LOW CARBON GREEN GROWTH ROADMAP FOR ASIA AND THE PACIFIC

[Background Policy Paper]

The Impact of Climate Change on the Agricultural Sector: Implications of the Agro-Industry for Low Carbon, Green Growth Strategy and Roadmap for the East Asian Region

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1. Introduction

Climate change refers to changes beyond the average atmospheric condition that are caused both by natural factors such as the orbit of earth's revolution, volcanic activities and crustal movements and by artificial factors such as the increase in the concentration of greenhouse gases and aerosol. Climate change by global warming, which refers to the average increase in global temperature, has become a megatrend that will lead to significant global changes in the future. Concerning its impacts, the UN Intergovernmental Panel on Climate Change (IPCC) presented considerable scientific evidences in its fourth report on climate change (2007) and they have become clearly recognized worldwide. In addition, people have become more aware of the fact that global warming cannot be avoided due to the continued increase in greenhouse gas emissions and the changes in the climate system. The Club of Rome Report 1972 officially raised global warming as an international issue and, in 1985, World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) officially declared carbon dioxide as the principal cause of global warming. In order to effectively cope with the global warming issue, Intergovernmental Panel on Climate Change (IPCC) was organized in 1988 and has carried out systematic research and in-depth studies on climate change.

According to the fourth report of UN IPCC (2007) on climate change, it is indisputable that global warming has serious impacts on the earth and it is very likely that the increase in greenhouse gas emission by anthropogenic activities has caused global warming since the mid-20th century. Especially, this report warns us that, if mankind continues its present level of consumption of fossil fuels (e.g., oil and coal), the average temperature of the earth will rise by up to 6.4℃ by the end of the 21st century (2001~2100) and the sea level will rise by 59㎝. In fact, the average temperature of the earth has risen 0.74℃ over the past 100 years (1906~2005) (Korea Meteorological Agency, 2008).

Global warming not only causes a change in average temperature and precipitation but also increases the frequency of floods, droughts, heat waves, and the intensity of typhoons and hurricanes following the change in temperature and precipitation patterns. The impacts of climate change are also shown in various other forms throughout the world, including the rise of sea level, decrease in glaciers, northward movement of plant habitats, changes in animal habitats, rise of ocean temperature, shortened winter and early arrival of spring.

As the acceleration of global warming affects not only ecological systems but also human life, it has become an important issue both nationally and internationally. Approaches to deal with the issue of global warming are divided largely into mitigation measures, focusing on reduction and absorption of greenhouse gases, the causative factors, and adaptation measures to minimize the damages by climate change. So far, the global warming issue has focused on the mitigation of greenhouse gases based on international environmental conventions such as IPCC and Kyoto Protocol. For agriculture, however, the focus has been shifted to adaptation and adaptability based on the assessment of the impacts of climate change and vulnerability to it. IPCC emphasizes that it is very important for the agricultural sector to adapt to climate change. This is because even if greenhouse gas emissions decrease, global warming will still continue for the next several decades due to its previously emitted greenhouse gases.

It takes at least 5 to 10 years to assess the impacts of climate change and the vulnerability to it and prepare proper countermeasures against it. Especially, as agriculture is climate-dependent and thus susceptible to climate change, it is very urgent to prepare adaptation measures against climate change. Proper countermeasures drawn based on scientific diagnosis and assessment of the impacts of climate change on East Asian countries' agriculture are essential in establishing the vision and administrative policies of future agriculture. This will also provide valuable information for local governments in establishing mid to long-term agricultural development plans and for farming households to prepare their production plans.

2. Diagnosis and Forecast of Global Climate Change

2.1. Current Conditions of Global Warming

Climate refers to a long-term variation in the atmospheric condition of a specific region or regions, and climate change means a gradual change in the climate system both by natural and artificial causes. Climate change is caused by the change in each component of the climate system such as atmosphere, hydrosphere, biosphere, cryosphere and lithosphere or by complicated interactions among those components. The causes of climate change are largely divided into natural causes and artificial causes. Natural causes include the change in solar activity, volcanic eruption, sea water temperature, ice cap distribution, westerly waves and atmospheric waves. On the other hand, artificial causes include carbon dioxide emission from industry and agricultural production activities, deforestation, acid rain and the destruction of the ozone layer by Freon gas, with global warming by the increase of greenhouse gases as the representative (Presidential Advisory Council on Education, Science & Technology: PACEST, 2007).

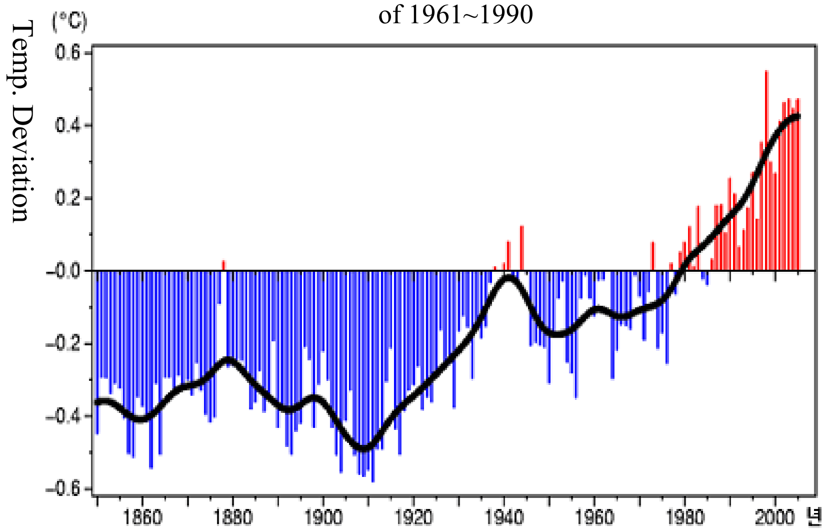
Global warming refers to the average increase of the Earth's temperature due to the greenhouse effect caused by carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbon (HFCs), perfluorocarbon (PFCs) and sulfur hexafluoride (SF_6).[1] Global warming, meaning a continuous increase of the Earth's temperature due to the greenhouse effect, started from the time of

[1] Greenhouse effect refers to a phenomenon where the atmospheric elements, such as water vapor and carbon dioxide, shield the solar energy that has reached the Earth, preventing it from radiating outside of the Earth's atmosphere, re sulting in a rise in the average temperature of the Earth's atmosphere. This idea was first proposed by a Swedish ch emist Svante Arrhenius in 1896 in his study that the increase in carbon dioxide concentration in the atmosphere mig ht result in a rise in temperature (Kim Chang-gil and *et al*, 2009).

the Industrial Revolution which was accompanied by a rapid increase of fossil fuel consumption. This issue has attracted international interests as the scientific knowledge of climate has accumulated since the 1970s and it has been widely accepted by scientists that the anthropogenic greenhouse gas emissions are the cause of global warming.

The global greenhouse gas concentration based on carbon dioxide is estimated to have increased from 280ppm before the Industrial Revolution (1750) to 379ppm in 2005. According to an analysis of the average temperatures of the Earth (Climate Research Unit, 2009), the increase of the Earth's average temperature so far, since the Industrial Revolution, appears to be much higher than the increase before the Industrial Revolution. Specifically, global warming has significantly accelerated since 1980 and the average temperature of 1998 was shown to be 0.58℃ higher than the average temperatures of 1960~1990. As shown in the Figure 1, 11 out of 12 hottest years since 1850 were recorded to be in the last 12 years.

Figure 1. Temperature deviation from the average temperature of 1961~1990



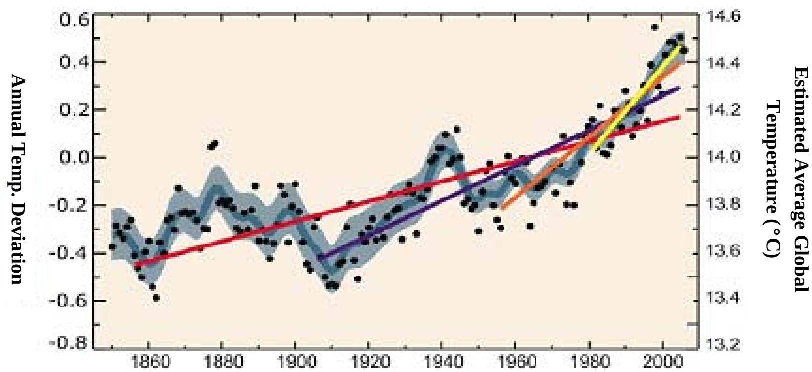
Source: Climate Research Unit (2006).

To make a systematic and reliable diagnosis of global warming, scientific analysis of climate change has been periodically made by IPCC since 1990. So far, IPCC has published its First (1990), Second (1995) and Third (2001) Assessment Report and its Fourth Assessment Report was being prepared as its Working Group I (Physical Science of Climate Change), Working Group II (Impacts, Adaptation, Vulnerability) and Working Group III (Mitigation of Climate Change) announced their reports in April 2007 (IPCC, 2007).[2]

[2] IPCC is an international organization founded in 1988 and its 4th Assessment Report published in April 2007 involves 2,500 scientists from around the world, over about 6 years of research, and 130 countries acknowledged the validity of the Report (Presidential Advisory Council on Education, Science and Technology, 2007).

IPPC WGI Report, which was prepared based on physical science, suggests that the atmosphere's carbon dioxide concentration has increased by about 1.4 times (379ppm in 2005) over the past 100 years, in comparison to the pre-industrialization concentration (280ppm). Accordingly, it is estimated that the average global temperature has risen 0.74℃ (0.56~0.92℃) over the past 100 years (1906~2005) <Figure 2>. Especially, the average temperature of the Northern hemisphere in the late 20^{th} century, which appears to be the highest temperatures recorded since 1850 and the temperature rise during the last 20 years is shown to be more than twice that of the past 100 years. This report states that there is no doubt that global warming is occurring in the climate system and affirms that greenhouse gases are an artificial cause of global warming.[3]

Figure 2. Average global temperature and change trend



Source: IPCC(2007)

As global warming continues, the temperature of the North Pole and the South Pole have risen, accelerating the rate of ice cap melting, shortening the ice-breaking period in the polar lakes and thus causing a significant rise in sea level. Furthermore, global warming causes extreme climatic phenomena such as flood, drought and heat waves, increasing the occurrence of natural disasters worldwide (Korea Meteorological Agency, 2008).[4]

2.2. Current Conditions and Forecasts of Global Climate Change

As global climate change is affected by various factors such as regional characteristics, socioeconomic variables and meteorological variables, it is forecasted by making several feasible

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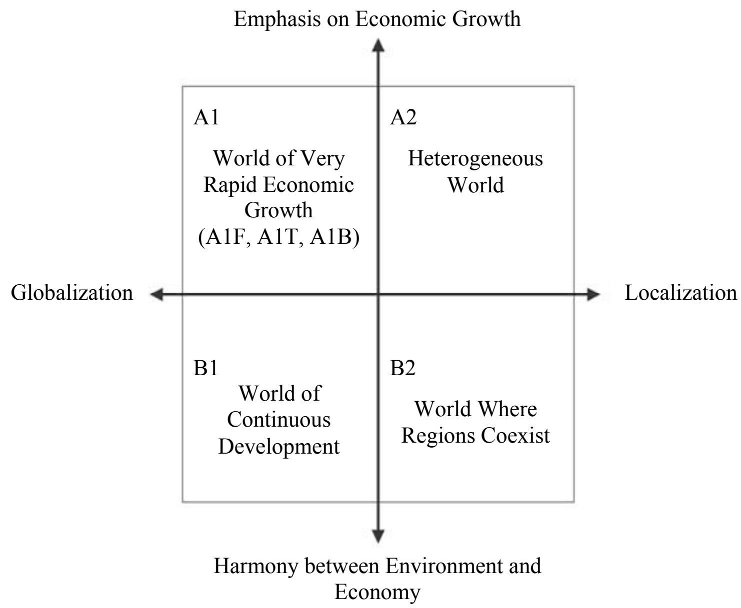
[3] IPCC 3^{rd} Assessment Report 2001 estimates that the temperature has risen by 0.6℃ for the past 100 years and that it might have been caused by artificial causes. But, the 4^{th} Assessment Report uses assertive expressions.

[4] A few examples of natural disasters caused by global warming include flood in China in 1995, inundation of the Rhine in 1997, flood in the eastern Europe in 2000, flood in Mozambique and Europe in 2000, and flood in Bangladesh in 2004. More recently, there were massive flooding in Bangladesh (affected 13.7 million people), Pakistan (affected 20 million people) and China (affected 139 million people) in 2010.

scenarios. The IPCC Assessment Report provides greenhouse gas emission scenarios by forecasting the change in greenhouse gas concentration according to demographics and socioeconomic development. The Special Report on Emission Scenario (SRES) presents four main scenarios (A1, A2, B1, and B2) and three other scenarios (A1F, A1T, A1B) modified according to their technological emphasis in the A1 scenario <Figure 3>.

Figure 3. Conceptual diagram of scenarios for estimating climate change



Source: Kim, Chang-Gil and et al. (2009), p.21.

The A1 scenario assumes a very-rapid economic growth, in which the rapid growth of the global economy and population peaks in 2050 and declines thereafter, in which then new efficient technologies are introduced. It is divided into three groups according to the alternative development of energy technology. The three scenarios are the fossil intensive scenario (A1F1), non-fossil energy scenario (A1T), and balanced-energy source scenario (A1B)

A2 is the scenario for a heterogeneous world with a high population growth rate, a low economic growth rate, and the most diversified but slowly developing technologies.

The B1 scenario assumes the same population growth rate as that of the A1 scenario but at a lower economic growth rate. In this scenario, the economic structure changes toward a service and information economy and the sustainable development is pursued with an emphasis on clean and resource-efficient technologies.

B2 is a scenario for a world where regions coexist with each other in harmony. This scenario assumes the intermediate level of population and economic growth between A1 and B1, and focuses on regional solutions for economic, social and environmental sustainability.

The average global temperature by the end of the 21st century is estimated to rise by 1.1~6.4℃ from the period of 1980~1999, and the sea level is forecasted to rise by 18~59cm due to heat expansion and the loss of land glaciers <Table 1>.

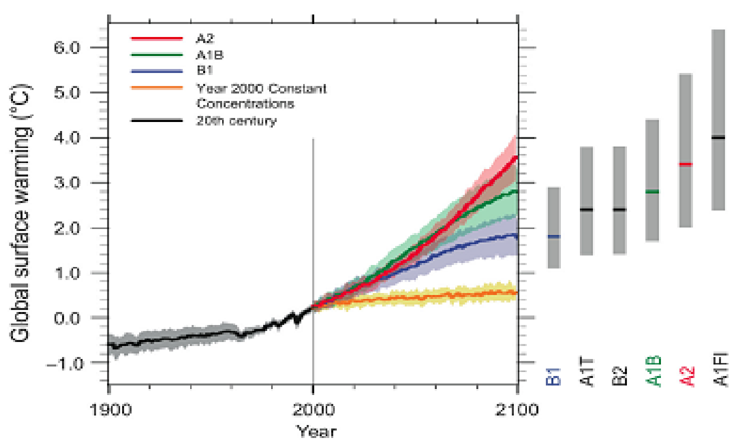
Table 1. Estimated temperature rise in 2100 under each scenario

Scenario	Temperature Change (℃)		Sea Level Rise (cm)
	Optimal Estimation	Expected Range	
Very rapid economic growth (A1FI)	4.0	2.4~6.4	26~59
Non-fossil intensive energy (A1T)	2.4	1.4~3.8	20~45
Balanced-energy source (A1B)	2.8	1.7~4.4	21~48
Heterogeneous world (A2)	3.4	2.0~5.4	23~51
Continuous development (B1)	1.8	1.1~2.9	18~38
Coexistence of regions (B2)	2.4	1.4~3.8	20~43

Source: IPCC (2007), p. 8.

Estimates of future climate change vary greatly from scenario to scenario. In the continuous development scenario (B1), in which environmental conservation and economic development are compatible with each other, temperature change is estimated to be about 1.8℃ (1.1~2.9℃), while the rise of about 4.0℃ (2.4~6.4℃) is expected under the very rapid economic growth scenario (A1) based on fossil-intensive energy sources. By 2030, however, it is estimated in all scenarios that the temperature will rise at the rate of 0.2℃ for every 10 years <Figure 4>.

Figure 4. Estimated trend of temperature rise under each scenario



Source: IPCC (2007).

According to the fourth IPCC Assessment Report, it is anticipated that the impacts of climate change will vary greatly with the degree of temperature rise and the latitudinal locations. When the temperature rise is less than 1℃, damages by natural disasters such as water shortage and floods are foreseen in some areas. However, the report warns that if the temperature rises by 2~3℃, most areas will be subject to damages by natural disasters and about 20~30% of animals and plants will be subject to endangerment. Furthermore, if the temperature rises by more than 3℃, substantial economic and environmental damages are expected, including chronic water shortages, ecosystem destruction, reduced food production, and increased occurrences of diseases.

3. Impacts of Climate Change on the Agricultural Sector

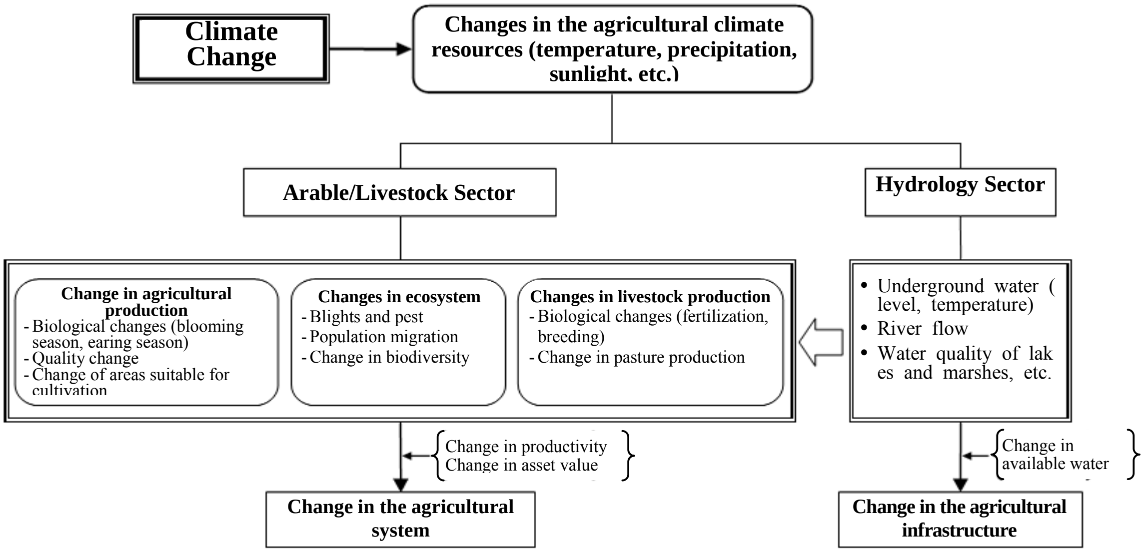
3.1. Conceptual Approach

Agricultural production is carried out through the selection of crops suitable for the climate of a specific region and application of proper farming methods. Therefore, agriculture is a climate-dependent bio-industry with notable regional characteristics. Regional characteristics refer to the ecosystem characteristics determined by the climate of the region. Climate change disturbs the agricultural ecosystem, resulting in the change in agricultural climatic elements such as temperature, precipitation, and sunlight, while further influencing the arable, livestock, and hydrology sectors.

The flow of the impacts of climate change on the agricultural sector can be illustrated as shown in <Figure 5>. First of all, the impacts of climate change on the arable and livestock sector are made known by biological changes including the change of flowering and harvesting seasons, quality change, and shift of areas suitable for cultivation.[5] Climate change affects the agricultural ecosystem, giving

[5] The impacts of climate change on agricultural production are divided into primary impacts and secondary impacts. T he primary impacts refer to the changes in the composition of the atmosphere due to increased greenhouse gases, whi ch include the change in crop growth response and the change in energy and moisture balance in the farmland. The s econdary impact caused by the change in agricultural climate resources affected by the primary impacts include the s hift in suitable places for cultivation and physical and chemical changes in agricultural soil (Na, Young-Eun, and *et a l.*, 2007, p.94).

Figure 5. Flow of the climate change impact on the agricultural sector



Source: Kim, Chang-Gil and et al. (2009), p.36.

rise to blights and pests and causing population movement and change in biodiversity. In the livestock sector, climate change brings about biological changes in areas such as fertilization and breeding and also affects the growing pattern of pastures.

Climate change affects the hydrology including underground water level, water temperature, river flow, and water quality of lakes and marshes, by impacting precipitation, evaporation, and soil moisture content. In particular, the increase of precipitation by climate change leads to an increase of outflow while the temperature rise increases evaporation, resulting in the reduction of outflow. In order to understand the quantitative impacts of climate change on water resources, a deterministic hydrology model, based on the general circulation model, is used.

As illustrated above, climate change has a wide range of impacts on the rural economy including agricultural productivity, revenues of the farm household and asset values, and it also affects the agricultural infrastructure through the change in water sources available for agriculture.

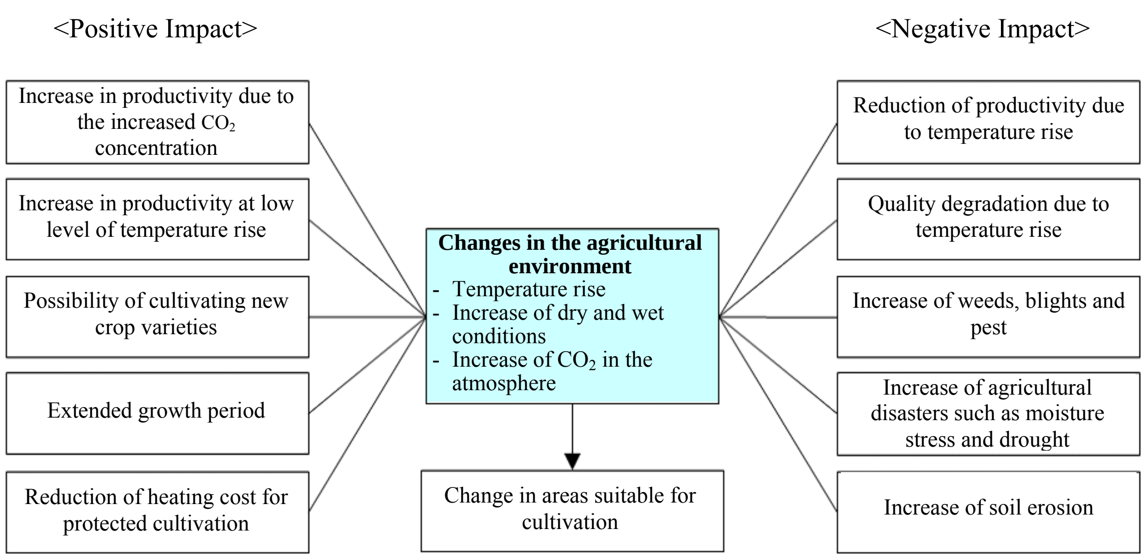
So far, the quantitative analyses on the impacts of climate change on the agricultural sector have been experimental centering on cross-sectional analysis. The experimental analyses are carried out on the basis of agro-economic simulation models. They are similar to the controlled experiments in which related variables are regulated, in that variables related to greenhouse gases such as temperature levels and carbon dioxide emissions levels are regulated. In these experiments, the impact of climate change on agricultural production can also be estimated.

Agro-ecological zone analysis is carried out by using the crop simulation model (called the crop model for short) that tracks the changes in agricultural production and agro-ecological zones that have resulted from climate change. Crop growth is determined by the combined action of three elements, those being the genetic characteristics of crop, cultivation technology, and environment (climate, soil, etc.). The crop model refers to a computer program that can estimate the crop growth and its quantity when these three elements are entered. Using the crop model, it is possible to estimate and analyze agricultural production under climate change. The Crop estimation through the Resource and Environment Synthesis (CERES) model developed in the USA by integrating the crop model and the resource environment can assume a certain situation that is likely to happen and forecast its possible results.

To analyze how and to what extent the change in temperature and precipitation following global warming affects the agricultural sector various experiments, simulations and research methods are carried out both in laboratories and in the field. As the impacts of climate change on the agricultural sector vary with the related variables, it is difficult to generalize certain analytical results. Therefore, what is attempted here is to classify the impacts of climate change into positive and negative ones based on the results that researches have gathered thus far in related fields <Figure 6>.

The positive impacts of global warming include the increase in crop productivity due to fertilization effect caused by the increase in carbon dioxide concentration in the atmosphere, expansion of the areas available for production of tropical and/or subtropical crops, expansion of two-crop farming due to the increased cultivation period, reduction of damages of winter crops by low temperature, and reduction of heating cost for agricultural crops grown in the protected cultivation facilities.

Figure 6. Potential impacts of global warming on the agricultural sector



Source: Kim, Chang-Gil and et al. (2009), p.38.

Negative impacts of global warming include reduced crop quantity and quality due to the reduced growth period following high levels of temperature rise; reduced sugar content, bad coloration, and reduced storage stability in fruits; increase of weeds, blights, and harmful insects in agricultural crops; reduced land fertility due to the accelerated decomposition of organic substances; and increased soil erosion due the increased rainfall.

In addition, each crop requires different climate and environmental conditions to grow. So, if climate change like temperature rise occurs, the boundary and suitable areas for cultivation move north and thus the main areas of production also change. The change in the main areas of production might be as a crisis for certain areas but might be an opportunity for other areas, so it cannot be classified either as a positive or as a negative impact.

In sum, the impacts of climate change on the agricultural sector have ambivalent characteristics of positive impacts creating opportunities and of negative impacts with costs. Therefore, it is very important to formulate adaptation strategies that can maximize the opportunities and minimize the costs that will lead to sustainable agriculture development.

3.2. Climate Change Impacts on Korean Agriculture[6]

3.2.1. Impacts on the Agricultural Ecosystem

An agricultural climatic area is divided into agricultural climate zones according to different agricultural climatic conditions. Average temperature of each agricultural climate zone has risen by 0.95℃ for the past 35 years (1973~2007). The climate zone that has shown the lowest temperature rise is the Yeongnam inland/mountain zone (Yeongju, Mungyeong, etc.), which recorded a 0.2℃ rise. On the other hand, the mid-northern inland, the central inland, and the southeastern coastal zones had seen a temperature rise of 1.36~1.47℃. Especially, the average temperature of the mid-western planar zone (Seosan, Boryeong, etc.) and the Charyeong southern planar zone (Gunsan, Buan, Jeongeup, etc.); the granaries of Korea rose by 1.05~1.33℃ and the Taebaek highland zone, including Daegwanryeong, also experienced a temperature rise of 1.04℃.

Meanwhile, precipitation had increased by 283㎜ on average for the past 35 years (1973~2007). The Taebaek highland zone including Daegwanryeong, the Taebaek semi-highland zone, and the Yeongnam inland/mountain zone had the greatest increased rate of 452~778㎜, while the Yeongnam inland zone (Milyang, Jinju, etc.) had the lowest increased rate of 132㎜. The increase of precipitation tends to have increased rapidly in summer but decreased slightly in winter since the 1970s.

Temperature increase by global warming has given rise to new types of blights and pests, causing damages to crops. Especially, damages to apples, peaches, grapes, and soybeans, by brown grasshoppers, are reported to have been increasing. The first case of damage by brown grasshoppers was reported in Chungju and Danyang in Chungbuk Province and many cases of extensive damages to peaches and grapes in the orchards near the mountains in Okcheon, Cheongwon and Boeun around Yeongdong, Chungbuk Province and Suwon have been reported since 2006, amounting to 20ha of damaged area. In 2007, about 30ha of the orchards across the Chungbuk Province was reported to be damaged. Rice stripe tenuivirus, a viral disease for rice, has spread north, extending the damaged areas up to 14,137ha across the nation including Gyeonggi, Chungnam, Jeonam, Jeonbuk and Gyeongnam Provinces. For fruit trees, Lycorma delicatula is the pest that damages grapes, peaches, and apples. Since first detected in 1979, the cases of damage by Lycorma delicatula have not been reported for a while. In 2007, however, it returned to damage grapes in Yeongi County in Chungnam Province and Suwon in Gyeonggi Province. It was reported that it damaged about 91ha of grape orchards in Suwon in 2008.

[6] This section on analyzing climate change impacts in Korean agriculture was drawn from the research report by Korea Rural Economic Institute (Chang-Gil Kim, et al. 2009).

3.2.2. Impacts on Agricultural Production

For rice, the cultivation period is the basic condition for planning its production, which is decided by the climate conditions and the rice variety. Among several agricultural climate conditions, temperature is the critical factor in deciding the rice cultivation period. In general, rice is a summer crop and when the temperature rises, the area available for cultivating rice extends north and the variety and cultivation method also changes for adapting to the temperature change. For rice varieties for transplantation, the cultivation regions suitable for early-maturing variety rice will become suitable for medium-maturing variety rice and those for medium-maturing variety will become suitable for late-maturing variety. It is reported that even the mountain areas at an altitude of 600m or higher, where rice cultivation has not been possible due to low temperature, may also become suitable for cultivating some early-maturing varieties of rice.

According to the meteorological data for Korea, the proper season for earning of rice (average temperature during the ripening period: 21~23℃) was around August 15 in the 1970s but in the 2000s, it was delayed about a week to August 21. The average temperature of 21~23℃ during the ripening period is favorable for the production of high-quality rice. If the average temperature during this period is higher than this range, rice cannot ripen fully. As a result, grains weigh less, contain more protein, and become less tasty and nutritious. Temperature higher than the average temperature during the ripening period results in the production of poor-quality rice.

Suitable areas for cultivating barley have been selected so as to avoid damages by severe cold during the cultivation period. At present, barley is cultivated in such areas as Donghae and Yeongduk along the east coast, Sacheon and Buseong along the south coast, and Yeonggwang and Gunsan along the west coast, but rarely cultivated in midland areas. The reason for such a shift in the suitable cultivation region for barley is because the coastal areas are less cold than the midland areas in winter, the temperature during the ripening period for barley is lower than the midland, and thus grains can ripen to their full weight. It is analyzed that, as 'mild winter' continued from 1987 to 2000 in which temperatures remained within the range between 1.5~2.5℃, the limit line for cultivating winter barley has been readjusted. According to the analysis of the average and lowest temperatures in January, for 12 years from 1987 to 1998, done for the study on winter barley cultivation regions following global warming by the National Academy of Agricultural Science (NAAS, 2000), the safe zone for winter barley cultivation has shifted far north.

Hot-temperature fruits and vegetables that require hot temperatures to grow such as watermelons, peppers and tomatoes, grow faster and have better quality including higher sugar content, as temperatures rise until it reaches the growth inhibition limit (35℃). On the contrary, for open-field vegetables that favor cool temperatures such as radish and Korean cabbage, high temperatures may result in lowered quality. With regards hot peppers, at temperature below 15℃ or above 30℃, the plant pollens are not properly set to the fruit, many of the fruits drop despite being set. Strawberries also have flowering problems at high temperatures. Some vegetables like onions, green onions and lettuce may have problems at high temperatures, as it causes flowers to split. When the temperature rises, it is possible to save energy for heating greenhouses in winter. Also, it becomes possible to cultivate winter cabbages, which have been cultivated in greenhouses in the subtropical island of Jeju and in the fields of the southern coastal areas.

Climate change not only affects the growth of fruit trees but also their quality, harvest time and storage. Apple trees are perennials that can produce fruits for a long period of time over 10 years in the same place once they are planted. Therefore the change in climatic conditions significantly affects the productivity and quality of apples. The average annual temperature in the areas in Korea where apples are cultivated is lower than 13.5℃. It is known that if the temperature goes higher than this temperature it is hard to produce good-quality apples. The regions suitable for cultivating apples should have an average annual temperature of 13℃ or less and the winter temperature characteristics of midlands or basins. Due to global warming, the regions suitable for apple cultivation have shifted north and/or to the highlands. The cultivation regions for pears, peaches, grapes, and sweet persimmons have also shifted north and some areas in the south region have become unsuitable for cultivating those fruits due to high temperatures. Also, due to temperature rise in the south region, where there is not much wind, the cultivation of kiwi fruits has become popular, and in Jeju island, subtropical fruits are being cultivated.

3.2.3. Impacts on the Agricultural Economy

The agro-economic model, which uses the crop production function for analyzing the economic impact of climate change, creates a problem of underestimation as it does not reflect the indirect impact of climate change such as crop conversion and adjustment of input factors for adaptation to climate change. As suggested in the Introduction of this paper, the Ricardian model was developed to solve this problem (Mendelsohn, Nordhaus, and Shaw, 1994). This model assesses the economic impact of climate change by estimating the current value of farmland price as the discounted value of future rent. Basically, it assumes that, in a long-term balanced state in which all production elements that change along with climate change, farmland price represents the quasi-rent which is the profit from utilizing the farmland.[7] The Ricardian model has an advantage with regard to climate change impact assessment as it can include adaptation that cannot be accurately measured or identified. It measures the change in farmland value or revenue by taking into consideration both direct impacts, such as change in crop productivity due to climate change and indirect impacts, such as replacement

[7] The quasi-rent is a concept closely related to the economic rent, meaning that the profit from the elements fixed for short-period of time disappears in the long run. Calculated by deducting the opportunity cost or total variable cost fro m the total income, the quasi-rent is considered the same as producer surplus.

effect of input production factors and change in farmland utilization, so that it is widely used for analyzing the economic impact of climate change (Kim Chang-gil and *et al*, 2008).

To forecast climate change, 27 cities and counties that are main production regions of Korean cabbage, radish, red pepper, garlic, apples, and pears were analyzed in addition to main rice production regions such as Gimje and Dangjin. On the assumption that climate information of all observatories affects the climate of each city and county, all observatories that had continued providing climate information between 1988~2007 were included in our analysis, which were 57 out of 79 observatories in Korea. To estimate the long-term impact of climate change on agriculture, the average of 20-year data from each observatory was used and to investigate the seasonal impact of climate change on agriculture, climate data about January, April, July, and October was applied. It was based on the assumption that the temperature in January affected the occurrence of blights and pests in April, and temperature and precipitation in July had a significant impact on crop harvests in October.

To apply the Ricardian model, socioeconomic variables and soil and geographic data were used as well as climate variables. For farmland price, the internal data from the Korea Rural Economic Institute was used. In order to prevent bias in farmland price, the average price of rice fields and dry fields only in the agricultural development regions was used. Agricultural gross income and crop income data was taken from KOSTAT data by provinces as there was no municipal data. GDP per capita in each region was also taken from the provincial data provided by KOSTAT. Data about the ratio of fields damaged by sea, wind or water, ratio of wet fields, inclination, and drainage grade was taken from Korean Soils Information.

For estimations using the Ricardian model, regression analysis was carried out by setting the algebraic linear function for farmland price with climate variable, square of climate variable, socioeconomic variable, and soil variable. The farmland price involves future investment value depending on its location in addition to future value of agricultural income from the farmland. Therefore, in order to differentiate the influences of farmland price in a specific region and of independent variables on the entire land price, weighted regression analysis approach was applied that carried out regression analysis by weighting all variables with farmland area or crop income. The regression analysis was carried out in three types: regression analysis only for the farmland price weighted with farmland area, using climate variables (Model 1); regression analysis including other variables (Model 2); and regression analysis that weighted variables with crop income (Model 3). Though there might have been differences to some extent, it appeared that all three models produced similar results for climate variables. The analytical result showed that the rise of average annual temperature had a negative impact on farmland prices but that the average annual/monthly precipitation had a positive impact. When climate variables and other independent variables were included, it appeared that both the result of weighting variables with farmland area and that of weighting them with crop income had a nonlinear relationship. When the quadratic term for the climate variable had a positive value, it meant that it was at the lowest climate condition for cultivation and thus the farmland value went up if the region was above that climate condition. On the contrary, when the quadratic term had a negative value, it meant that there was an optimum climate condition at which the farmland value was highest.

Other than climate variables, independent variables appeared to have the same sign consistently in both models. It was shown that both the per capita production and population growth rate of a region positively affected the farmland price. In other words, it can be interpreted that as income and population grows, the demand for farmlands increased resulting in the rise in farmland price. On the other hand, soil erosion and inclination, both considered negative factor in agriculture appeared to have a negative impact on the farmland price. Contrary to expectations, the ratio of frequently damaged lands had a positive impact on the farmland price. This is likely because, though 53 out of 80 cities and counties appeared to have no damaged lands, most of the cities and counties in metropolitan areas, where the farmland price was relatively high, were included in the damaged areas and so the ratio was also high.

The result of estimation based on the algebraic linear model shows that, when temperature rose by 1℃ from the average annual temperature (12.4℃), the farmland price fell by approximately 14,550 thousand won/ha (Model 2) and by 19,240 thousand won/ha (Model 3). These prices correspond respectively to 5.7% and 7.5% of the average farmland prices for 80 cities and counties. Meanwhile, precipitation that had a positive impact on farmland price if it increased by 1㎜ from the average monthly/annual precipitation (110.8㎜), i.e., if it increased 12㎜ a year, the farmland price appeared to rise by 330 thousand won/ha (Model 2) and 360 thousand won /ha (Model 3).

According to “A Case Study on Prediction of Climate Change Impact on the Korean Peninsula” by the Ministry of Environment, temperatures in 2020 in Korea will rise by 1.2℃ and precipitation will increase by 11%. In this case, the temperature rise will result in the farmland price drop of 14,550~19,240 thousand won/ha but at the same time the precipitation increase result in the farmland price rise to 4.03~4,40 million won/ha. Therefore, the overall impact of climate change on farmland price could be evaluated as a drop of about 13.43 ~18.68 million won/ha.

In analyzing the economic impacts of climate change, it is crucial for the Ricardian approach to derive as correct a farmland price as possible under perfect competition. In a country like Korea where land area is small and population is large, the demand for land utilization is very diverse and thus it is difficult to reflect pure future value and there is a high possibility of overestimating it. For farmlands adjacent to a city, it becomes more difficult to calculate a proper land price if the demand for development increases or a speculative demand arises. Also, in Korea where the free trading of farmlands is restricted, the value of a farmland might be underestimated.

The reason why the Ricardian approach is deemed useful despite the above-mentioned limitations is because it is appropriate for the market economy theory and it estimates the equilibrium assuming that all elements including the adaptation measures to climate change are optimized. In other words, the Ricardian approach has more economic implications in comparison to other economic analyses as they assess the impact of climate change under the existing conditions using the production function rather than assuming the optimized condition.

3.3. Climate Change Impacts on Chinese Agriculture

Climate change impacts on Chinese agriculture and livestock farming include the increase in unstable factors for agricultural production, severe drought and heat injuries in some regions, and worsening of freezing injury in early spring because of the accelerated crop growth periods due to global warming. The forage yield and quality have decreased and the loss of agriculture and stock farming by meteorological disasters has increased.

The climate change impacts on agriculture and livestock farming is expected to last into the future. It is expected that, due to climate change, the yield of three major crops in China such as wheat, rice, and corn will decrease and the productivity of Chinese agriculture will drop by 5~10% by 2030. In the late 21st century, the yield of the three major crops in China will decrease by up to 37%, affecting its long-term food security. The irrigated areas in China accounts for 47% of the entire cultivated acreage and two thirds of the food production come from the irrigated area. When moisture is reduced by 1%, the irrigated area is reduced by more than 1%, causing a serious impact on China′s food production. The yield of frigid crops in most of the northern regions will also decrease considerably and the forage growth in drought or semi-drought areas will reduce as well (Kim Chang-gil and *et al*., 2009).

Climate change will alter the production distribution and structure of Chinese agriculture. Global warming will bring about a rise in the average annual temperature of China, the rise in suitable temperature for agriculture, and the extension of growth period, shifting the cultivation areas far north. For wheat as an example, the northern limit for cultivation which is now the Great Wall will shift to Shimyang. By 2050, global warming will turn most of the present 2-crop farming areas into 3-crop farming areas and shift the present 3-crop farming areas in the Long River valley about 500km north to the Yellow River valley. The 2-crop farming areas will shift to the middle of the present 1-crop farming areas and the 1-crop farming areas will be reduced by 23.1%. Climate change that is mainly characterized by temperature rise will definitely accelerate the increase in gross food production in the northeastern region, restrain the gross food production in Hubei and the northwestern and southwestern regions to some extent, but will rarely affect the gross food production in Huadong and Jungnam regions.

Climate change will significantly increase the production costs of Chinese agriculture. Extreme climate change in China will result in an increase in torrential rain and precipitation. Especially in the 1990s, the precipitation and the rate of torrential rain had increased in the Long River valley and the southern region of the Long River, the frequency of heavy rain and flood also increased in the Yellow River and the Hoehwa valleys, and heat waves in the summer time also increased. The increase in such extreme weather conditions will increase the frequency of disasters, resulting in insecure food production and an increase in production cost.

Climate change in China is also expected to affect the crop blight and pests. According to statistics, it is expected that the agricultural production of China will have a loss of 20~25% of its gross agricultural production due to blights and pests (Government of China, 2004). Global warming will expand the activities of blights and pests that had been limited by low temperature conditions, resulting in an adverse impact on crop growth. At the same time, the greenhouse effect will lengthen the viable period of some blights and pests, aggravating the crop damages.

Under the scenario of doubling the concentration of carbon dioxide in the atmosphere, the majority of areas in China would experience climate warming and heat resources would increase. If the conditions of water, fertilizer and crop variety could meet the demands of such changes, it would be favorable for crop growing and photosynthesis. After climate warming, the areas north of the Yangtze River in China, especially in the middle-altitude and plateau areas, the crop growth season would start earlier and close later, and the potential growth season would be prolonged. However, after the climate warming, because the growth of crops is accelerated, the fertility period would be shortened generally. This would produce adverse effects on material accumulation and grain output. At the same time, the trend of drought and the deterioration of soil moisture conditions as a result of climate change would not be beneficial to wheat growth in China.

The spatial and temporal distribution of climate resources would be affected by climate warming, and the present cropping system would change accordingly. The cultivated area of a single cropping system might drop by 23%, the north boundary of a double cropping system might move northward to the middle part of the region of the present single cropping system, and the proportion of a triple cropping system might change from the present 13.5% to 36%. The northern boundary for a triple cropping system would move northward by approximately 500 km from the Yangtze River basin to the Yellow River basin.

With climate warming, a change would take place in the localities of major crop strains in China. Some crop strains currently popularized at some regions for specific climate conditions and might not be able to adapt to the changed climate conditions. New crop strains must be cultivated at appropriate time. The problem of high temperatures caused by climate warming might be offset, to a certain extent, by the adjustment of crop patterns and structure and also by making use of the temperature adaptability of crops. However, because of the impacts of other factors such as moisture content, it is hard to affirm whether the temperature increase would result in the increase of crop index, or even total yield.

Via simulations of the impacts of climate change on agriculture in China, some studies have shown the impacts of climate warming on the yield of major crops in China under 2×CO2 scenario. It is found that the impacts of climate warming on the yield of spring wheat would be larger than that of winter wheat; regarding single rice, the fall of crop yields would increase gradually from the south to the north with a rate between 6~17%; yield of early rice will drop and the least drop will occur in the central south part of the Yangtze River, while in the surrounding areas, particularly in areas in the west, there would be a considerable reduction in the yield (generally between 2~5%); yield of late rice in the north-western part of the areas south of the Yangtze River would all drop significantly, while that in the south-eastern part would drop less. Spring and summer maize yields would be reduced by 2~7% and by 5~7% respectively, and irrigated and non-irrigated maize yield would be reduced by 2~6% and about 7% respectively due to global warming.

Along with climate change, occurrence of unusual disasters such as drought, flood, high temperature and freezing events might increase. The results of the simulation showed that under the assumption of no changes for the present planting system, planting varieties and production level, the total grain production might drop by about 10% due to climate change and extreme climate events during the period of 2030~2050. The production of three major crops – wheat, rice and maize – might all be reduced. Although climate change will unlikely affect China's capacity of producing grains on a self-sufficient basis, the country would require enhanced agricultural production management methods, among others, to meet the climate challenge.

3.4. Climate Change Impacts on Indian Agriculture

Food grain production in India has increased spectacularly due to the Green Revolution from 50 Mt in 1951 to 212 Mt in 2002, and the mean cereal productivity has increased from 500 kg/ ha to almost 1800 kg/ ha (Government of India, 2004). These increases were largely the result of area expansion, large-scale cultivation of new high yielding semi-dwarf varieties since the early 1960s, and the increased application of irrigation, fertilizers and biocides, supported by progressive government policies. Currently, Indian agriculture has 190 million ha gross sown area (142 million ha net sown area), and 40% of this is irrigated. There have been similar revolutions in the production of milk, fish, eggs, sugar, and a few other crops. India is now the largest producer of milk, fruits, cashew nuts, coconuts and tea in the world, the second largest producer of wheat, vegetables, sugar and fish, and the third largest producer of rice. This growth in agricultural production has also led to considerable surplus food stocks purchased by the government.

The droughts of 1987, 1999~2000, and of 2002~2003 could generally be managed and did not lead to severe problems of food security because of these buffer stocks. Despite this progress, food production in India, on an aggregated scale, is still considerably dependent on the rainfall quantity and its distribution. The summer monsoon (June through September) contributes to 78% of India's annual rainfall and is a major water resource. It is important to recognize that the Green Revolution was largely confined to the irrigated areas. In the past 50 years, there have been around 15 major droughts, due to which the productivity of rain fed crops in those years was affected. Limited options for other income and widespread poverty continue to threaten the livelihoods of millions of small and marginal farmers in this region.

The food security of India may be at risk once again in the future due to continued population growth. By 2050, India's population is projected to grow to 1.6 billion. This rapid and continuing increase in the population implies a greater demand for food. The demand for rice and wheat, the predominant staple foods, is expected to increase to 122MT and 103Mt, respectively, by 2020, assuming medium income growth. The demand for pulses, fruits, vegetables, milk, meat, eggs and marine products is also expected to increase very sharply. This additional food will have to be produced from the same or possibly shrinking land resource base, because there is no additional land available for cultivation. It is estimated that the average yields of rice, wheat, coarse grains, and pulses need to increase by 56, 62, 36 and 116%, respectively, by 2020. Although there is pressure to increase production in order to meet higher demands, there has lately been a significant slow down of the growth rate in production and yield from the cultivated areas. The annual rate of growth in food production and yield peaked during the early years of the Green Revolution, but since the 1980s, it has declined since the 1980s.

The perceived gradual increase in environmental degradation, the early signs of which are becoming visible in areas that benefited largely from the Green Revolution technologies, is further compounding the problem. There is now great concern about decline in soil fertility, change in water table depth, rising salinity, resistance of harmful organisms to many pesticides, and degradation of irrigation water quality as, for example, in north-western India. Nutrient removal by crops over time has exceeded its application and consequently, farmers now have to apply more fertilizers to realize the same yield as achieved 20~30 years ago. The introduction of canal irrigation in Haryana has resulted in almost 0.5 Mha being affected by soil salinity. The rapid increase in the number of tube-wells during the last three decades has resulted in an over-exploitation of groundwater in many blocks, leading to declining water tables. In some canal irrigated districts, on the other hand, the water table has risen, resulting in increased problems of salinity. Several pathogens and insect pests have also shown a tendency to increase under the intensive farming systems such as the rice wheat system.

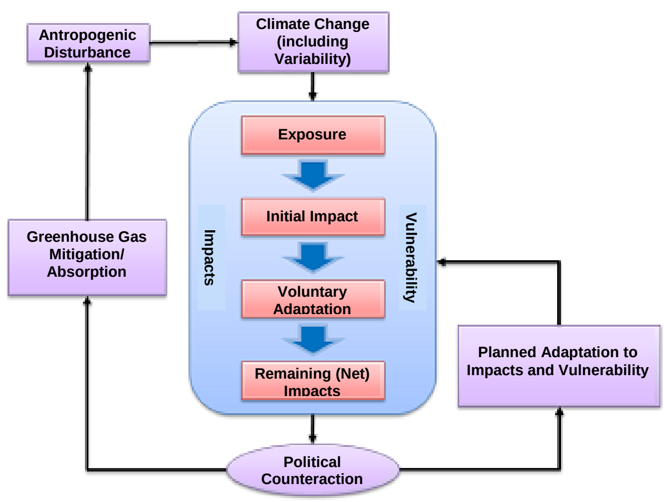
In the 21st century, one of the great challenges for Indian agriculture will be, therefore, to ensure that food production is in line with both poverty reduction and environmental preservation. The roadmap of sustainable agricultural development may also have to consider two additional important global drivers of change in agriculture in the coming decades: globalization and climate change. The on-going globalization process and multilateral trade liberalization associated with the World Trade Organization (WTO) is forcing India to make structural adjustments in the agricultural sector to increase its competitiveness and efficiency.

4. Mitigation and Adaptation Strategies for the Agricultural Sector

4.1. Countermeasures against Climate Change

It has been known that climate change has resulted from the disruption of the energy balance for the global climatic system caused by the increase of greenhouse gases and aerosol in the atmosphere and the changes in land covering and solar radiation. Especially, it has been suggested by the results of scientific analyses that global warming is very likely to have resulted from human activities (IPCC, 2007). Countermeasures that the agricultural sector can consider in the face of risks and challenges of climate change, represented by global warming, are largely divide into the mitigation method that reduces the scale and rate of climate change by mitigating and absorbing the greenhouse gas emission and the adaptation method that admits the inevitability of global warming, understands the impacts of climate change, and minimizes the damages it could cause <Figure 7>.

Figure 7. Approaches to the countermeasures against climate change



Source: IPCC (2007).

Once climate change starts, components of the climate system (such as the atmosphere, hydrosphere, cryosphere, biosphere, lithosphere, etc.) are initially affected by climate change by being exposed to it and attempting to adapt themselves to that stimulus voluntarily. However, if the impact of climate change is huge, the climate system cannot handle the impact only through voluntary adaptation and thus planned adaptation that needs special measures should be attempted. If climate change still has an impact on the climate system even when the planned adaptation is in effect, it is said that there is a remaining impact. As it is difficult for systems to adapt to climate change, efforts have focused on reducing the scale of climate change through mitigation measures such as greenhouse gas reduction and absorption. Mitigation that reduces greenhouse gas emission contributes to avoiding, reducing and postponing various impacts of climate change. As climate change mitigation and adaptation are closely interrelated with each other, mitigation can be considered as belonging to adaptation measures in the long-term perspective. Therefore, adaptation to climate change is not optional but rather a compulsory countermeasure against climate change.

Mitigation measures for the agricultural sector include the improvement of cultivation methods through improved irrigation and fertilization control for the arable sector to suppress major greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O), improvement of animal excretion treatment technologies in the livestock sector, and carbon fixing for the farmland soil.[8] In relation to the countermeasures against climate change for the agricultural sector, this study focuses on the adaptation plans based on the analysis of the impacts of climate change.

4.2. Strategies for Climate Change Mitigation

In reality, it is almost impossible to implement the first-best solution to accurately measure the external effects of global warming and impose the economic costs to the specific greenhouse gas emitters. Under this background, the second-best solution for developing relevant policy programs and forming appropriate portfolios to approach is addressed as a practical method using a policy mix. Considering the given circumstances in a realistic manner, the means for greenhouse gas reduction are classified into economical means, regulatory means, voluntary agreement, R&D and popularization, information provision, and promotion of public awareness.

Economic means refer to policies that utilize market mechanisms, such as charges, carbon tax (or greenhouse gas tax), emission trading scheme, and subsidy.

Greenhouse gas charge, a scheme to impose a charge equivalent to the input price for the unit emission of greenhouse gas to the specific greenhouse gas emitters, is an ideal economic means to achieve efficient resource distribution using fiscal incentives. In order to put this scheme in force, greenhouse gas emissions of each emitter should be monitored and the emitter should be charged according to the actual amount of emission.

The taxes to reduce greenhouse gas emissions can be divided into carbon tax and greenhouse gas tax. Carbon tax is a system to impose taxes in proportion to the carbon content of fossil fuels used. In reality, because of the convenience of assessment and collection, carbon taxes have been put into

[8] The measures to mitigate climate change impacts, focused on the reduction and absorption of greenhouse gas emissi on in the agricultural sector are suggested in the article by Kim Chang-gil and *et al.* (2007, p.97-118).

practice in the form of a product charge. Greenhouse gas taxes differ from carbon tax in that the former is based on the amount of gas emissions while the latter is based on the input amount (or production amount) of fossil fuel which is the source of gas emissions. Though carbon tax is the same as a greenhouse gas tax, in that both can maintain the input amount of fossil fuels at efficient levels, the former is more feasible as it sets the input amount of fossil fuels as its basis for taxation. Unlike a greenhouse gas tax, which requires the taxation office to monitor the accurate amount of greenhouse gas emissions, carbon tax requires the taxation office to monitor only the shipping stage or the distribution stage of fossil fuels for taxation. As tax is input into the fossil fuel price, the input price of greenhouse gas can be reflected in the end users' decision-making. Therefore, the administrative cost for putting a carbon tax in force is relatively small.

An emission trading system is a scheme that sets emission credits based on total greenhouse gas emissions and permits the trade of the credits in the market. The demand and supply of emission credits is determined by the pricing function together with its market demand. If a certain greenhouse gas source can emit greenhouse gas at a lower cost, the emitter can reduce its emission, get as much emission credit as the reduced amount, and sell the emission credit on the emission trading market for a profit.

Subsidy is a system by which the government permits greenhouse gas emitters the right to emit greenhouse gases to a certain level and compensates them with subsidy if they give up a certain portion of the right granted to them. In order for the subsidy system to operate properly, the government should have a correct understanding of various information such as technology level, cost and reduction potential of the subsidized.

To ensure the appropriate operation of economic means that are based on the market function, reliable data and information should be collected regarding the social marginal cost of greenhouse gas emissions and the social benefits of greenhouse gas reduction.

Direct regulation is a scheme in which the government regulates emission standards using various policies and measures under law to ensure that emitters can comply and meet the required greenhouse gas emission level. An emission standard is a policy measure that specifies total greenhouse gas emission caps for each source and ensures compliance of the emitters, which is simpler and clearer than other policy measures, so that the government can introduce it and put it into force without difficulty. Examples of regulatory measures applicable to the agricultural sector include emission cap, chemical fertilizer spraying standard, manure and liquid fertilizer spraying standard and breeding density regulations.

Voluntary agreement is a non-regulatory policy measure by which firms (business establishments or farmers) and the government voluntarily agrees on greenhouse gas reduction targets, reduction plans, and the scale of government support to achieve. Voluntary agreements for greenhouse gas reduction in the agricultural sector include Good Farming Practices (GFP) and the voluntary development of resource-recycling villages by residents. Under the voluntary agreement scheme, greenhouse gas reduction targets are determined by voluntary agreements, so there is no disciplinary measure against noncompliance with the target. Therefore, it might not be an effective policy measure in achieving the national greenhouse gas reduction target.

In addition, there are R&D and popularization for GHGs reduction and capture technologies, and information provision and public awareness enhancement for greenhouse gas monitoring.

Each policy measure for greenhouse gas reduction has advantages and disadvantages with respect to economic efficiency, environmental effectiveness, policy adaptation and feasibility. Therefore, in order to put any policy in force, it is desired to establish a portfolio of mixed policies based on the comprehensive evaluation of the given circumstances of each policy rather than to select and promote any one policy program. As it is not easy to pick one feasible policy mix, preliminary evaluation through policy simulation should be carried out and foreign cases where relatively successful policies are in force should be benchmarked.

4.3. Strategies for Climate Change Adaptation

4.3.1. Basic Framework for Adaptation

The concept of climate change adaptation has various definitions. According to IPCC, adaptation is defined as "adjustment in natural and human systems in response to actual or expected climatic stimuli and their effects." UNFCCC defines adaptation as "regulating process of ecological and socioeconomic systems to reduce possible damages from actual and expected climate change, that is, actions taken to help communities and ecosystems cope with changing climate conditions."

As adaptation contributes to reducing the negative risks of climate change and provides opportunities to use the climate for positive effects, it plays an important role in mitigating the impacts of climate change. Adaptation includes both actions taken to directly mitigate the damages from the climate and enhance the future adaptive capacity and actions to contribute to indirectly mitigating the damages from climate change.

Implementation of adaptation should satisfy several conditions including economic strength, technology, information, infrastructure, institutions, and equity, which are referred to as the components of adaptive capacity. Sometimes, adaptation may be implemented for free or at low cost. But in most cases, implementation for viable adaptation measures accompanies a certain amount of expenses. In addition, implementation of adaptation presupposes applicable technologies. It is also necessary for the effective implementation of adaptation measures that the necessity of adaptation measures should be acknowledged and most suitable adaptation measures should be selected through the assessment of available adaptation measures.

In relation to adaptation to climate change, adaptive capacity or adaptive capability refers to the potential of a specific system to regulate itself, reduce potential damages, or use opportunities in response to climate change, or to cope with the consequences of climate change (IPCC, 2001). It other words, it refers to the ability to effectively plan and implement adaptation and to respond to increasing risks and pressure in order to reduce the frequency and extent of the harmful consequences of climate change. Though the adaptive capacity can be obtained through a combination of abovementioned components, the relative importance of components varies with the circumstance in which adaptation is implemented and the nature of the disaster. Each component is neither independent nor exclusive of one another, but closely interrelated with one another. The components that affect adaptive capacity include the system's accessibility to wealth, information and technology; relative distribution of education and health care; and social flexibility.

Meanwhile, vulnerability refers to the risks of climate change without adaptation, such as the extent of adverse impacts from climate change including climate variability and extreme climate phenomena and the extent of being not able to cope with the adverse impacts. Therefore, vulnerability can be considered as a function of the scale and speed of climate change to which the system is exposed, and the sensitivity and adaptive capacity of the system. Here, the sensitivity of the system refers to the extent of impacts that climate disturbance has on the system. Namely, it is the system's capacity to adapt itself to changes. Adaptive capacity means the capacity of a system, region or society to adapt itself to the climate change impact, and the expansion of adaptive capacity is a substantial means of coping with the uncertainty of climate change. An assessment of vulnerability must precede the establishment of adaptation policies for climate change, and it requires the impacts of the present climate to be assessed first. The impact assessment enables one to identify what system is vulnerable in what part. Elements to be considered for the assessment of vulnerability include definite estimation of climate change, identification of the subjects of vulnerability, estimation of socioeconomic exposure to climate change, and adaptation to the expected climate changes.

Types of adaptation to climate change are divided into those reducing the sensitivity of systems significantly affected by climate change (enhancement of the storage capacity of reservoirs, cultivation of heat-resistant crops, and preparation against floods, etc.), those changing the exposure of a system to the impacts of climate change (utilization of the investment in provision against risks and Early Warning System), and those increasing the resilience of social/ecological system (resource preservation). Resilience in adaptation to climate change refers to the capacity of a community or biological system to organize or adapt itself to stresses and changes by absorbing the changes and/or obstacles. It can be interpreted as the extent of a system to withstand changes and stresses while maintaining its functions and structure.

Types of adaptation are classified according to such factors as the characteristics, intention, and point-of-time of the system. The system is divided broadly into natural systems and human systems. Adaptation is classified into autonomous and planned adaptation depending on intention; pre-adaptation and post-adaptation depending on the point-of-time; short-term and mid/long-term adaptation depending on the term; and adaptation for each rural household unit, community unit, and nation depending on the spatial range. It can also be divided into pre-adaptation and post-adaptation depending on the time of application and into short-term and mid/long-term adaptation depending on the period of application. In addition, it can be roughly classified into the national-level, regional-level, sector-level, and project-level adaptation depending on the scope of application.

Main groups in charge of implementing adaptation measures are broadly divided into the private sector including agricultural people and the concerned enterprises and the public sector including the central and the local governments. The private sector's goal is to maximize private profit, while the public sector pursues public value. Representative cases of application according to response time and the main sectors in charge are listed in the following table <Table 2>.

Table 2. Cases of adaptation according to response time and main sector in charge

		Response Time	
		Pre-adaptation	Post-adaptation
Main sector in charge of response	Private Sector	• Utilization of the private insurance market • Private R&D and investment	• Change of crop cultivation and applicable agricultural techniques • Regulation of the insurance market • Verification of adaptation options of the minimum expense
	Public Sector	• Utilization of Early Warning System • Construction of public infrastructure (irrigation systems) • Communication of risks Utilization of subsidies • Publicly available R&D	• Recovery from the aftermath of disasters • Compensation for the consequences of the impacts • Insurance contract • Compensation system • Subsidies and supports

Source: OECD (2006b).

In reality, a wide variety of programs for the agricultural sector's adaptation to climate change are in effect depending on the national and/or regional conditions. For Canada, adaptation measures are classified into five programs: research and development (crop development, meteorological and climate information system, resource management innovation), government programs and insurance (agricultural subsidies, private insurance, resource management program), agricultural production techniques (agricultural production, land utilization, irrigation, cultivation time control), and financial management for farm households (crop insurance, crop future trading, income stabilization program, household income) (Smit and Skinner, 2002). Japan classifies the adaptation measures for the agricultural sector against climate change into 12 categories: preservation of water and soil, improvement of the soil quality, tillage activities, efficiency of water use, governmental and customary policies, R&D of new technologies, construction of infrastructure, education and public acknowledgement, land management, water resource management, human activities, and farmhouse adaptation at other levels. In the study done by Ministry of Environment to establish a master plan for adaptation to climate change, Korea classifies adaptation measures for the Korean agricultural sector into five categories: technical measures (28 measures), legal and institutional measures (7), economical measures (7), public relations and education (6), assessment (monitoring and vulnerability assessment, 14), totaling 62 detailed measures (Kim Chang-gil and *et al*., 2009).

4.3.2. Priorities of Adaptation Measures to Climate Change in Korean Agriculture

To determine the priorities of adaptation measures to climate change, the Analytic Hierarchy Process (AHP) is applied.[9] Solving decision problems using AHP generally involves four steps: decision hierarchy setting; pair-wise comparison of assessment criteria; weight estimation; and weight aggregation. Decision hierarchy setting is a step to set decision hierarchies for matters to be determined, by classifying each element of the matters into final objective, assessment criteria, and option. The highest hierarchy is set as the most comprehensive objective of decision-making. The next hierarchy consists of various comparable attributes that affect the objective of decision-making. The lowest hierarchy is composed of options to choose from.

To determine the priorities of adaptation measures to climate change, efficiency, effectiveness, feasibility, and acceptance are set as assessment criteria. The efficiency is to compare the cost and benefit of an adaptation policy; the effectiveness is to assess the extent of achievement of the adaptation policy objective; the feasibility is to assess whether the policy-making authorities can actually enforce the adaptation policy; and the acceptance by agricultural people is to assess whether the agricultural people would readily accept the adaptation policy.

Options for adaptation measures to climate change for the agricultural sector have been selected, total 19 items, including: R&D (breeding, production technology development, base technology development, resource management innovation, and climate information system); infrastructure management (farmland management, agricultural water management, agricultural facility

[9] AHP is a decision-making methodology developed by Saaty in the 1970s, which is useful for decision-making for problems or uncertainties that cannot be qualified through pair-wise comparison of elements of the hierarchy. It identifies the weight of each objective hierarchically to compare the priority of each option, so that not only the quantitative data but also the qualitative data can be considered at the same time. For more information about the determination of priorities of policy programs for the agricultural sector using AHP, see the article by Kim Chang-gil and *et al* (2004, p.156-163).

management), economic means (provision of grants), legal and institutional improvement (insurance system expansion, resource management system setup, formulation of plans for each region), manpower training and education (manpower training, education/public relations), monitoring (assessment of adaptation and vulnerability), and technology and management applicable to farm households (production technology management, soil management, water management, farm household finance management) .

As climate change would occur over a considerable period of time, the roadmap for adaptation has set a target year of 2030 in three phases: short-term base buildup phase (2010~2013), mid-term take-off phase (2014~2019), and long-term settlement phase (2020~2030). The roadmap is presented for each phase, covering seven major categories such as R&D, infrastructure management, economic means, legal and institutional improvement, public relations and education, monitoring, and technology & management applicable for individual farm household <Table 3>.

Table 3. Roadmap for implementing the adaptation measures in agricultural sector

Adaptation measures	Base buildup phase (2010~2013)	Take-off phase (2014~2019)	Settlement phase (2020~2030)
R&D	- Develop new breeds that are in great demand and resistant to heat. - Popularize new cultivation technologies for fertilization and sowing. - Prepare the maps for suitable places for cultivation and crop distribution. - Researches to identify physiological effects of global warming. - Develop forecast models to prevent blights, pest and weeds. - Develop and utilize early warning systems. - Develop water resource management systems to prevent natural disasters including drought and flood.	- Popularize the breeds adapted to global warming. - Provide the information about adaptation to global warming and build up the training system. - Promote the crop transformation evaluation studies. - Sophisticate the early warning system. - Promote the facilities to optimize the efficiency of water utilization. - Promote the water resource management system in prevention against natural disasters such as drought and flood.	- Build up the adaptation system to global warming. - Convert to the agricultural production system that makes the most of global warming. - Build up the crop transformation evaluation system. - Build up the early warning system - Popularize the farming simulator - Promote the water resource management system in prevention against natural disasters such as drought and flood.
Infrastructure management	- Popularize the technologies to reduce carbon emission from rice fields and dry fields. - Popularize the no-tillage farming methods. - Establish the standard for water-saving irrigation. - Modernize the agricultural infrastructure. - Popularize the energy-saving technology for the protected horticulture.	- Promote the reduction of carbon emission from rice fields and dry fields. - Expand the no-tillage farming methods. - Popularize the standard for water-saving irrigation. - Build up the automated agricultural water management. - Expand the energy-saving technology for the protected horticulture.	- Promote the reduction of carbon emission from rice fields and dry fields. - Settle the no-tillage farming methods. - Build up TMTC system. - Expand the energy-saving fusion technology for the protected horticulture.
Economic means	- Consider paying the carbon grant to the agricultural people who practice low-carbon farming methods. - Introduce the investment incentive for water saving. - Support high-efficiency irrigation system	- Expand the carbon grant for the low-carbon adaptation menu methods. - Promote the investment incentive for water saving. - Consider charging the use of agricultural water	- Promote the carbon grant for the low-carbon farming methods.

Table 3. Roadmap for implementing the adaptation measures in agricultural sector

Adaptation measures	Base buildup phase (2010~2013)	Take-off phase (2014~2019)	Settlement phase (2020~2030)
Legal & institutional improvement	- Expand the insurance system for agricultural disasters. - Expand the insurance system for damages by flood and storm. - Operate the farm household income stabilization program. - Establish the global warming adaptation committee. - Introduce the system for calculating the crop damage. - Formulate the long-term development plan for rural villages. - Operate the special task force team for main areas of production.	- Promote the insurance system for agricultural disasters. - Promote the insurance system for damages by flood and storm. - Settle down the programs to help farm households have stable income. - Operate the global warming adaptation committee. - Build up the system for calculating the crop damage. - Settle down the long-term development plan for rural villages.	- Promote the insurance system for agricultural disasters. - Promote the insurance system for damages by flood and storm. - Settle down the programs to help farm households have stable income. - Operate the global warming adaptation committee. - Settle down the system for calculating the crop damage and the support system.
Public relations & education	- Train the agricultural people specialized in risk management. - Train the consultants specialized in risk management. - Expand the education of farm households in the insurance for crop disasters and the risk management.	- Train the agricultural people specialized in risk management. - Utilize the consultants specialized in risk management. - Popularize the manual about adaptation to global warming. - Build up the adaptation education system.	- Train the agricultural people specialized in risk management. - Complement the manual about adaptation to global warming. - Build up a systematic education system for each subject related, for their adaptation to global warming.
Monitoring	- Introduce the impact assessment model for productivity forecast and biological changes. - Build up the agricultural ecosystem monitoring system.	- Utilize the impact assessment model for productivity forecast and biological changes. - Operate the system for assessing the environmental impact on crop growth. - Make mid/long-term forecasts of the world food demand and supply.	- Build up the system for assessing the environmental impact of alternative water use on crop growth. - Make mid/long-term forecasts of the world food demand and supply.
Technology & management applicable to farm households	- Control the crop growth rate, greenhouse cultivation, agricultural chemicals, and weeds. - Cultivate the crops adapted to climate change. - Fertilize the soil by improving the alkali soil. - Install the water management for individual farm households. - Utilize the risk avoidance crop insurance.	- Fertilize the soil by improving the alkali soil. - Prepare the irrigation schedule to enhance the efficiency of water use. - Participate in the income stabilization program - Diversify the farm household revenues through crop diversification.	- Change the places of cultivation to proper climate. - Fertilize the soil by improving the alkali soil. - Prepare the irrigation schedule to enhance the efficiency of water use.

Among major tasks for each phase, those that have to be implemented continuously are not easy to be placed in a certain phase. The development of adaptation technologies to climate change is the one that has to be implemented continuously in all phases so as to prevent and/minimize the damages caused by climate change. It is especially important to develop breeds that are in great demand and resistant to disasters and heat. This is an urgent task that should be continuously carried out to ensure that the developed breeds can be popularized to individual farm households. In the infrastructure management category, farmland management, agricultural water management, and agricultural facility management are the allotted main tasks for each phase. In particular, the popularization of no-tillage farming methods is an important task for mitigating and adapting to climate change, so that it has to be carried out continuously. In the economic means category, introduction of the low-carbon grant is a key task that needs to be done in the base buildup phase but also has to be carried on afterwards. In the legal and institutional improvement category, the agricultural disaster insurance system needs to be carried on continuously so that it can be securely settled down. Public relations and education should also be carried on with special interest in order to form consensus about adaptation to climate change. In the monitoring category, the tasks for developing a model to make mid/long-term forecasts of the world food demand and supply should be carried out in each phase. In the category of technology and management applicable individual farm households, effective programs should be developed in each phase in relation to R&D so that the developed adaptation technologies can be actually popularized to individual farm households.

4.4. Countermeasures for Climate Change in China

The Chinese government has the following four principles in dealing with climate change: 1) Cope with climate change to ensure sustainable development; 2) Attach equal importance to mitigation of and adaptation to climate change; 3) Convert the traditional production method and consumption pattern to cope with climate change; and 4) The whole country should be involved.

The Chinese government's countermeasures for the agricultural sector against climate change are largely divided into greenhouse gas mitigation measures and adaptation measures for climate change. The greenhouse gas mitigation measures are to continue popularizing the low-emitting multi-harvesting rice varieties and half-drought type cultivation techniques; adopt scientific irrigation methods and soil-verified fertilization techniques; research and develop high-quality ruminant breeding technology and stockbreeding management technologies of scale; strengthen the management of animal excrement, wastewater and solid wastes; enhance the efficiency of methane utilization; and control the methane emission.

Adaptation measures to climate change are as follows: strengthen the measured forecast level for the extreme meteorological disasters by supplementing the measured forecast emergency action mechanism, the multi-department decision-making mechanism, and ensure comprehensive community involvement mechanism in provisions against various disasters; establish a meteorological disaster defense process by 2010 that can play a fundamental but essential role in securing the economic society; improve the comprehensive measured forecast level, defense level, and disaster mitigation capacity to cope with extreme meteorological disasters; and form 24 million ha of new grassland and clear 55 million ha of degraded, desertificated, and/or alkali grasslands by 2010, by strengthening such adaptation measures farmland construction, cultivation system adjustment, resistant variety selection and development, and biotechnology development.

The Chinese government has enacted and enforced “Agriculture Act,” “Grassland Act,” “Fisheries Act,” “Land Management Act,” “An Ordinance on Emergency Measures against Sudden Critical Animal Epidemic,” “An Ordinance on Pasture Fire Prevention” as climate change adaptation policies. The government has also made efforts to establish and supplement the political and regulatory system for the agricultural sector’s adaptation to climate change. In addition, they have strengthened the agricultural infrastructure construction, promoted the construction of farmland irrigation systems, expanded the irrigated agricultural area, and improved the irrigation efficiency and the general piping level for farmlands. Furthermore, they have popularized the water-saving technology for hardy crops, enhanced the agricultural disaster prevention, reduction and generation production capacity, and developed some varieties that can endure high temperature, blight, and pest.

In the future, China is planning to further expand the popularization of high-quality varieties and increase the covering rate of high-quality varieties. Also, it will strengthen the prevention of critical animal epidemics, establish and supplement the anti-epidemic measures for animals, and strengthen the measured forecast level for animal epidemics.

The Ningxia Region, one of five self-governing regions located in northwestern China, is the poorest region in China. Its weather is characterized by dry and distinctive seasons, average annual temperature of 5-9℃, and precipitation at 262mm. In the Ningxia Region, three characteristic agricultural systems of China are present: 1) utilization of rainwater; 2) utilization of rainwater and irrigation water; and 3) utilization of irrigation water. The region has a high level of poverty, has a lot of experiences in damages caused by meteorological disasters, and the region is also vulnerable to climate change. The Ningxia Region’s climate had been stable but its average temperature has risen by about 0.6~1.2℃ for the past 10 years and the droughts became worse in 2004~2006.

The northern Ningxia Region is the area irrigated from the river flows from the Yellow Sea. This region’s main agricultural products come from corn, spring wheat, rice, and potato cultivation through intercropping, and its main livestock farming product is chicken. The central dry area has a vast pasture that uses both irrigation water and rainwater. Due to dry weather, only corn, spring wheat, and potatoes can be cultivated and some cows and sheep are raised. The southern mountain area is humid, which cultivates using rainwater, but it is still very dry. Main crops cultivated in this area are potatoes, and the main livestock farming products include beef cattle, sheep, pigs, and poultry. Because of such regional characteristics, the Ningxia Region formulates its adaptation objectives taking into consideration how climate risk will affect each area. Furthermore, it pursues policies that can integrate its main development objectives and the objectives for adaptation to climate change. Therefore the following steps should be take:, when considering the adaptation policy by the unit of region, in-depth research about the corresponding region including its natural conditions, climate system and crops cultivated in the region should be carried out; the policies differentiated for each region should be formulated based on the research results; and the existing policies should also be taken into consideration.

In response to climate change, the farming households in the Ningxia Region have taken some adaptation measures. First of all, in provision against dry weather and drought, they harrow their fields and uses film covering and/or sand cover to maintain the moisture content of the soil. Harrowing is the most widely used measure in the Ningxia Region, especially in the southern area and in Huinong and Helan in the northern area. Film covering is used in Huinong, which has a different effect depending on the crop type. For potatoes, it has been seen to increase the yield by 30%. Sand covering is used only in Haiyuan, which is known to be effective against drought.

In order to secure water, various rainwater collection measures are taken and the three areas use very different methods. To save water, irrigation is used as well, which applies mostly to the northern irrigated areas but has some difficulty in popularization as it requires supplying water to furrows without the irrigation facilities. The Ningxia Region has a high non-farming income rate of about 50% and thus has a relatively low income vulnerability to climate change. A lot of residents have moved to other areas with a better environment, and they evaluated moving as a successful adaptation measure.

Table 4. Adaptation measures for the farmers in the Ningxia Region

Type of adaptation	Description
Measures to maintain the moisture content of the soil against dry weather and drought	▪ Use various methods to increase the moisture content of the soil. ▪ Harrow the fields and use film covering and/or sand cover.
Rainwater collection	▪ Use different rainwater collection methods - The northern area rarely collects water as it has rich water resources. - The central area collects rainwater in the underground reservoir. - Jinyuan in the southern area collects rainwater in the underground reservoir.
Water-saving irrigation measures	▪ Water-saving irrigation is used mostly in the northern area.
Non-farming income	▪ All three areas have a high non-farming income rate of about 50%.
Moving	▪ Ningxia residents have move to the areas with a better environment.

5. Low Carbon Green Growth Strategy/Roadmap for the Agricultural Sector

5.1. The Concept of Green Growth

Sustainable development means achieving sustainable economic growth reconciled with environmental protection. Since its first appearance in the *Declaration of the United Nations Conference on the Human Environment* in 1972, this concept was then solidly established by the World Commission on Environment and Development (WCED) in 1987, and came to serve as a basis for the *Rio Declaration on Environment and Development* in 1992 and its acting plan, *Agenda 21*. The concept of sustainable development sprang from a reflection on the economic paradigm of mainstream economists, which revolves around the 'growth first, clean up later' idea where one believes that the economy should develop first and environmental damage is dealt with later. The WCED defines sustainable development as "development that meets the present without compromising the ability of the future generation to meet their own needs" (Kim Chang-gil and Kim Jeong-ho, 2002, p.7-9).

The concept of green growth was created in order to increase the possibility for policy enforcement in sustainable development, whose concept is abstract and broad-based covering the three aspects of economic feasibility, environmental protection and social equity.[10] In other words, green growth is a qualitative growth that enhances the standard of living through the attainment of ecological and economic soundness. The Korean government presents green growth as "economic growth that minimizes environmental pollution and greenhouse gas, while creating a new growth engine and jobs" (Presidential Council for Future and Vision, 2009). In addition, the relevant framework act defines green growth as "growth achieved by saving and using energy and resources efficiently to reduce climate change and damage to the environment, securing new growth engines through research and development of green technology, creating new job opportunities, and achieving harmony between the economy and the environment" (Article 2, Section 2 of *the Framework Act on Low-Carbon Green Growth*). As green growth is variably defined, it can be understood as a complex and open-ended concept that accepts a new civilization and an order of change. Within this context, we can understand that green growth is a concept in the making, subject to the discussions of the future.[11]

[10] The term "green growth" was newly coined by the *Economist* magazine (January 27, 2000). It is more widely used in journals than in academic circles. In 2005, UN ESCAP's Ministerial Conference on Environment and Development had an in-depth discussion on this new concept before it started to be widely used after Davos Forum. (UN ESCAP, 2006: Kim Chang-gil and Jeong Hak-kyun, eds., 2008, p.31). The OECD's ministerial council meeting held in June 2009 adopted the Declaration of Green Growth.

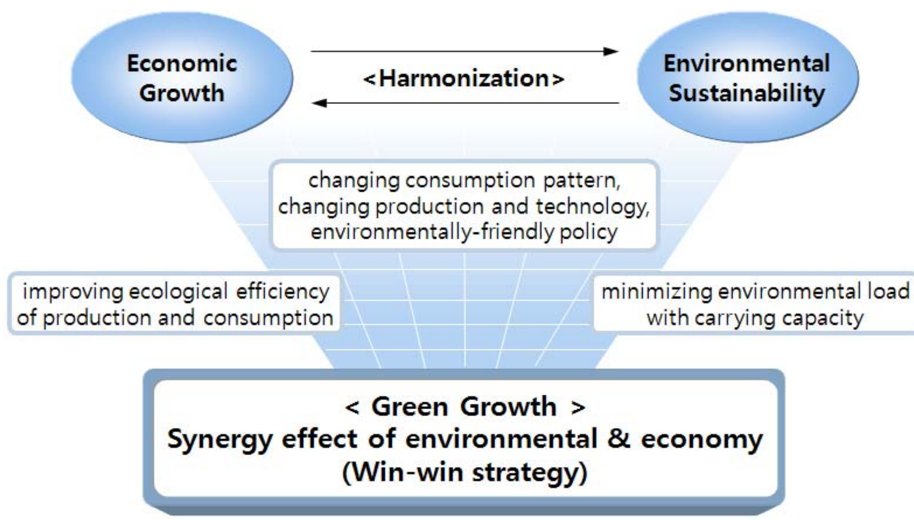
[11] Green growth is a newly-conceived term defined as 'a growth that effectively and fairly joins the efforts made by the international community to deal with climate change and continuously minimize the per capita income gap with developed nations' (Han Jin-hyee and Kim Jae-hoon, 2008, p.19).

The operating principle of the green growth policy is to turn the vicious cycle between the environment and economic growth into a virtuous cycle through a transformation into a newly established growth pattern and economic structure. Under the new paradigm of qualitative growth, the essential factors of production are new ideas, transformational innovations, and state-of-the-art technology. The economic growth based on these drivers is expected to generate substantially intensive, qualitative growth unlike the extensive quantitative growth of the past.

Therefore, green growth continuously enhances productivity by putting green capitals (i.e., green technology and green knowledge) into the production process, thereby reducing pollution and expanding natural capital (energy and environmental resources). As a result, green growth brings about changes in production, technology and consumption patterns and ecological efficiency by taking into account environmental capacity and economic and environmental aspects of production and consumption <Figure 8>.

Green growth involves policy regime and social value as it aims to achieve economic growth through a low-carbon society and green industrialization. The realization of green growth is accompanied by a significant amount of economic costs and efforts, and above all, it requires us to move away from our existing patterns of living. Thus, for green growth to be materialized, economic incentives, development and the distribution of green technology, and understanding and cooperation of relevant bodies, are of the utmost importance and urgently require a paradigm shift and swift response.

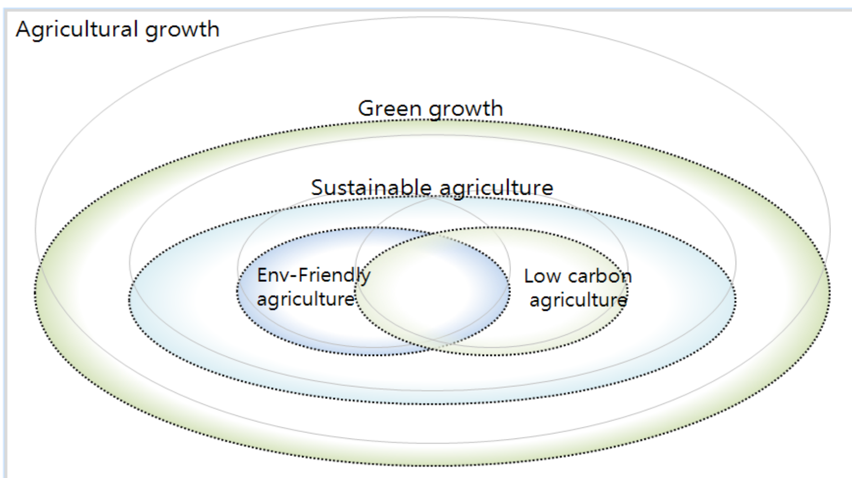
Figure 8. Mechanism to Achieve the Goals of Green Growth



Green growth in the agricultural sector is more comprehensive than sustainable agriculture, and it means a growth that guarantees environmentally sound and economically viable growth that takes into consideration environmental capacity in the agricultural ecosystem. Green growth in the agriculture sector is achieved through a shift in agricultural practice that takes into account the environmental capacity of each different region and the water system, low-carbon agriculture via greenhouse gas reduction and higher absorption capacity, and energy efficiency and savings. Green growth can be realized by shifting to a sustainable agricultural system including environmentally-friendly, low carbon agriculture. Thus, green growth in the agricultural sector can be regarded as more comprehensive than sustainable agriculture <Figure 9>.

In the meantime, green growth in the agri-food sector means a growth through a shift towards an environmentally sound, low-carbon life cycle in the agricultural aspects of not only production but also distribution, processing and consumption.

Figure 9. Conceptual Position of Green Growth in Agriculture



Agriculture that pursues green growth can be defined as green agriculture. However, the term is not widely used. Several terms are being used in the agricultural sector with respect to the green concept. However, special attention should be paid to how they are actually related to green growth. For example, China uses the term "green food" to increase the public familiarity with the concept of environmental friendliness, and the term is relevant to green growth to some extent. In Korea, "green revolution" refers to a drastic increase in productivity through the development of high-yield rice varieties (for example, the new rice variety "Tongil" IR667), but it is hardly related to green growth. By contrast, the term "second green revolution" is being used to describe the planting of wheat, green manure crops and fodder crops on idle lands during the winter season, and it is significantly relevant to green growth in the agricultural sector as it involves energy saving and greenhouse gas mitigation.

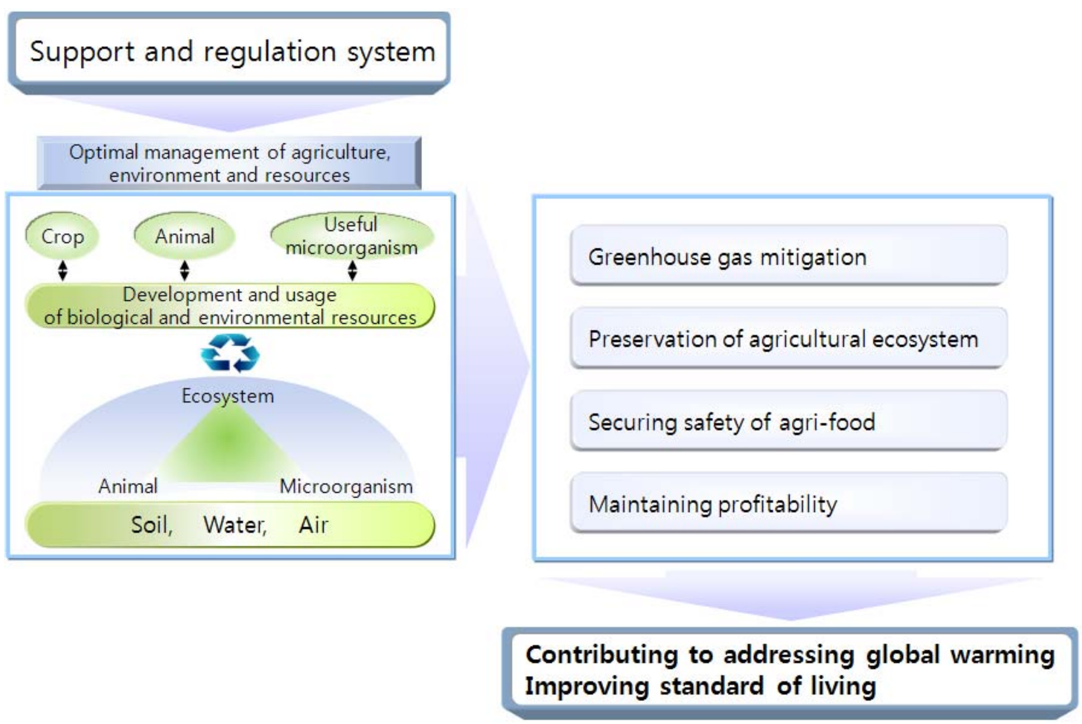
5.2. Strategies for Green Growth in the Agricultural Sector

5.2.1. Basic Directions and Implementation Methods

Shifting from pre-existing conventional agricultural growth to low-carbon green growth (LCGG) requires the formulation of a vision and specific goals. An appropriate vision should reconcile agriculture with the environment, mitigate greenhouse gases and improve the agricultural ecosystem, which contributes to the lessening of negative effects of global warming and improves the living standards for present and future generations <Figure 10>.

As a basic direction to develop an LCGG action plan, a resource-cycling agricultural system should take its root based on the 3R cycle of "Reduced ↔ Recycled ↔ Reuse". It should be followed by the transition of the agricultural production goal from maximization to optimization. In other words, the agricultural production goal should be shifted from maximizing production to optimizing production by taking into account the local agricultural environment and greenhouse gas emitting and absorbing conditions.

Figure 10. Vision and Goals of Low Carbon Green Growth



For the reduction of greenhouse gases and improvement of living standards, a policy combination of support, regulation and compensation should be formulated so that the right policy mix entails consolidation and coordination for environmental policies. To minimize the inconvenience and economic costs that come along with green growth, green technology should be actively developed and disseminated. Lastly, it is no less important that relevant bodies share a common understanding through information sharing, education and promotion.

5.2.2. Implementation Methods

As it takes a considerable amount of time to establish an agricultural system that promotes low-carbon green growth with respect to obligatory greenhouse gas reduction, action plans should be devised based on a three-stage process by the target year of 2030, this includes the: groundwork establishment stage, utilization stage and settlement stage.

The groundwork establishment stage (2010~2013) involves policy promotion to foster environment-friendly agriculture and the establishment of a production base for renewable energy and a pilot project under the Kyoto mechanism to reduce greenhouse gases. Greenhouse gas absorption includes identifying the role of soil organic carbon and estimating the storage of organic carbon in the farmland. And the absorption process involves the development of a prediction system to increase the productivity of agricultural products and biota, and the development of varieties with an ability to adapt to global warming. The utilization stage (2014~2019) should pursue the development of database for greenhouse gas emissions, dissemination of greenhouse gas mitigating technologies, expansion of the use of the Kyoto mechanism and application of incentive programs aimed at enhancing the absorbing capability. The last settlement stage (2020~2030) means the establishment of an agricultural production system that is based on low-carbon green growth and pursues an optimal policy combination of programs in various areas, including greenhouse gas mitigation, and greenhouse gas absorption and adaptation to global warming.

A roadmap should be drawn at every stage to ensure the establishment of a low-carbon green growth system by implementing green growth programs in each stage of various fields for greenhouse gas mitigation, absorption, and adaptation.

The greenhouse gas mitigation of the groundwork establishment stage involves the dissemination of greenhouse gas reduction technology, planting of bioenergy crops, and formulation of emission trading schemes and pilot projects for developing a Clean Development Mechanism (CDM). The utilization stage includes the development and dissemination of tailored technology for each region, the establishment of a bioenergy production system and an emission trading scheme. The settlement stage seeks to supplement the greenhouse gas management system and establishing a low-carbon green system.

The greenhouse gas absorption stage should lay down a foundation to identify the role of soil organic carbon, estimate the storage of organic carbon and build a utilization base. The utilization stage should introduce a direct payment for low carbon, and the settlement stage should include the establishment of an agricultural system that maximizes the ability to mitigate and absorb greenhouse gases. The greenhouse gas adaptation should -in its groundwork establishment stage- be able to develop a prediction and evaluation model for the productivity of the agricultural sector and biota, establish an eco-monitoring system, and develop crop species that can adapt to global warming.

The utilization stage should involve the development and distribution of an adaptation manual, establish an early-warning system, disseminate plant varieties with an ability to adapt to global warming, and establish educational systems.

5.2.3. Core Tasks for Implementing Strategies

5.2.3.1. Establishment of a Resource-Cycling Agricultural System

In order to achieve green growth in the agricultural sector, environmentally friendly agriculture should be built based on a solid resource-cycling system linked with related industries that are environment-friendly. As part of this plan, two environmentally friendly agricultural complexes (one that is small in size of about 10ha and the other is bigger with a size of about 1,000ha) will be utilized as a basis for the expansion of production and distribution in an environment-friendly atmosphere. It is recommendable that *Regional Circulation Agriculture Support Center* (tentatively named) is created and operated to help these complexes take root in an environmentally-friendly resource-cycling agricultural system. Especially for the transition to an environmentally friendly agricultural system that is suitable for each region, an effective implementation plan should be formulated so that *Regional-Based Maximum Nutrients Loading System* could be carried out as early as 2007 (Kim Chang-gil and *et al*., 2008).

An industry of environmentally friendly machinery will be fostered to build a sound environment-friendly agriculture. Organic fertilizer and by-product fertilizer will be combined to improve the fertilizer processing standards, and an industry base should be established for the strict management of inferior organic fertilizer and post management of agricultural machinery through mandatory listings.

5.2.3.2. Integration of Agricultural Policy and Low-Carbon Eco-Friendly Policy

Green growth pursues a harmonization between agricultural activity and the environment through a paradigm shift toward a low-carbon agricultural system that mitigates or absorbs greenhouse gas. A transition to low-carbon green growth cannot be achieved only by implementing environment-friendly cultivation programs, but it requires a reorganization of the current agricultural policy system. To maximize the efficiency in using agricultural resources, while minimizing environmental pollution, an environmental evaluation test should be conducted on all agricultural policy programs so that the programs can be combined or made consistent with the low-carbon policy.

For integration of agricultural policy with environmental policy, efforts should be made to introduce a direct payment scheme for low-carbon agriculture, which is the most representative program for Environmental Cross Compliance (ECC).[12] When various kinds of low-carbon agricultural systems are practiced to encourage voluntary greenhouse gas reduction, a direct payment scheme for low-carbon agriculture, such as manual-type direct payment that provides a proper incentive through monitoring, can encourage farmers to actively participate in low-carbon green growth.

5.2.3.3. Activation of Climate Smart Agriculture

A new initiative that calls for agriculture to be part of the solutions to climate change, and not part of the problems, has been launched at the COP16[13] climate negotiations from November 29 to December 10, 2010 in Cancun, Mexico.[14] It advocates getting the right policies and programs in place that will increase farm productivity and incomes, make agriculture more resilient to variations in climate and make the sector part of the solution to climate change by sequestering more carbon into the soil and biomass. There is a growing recognition that agriculture in developing countries must become “climate smart” to cope with the combined challenges of feeding a warmer, more heavily populated world. The Food and Agriculture Organization (FAO) suggested food security and climate change should be addressed together, by transforming agriculture and adopting practices that are "climate-smart" to eradicate hunger from the world.[15] Climate smart means agriculture that sustainably increases productivity and resilience to environmental pressures, while at the same time reduces greenhouse gas emissions or removes them from the atmosphere. The FAO stressed that a variety of climate-smart practices already exist and are being used in some places, providing examples that could be more widely implemented in developing countries. Agriculture in developing countries must become 'climate-smart' in order to cope with the combined challenge of feeding a warmer, more heavily populated world. There are a number of areas where changes in the food production sector are required. Farming must become more resilient to disruptive events like floods and droughts through improving agricultural water and soil management. The vulnerability of farming communities to

[12]Environmental Cross Compliance (ECC) refers to a conditional compensation program that gives compensation to eligible farmers if they meet certain specific requirements regarding environmental goals.

[13] COP16 is the official name of the Cancún summit, which is the 16th Conference of the Parties (COP) under the Un ited Nations Framework Convention on Climate Change (UNFCCC).

[14] In the UNFCCC COP16, global leaders and policy makers have been debating a global climate change deal but no concrete agreement has been made. The Roadmap for Action: Agriculture, Food Security and Climate Change, a new reiteration of the workplan launched at the Hague conference last month, proposes key actions to be taken to link agriculture-related investments and policies with the transition to climate-smart growth (FAO, 2010; UNFCCC, 2010).

[15] The Food and Agriculture Organization of the UN (FAO, 2010) has a new report out on precisely this issue: "Climate-Smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation, and Mitigation.

climate-related disasters must be reduced, and better warning and insurance systems to help them cope with climate-related problems need to be established. In this note, agriculture has to find ways to reduce its environmental impacts -including lowering its own greenhouse gas emissions- without compromising food security and rural development. The FAO's report goes on to highlight examples from around the world of how farmers are already moving to tackle these issues and adopt new, climate-smart practices In order to transform into climate smart agriculture, agriculture must produce more food, waste less, and make it easier for farmers to get their produce to consumers. In addition, farming must do a better job of managing natural resources like water, land and forests, soil nutrients and genetic resources to be more resilient to natural disasters. The report also argues that greater coherence among agriculture, food security and climate change policy-making is urgently needed. Policies in all three of these areas impact smallholder production systems and a lack of coherence can prevent them from capturing synergies. Improving mechanisms for getting data, science and know-how to farmers so they can adapt is another area in need of attention. In particular, key requirements for an enabling policy measures to promote climate-smart smallholder agricultural transformation is greater coherence, coordination, and integration between climate change, agricultural development and food security policy process. In addition, adequate investment in national climate-smart agricultural formulation, research and extension, including capacity building, is important in supporting action by farmers (FAO, 2010).

The most significant achievement of the COP16 was the establishment of the Green Climate Fund. Its purpose is to finance poorer countries to develop less pollution-intensive energy sources, and adapt to a changing global climate as natural disasters increase in frequency and intensity, and infrastructures are taxed to cope with more severe natural conditions. Developed nations are committed to contributing up to $100 billion dollars annually to the fund by 2020, resulting in a massive resource that poorer nations will be able to draw upon. The new fund will be managed under the auspices of the UN rather than the World Bank, although the bank will still be involved as the interim trustee of the fund subject to a review three years after the launch of the fund.[16]

5.2.3.4. Development and Dissemination of Low-Carbon Green Technology

Green technology refers to technology that minimizes the use of materials and energy, decreases environmental load and weakens entropy through the circulation and utilization of renewable materials and energy for the purpose of establishing a low-carbon paradigm. Therefore, green technology pursues the minimal use of energy and materials and promotes material circulation and

[16] The Cancun Accord also outlined plans to create a framework for the proposed Reducing Emissions from Deforestation and Degradation (REDD) mechanism that will see developed nations provide finance to help developing countries protect forests. Policy guidelines were issued to developing countries to develop national strategy, baselines and monitoring system. The $4.5 billion dollars pledged so far to help set up. REDD from the 'fast-start' funding promised at Copenhagen in December 2009, while longer-term financing would be drawn from the newly formed Green Climate Fund (UNFCCC, 2010).

dynamic balance in the realm of nature and renewable energy technology. In addition, green technology entails an adjustment of input and production to the extent that the natural ecosystem can handle.

Green technology with aforementioned characteristics is manifested in the form of four distinctive technologies: greenhouse gas mitigation technology, energy efficiency technology, clean energy technology and new environmental technology.

First, greenhouse gas mitigation technology in agriculture includes mitigation technology for reducing methane and nitrous oxide in farmlands, soil organic carbon storage technology, technology for improving intestinal fermentation of ruminant animals and animal manure treatment facility, and technology for biomass utilization and fossil fuel reduction. Most of these technologies are at commercialization stage thanks to the technology development effort so far, which is a significant technological achievement. Nevertheless, greenhouse gas mitigation technology is not widely used in the rural scene due to a low level of technology acceptance by farmers.

Second, energy efficiency technology includes technologies improving heat recovery ventilators and heat exchangers. Technology development in this area has gone to such a great extent that heat exchanger improving technology for warm air heaters and exhaust heat recovery facilities for warm air heaters are already at the distribution stage. Technology development and formulation of complementary plans for achieving economic efficiency should continue so that energy efficiency technology can be easily accessible in rural areas.

Third, clean energy technology refers to a technology that utilizes clean energy sources, such as geothermal, solar power (photovoltaic), wind power, and multifold thermal covers and water filter protection curtains. Clean energy technology also involves the development of production models for cellulose crops to produce bio-ethanol, such as canola, sweet potato for ethanol and C4 (non-food crops), and Korean cellulose ethanol. Fourth, new environmental technology includes bio-crop protection agents using natural materials, biological pesticide such as environmentally friendly micro-organisms and natural enemies, development of urban building-type plan systems for crop production through the convergence of agriculture and cutting-edge technologies, such as nanotechnology (NT), biotechnology (BT), information technology (IT), environment technology (ET) and crop production technology using LED. More efforts should be made for the commercialization of new convergence green technology, including the production of rice bran products using supercritical fluid (materials put onto temperature and pressure above critical level) and the introduction of bio-refineries for rice.[17]

[17] Bio-refinery refers to a technology that does not use oil to produce industrial materials and energy, but produces raw materials for the energy industry, such as renewable biomass (rice, rice bran, corn) to prepare for oil depletion, and to significantly reduce climate change and environmental pollution.

Green technology of the future is actively involved in the development of state-of-the-art technologies, such as NT, BT, IT, and ET, leading to the expectation that convergence technology will be expanded in the agricultural sector. And more attention and support need to be paid to the installment and expansion of plant factories and vertical farms that use such convergence technologies.

5.2.3.5. Development of Policy Programs Based on Carbon Information

In order to effectively pursue green growth, the success of which largely depends on the greenhouse gas reduction in each sector, it is essential to develop policy programs that actively utilize carbon information. One of the major policy options is carbon labeling. It seeks to achieve the reduction of market-oriented greenhouse gases by quantifying carbon emissions during the entire life cycle of a product from production to transportation, distribution and disposal. It allows this information to be available to consumers and induce them to lead a low-carbon, greener life. Korea introduced a carbon reduction labeling system of its own in February 2009. In the agri-food sector, its implementation is currently limited to processed products such as precooked rice and tofu, but it is necessary to expand the system to agricultural commodities and other food-related areas through appropriate measures including the establishment of GHGs inventory along the steps of production, processing and consumption.

Different types of carbon emission trading are currently in place where carbon emission rights - the right to emit greenhouse gases- are commercialized and traded. The trading market types can be categorized into "allowance-based market" and "project-based market" depending on what origin the right is based upon, and into "mandatory carbon market" and "voluntary carbon market" depending on whether the reduction is compulsory by the Kyoto Protocol.

Clean Development Mechanism (CDM), a regime of the project-based market, can be considered for introduction in the agricultural sector. The utilization of CDM is still in its early stages in the domestic agricultural sector, but has a huge potential to contribute to greenhouse gas reduction and green growth if potential business items are explored and identified by benchmarking overseas CDM operation cases. The launch of CDM projects should be more actively considered including the establishment of internationally-approved animal waste biogas plants and bioenergy projects using agricultural byproducts. In order to boost CDM projects in the domestic agricultural sector, feasibility studies should be conducted first on projects with a higher possibility of greenhouse gas reduction, such as methane reduction in livestock waste disposal facilities and utilization of biomass and bioenergy.

The second option to consider in regard to emission trading system (cap and trade scheme) is to trade the emissions reduced in the agricultural sector with players in the non-agricultural sectors. The cap and trade scheme, the implementation tool of the Kyoto Protocol, is operated or test-operated in the EU, Britain, Canada, Denmark and Japan. Each country committed to the Protocol allocates emission allowances to domestic sectors and companies to achieve the mandatory reduction targets under the Protocol. A company that fails to reach the target can purchase emission rights from other sectors. It is necessary to develop appropriate programs for early reduction or absorption of greenhouse gases under a new market-oriented policy that can encourage farmers to participate in carbon reduction efforts.

5.2.3.6. Utilization of Green Finance in the Agricultural Sector

Green finance stems from "environmental finance" or "sustainable finance" used in foreign countries, but in Korea it implies something more comprehensive and economy-oriented. Green finance is a concept that incorporates indirect support for green industries by including the process of environmental risk management, etc. Green finance in Korea has been actively planned and pursued mostly by state-run financial institutions. Non-governmental financial institutions have recently started to engage in green finance by devising green products and systems in support of green industries, but there have been little tangible results.

An example of green finance in the agricultural sector is "Green World Installment Deposit" launched by the National Agricultural Cooperative Federation, which applies up to 0.6% of preferential interest rates to the deposit if the subscriber participates in low-carbon, green growth-related activities. As another example of green finance, LIG Insurance Company introduced a special policy for losses related to eco-friendly agricultural products. Under the policy, if pesticide residues are detected in eco-friendly products purchased by consumers, the producer of such products is compensated for the costs to redeem the consumer confidence on the concerned products and to prevent future occurrence of such cases (e.g., direct compensation to consumers). Measures to promote green finance in the agricultural sector include financial support for the introduction of green energy technology in capital-intensive areas such as protected livestock and horticulture; financial assistance for agricultural production facilities utilizing green technologies for energy saving and higher efficiency in production as well as for packaging and transportation in the process of distribution; and creation of agricultural investment funds to provide loan programs with preferential rates for businesses distributing green agricultural technologies.

5.2.3.7. Education and Communication for Green Growth

The shift to a low-carbon green growth regime will require substantial investment and support for education and training programs aimed at promoting active participation in the green growth effort of relevant players such as farmers, businesses and policy makers. Actions on the spot for low-carbon green growth in agriculture are led by the Agricultural Research and Extension Services of each province, the Agricultural Technology Centers in municipalities, local producer groups, and leading farmers. Therefore, structured education and communication programs targeting core leaders in the sector should be one of the priorities.

6. Conclusions and Policy Implications

Scientific diagnosis and assessment of the impact of climate change on the agricultural sector is essential for formulating the vision of future agriculture and the direction of agricultural administration. Specifically, it can provide useful information for formulating the long-term agricultural development plan for each region and the adaptive measures for farming households.

This paper was carried out in order to suggest scientific and phase-by-phase counterstrategies to prevent against climate change through the diagnosis of climate change phenomena and in-depth analysis of climate change impacts on the agricultural sector. The countermeasures for the agricultural sector against climate change have mostly focused on greenhouse gas mitigation. However, more interest and policy support should be directed to adaptation measures in consideration of the inevitability of global warming and the characteristics of climate-dependent agriculture. In particular, it is necessary to understand that the countermeasures for the agricultural sector against climate change are to minimize the risks of climate change and utilize it as an opportunity. For this, proper education and training programs for agriculture workers, public officials and the personnel from the related agencies should be developed and put into practice so that they can properly cope with climate change. It is also urgent to expand the adaptation measures of the agricultural sector that have been limited to research and development, to more active policy programs including popularization of technology and adaptation manuals to agriculture workers and proper incentive programs. As shown by the result of questionnaire research from farmers, they are highly interested in adaptation to climate change and very willing to participate in carbon reduction program, it is necessary to develop technologies and customized programs that they can apply in the field. The improvement of agricultural production infrastructure has focused on the farmlands for rice farming to become self-sufficient in food production, such as securing water resources in preparation against drought, preventing floods, and arranging for mechanized farming. Now, more scientific measures in water and facility management should be formulated and implemented in preparation against unusual weather including localized torrential rain and typhoon. In ensuring the effective implementation of the agricultural sector's adaptation strategies, it is necessary to divide roles properly between the concerned bodies such as the government, farmers, researchers, and other related institutions and to build up the integrated management system for comprehensive planning and implementation for those adaptation strategies.

In the age of the so-called "energy-climate era," a new development strategy is required to replace the conventional growth strategy which is faced with many limitations. In preparing for the future, low-carbon green growth has become the main stream as an inevitable core task to be performed home and abroad, and it is anticipated that there will be a lot of discussions in relation to the preparation of a green growth strategy to cope with global warming for a considerable period of time. As the agricultural sector takes up a very low portion of the total amount of domestic greenhouse gas emissions, with approximately 3%, there is a possibility that proper attention may not be paid to the administration of greenhouse gas reduction activities in the agricultural sector. In this regard, we need to benchmark advanced countries such as the U.S., Europe and Japan where the agricultural sector is given significant attention in terms of implementing green growth. The agricultural sector has a significant potential to contribute not only to the administration of national greenhouse gas reduction but also to the national development of green industries in the future.

Given that the growth paradigm of agriculture so far has been based on a productivity-oriented quantitative approach, green growth implies a significant paradigm shift into a qualitative approach which takes both productivity and ecology into account. In light of this shift, Korea's agricultural sector should leave the old paradigm behind and pro-actively seek measures to play a part in resolving global warming and achieve a balance between agricultural development and environmental protection. In order to accomplish green growth in the agricultural sector, we should create an innovative way to turn inconvenience into a growth engine by leaving existing convenience and inertia behind, and by achieving a shift in thinking among relevant parties, to ensure that inconvenience and hazard can be properly managed. For this to happen, an amicable atmosphere should be created with a bold paradigm shift, where the suggestion of various ideas and active discussion can take place. First of all, it is urgent that we come up with an implementation strategy that allows us to maintain the unique characteristics of agriculture as a green industry, and thereby eventually achieve green growth by actively developing public functions, such as atmospheric purification and environmental protection through agricultural production innovation and clean technology. It is particularly necessary to establish green governance where all farmers, relevant organizations and policy makers concerned can work together, where a strong will to implement green growth and an effective execution system are required to accomplish green growth. However, the policy to promote environmentally friendly agriculture itself is not enough to ensure an assured transition toward a low-carbon agricultural system, but reorganization of the overall agricultural system is needed. Above all, agricultural policy and low-carbon environmental policy should be properly integrated so that the concept of green growth in the overall agricultural sector takes root. In order to maximize the policy effectiveness through a proper combination of policy instruments in various relevant sectors, a green innovation system should be established where policymakers, researchers, relevant organizations, farmers and other relevant bodies can have proper understanding of green growth and share their roles. In addition to that, a systematic stage-by-stage strategy to develop technology should be devised and implemented on a steady basis so that green technology reduction or absorbing of greenhouse gases in the agricultural sector can be utilized as a growth engine. When green growth in the agricultural sector is successfully implemented, agriculture will solidify its position not only as a green industry that manages national land in an environmentally sustainable manner but also as a life industry that supplies safe agricultural products and manages national greenhouse gas emissions.

Systematic researches into the impacts of climate change on the agricultural sector and the formation of counterstrategies to fight against climate change have to be done as an interdisciplinary research among agricultural science, ecology, agricultural engineering, hydrology, meteorology, and agricultural economics. For a more reliable analysis of climate change impacts, efforts need to be made to develop integrated models consolidating the estimates produced by climate change scenarios, the simulation analysis based on agricultural characteristics, and the economic analysis reflecting the socioeconomic factors of agriculture. Furthermore, future studies should carry out a more detailed analysis for the economic and policy effects of each adaptation measures for the agricultural sector.

The multiple challenges the East Asian Region is facing in terms of climate change, degradation of ecosystems, food insecurity require an integrated approach. The challenges and many of the solutions are understood. Now is the time to get down to earth and take urgent action on solving those issues towards a sustainable, inclusive and resource efficient path. The notion that green growth and climate-smart agriculture can help to solve urgent issues has been the basis for developing and starting the roadmap for the East Asian Region. The roadmap for action is part of an ongoing process to identify, stimulate and broaden actions. At the same time it is a stepping stone to further initiate and broaden the partnerships and its activities with inclusive engagement by all stakeholders, such as the private sector, governments, scientists, non-governmental organizations, and farmers.

7. References

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