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Societal response to challenges of global change and human sustainable development

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It is now widely accepted that carbon emission from human activities is an important driving force in global warming, and global change has a deep impact on sustainable development of human society. To meet the challenges of global change, the international community has reached a consensus that developed countries take strict actions in emission reduction, whereas developing countries take spontaneous efforts in reducing emissions under the guiding principle of common but differentiated responsibilities, with an agreed goal to restrict global surface temperature increase due to human activities to within 2°C of pre-industrial levels. However, there is no clear pathway to reach this goal. A number of related questions must be addressed on principles to be followed, research emphasis and policy measures. Here we argue that response policies to address global change issues must be based on balanced development at regional and international levels, and on advancements in science and technology. This requires consideration of harmony not only between humans and nature but also within human societies, to properly deal with the relationship between global change and sustainable development. We must make equal efforts toward carbon emission reduction and carbon sequestration, and toward mitigation and adaptation. There should be more research support to reduce uncertainties in our understanding of global change. Addressing the challenges of global change creates great opportunities for the development of human society. This will facilitate transformation of energy use structure, improve and restore ecological functioning of the earth environment, transform production modes and ways of living in human society, and promote harmonic and balanced development at regional and international levels.

uncertainty in understanding, principle for mitigation and adaptation, response strategy, development opportunity

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1 Societal response to challenges of global change: Progress and issues

Global change refers to changes in earth system functions at a global scale, caused by natural and human factors. It includes atmospheric and ocean circulation, hydrologic and biogeochemical cycles, and changes in resources, land use, urbanization, economic development, and others.

Global warming is a prominent signal of global change. The IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment Report pointed out that the earth's surface temperature has increased 0.74°C between 1906–2005, and there is a 90% likelihood that warming over the second half of the 20th century was attributable to an increase in CO_2 emitted by anthropogenic activities [1]. The warming

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trend in China is consistent with that of the rest of the world; China's land surface temperature increased 1.38°C from 1951 to 1999 [2].

Global change has not only caused changes to the natural environment, but also had a deep impact on socioeconomic development. How to respond to global change and to realize sustainable development are major challenges to the development of human society.

Based on scientific understanding and political consensus about the potential impact of human-caused global warming and future climate change, significant political, economic and technological efforts have been made by the international community during the past 30 years to further understand the mechanisms of global change, mitigate and adapt to climate change, and reduce its negative impact as exemplified by the UNFCCC (United Nation Framework Convention on Climate Change; United Nations, 1992) [3] and Kyoto Protocol [4]. Much progress has been made, which can be summarized by three aspects.

1.1 Improved understanding on the impact of global change on sustainable development of human society

Global change has tremendous impact on the natural ecosystem as well as human society. If response is insufficient, sustainable development will be placed at great risk. If we are unable to effectively control the concentration of greenhouse gases in the atmosphere, global temperature may increase between 1.1–6.4°C. If global temperature were to increase by 1.5–2.5°C, 20%–30% of worldwide species would be in danger of extinction. If global temperature were to increase by 2–3°C, ice cover in Greenland would be significantly reduced, causing 30% of global coastal areas to be submerged by oceans. Noticeable changes would also be observed for other land processes. The occurrence frequency and intensity of extreme weather events such as heat waves, drought, and strong precipitation would increase. These would result in environmental risks, water shortages, grain yield reduction, disease outbreaks and health risks to human society [1].

1.2 Recognition of human activities as key driving forces in global change

Human activities are the primary reason for global warming over the second half of the last century [1]. This is the consensus of a majority of scientists that has been formed over the past several decades. Why are human activities the key driver of global warming? To answer this question, the role of greenhouse gases and their effects must be addressed. The naturally and human caused water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) in the atmosphere can absorb and emit radiation emitted from the earth surface, atmosphere and cloud in certain wavelengths of the thermal spectrum. The heat is captured in the earth surface and troposphere causing temperature increase on earth surface and in the lower layer of the troposphere. This is known as the "greenhouse gas effect". These atmospheric components are called "greenhouse gas". The global warming since the second half of the 20th century is mainly caused by the increase in atmospheric concentration of CO_2 and other greenhouse gases. These gases are mainly produced from fossil fuel combustion, land use change and forest damage; all byproducts of human social and economic development.

Ice core data from Antarctica indicate that from 1000 through 1800 A.D., atmospheric CO_2 concentration fluctuated around 280 ppm [1]. However, there has been a steep rise since the Industrial Revolution, and atmospheric CO_2 concentration reached 380 ppm by the end of the last century.

Changes of many key earth system parameters have been influenced either directly by human activities or indirectly by global warming. Research has been carried out to study the basic mechanisms of how human activities influence global change and the socioeconomic factors of that change, and to determine potential thresholds.

1.3 Preliminary consensus of the international community on addressing global change issues

Governments of many countries are very concerned with global change. In 1992, the UNFCCC was proposed at the world environmental summit [3]. An important principle is "common but differentiated responsibilities". Common responsibility stipulates that every nation should make efforts to protect the global environment; differentiated responsibility stipulates that different nations may contribute to environmental protection based on their own capacities. Developed countries were to undertake a leading role in reduction of greenhouse gas emissions, and provide technologies and financial support to developing countries in their efforts to reduce emissions.

In 1997, the Kyoto Protocol was signed. It specified that from 2008 to 2012, major developed countries were to be the first to reduce CO_2 emissions and other greenhouse gases.

In 2009, the Conference of the Parties (COP) to the UNFCCC passed the Copenhagen Protocol [5]. This sustained the principle of the "common but differentiated responsibilities", and re-emphasized the forceful reduction of carbon emissions by developed countries and spontaneous mitigation action by developing countries. Further, a general consensus was reached on key issues such as global long-term goals, investment and technological support, and transparency.

In the 2010 Cancun Agreement, international society developed a strategy based primarily on reduction of greenhouse gas emissions. The goal for the end of the 21st century became to control temperature rise to within 2°C of pre-industrial levels. This is the well-known 2°C threshold criterion [6,7].

China has paid much attention to global change issues. The National Strategy in Response to Climate Change was announced and begun to implement in 2007 [8]. The Chinese government decided to transform its economic structure with the aims of saving energy, improving energy use efficiency, developing renewable energy, optimizing energy structure, and greening the country. All these actions have generated substantial successes.

Although efforts have been made by all nations, the gap between climate change agreements and the actual situation remains large. The actions stipulated in these agreements have been hampered by political and diplomatic gaming, economic and technological costs, plus energy and resource allocation issues [9,10]. 2012, the final year of the first commitment period under the Kyoto Protocol, has passed away but we obviously did not meet the pre-set emission reduction targets. Only a few developed countries took solid steps toward reducing emissions. We still face tremendous challenges in responding to global change issues.

2 Temporal background of human response to global change and criteria for addressing global change issues

Over the past century, tremendous changes that were greater than any during the previous thousands of years, took place. Why did human activity in recent centuries cause global warming? We must investigate the socioeconomic background of the present era, and then develop a set of criteria to be applied in our response to global change. The current background includes the following.

2.1 Advancements in science and technology

The history of human evolution is a process of human harnessing of technology in modification of nature. This can be dated to the period in which humans learned to make simple tools. Since then, humans have made continuous efforts to apply their wisdom to create a world more suitable for living. At the beginning of the 20th century, thanks to relativity theory, quantum mechanics and other breakthroughs in scientific theories, science and technology have rapidly developed. Over the past several decades, there has been a modern technological revolution centered around information technology. This marks a great stride in development from an industry-based economy to a knowledge-based one, or from an industrial society to an information society. Production methods, human lifestyle and the earth environment have been dramatically altered owning to global industrialization and informatization, excessive energy use, accelerated population growth, and rapid expansion of cities. It can be anticipated that future development of human society, including meeting the challenges of global change, will rely heavily on further advances in science and technology, and on creatively combining the natural and social sciences [11,12].

2.2 The globalization process

Driven by increased productivity and the advancement of science and technology, particularly technological advancement in the information, communication and transportation sectors, information and material exchanges have been dramatically intensified, leading to well-connected international networks of economies, science, technology and culture. Production and scientific research can be easily organized across national and regional boundaries, allowing more optimized integration of various production elements and scientific activities at global scale. The interests of various nations are intermixed, interconnected, inter-supportive and inter-constrained. The world is becoming an earth village. We must take a global perspective in addressing global change issues.

2.3 The idea of sustainability and its implementation

Science and technology can be considered a double-edged sword. On the one hand, development of science and technology brings significant benefits to human society by improving living conditions, lengthening lifespan, and generally creating a better lifestyle for people. On the other hand, during the process that scientific and technological results are applied, they have also caused a series of problems related to ethics, the environment, global climate change and disasters. These are of great concern to society. The earth is a non-linear system. Small changes in some of its components can cause vast, irreversible changes at the entire system scale [13,14]. Therefore, the interests and fate of human beings are closely linked with the environment. The fact has made people question how human society should develop in harmony with global change, so as to achieve sustainability [15].

In summary, global change originated from the advancement of science, technology and economic development. Therefore, the solution to global change issues must be based on development, and the key is further advancement of science and technology. In the meantime, any solution for global change issues should be based on full consideration of the globalized international environment and the idea of sustainability. These are the criteria that must be followed to develop any practical solutions to global change problems.

3 Meeting the global change challenges and sustainable development

Over the past 30 years, through the joint efforts of scientists and decision makers worldwide, the science of global

change has made great strides, and actions have been widely undertaken in response to global change [16]. Despite of this, our capability and progress in addressing global change issues is still limited. The major reason is that our scientific understanding of global change is inadequate to fully support human management of the earth system. Therefore, we should follow the laws of the earth system itself, and take into account the relationship between the earth system and human activities. We should enhance international coordination to mold a consensus as soon as possible on innovative management of the earth system, based on the premise of rapid progress in science and technology, rapid globalization, and the idea of global sustainability.

3.1 Properly dealing with the relationship between meeting the challenges of global change and sustainable development

Sustainable development and addressing challenges of global change are dependent on each other, and both aspects are indispensable. They should therefore be considered jointly. The conception of sustainable development is an important conclusion drawn from human history of successful practices and lessons of failure by humans. Sustainable development not only requires harmony between humans and nature, but also among human societies themselves. Historical experience indicates that the root cause for social discord is developmental imbalance. Imbalance of regional development within a nation may cause civil strife there. Stereotyping or enlarging developmental imbalance among different nations makes it difficult to achieve long-term peace and stability. It would therefore be impossible to achieve the goal of sustainable development.

At present, global change is a challenge to all mankind. The purpose of addressing global warming issues by the international community is to resolve the discord between humans and nature resulting from human activity. However, this cannot be realized by sacrificing the development of human society, particularly if this has a cost of creating a developmental imbalance within the international community. If this were the case, the discord between humans and nature could never be solved. This in turn could destroy the harmony between different nations.

The current problem is that we lack a relatively fair emission reduction scheme, one that takes the historical responsibilities of different nations and their future development into consideration. Additionally, international carbon transfer has not been considered in the assessment of greenhouse gas emissions among various nations. The development rights of developing countries have been largely ignored.

Current global warming is mainly caused by human-emitted greenhouse gases, therefore reducing carbon emissions has become a basic strategy for society to prevent the continuation of global warming. How best to allocate emission quotas among various countries to ensure fair development in both developed and developing countries remains the most challenging question [17,18].

First, the means for realizing development in both developed and developing countries under a fair framework must be investigated. Adhering to the goal of keeping global temperature increase under 2°C, if the atmospheric concentration of CO_2 is kept at the 450 ppm level, based on the world's 2005 population, annual per capita carbon emissions should be maintained at under 0.82 tons, equivalent to 2.99 tons of CO_2 between now and 2050 [19]. However, the problem lies in that how to ensure development in developing countries during the execution of the above emission goal. According to a human development index (HDI) established by the United Nations, an average of 0.82 tons carbon emission per year (tC/year) per capita corresponds to the poverty level [20]. This implies that if the goal of carbon emission were set at 0.82 tC/year per capita before clean energy can almost completely replace fossil fuels, undeveloped nations would remain near the poverty line. This is clearly unfair and cannot support a harmonious world, nor can the goal of sustainable development be realized.

The second question is how to balance the historical responsibilities and future contributions of carbon emissions. A recent assessment has been made of the historical responsibilities and agreed emission reductions between developed and developing countries, using two earth system models. One was developed in China and the other in the United States [21]. The assessment results are very similar. The conclusion is that developed countries have two-thirds of the historical responsibility for causing global warming, but their agreed future carbon emissions can only slow future global warming by one third. In contrast, while developing countries have had only one third of the historical responsibility for warming, they have agreed to take up to two-thirds of future carbon reductions. This is clearly unfair.

The third question is how to make reasonable emission estimates for each country. Carbon emissions produced by developed countries stabilized between 1990 and 2008, but the trend for developing nations has been increasing. However, the transfer of carbon emissions through international trade has been ignored in their calculation for a specific country [9]. The stabilization of carbon emissions in developed countries is partially attributable to their increased import of high energy consumption merchandise, such as steel and solar panels, from developing countries. Therefore, their own emissions have been reduced. To develop fair international emission reduction goals, we must clearly divide responsibilities based on carbon consumption instead of carbon production [9].

To realize sustainable development, we must ensure balanced development among various regions and countries. In our efforts to meet the challenge of global change, the international community must obey the principle of common but differentiated responsibilities. We must give overall consideration to harmony between humans and nature and

among human societies themselves, so as to reach a scientifically sound and practical (particularly for developing countries) scheme for carbon emission reduction and climate change adaption.

3.2 Taking action toward increasing carbon sequestration as equally important as reducing carbon emissions, and adaptation to global warming as equally important as mitigation

Although the international community must concentrate on and take action toward reducing carbon emissions, it is equally important to consider carbon sequestration by land and oceans. More attention should be paid to this process. It is important to increase carbon sequestration in land and oceans to slow global warming. The carbon sequestered by global forests between 1990–2007 was 2.4±0.4 Pg C per year [22], accounting for one quarter of total carbon sequestration by the terrestrial ecosystem. This can offset 33% of total industrial carbon emissions [23]. Annual change of plant productivity directly controls annual change of atmospheric CO_2 concentration. Therefore, afforestation, effectively protecting the forest ecosystem, and exploring the carbon sequestration capacity of the earth system itself can play indispensible roles in slowing the global warming process [24]. This is particularly important to developing countries. In recent years, China has implemented afforestation engineering and forest protection measures capable of sequestering over 3 million tons of carbon annually [22]. Moreover, afforestation provides other benefits to the ecosystem, such as improving the environment, purifying the air, adjusting the climate, preventing wind damage, and sand fixation.

Geoengineering as an effective measure to retard global warming has been widely noted in the worldwide scientific community [25]. In short, geoengineering is an artificial large-scale approach to slow or offset the warming effect via altering the energy balance of earth surface radiation or reducing the concentration of atmospheric greenhouse gases.

A recent study based on a model simulation indicates that under various scenarios of greenhouse gas emissions, geoengineering approaches including SO_2 aerosol injection to the stratosphere and space mirror installation may effectively stop the trend of rising sea levels caused by global warming, and could help restore sea levels to previous levels [26]. At present, an integrated assessment on the effects of geoengineering is urgently needed to formulate practical schemes for addressing global change issues.

Equally important as mitigation, adaptation is an important component in response to climate change. Adaptation activities, with the goal of increasing defense and recovery capacity, can effectively minimize climate change effects, thereby reducing the pressure for emission reductions and eventually buying the time required for transformation to low-energy modes of production. If global change impacts become increasingly prominent while mitigation cannot be quickly achieved, taking proper adaptation measures is an urgent and important choice, particularly for developing countries.

At present, two kinds of research questions need to be addressed in making adaptation plans. The first is how to meet the human demand for food, energy, water and other ecosystem service functions. The second is how to change our lifestyle to find new development routes under global change.

3.3 Strengthening scientific research to reduce uncertainty in our understanding of global change

It is widely recognized that there exists large uncertainty in our scientific understanding of global change [27]. It is normal to have such uncertainty from a scientific perspective. However, as the starting point for climate policy-making and handling climate change-related international affairs, the potential risks to the human society and the economy caused by uncertainties in our scientific understanding of global change cannot be neglected. Uncertainties in our understanding of global change need to be considered as follows.

First, the evidence of climate change over the past 2000 years. It has affected our judgment about the contributions of natural and anthropogenic forces to global warming in the 20th century and the future trend of climate change. For example, one question about which significant consensus has not been reached in historical climatology is whether there was a Middle Age warming period or other warming periods that were warmer than the 20th century [28].

Second, the sensitivity of climate system to CO_2 concentration. It is the theoretical basis for attribution of human activities to global warming. Based on analysis of observational data, there is no complete consistency between the trend of atmospheric greenhouse gas concentration and that of temperature change. For example, emission of global greenhouse gases increased twofold between the 1940s and 1975, but the average global temperature dropped by 0.1°C over the same period [1]. Because the climate system is a nonlinear system, the concentration change of greenhouse gases affects the earth surface temperature in multiple ways in addition to greenhouse effect. The response of earth surface temperature to the concentration of greenhouse gases in the atmosphere is dependent of the integrative effect of these multiple processes.

Third, the simulation capability of climate models. As a primary tool in climate change research, these models have direct impact on the reliability of future projections. Although the differences between model simulation results and those from observation have been substantially reduced owning to constant model improvement, some discrepancies remain unacceptably large. Using simulation of air temperature as a function of elevation as an example, researchers

compared model results with actual observation data. The results indicate that the greatest temperature rise is at 10 km above ground, twice as large as that at ground level. The observed data indicate that the greatest temperature rise is at ground level, and that the temperature increase through the entire troposphere is less than that at ground level. These results clearly contradict each other [29].

Fourth, scientific interpretation of the extent of impact of the 2°C threshold on nature and humans. The 2°C threshold refers to the agreement reached in Cancun [6,7]. Its goal is to control temperature increase to within 2°C of pre-industrial levels by the end of the 21st century. This is the basis used by every country in developing plans to reduce greenhouse gas emissions. Its importance is that it determines the upper limit for greenhouse gas concentration in the atmosphere and the upper limit for anthropogenic carbon emissions. An increase or decrease of this threshold, even by 0.1°C, would greatly impact the response strategy of global society, influencing economic growth, productivity and lifestyle in every country. However, different climate models have produced a large range (2.0–4.5°C) of temperature change [30]. The uncertainty of these findings remains large.

Fifth, the decadal variability of the climate system. The decrease of global surface temperature during 1940s–1975s and the slowing down of the global warming trend during the past 10 years may all be due to the natural variability of the climate system at the decadal scale. Therefore, it is important to enhance research on the decadal variability of the climate system and its causes so as to improve our understanding of global warming, particularly to accurate predict climate change in the future decades.

Sixth, synthetic observation and data integration. Long time series, high quality observational data and their assimilation with earth system models can help reduce the uncertainty in our understanding of global change. Therefore, it is necessary to develop a data sharing mechanism that can facilitate data fusion and assimilation such that high quality, continuous, uniform, and integrated earth observation systems can be made possible for joint observation and monitoring of parameters and processes of global change.

In the future, the international community should carry out more multi-factorial, multidisciplinary, and internationally collaborative research, to minimize the uncertainty in scientific understanding of global change. In the meantime, there should be more effort toward making sustainability-oriented global change studies, to strengthen research on global change issues in the social development, and to use the results to support sustainable development.

4 New opportunities brought about by addressing global change issues

Addressing global change is not simply a challenge; it also creates great opportunities. Various response strategies based on criteria mentioned above, are actually creating innovations in earth system management. These will have historical and incalculable impacts on production modes, lifestyle and international relations. It is anticipated that by constantly seeking better solutions to global change problems, new models of living and development throughout society will gradually come into being.

4.1 Facilitating strategic transformation of human energy consumption

Humans can harness nature because they have the capability to think and create. Humans use the energy available in nature to enhance their own power. This has increased the capability and extent of humam activity. As the economy, science and technology advance further, the energy structure is undergoing a change. This change is a de-carbonization process.

In early times, humans obtained energy in the form of fuel from grass and wood. Then, coal, oil and gas in solid, liquid and gaseous state were discovered, which all belong to the class of hydrocarbon fuels. The historically continuous process of exploration to find new forms and uses of new hydrocarbon-based energy is actually a de-carbonization process [31]. Every energy revolution reduces the carbon in fuel and increases hydrogen. The ratio between the number of carbon and hydrogen atoms in woody fuels is 10∶1. It is 2∶1 in coal, 1∶2 in oil and 1∶4 in natural gas [32,33]. Every such de-carbonization process advances human society and civilization. The natural adjustment process of human energy structure throughout history and the present conscious reduction of carbon emissions in response to global change strongly coincide. Therefore, current carbon emission reduction measures will speed the energy structure change and have important historic significance for human survival and social development.

4.2 Facilitating historic transformation of the earth environment

At present, developed countries have green mountains and clear water, but many developing countries lack vegetation cover and have a poor ecological environment because of war and poverty. Reducing CO_2 concentration in the atmosphere can be achieved through emission reduction. It can also be achieved through recovering vegetation cover so that more carbon can be absorbed by this vegetation. Planting trees and grass can contribute to halting global warming, while helping reduce deterioration of the environment in developing countries. Forest coverage in China has increased from 8.6% in the late 1940s [34] to 20% at present [35]. In some relatively undeveloped regions of the country, the increased forest cover has substantially improved the local environment. The new function of afforestation to

counteract global warming will give a new impetus to reforestation movements in developing countries. We believe that these countries can increase forest cover via their own efforts and international aid. By doing so, they can contribute to mitigating global change. Through constant afforestation efforts and grass planting, the global environment will certainly be considerably improved.

4.3 Promoting fundamental transformation of production modes and human lifestyles

For a long period, humans have been accustomed to taking resources from nature, but generally lack the concept and capability of protecting it. Over consumption of energy and other natural resources has caused enormous natural disasters that have placed human life and property at risks. Response to global change requires fundamental changes in methods of production, lifestyles and tremendous efforts in reducing consumption of resources and waste of energy. Many countries have called for such changes. China has proposed development of a resource-saving and environment-friendly society, which has been adopted as state policies. We believe that these measures will facilitate rudimentary transformation of current modes of production and lifestyle in current society.

4.4 Promoting transformation of human society toward a more harmonious world

From a historical perspective, human society has passed slave and feudal societies that compete for land, to the present capitalist society that competes for market share and capital. Ours is a competition-based history on various scales, ranging from individual and regional to national levels. When a nation is faced with danger from foreign invaders, this can result in the formation of united forces. Under pressure from global environmental change, for the first time in its entire history, human society is faced with a common threat. If dealt with improperly, we run the considerable risk of tremendous setbacks. The threat becomes shapeless charisma, one that forces all of humankind to join hands and set aside disagreements and conflicts to address the common challenge.

In summary, we are optimistic about the future of human kind. During their historical migration, humans experienced various types of climate change, disease outbreaks, and countless disasters. Human kind has not only survived but also has mastered sophisticated science and technology, and built a strong economic base for society. A solid network of collaboration has been established, and we are confident that through joint efforts, we can build a beautiful future for human society.

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