone' etc. • R&D for sustainable future energy systems and built environment: e.g. research to improve the integration of national land and energy plans, and to prepare for electric-based transportation pattern of the future
Social will	Paradigm of Low-Carbon Society	• Energy efficiency, Energy shift, and Natural sink	• Increase of R&D investment in low-carbon technology : investment in advance for the social cost of climate change • Establish an adequate national reduction goal for greenhouse gas emissions • Apply and spread the carbon tax and emission trading system • Facilitate the change of consumption pattern through carbon-footprint labeling for products • Strengthen R&D of low-entropy energy technology: off-shore wind power, second/third-generation photovoltaics, battery/fuel cells, smart/micro-grid, energy storage and transmission technology • Facilitate of soft solutions for a LCS: establish related DB & knowledge banks

Notes: CDM means CLean Development Mechanism.

5.2 Challenges in National Strategy and S&T Policy to Respond to the Megatrend in Environment

To effectively respond to the megatrend in environment, it is necessary to strengthen international cooperation to control temperate increase within 2℃ in 2050, compared with that of pre-industry age. A contingency plan should be developed for the temperature increase of more than 2℃ in 2050. The key contents of this plan should cover such topics as food, water resources, flood, ecosystem, climate refugees and conflicts.

In addition, environmental tax should be introduced and applied to a wider extent to prevent the reduction of environmental capital. At the same time, it is also necessary to promote eco-trust for the preservation of eco-system and to make urban structures eco-friendly. Wide application of policies and S&T that stimulate water demand management and water recycling is also desirable. An international mechanism (e.g. a mechanism like Clean Development Mechanism) that promotes a transition of the economy in developing nations away from that based on the disruption of environmental resources is also required.

5.3 Challenges in National Strategy and S&T Policy to Respond to the Geopolitical Megatrend

To effectively respond to the geopolitical megatrend, it is necessary to develop a plan to prepare for the depletion of energy and resources (e.g. scarce minerals) and the decrease of environmental capital accompanied by the growth of the BRICs. It is also needed to strengthen the cooperation and joint R&D in East Asia to effectively address the cross-border pollution in the region. Besides, it is important to develop a scenario of Korea's reunification considering the influence from the growth of China and Russia. In this scenario, the possibility of massive migration of North Koreans should be included.

5.4 Challenges in National Strategy and S&T Policy to Respond to the Megatrend in Energy

To effectively respond to the megatrend in energy field, it is necessary to develop a contingency plan to prepare for high oil prices (e.g. $200 per barrel or higher). This plan should include the measures to cope with energy poverty. Additionally, it is necessary to pursue a strategy to shift industry and service into being low energy/resources-consuming but knowledge-intensive. At the same time, it is important to implement policies of the carbon pricing and the incentives for energy saving and efficiency.

It is also reguired to pursue policies that weaken the country's path-dependency on high-carbon growth. For this purpose, Korea should lead through examples, including carbon neutralization of public buildings, and foster social energy enterprises with close linkage with regional economy.

It is desirable to strengthen R&D for new combination of 'sources' and 'carriers' of future energy. For example, such combinations of renewable energy and electricity/battery or renewable energy and hydrogen look promising. In accordance with the future energy shift, Korea should develop 'a long-term national strategy for improving built environment'. In this strategy, the prospects for population structure, real estate economy, and reunification should be reflected. As part of this strategy, a quota system for energy production within new buildings to generate renewable energy and some special zones like 'Zero-Carbon Special Zones' should be established.

The R&D to achieve sustainable future energy system and built environment is necessary. A study on future transportation system using electricity as main energy source and a study on the integration of national land and energy plans may be the examples.

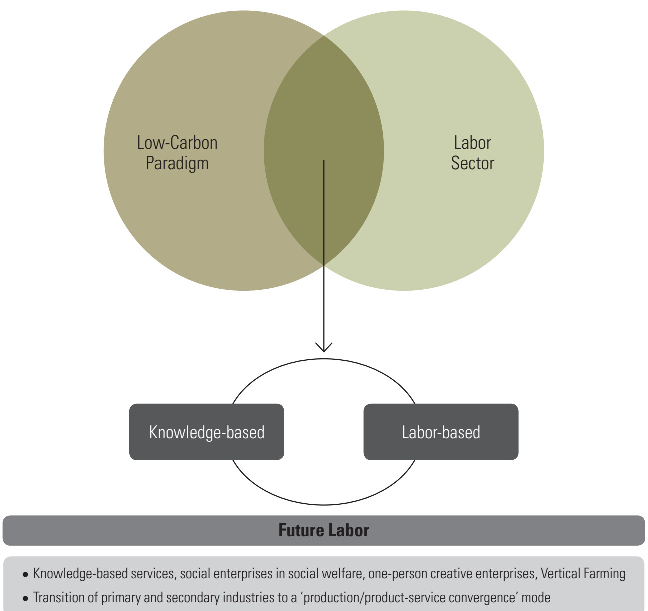
5.5 Challenges in National Strategy and S&T Policy to Respond to the Paradigm of LCS

To effectively respond to the paradigm of LCS, it is crucial to expand R&D investment in low-carbon technologies. This means Korea should make preemptive investments to reduce economic losses to be caused by climate change (e.g. 0.5% of GDP or more). It is also important to develop national long-term scenarios for reducing GHG emissions. The energy-mix plan should be prepared for both tight and loose scenarios.

At the same time, Korea should adopt carbon tax and emission trading system and apply them to a broader extent. It is desirable to foster changes in consumption patterns by introducing carbon footprint labeling system for products. The carbon footprints for products should be tracked covering their whole life cycle, from materials sourcing to production, distribution, consumption and disposal.

With the realization of a LCS, it is necessary to connect a strategy that promotes labor force participation (see FIGURE 9). The simultaneous pursuit of knowledge and labor is key to link the LCS paradigm to the labor sector in long-term. This means it is essential to transform the economic system into one that reduces resources input (energy and materials) but increases labor input. In line with this transformation, it is required to implement policies for the increase in labor force participation through knowledge-based service, social enterprises in social welfare sector, creative venture

FIGURE 9 Link between the Low-Carbon Paradigm and the Labor Sector



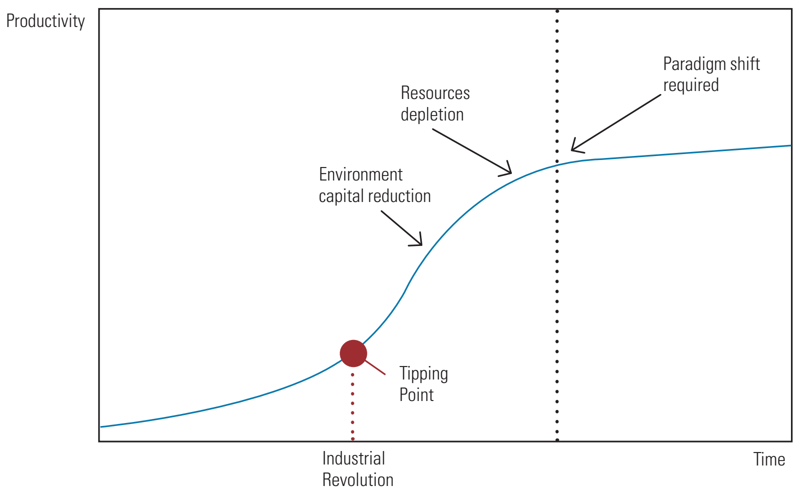
companies, or vertical farming. Also, the shift of traditional 1st or 2nd industries into the 'product and service convergence' mode that combines production with service is worthwhile for stimulation. The R&D for low-entropy energy technologies should be reinforced. The examples include off-shore wind power, 2nd and 3rd generation photovoltaics, battery/fuel cell, smart/micro grid, and energy storage and distribution technology.

In the long term, Korea should prepare the era of qualitative development, which implies socio-economic transformation based on 'dematerialization' (see FIGURE 10). The era of qualitative development means the future era when productivity improvement becomes difficult to be sustained. The decrease of environmental capital and the resources depletion will push productivity to reach its limit.

A path to address the limit in productivity enhancement in the future is to promote low-carbon technology including energy efficiency (Weizsäcker et al., 1997). Low-carbon technology may contribute to the maintenance or enhancement of productivity, due to its mitigation of progress of environmental capital decrease and resources depletion.

Another substantial path is to stimulate low-entropy soft solutions, e.g. with establishing the soft solutions database or knowledge bank. Soft solutions can reduce energy and material input, as they prefer the systematic solutions such as demand management, approach improvement and diffusion of best practices to the supply-based solutions.

FIGURE 10 S-Curve of Productivity Enhancement in the Human History and the Transition to a Qualitative Development Paradigm



References

Attali, J. *"Survivre aux Crises."*, Paris : Librairie Arthème Fayard. 2009.

BP (British Petroleum). *"British Petroleum Statistics 2005."* 2005.

Canton, J. "The Extreme Future." Dutton. 2006.

CAT (Center for Alternative Technology). *"Zero Carbon Britain 2030."* 2010.

DOE (U.S. Department of Energy). *"Strategic Significance of America's Oil Shale Resource."* 2004.

EIA (Energy Information Administration of USA). *"International Energy Outlook 2004.* DOE/EIA-0484. 2004.

____. *"International Energy Outlook 2006."* DOE/EIA-0484. 2006.

Goldman Sachs. "Dreaming With BRICs: The Path to 2050." *Global Economics Paper* (2003), No. 99.

IPCC (Intergovernmental Panel on Climate Change). *"IPCC 4th Assessment Report."* 2007.

Royal Society. *"Tomorrow's water supplies."* 2004.

RSBS (Research on the Scientific Basis for Sustainability) of Japan, *"Science on Sustainability 2006."* 2005.

Schwartz, P. and D. Randall. *"An Abrupt Climate Change Scenario and Its Implications for United States National Security (Marshall's report)."* GBN. 2003.

Stern, N. *"Stern Review: The Economics of Climate Change."* 2006.

UN (Population Division). *"World Population Prospects: The 2006 Revision."* 2006.

Weizsäcker, E. U., A. B. Lovins and L. H. Lovins. *"Faktor Vier."* Knaur. 1997.

Wingert, J.-L. *"La via après le pétrole."* Autrement. 2005.

Yoo, E. S. *"Driving Forces of Low-Carbon Society and Characteristics of Related Technologies."* Science & Technology Policy Issues. Science & Technology Policy Institute. 2008.

APPENDIX I - BASIC DATA APPLIED TO OUR MODEL

· **Population**

Size: 6.514bn persons (2005), 9.15bn persons (2050)

Source: UN Population Survey

· **Production amount of the world economy**

Size: US$6.1tn

Source: DICE Model of 2007

· **Size of the world capital**

Size: US$137tn

Source: DICE Model of 2007

· **Annual depreciation rate of capita**l

Size: 10%

Source: DICE Model of 2007

APPENDIX II - DETAIL OF OUR MODEL FOR QUANTITATIVE ANALYSIS

sets

T time period /2005*2050/

tf first period

tl last period

SCALARS

DK Depreciation rate on capital per year /.100/

GAMA Capital elasticity in production function /.300/

Q0 2005 world gross output trill 2005 US dollars /61.1/

K0 2005 value capital trill 2005 US dollars /137.0/

EMISSION_2005 emission adjusted for 2005 /3.261/

r rate of social time preference per year /.015/

sd scale factor for damages /0.01/

sa scale factor for abatement /0.001/

PARAMETERS

AL(T) level of total factor productivity

POP(T) total population

POP1564(T) population 15-64

LPOP(T) labor force in POP1564

ZK(T) dummy for damages to capital

ZE(T) dummy for emission

ZP(T) dummy for labor force

zy(t) dummy for productivity

zkk(t) dummy for zk(t)

VARIABLES

C(T) consumption

K(T) capital stock

I(T) investment

S(T) savings rate

DAMAGE(T) damages

EMISSION(T) emission

ABATE(T) abatement

UTILITY total utility

Y(T) gross world product

UTILPC(T) utility per capita

EQUATIONS

CC(T) consumption

KK(T) capital balance

KK0(T) initial condition of K

KC(T) terminal condition of K

SEQ(T) savings rate

YE(T) world gross products

UTIL objective function

UTILPCEQ(T) utility per capita

EMISSIONEQ(T) emission

DAMAGEEQ(t) damages

ABATEQ(T) abatement

EMISSIONEQ(T).. EMISSION(T) =E= (1-ZE(T))*(-GSIG(T))*(1/(1+EXP(-ORD(T))))*Y(T);

```
DAMAGEEQ(t).. DAMAGE(t) =e= sd*(1/
AL(T))*EMISSION(t)*(1/(1+EXP(-ORD(T))));

KK(T+1).. K(T+1) =L= (1-DK-
ZKK(T)*ZK(T)*DAMAGE(t))*K(T)
+I(T)*(1-ZK(T)*ABATE(T));

ABATEQ(T)$(ORD(T) GT 6).. ABATE(T) =E=
sa*ZE(T)*y(T) ;

KK0(TF).. K(TF)=E= K0;

KC(TL).. r*K(TL) =L= I(TL);

YE(T) .. Y(T) =E= AL(T)*(ZP(T)*LPOP(T))**(1-
GAMA)*K(T)**GAMA;

SEQ(T).. S(T) =E= (I(T)-ZK(T)*ABATE(T))/Y(T);

CC(T).. C(T) =E= Y(T)-I(T) - ZK(T)*ABATE(T) ;

UTILPCEQ(T).. UTILPC(T) =E= C(T)/
(ZPOPTOTAL(T)*POP(T));

UTIL.. UTILITY =E= SUM(T, UTILPC(t));
```