J. Geogr. Sci. (2008) 18: 387-399
DOI: 10.1007/s11442-008-0387-8

© 2008 Science in China Press Springer-Verlag

A quantitative comparison and analysis on the assessment indicators of greenhouse gases emission

ZHANG Zhiqiang[1], QU Jiansheng[1,2], ZENG Jingjing[1]

1. Scientific Information Center for Resources and Environment, Lanzhou Branch Library of National Science Library, CAS, Lanzhou 730000, China;
2. MOE Key Laboratory of Western Environmental Systems, Lanzhou University, Lanzhou 730000, China

Abstract: Anthropogenic greenhouse gases (GHG) emission and related global warming issues have been the focus of international communities for some time. The international communities have reached a consensus to reduce anthropogenic GHG emissions and restrain global warming. The quantitative assessment of anthropogenic GHG emissions is the scientific basis to find out the status of global GHG emission, identify the commitments of each country, and arrange the international efforts of GHG emission reduction. Currently the main assessment indicators for GHG emission include national indicator, per capita indicator, per GDP indicator, and international trade indicator etc. The introduction to the above indicators is put forward and their merits and demerits are analyzed. Based on the GHG emission data from the World Resource Institute (WRI), the US Energy Information Administration (EIA), and the Carbon Dioxide Information Analysis Center (CDIAC), the results of each indictor are calculated for the world, for the eight G8 industrialized countries (USA, UK, Canada, Japan, Germany, France, Italy and Russia), and the five major developing countries including China, Brazil, India, South Africa and Mexico. The paper points out that all these indicators have some limitations. The Indicator of Industrialized Accumulative Emission per Capita (IAEC) is put forward as the equitable indicator to evaluate the industrialized historical accumulative emission per capita of every country. IAEC indicator can reflect the economic achievement of GHG emission enjoyed by the current generations in every country and their commitments. The analysis of IAEC indicates that the historical accumulative emission per capita in industrialized countries such as UK and USA were typically higher than those of the world average and the developing countries. Emission indicator per capita per GDP, consumptive emission indicator and survival emission indicator are also put forward and discussed in the paper.

Keywords: global warming; greenhouse gases (GHG) emission; assessment indicator; Industrialized Accumulative Emission per Capita (IAEC); emission indicator per capita per GDP

Received: 2008-04-11 **Accepted:** 2008-07-25
Foundation: The Key Project for Knowledge Innovation Program of CAS, No.KZCX2-YW-501; The Western Talent Project of CAS in 2005; The National S&T Pillar Program, No.007BAC03A11-05

Author: Zhang Zhiqiang (1964–), Ph.D and Professor, specialized in the study of ecological economics & regional sustainable development and the strategic research on the development of Earth science. E-mail: zhangzq@lzb.ac.cn

The global climate system is currently undergoing significant changes, especially the century-scale climate change, a large number of observations have been recorded as evidence. According to the Fourth Assessment Report issued by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007), the average surface temperature has increased by 0.74℃ over the past 100 years (1906–2005). The international scientific communities state more than 90% certainty that human activity "very likely" has been the primary cause of rising temperatures worldwide since 1950 (IPCC, 2007).

Greenhouse gases (GHG) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), ozone (O_3), and water vapor (H_2O). The CO_2 contribution to global warming is the greatest. The enhancement of human activities (such as the use of large quantities of fossil fuels, land use and land cover changes, cement production, etc.) increase the global atmospheric concentrations of greenhouse gases greatly. Take CO_2 for example, the atmospheric concentrations of CO_2 was 280 ppm before the industrialized revolution, its concentration has reached 379 ppm in 2005, far more than the change range caused by the natural factors in the past 650,000 years (IPCC, 2007).

It has become the consensus of the international communities that human society must reduce anthropogenic GHG emissions in order to restrain global warming. But there are still many conflicts among the counties all over the world, especially between the developed and developing countries. It is also very important to give a widely-agreed assessment of GHG emissions for balancing all the interests and rebuilding the new framework after 2012. In this paper, we analyzed the status quo of global GHG emissions; systematically summarized and discussed the existing assessment indicators for GHG emission, evaluating the merits and demerits of each indicator through quantitative analysis; and explored the establishment of a new integrated assessment indicator and method that could embody the equity between intra-generation and inter-generation in the GHG emissions, providing a basis for understanding scientifically the global GHG emissions status, and evaluating reasonably the GHG emissions in each country.

Based on the GHG emission data from international organizations, such as the World Resource Institute (WRI), the US Energy Information Administration (EIA), we selected the eight G8 industrialized countries (USA, UK, Canada, Japan, Germany, France, Italy, Russia), as well as the five major developing countries including China, Brazil, India, South Africa, Mexico as the objects of analysis to assess quantitatively. The GHG emissions of these countries are the focus of international concern, and their current and future emission reduction policies will affect the achievement of international GHG emission reduction targets. It has important realistic meaning to analyze the current GHG emissions of these countries.

1 Increasing tendency of global GHG emissions

Since the latter half of the 18th century human society has entered the industrial revolution where fossil fuels were widely used. The expanded scale in the use of fossil fuels by human led to the dramatic increase of the GHG emissions since 1850.

Synthesizing the data from the Carbon Dioxide Information Analysis Center (CDIAC), the World Resource Institute (WRI), and the US Energy Information Administration (EIA), since the first industrial revolution that started in 1751, it is shown that the global accumulative emissions have reached 1.16 trillion tons of CO_2 (up to 2004).* Most of the CO_2 was emitted after the second industrial revolution that started in the middle of the 19th century. The accumulative emissions of GHG after 1850 made up 99.6% of the emissions since 1751. After 1950, the globe entered into the third technological revolution, and the GHG emissions increased more rapidly; the accumulative emissions of GHG during this period accounted for 80.75% of the accumulative emissions since 1751 (Figure 1).

GHG emissions are closely related with the industrialized level, the developed countries have made a greater contribution to the increase in GHG concentrations (Figure 2). The total emissions of GHG in developed countries show 2.95 times higher than those in developing countries between 1850 and 2004, accounting for the 79.3% of the global total emissions. Since the third technological revolution, the emission gap between the developed and developing countries has somewhat narrowed because of the development of the economy of the developing countries. The total emissions of GHG in developed countries were 96.3 times of those in developing countries in 1900, and fell to 13.7 times in 1950. The emissions in developed countries were basically 3 times those in developing countries until the 1980s.The gap has been about 1.6 times since the 1990s. Therefore, developed countries are the main contributors to global GHG emissions, and they should have historical responsibility to most GHG emissions since the industrial revolution.

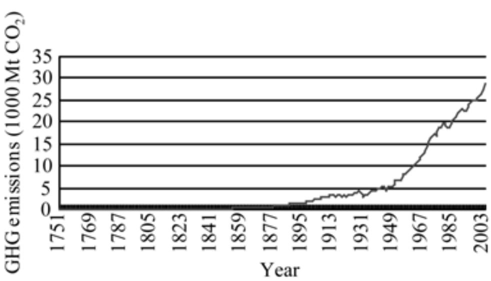

Figure 1 GHG emission trend of the world, 1751–2004

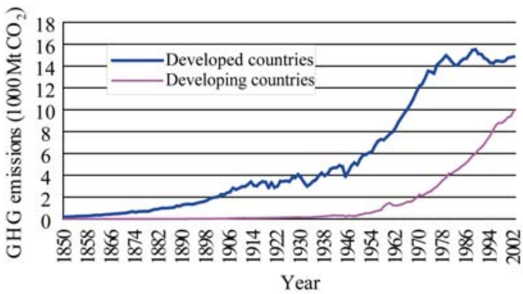

Figure 2 GHG emission trends of developed and developing countries, 1850–2002

2 Indicators for GHG emissions and their results analysis

The generation of the assessment indicators for GHG emissions stemmed from the need of identifying the commitments of each country, and the initial evaluation was calculating the GHG emissions of each country under the United Nations Framework Convention on Climate Change (UNFCCC). In the evaluation of GHG emissions, some indicators have been shaped gradually such as national indicator, per capita indicator, per GDP indicator, international trade indicator etc, and the indicator system evaluating the GHG emissions of each country has been formed in various ways.

*According to the current monitoring results of GHG emissions, it is easy to estimate the GHG emissions from fossil fuels, and the results are credible, representative, and fossil fuels are proved to be the main source of atmospheric GHG. So the main target is to perform GHG evaluation at present. In this paper, we focus on the GHG emitted from fossil fuels (primarily CO_2), and the units are in carbon dioxide equivalent (CO_2e).

2.1 National indicator

National indicator is in the unit of the nation to calculate the GHG emissions, which was applied earliest, especially in the late 20th century when the GHG issue and discussion on emission reduction were burgeoning. The national indicator based on the national and regional borders and its results had once played a key role in the establishment of the global climate policies and distribution of the commitments. The UNFCCC and *Kyoto Protocol* are based on the assessment of the GHG emissions in each country in 1990. Due to the consensus that the accumulative emissions in developing countries are historically smaller, according to “common but differentiated” responsibilities, developing countries are not obliged to quantify emission reductions temporarily.

According to the difference of time scales, national indicator could be divided into the indicator in a certain year and the indicator for a period of time. If breaking through the country border constraints, national indicator will continue to be developed into regional indicator (such as Europe) and local indicator (such as California).

2.1.1 Analysis of the GHG emissions of G8+5 countries Utilizing the data from WRI and EIA, we calculated the GHG emissions of G8+5 countries between 1850 and 2004 (Figure 3), and the percentages of accumulative GHG emissions of G8+5 countries accounting for the global emission between 1850 and 2004 (Figure 4). The analysis indicated that developed countries were the main GHG emitters, and since 1850, 29% of the global GHG emissions have been emitted by USA, 61% by G8 countries, whereas the total emissions of the five major developing countries have been less than 13%.

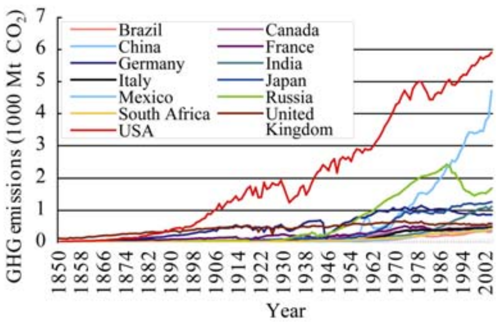

Figure 3 GHG emission trends of G8+5 G8+5countries in 1850–2004

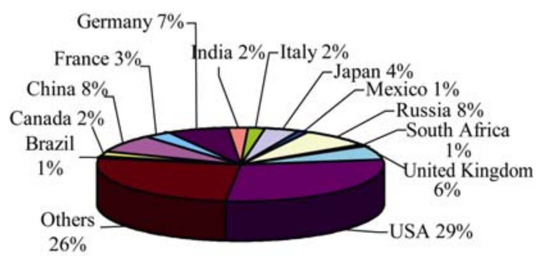

Figure 4 Percentages of accumulative GHG emissions of countries accounting for global emissions in 1850–2004

2.1.2 The merits and demerits of national indicator National indicator has played an important role in determining the commitments of emission reduction in the first commitment period (2008–2012). It is the first time to evaluate the GHG emissions from the view of national (or regional) borders, especially under the circumstances that countries are the main bodies in emission reduction, it is undoubtedly the most convincing indicator.

National indicator focuses on evaluating the current annual emission of each country, neglecting the great differences of historical accumulative emissions among the countries. In addition, the emission quota is the common resource of human beings and it does not reflect the intra-generation equity of global emission permit. The global common resource should be distributed on the basis of population; however, the large differences of population among countries limit the national indicator as a basis for emission permits (embodying the development rights). The industrialization that causes emission in developing countries began in the 1950s. Even after the 1980s, their historical emissions are small, and their needs to development are urgent, but the emission quota is beginning to decline. If emissions were bound, the development opportunities in developing countries would have been severely affected. As a result, it can't be accepted by newly industrializing countries.

2.2 Per capita indicator

The main sources of GHG emissions are the use of fossil fuels, which is an inevitable product in the industrialization processes. Modern industry is built on the basis of abundant utilizations of fossil fuels including energy, and modern social life presents the possession and consumption of resources everywhere. Given that the development of society is ultimately for the development of human beings, per capita indicator is very meaningful. Under the circumstances that the low-carbon economic pattern is not established yet, the level of per capita emission directly reflects people's living standard and the degree of limited emission quota possessed by people in different regions. If a new emission reduction pattern could be established in accordance with per capita emission, it would embody the equal rights for all to survive, develop, and utilize the common resources on the Earth to the largest extent, as well as would help to ensure the development rights and interests of people in developing countries, whose per capita emissions are low.

2.2.1 Analysis of the per capita emissions of G8+5 countries In general, the per capita emissions of developed countries are higher than those of developing countries (Figure 5), furthermore, given the export of carbon-intensive products in developing countries, their per capita emissions would have been lower. For instance, the per capita emission of USA was 20.18 tons in 2004, the world was 4.24 tons, and China was just 3.62 tons. The per capita emission of USA was 5.6 times of that of China in 2004. Figure 6 clearly reflects the per capita emissions of G8+5 countries in 2004, indicating that all the per capita emissions of G8 countries were higher than the global average, all the per capita emissions of developing countries except South Africa were lower than the global average.

2.2.2 The merits and demerits of per capita indicator Per capita indicator concerns the emission assessment focusing on the people, reflecting the global common resources per capita, namely it is based on the fair development opportunities. Especially the per capita

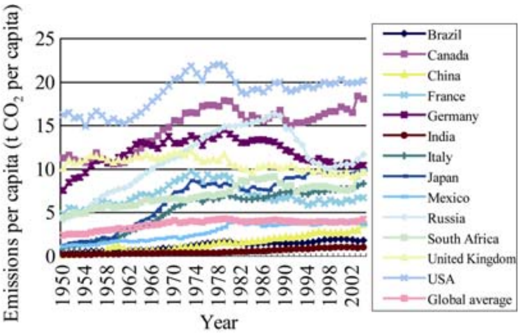

Figure 5 Trends of GHG emissions per capita of G8+5 countries in 1950–2004

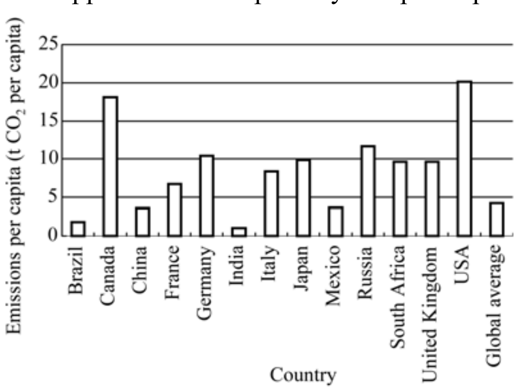

Figure 6 GHG emissions per capita of G8+5 countries in 2004

emissions of developing countries are smaller, thus it is beneficial for developing countries, which could provide them the development space. Additionally, per capita indicator could supply the carbon cost information for the residents in various regions and countries, which will help for the scientific promotion of the emission reduction.

The total population of developed countries is always small, and the gross domestic product (GDP) is large. As a result, their per capita emissions are fairly high, if combined with the commitments of each country, the developed countries were obviously unwilling to accept reductions. Some politicians and scholars in developed countries believe that the different degree of development for each country is historical and the present generation can not shoulder the obligation inherited from their ancestors and predecessors. The objective of the commitments should be the same for all the contemporary people in the world considering that everyone has the duty to protect the earth's environment. Under the circumstance, a global united framework for emission reduction and assistance has not yet been established. It is impossible to enter into an era of sustainable low-carbon economy that makes the developing countries that make up 80% of the world's population (United Nations Population Fund, 2007) reduce emission and slow down the pace of their development, without a reciprocal technological and financial assistance from developed countries.

2.3 Per GDP indicator

Emissions per GDP are the measurement indicator of the GHG emission intensity in the economic growth. The core thought of *Clear Skies & Global Climate Change Initiatives*, which is also called alternative to *Kyoto Protocol* after USA withdrew from it in 2001, is combining emission reduction with economic development; namely reducing the GHG emission intensity per GDP without damaging economic growth (US Census Bureau). The goal is to decrease 18% of the GHG emission intensity between 2002 and 2012, namely declining from 0.671 kgCO_2 per US dollar of GDP in 2002 to 0.554 kgCO_2 per US dollar of GDP in 2012*. The voluntary gradual emission reduction per GDP is an abatement pattern which affects the economy relatively smoothly. The goal determined in the China's 11th Five-Year Plan is to cut down 20% of energy intensity per GDP. From the view of developing countries, this voluntary emission reduction is so great that it is undoubtedly the most current positive scheme of reducing the emissions per GDP.

2.3.1 Analysis of per GDP emissions of G8+5 countries According to the assessment of per GDP emissions of each country, we obtained the general information of each country's level of industrialization and energy efficiency. Figure 7 shows the tendency of CO_2 emission per GDP for each country, reflecting the large differences among them. The CO_2 emissions per GDP of developed countries are the lowest. For instance, CO_2 emission per GDP of USA was 0.55 kg per US dollar of GDP in 2004, Japan's CO_2 emission per GDP was 0.36 kg per US dollar of GDP, whereas China's was 0.72 kg per US dollar of GDP (US dollar converted by purchasing power parity) (WRI, World Bank). In general, developed countries' CO_2 emissions per GDP are lower, but developing countries' are higher, which could be caused by the high-energy-consumption industries and the low level of the production processes in developing countries. CO_2 emission per GDP of Russia and South Africa are the highest, and the descent trend of China's CO_2 emission per GDP is the most obvious in Fig-

* Due to the various sources, the data are different from that of USA in section 2.3.1

ure 7.

2.3.2 The merits and demerits of per GDP indicator Per GDP indicator shows the energy efficiency, which would guide each country to improve the energy efficiency and transform into low-carbon economy. After the establishment of international carbon tax in the future, the countries that have the low emission per GDP can create a more favorable competition environment for their products.

Using per GDP indicator to measure the economic development and emission right for each country might restrict the emission activities in the countries where per GDP emissions are high. However, the phases of development between developed and developing countries are different, and there exists a notable gap in the level of economic technology, which is the reason why emissions per GDP of developing countries are always high. Considering the existing competition among countries, the application of per GDP indicator essentially restricts the development of developing countries. The huge social welfare brought by the development of developed countries does not serve developing countries. As a result, limiting the emissions of developing countries by per GDP indicator clearly deviates from the principle of fairness, and per GDP indicator can not be used to identify the commitments of each country.

2.4 International trade indicator

GHG emissions ultimately serve the human social and economic activities. The assessments on the GHG produced by human activities should be attributed to assessments on the corresponding goods and services. In the circulation of goods and services, the corresponding carbon emissions might be transferred. In the international trade of goods and services, carbon emissions could also be transferred. And the emissions should be calculated in the ultimate consumers of the goods and services. Thus, GHG emissions due to the manufacture of goods and services for international trade become an important indicator for evaluating the GHG emissions.

2.4.1 Transferred emissions in international trade Figure 8 showed the GHG emissions from international trade (Ahmad Nadim, 2003). If one country's emission difference of consumption and production is positive, the carbon emissions from imported products are more than those from exported products, indicating that its accumulative carbon

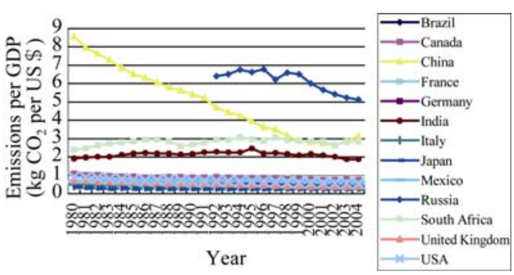

Figure 7 CO_2 emission per GDP unit of G8+5 countries in1980–2004

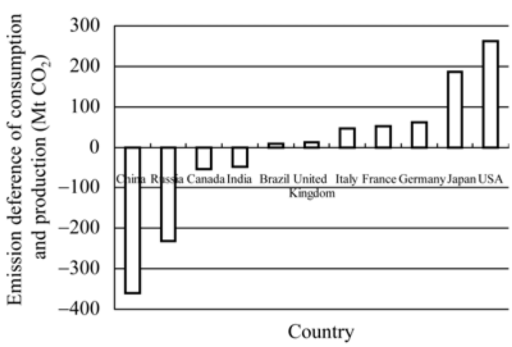

Figure 8 GHG emission difference of G8+5 countries in trade field during 1993–1998

emissions from consumption are higher than those from production, the overall effect is due to the exporting destinations. For example, USA imported products from China between 1995 and 1999, which embodied carbon emissions were 96.5 million tons CO_2e, 109.0 million tons CO_2e, 127.5 million tons CO_2e, 156.4 million tons CO_2e, and 168.3 million tons CO_2e, respectively, suggesting that the products consumed in USA have caused several million tons CO_2 to be emitted.

Tyndall Centre for Climate Change Research issued *Who Owns China's Carbon Emissions* in October 2007 (Tyndall Center for Climate Change Research, 2007), based on the data in 2004 to set out an initial assessment of emissions from the goods and services that China export. It concluded that about 1109 million tons CO_2 were emitted by China as a result of net exports in 2004, accounting for 23% of China's total CO_2 emissions in that year. This is comparable to Japan's CO_2 total emissions, and is more than double the UK's emissions in the same year. Considering the indirect emissions that originate from inputs used in the production of the traded goods (including emissions from production of raw materials and services sectors), the GHG emissions that China emitted for importers would be larger.

2.4.2 The merits and demerits of international trade indicator Focusing on the carbon emissions in the international trade of goods and services will be helpful to identify exactly the ultimate carbon emissions from the consumptions of goods and services for each country, to provide the accurate data for the fair measurement of a country's carbon footprint, and ultimately to determine the commitments of carbon emissions scientifically and reasonably.

There are many kinds of goods and services in the international trade, and it is hard to obtain the carbon emission intensity data for various goods and services in the international trade, so it is difficult to calculate the carbon emissions for each goods and services comprehensively and precisely. As a result, there are large errors in the current assessment.

3 The development of a new scientific, fair and acceptable indicator

The existing indicators have their own characteristics and application ranges, to which various countries show a different attitude, especially developed countries and developing countries. Considering the equity to measure the GHG emissions for each country and the promotion to establish a more reasonable framework for international emission reduction, we need to develop a new scientific, fair and acceptable indicator system, which could reflect the history, status, contribution and cost for each country's GHG emissions. The scientific base of international commitment framework and actions is the assessment indicator and its result that are widely accepted internationally. Based on this, we presented new indicators such as industrialized accumulative emission per capita and emission indicator per capita per GDP.

3.1 Industrialized accumulative emission per capita

Some scholars have explained the accumulative emission per capita for a certain period in various ways (Ren *et al*., 2002; Wang *et al*., 2002; Zhu *et al*., 1998; Ruddiman and Thomson, 2001; Ruddiman, 2003), which has offered clues for assessments on GHG emissions. The CO_2 emissions originating from human activities mainly started after the industrial revolution. In order to compare the accumulative emissions for each country's current population since the industrial revolution, we put forward a new indicator—industrialized accumulative emission per capita—to reveal accumulative emission per current capita in each country's industrial processes. Not only could it comprehensively and fairly reflect the real costs of environmental burden on the current generation caused by different industrialized accumulative emissions, but also could depict the environmental costs of economic miracle in developed countries which emitted a lot in history and have fine economic situations. As a result, it is useful to determine the distribution pattern of emission quota in the view of development equity for all.

Given the phases of development between developed and developing countries are different, and each country's emission intensity is various in each phase of industrialization, industrialized accumulative emission per capita could analyze different time phases of accumulative emissions per capita. In this paper, we calculated the historical accumulative emission per capita in some key phases of industry development from 1751 to 2004 (namely in 1751–2004, 1850–2004, 1900–2004 and 1950–2004).

Industrialized accumulative emission per capita can be calculated as follow: choosing the annual emission from 1751 to 2004 (the most recent year in which comprehensive data are available), calculating each country's or global accumulative emissions, divided by the population in 2004, that is:

$$Ec=(E_{1751}+E_{1752}+\cdots+E_{2004})/P_{2004} \quad (1)$$

GHG emission data were from the Carbon Dioxide Information Analysis Center (CDIAC) and the US Energy Information Administration (EIA), and population data came from the US Census Bureau. The results showed the global industrialized accumulative emissions were 181.4 tons CO_2 per capita, UK 1182.8 tons CO_2 per capita, USA 1094.8 tons CO_2 per capita, China 66.8 tons CO_2 per capita, and India 25.0 tons CO_2 per capita. The industrialized accumulative emissions per capita in industrialized countries (such as UK and USA) were typically higher than those of the world average and the developing countries. The industrialized accumulative emissions per capita of UK and USA were 17.7 times and 16.4 times of those of China, and 47.2 times and 43.7 times of those of India, respectively. Figure 9 revealed the industrialized accumulative emissions per capita in the four periods. Industrialized accumulative emissions per capita of UK and USA in 1751–2004 and in 1850–2004 were the highest, as time went by, industrialized accumulative emissions per capita of Russia, Germany, and Canada increased gradually, and industrialized accumulative emissions per capita of Russia in 1950–2004 were the first highest in the world, and USA followed. Industrialized accumulative emissions per capita of developing countries such as India, South Africa, China and Mexico are lower than the average of the world and developed countries in each period, however, the gap of industrialized accumulative emissions per capita between developed and developing countries has declined significantly.

3.2 Emission indicator per capita per GDP

Per GDP indicator reveals the carbon emission intensity in the economic growth, and per capita indicator shows the emissions enjoyed by each people. They both reflect the two significant aspects in GHG emissions: economic growth and survival and development of human beings. For the purpose of integrated assessment on the GHG emissions in the economic growth and survival and development of human beings for each country, we put forward a new indicator: emission indicator per capita per GDP so as to bring GHG emissions, the gross domestic product and population into an assessment system, evaluating the increase in the GHG emissions per capita per GDP. The formula for calculating the indicators is expressed as follows:

$$E_G = E_i/(G_i \times P_i) \qquad (2)$$

E_G represents the annual emissions per capita per GDP for certain country, with a unit of kg CO_2 per capita per \$100 million of GDP. E_i represents the GHG emissions in the year i, with a unit of kg CO_2; G_i represents the GDP in the year i, with a unit of \$ 100 million; P_i represents the population in the year i, with a unit of person.

Figure 10 showed the emission per capita per GDP* of G8+5 countries in 1980, 1990, 2000 and 2004. The tendency of emission per capita per GDP differs from that of emission per capita and emission per GDP. The highest emission per capita per GDP of G8+5 countries in 1980, 1990, 2000 and 2004 were South Africa, Russia and Canada successively, the others were relatively low. In general, the emission per capita per GDP shows a gradual decline trend. As for emission per capita per GDP, China is not the country with the highest emission.

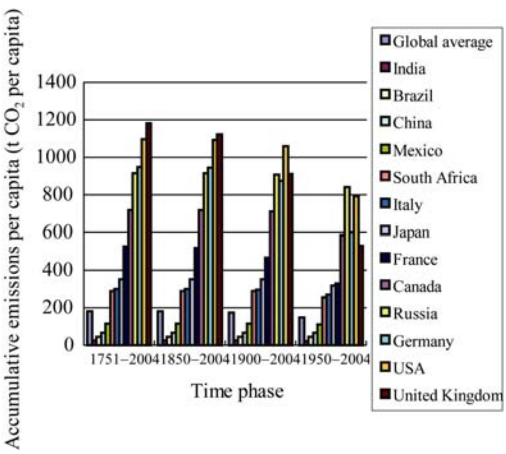

Figure 9 Industrialized accumulative GHG emission per capita of G8+5 countries in several industrialized phase

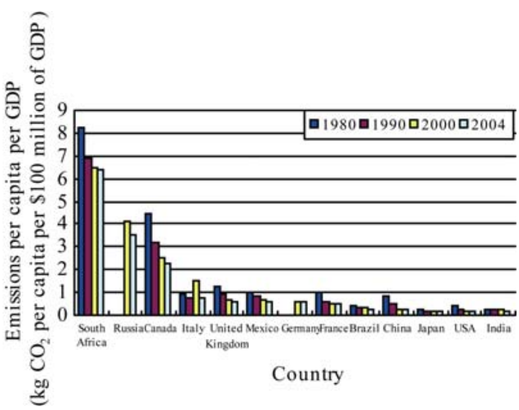

Figure 10 GHG emission per capita per GDP of G8+5 countries in specific years

Each country's emission per capita per GDP is affected by its GHG emissions, population and GDP. Generally, with the same emissions among some countries, if the GDP and the population were higher, the emission per capita per GDP would be lower. However, the indicator does not take into account the transferred emission in the international trade. Considering that a part of the emissions in a certain country did not serve its population, so it could be concluded that its emissions per capita per GDP would be lower. In addition, the low emission per capita per GDP does not mean the high energy efficiency in the country (for example, emissions per capita per GDP of some developing countries are low) or low GHG emissions (for example, biggest emitters have higher GDP or more population), just suggesting the country's emission has served more population or higher GDP.

* Lacking data of Russia and Germany in 1980 and 1990.

3.3 Consumptive emission indicator

Since the 1960s the international adjustment of industrial structure has enhanced the economic globalization, strengthened the international industrial division, and made the international trade more active, which has influenced the pattern of GHG emissions. On the one hand, due to the adjustment of distribution in energy-intensive and carbon-intensive industries, some countries and regions have gradually become the world's raw material base and manufacturing hub, increasing sharply the regional GHG emissions. On the other hand, the international trade of production means and consumption goods has improved greatly and transported more products to the world, enlarging the ultimate GHG consumers throughout the world.

From the view of fairness, product base should not bear the responsibilities of high GHG emissions bringing about by the difference of international division. The embodied energy in the exports should be attributed to the ultimate consumers. International trade indicator reflects the transferred emissions in the international trade to a certain extent. However it could not measure the GHG emissions of all goods and services consumed in a nation or a region. Consumptive emission indicator, assessment indicator based on the consumed GHG emission, can relatively fairly measure the commitments.

Firstly, consumptive emission indicator needs to establish a GHG emission factor including all the emissions from manufacture and daily life. Secondly, it needs to quantify all the goods and services consumed by a certain person (individuals or groups, regions) in a period (for example one year). Thirdly, multiplying the emission factor by all the consumptions to obtain their GHG emissions, the accumulation of consumption emissions is the total consumption emissions.

It is of great significance to establish emission indicator based on consumption for measuring GHG end consumptions, determining the responsibilities and commitments. However, a comprehensive assessment of consumption emissions still faces methodological difficulties, mainly identifying the emission factors of all the goods and services. Undoubtedly, it is necessary to build a standard system. It can not only serve to determine the commitments of emission reduction, but can also provide a significant support for the establishment of carbon tax and low carbon economy.

3.4 Survival emission indicator

GHG emission is related to the problems of environment and development, and environmental protection is still an issue of development. GHG emissions per capita of developing countries are about 17.8% of those of developed countries, and emissions per capita of the USA are 285 times of those of Rwanda, and 181 times of those of Nepal. Behind the great differences are the enormous differences in survival (life) qualities.

Establishing survival emission indicator that is based on the rights to humanistic development and meets the basic needs of survival and development for all countries, and sustainable per capita indicator that is in line with the sustainability of Earth's resource supply and environmental carrying capacity and can be accepted by all the countries, will promote the rational GHG emissions, bring emission reduction into the framework of human development, fair development and limited development so as to determine the best and consistent goal of emission reduction all over the world.

Establishment of survival emission indicator needs to define GHG emissions of the global population for basic survival and development. It might face greater difficulties: opposition from developed countries, challenges from scientificity and fairness of the indicator, and constraints on the emission goals. The deployment based on the emission reduction goals might be the radical scheme of reducing the emissions, and difficult to achieve in practice. From the angle of philosophy, the public and government should be aware of the lowest survival emission and the number of survival emission in the future. It will be helpful to formulate and implement the voluntary or mandatory emission reduction plan.

4 Results and discussion

Based on the main GHG databases worldwide, the quantitative historical sequences of global GHG emissions are given. Taking the eight main industrialized countries and the five major developing countries, the merits and demerits of main assessment indicators for GHG emission (including national indicator, per capita indicator, per GDP indicator, and international trade indicator etc.) are analyzed. Developed countries and developing countries have different attitudes towards the results of assessment indicator due to the various angles of attention and assessment results. The scientific base of international commitment framework and determination of the reduction responsibilities is to develop a new scientific, fair and acceptable indicator system for all.

Discussing the establishment and development of more scientific, reasonable and fair assessment indicator system, the new indictors such as industrialized accumulative emission per capita and emission indicator per capita per GDP are put forward and defined, and the significances of establishment of consumptive emission indicator and survival emission indicator are also put forward and discussed. The new indicators such as industrialized accumulative emission per capita and emission indicator per capita per GDP can evaluate each country's GHG emissions more scientifically, more reasonably and more fairly, which reveal the historical responsibility for majority of the GHG emissions and is helpful for development rights of developing countries.

Various assessment indicators and their results have different effects on the support of establishing a new cooperation framework to mitigate global warming for the international communities. However, the following facts should be known when utilizing any assessment results.

(1) Global warming of the climate system is the fact, emission reduction is the most important measure for mitigating climate change. However, there are still some controversies over issues such as whether GHG emissions play a key role and how much they did.

(2) Currently GHG emission statistical data still are based on the CO_2 data from fossil fuel. The GHG emission data from other sources are still difficult for widely-acceptable assessment. Considering the current GHG emission data are not comprehensive and precise, the assessment results in general are conservative, and the actual emissions would be greater than the current evaluation.

(3) GHG emission reduction is related to the interests of multi-stakeholders, all the controversies over the commitments should not be divided from the following facts. All the assessments indicated that developed countries should bear the historical responsibilities for the majority of the GHG emissions since industrialization. People in developed countries

enjoy the modern life brought out by long-term industrialization, while more people in developing countries are still in poverty. Therefore, developed countries should bear more commitments of emission reduction. The emission reduction should not deviate from the harmonious development goal for human society. Considering the global competition of economy and politics still exists, blindly emphasizing the common responsibilities will enlarge the division of global politics and economy, further expand the gap of economic development between rich countries and poor countries, and restrict the achievement of reduction goal as well.

(4) The lower industrialization development stage and the technology level are one of the key factors for improving energy efficiency and reducing emissions in developing countries. The introduction of high-efficiency technologies is one of the most effective ways for emission reduction in the developing countries. It is suggested that the international communities should bring the technology cooperation into the framework of international cooperation and adopt flexible, effective intellectual property rights and technology assistance patterns in the field of climate change technology cooperation.

Acknowledgements: We are grateful to Academician LI Jinghai for his invaluable assistance in the preparation of this paper. We are also grateful to Dr. Tsegay Wolde-Georgis at NCAR for revision of this paper.

References

Ahmad Nadim, 2003. A Framework for Estimating Carbon Dioxide Emissions Embodied in International Trade of Goods. OECD, Paris.

Carbon Dioxide Information Analysis Center. Global, regional, and national fossil fuel CO_2 emissions. http://cdiac.ornl.gov/

IPCC, 2007. Climate Change 2007: The Physical Science Basis. IPCC Secretariat.

Ren Guoyu, Xu Ying, Luo Yong, 2002. The status and history of CO_2 emission from world countries. *Meteorological Science and Technology*, 30(3): 129–134. (in Chinese)

Ruddiman W, 2003. The anthropogenic greenhouse era began thousands of years ago. *Climate Change*, 61: 261–293.

Ruddiman W, Thomson J, 2001. The case for human causes of increased atmospheric CH_4 over the last 5000 years. *Quaternary Science Reviews*, 20: 1769–1777.

Tyndall Center for Climate Change Research, 2007. Who owns China's carbon emissions? Tyndall Briefing Note No.23, October 2007.

UNFCCC. Kyoto Protocol. http://unfccc.int/kyoto_protocol/items/2830.php

United Nations Population Fund. State of World Population 2007. UNFPA, 2007.

US Census Bureau. IDB–Rank countries by population. http://www.census.gov/ipc/www/idbrank.html

US Energy Information Administration, 2006. International Energy Annual 2004.

US Government. Clear Skies & Global Climate Change Initiatives. http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html

Wang Weizhong, Chen Bin, Lu Chuanyi *et al*., 2002. The Koyto Protocol and allocation of carbon emission permits. *Journal of Tsinghua University* (Philosophy and Social Sciences), 17(6): 81–85. (in Chinese)

World Bank. DDP data. http://ddp-ext.worldbank.org

World Resource Institute. CO_2 emissions series data. http://www.wri.org

Zhu Xingshan, Liu Xuyi, Xu Huaqing, 1998. The fairness and efficiency problem of action to address climate change. *Environmental and Sustainable Development*, (3): 6–11. (in Chinese)