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Research article

Framework construction and application of China's Gross Economic-Ecological Product accounting

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ABSTRACT

In order to integrate resource consumption, environmental damage and ecological benefits into the evaluation system of social and economic development, and practice the green concept of "Lucid waters and lush mountains are invaluable assets", this research was based on the Green GDP and Gross Ecosystem Product accounting to develop comprehensive accounting indicators for Gross Economic-Ecological Product (GEEP). At the same time, the 2016 GEEP of 31 provinces in China is calculated. The results show that: 1) GEEP is a comprehensive ecological-economic accounting system based on weak sustainable development theory and welfare economics. GEEP follows the principle of GDP accounting and carries out value accounting for the final products of ecological and economic systems. Based on GDP, GEEP considers the ecological-environmental damage caused by human beings in economic product activities and the benefits of the ecological system to the economic system. 2) In 2016, China's GEEP was 126.6 trillion RMB, 1.6 times of GDP, among them, the cost of pollution damage was 2.1 trillion RMB, the ecological degradation cost was 0.69 trillion RMB, and the ecosystem regulating service was 51.4 trillion RMB. 3) The regional Gini coefficient based on GEEP was 0.44, which was 0.07 smaller than the regional Gini coefficient calculated based on GDP in 2016, thus GEEP accounting would benefit to shrink regional disparity. 4) Compared GEEP ranking with GDP ranking of all provinces, GEEP rankings in Inner Mongolia, Heilongjiang, Yunnan, Qinghai and Tibet have increased by more than 10 ranks compared with GDP, and Beijing, Shanghai, Tianjin, Hebei and Shaanxi, their GEEP ranking compared with the GDP ranking has descending more than 10 places.

1. Introduction

As an important indicator for assessing the Macro-economy, Gross Domestic Product (GDP) is a general measure of the overall economic performance of a country. However, the current National Accounting System has certain limitations and it cannot measure whether the economy develops towards a sustainable path (Hartwick, 1990; Hamilton, 1995; ShahaniDeneulin and Lila, 2009; Costanza et al., 2014). To this end, the international research began to establish a green national economic accounting system in the 1970s, by deducting the cost of natural resource consumption and pollution damage from the GDP accounting system. It is more reasonable to measure economic development results and national economic welfare more realistically.

Green GDP and Genuine Savings have been regarded as indicators of sustainability to a nation or region, in order to make up the deficiencies in the traditional System of National Accounts (Pearce and Atkinson, 1993; Hamilton, 1994,1996). The United Nations Statistics Division has issued and revised the Systematic Environmental and Economic Accounting System (SEEA) for three times(United Nations, 1993, 2003, 2012), providing a basic framework for the establishment of green national economic accounting to be adopted. SEEA allows for the integration of environmental information with economic information in a single framework. The value of environmental depletion is considered to be a cost against income; hence, in the sequence of economic accounts, the definition of depletion adjusted balancing items and aggregates entail deducting depletion from the measures of value added, income

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and saving (United Nations, 2012). However, the SEEA Central Framework does not incorporate ecological benefits into economic system, and the stock and flow accounting of ecological assets is supplemented in the SEEA Experimental Ecosystem Accounting.

How to monetize evaluation of depletion of natural resources and degradation of the ecological environment within a national accounting framework is one of the main difficulties to green national accounting. China sponsored the *Green GDP* and made public *Chinese Environmental and Economic Accounting Report 2004*(Wang et al., 2009) in 2006. The work reported that the cost to environmental pollution in 2004 was about 3.05% of GDP. The report was warmly welcomed and hailed by the international community, the first such report issued by the national government around the world. So far, Green GDP from 2004 through 2016 has been completed by the Chinese Academy of Environmental Planning institute. Basically, the SEEA has made some adjustments to China's specific situation and has joined the accounting for China's ecological degradation costs since 2008. China economic-environmental accounting technical guideline was published and It promoted the study of China's green national economic accounting system (Wang et al., 2009, 2013; Yu et al., 2009). It is the shortcoming of SEEA and green GDP that they only reduce the resources and environmental costs of economic system growth, but do not take into account all the ecological benefits provided by ecosystems, which is essential for human well-being (Costanza et al., 1997). This may lead to excessive pursuit of economic growth and damage to the ecological environment.

The ecosystem services are the direct and indirect benefits obtained by humans from their ecosystems (Costanza et al., 1997; De Groot et al., 2010; Obeng and Aguilar, 2018; Sannigrahi et al., 2018). The contribution of ecosystem to the world's economy and human well-being has been widely recognized in science and policy (Rodríguez-Loinaz and Alday JOnaindia, 2015; Millennium Ecosystem Assessment, 2005; Ouyang et al., 2016). However, improper information about ecosystem services, inadequate and inaccurate valuation of natural resources and ineffective conservation policy system are found to be the key challenges for developing a comprehensive ecosystem service valuation system (Turner and Daily, 2008; Tallis and Polasky, 2009; Matzdorf and Meyer, 2014). Chinese scholar Ouyang et al. (2013) proposed the concept of Gross Ecosystem Product (GEP), which fully accounted for the ecological benefits including ecosystem provisioning value, ecosystem regulating value, and ecosystem cultural value provided by the ecosystem annually. From an ecosystem perspective, GEP considers the benefits that ecosystems bring to economic systems. But it is also important to note that ecosystems cannot provide any benefits to people without the presence of people, their communities, and their built environment (Costanza, 2014). This has given rise to the degradation of non-marketed services as a result of actions taken to increase the supply of marketed ecosystem benefit (Rodríguez-Loinaz and Alday JOnaindia, 2015). Protecting and enhancing the provision of non-marketed ecosystem benefit is critical to both human and economic aspects. It is important to integrate of the ecosystem and economic systems into the same accounting system.

In order to incorporate environmental damage, ecological degradation and ecological benefits into the evaluation system of social and economic development, this paper constructs a comprehensive Gross Economic-Ecological Product (GEEP) accounting framework based on Green GDP and GEP accounting. At the same time, in 2016, GEEP accounted for 31 provinces, municipalities and autonomous regions of China, and the spatial distribution of GEEP is analyzed.

2. Framework of Gross Economic-Ecological Product and key index

2.1. Framework of Gross Economic-Ecological Product

The theoretical basis for GEEP is weak sustainable development and welfare economics theory. Weak sustainable development considers that capital stock can be replaced by different elements, allowing artificial capital to replace natural capital (Gao, 2004), which means ecosystem and economic system may replace each other and can be integrated into the same accounting system. Welfare economics realized that the purpose of economic activities is to increase the welfare of individuals in society. Individual welfare depends not only on the personal goods consumed by individuals and the government, but also on the quantity and quality of non-marketized goods and services in the ecosystem. Therefore, on the basis of the GDP of the economic system, it is also necessary to consider the damage to the ecological environment caused by human economic activities and the impact of ecosystems on the economic system.

GEEP is based on the gross domestic product of the economic system, with considering the damage to the ecological environment caused by human beings in economic production activities and the well-being of the ecosystem to the economic system as well. Therefore, the ecological benefits that ecosystems provide for humans should be combined with green GDP accounting. Among them, the damage of the ecological environment is mainly manifested by the cost of ecosystem degradation induced by human activities and the cost of environmental pollution damage. GEP expresses the well-being of ecosystems to humans, including three components: ecosystem provisioning services, ecosystem regulating services, and ecosystem cultural services. Since the value of ecosystem provisioning services and ecosystem cultural services have already been accounted in GDP system, deductions are required to avoid overlapping, that leads only the value of ecological regulating services of GEP conserved in GEEP system (Fig. 1). The conceptual model of GEEP is shown in Eq. (1).

$$\begin{aligned} GEEP &= GGDP + GEP - (GGDP \cap GEP) \\ &= (GDP - PDC - EDC) + (EPV + ERV + ECV) - (EPV + ECV) \\ &= (GDP - PDC - EDC) + ERV \end{aligned} \tag{1}$$

GGDP is Green Gross Domestic Product, GEP is Gross Ecosystem Product, $GGDP \cap GEP$ is the repeating part of GGDP and GEP, PDC is Pollution Damage Cost, EDC is Ecological Degradation Cost, EPV is Ecosystem Provisioning Value, ERV is Ecosystem Regulating Value, ECV is Ecosystem Cultural Value.

2.2. The principle of Gross Economic-Ecological Product

GEEP can be considered as a revision of GDP accounting system, and its accounting principles are basically consistent with GDP in terms of: 1) Accounting time-span is one year; 2) Only accounts for the final product and which does not include intermediate products. For instance, ecosystem regulating services are primarily the final services provided by ecosystems to economic systems and should not include some intermediate processes of support services; 3) GEEP by the nature of its concept, which is only flow amount rather than stock amount, the ecosystem regulating services, pollution damage costs and ecological degradation costs are only accounted when it occurred within one year. The value of ecological assets itself is not included in the GEEP accounting scope; 4) GEEP is a concept of monetarize value. Many of the eco-environment products in GEEP have no direct market value, and it is necessary to use the alternative market methods to assess the benefits that human derive from the ecosystems.

2.3. The index of Gross Economic-Ecological Product and data sources

2.3.1. Green Gross Domestic Product

GGDP is based on GDP and it deducts the cost of environmental pollution damage and ecological degradation caused by unreasonable consumption and production of human beings from GDP. Among them, the environmental pollution damage refers to the cost of environmental degradation caused by the discharges of various pollutants into the environment which is harmful to human health, agriculture and the surrounding ecological environment. Ecological degradation refers to

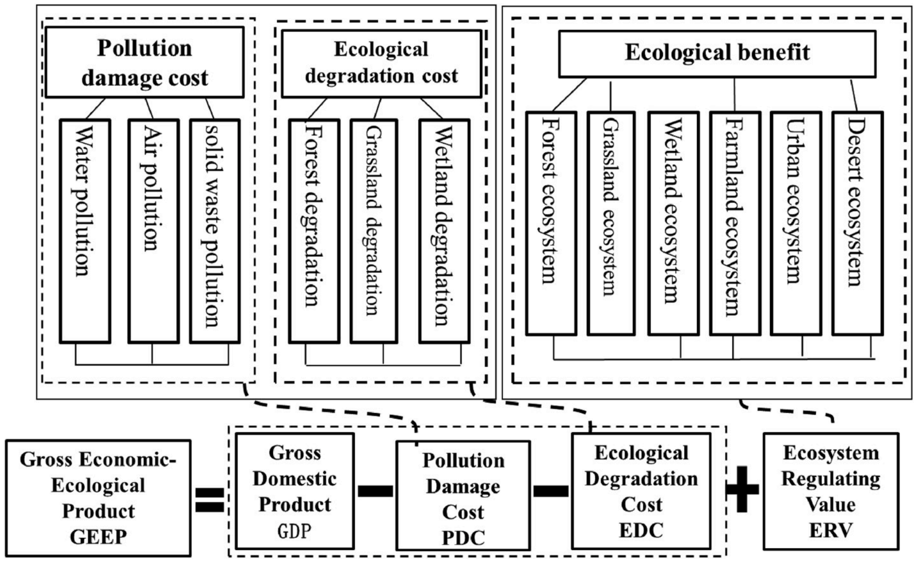

Fig. 1. Gross economic-ecological product (GEEP) accounting framework.

the loss of ecological service functions caused by the unreasonable use of the ecosystems.

2.3.1.1. The cost of pollution damage. The cost of pollution damage mainly includes the cost of air pollution, water pollution and the cost of the land occupied by solid waste. Among them, the cost of pollution damage caused by air pollution primarily includes four parts: human health damage caused by $PM_{2.5}$, crop production damage caused by acid rain and SO_2, damage due to outdoor building materials corrosion caused by acid rain and SO_2, and increased cost of cleaning caused by particulate matter. The human health damage caused by $PM_{2.5}$ is the main damage of air pollution. We adopted the MODIS aerosol product MOD04-10 KM data in 2016 and the $PM_{2.5}$ monitoring data of 338 cities above the prefecture level in China to invert the 10 km × 10 km gridded $PM_{2.5}$ concentration data and use the Disability-Adjusted Life Year (DALY) index to conduct the gridded assessment of the economic burden of human health, which consists of three parts: 1) all-cause premature death and death damage caused by air pollution, where economic loss is assessed by human capital approach; 2) increase in hospitalization rate and rest days of respiratory system and cardiovascular disease patients caused by air pollution and their economic loss, where economic loss is assessed by the disease cost approach; 3) number of new patients with chronic bronchitis caused by air pollution and their economic loss, where economic loss is assessed by using the approach of disability from disease.

The cost of water pollution damage mainly includes human health damage caused by drinking unsanitary water, agricultural damage caused by sewage irrigation, additional treatment costs of industrial water, economic loss of urban life quality and water shortage caused by water pollution (Table 1). Water shortage caused by water pollution is the primary damage of water pollution damage. Firstly, Water shortage should be estimated in an area which is the difference between water demand and actual water supply. Secondly, it is required to determine the proportion of pollution-caused water shortage in total water shortage by proportion of polluted water. Thirdly, the economic loss caused by pollution-caused water shortage can be calculated by calculating the loss of marginal benefit due to water shortage. For the accounting method of the indicators of environmental damage costs please refer to the book "China's Environmental Economic Accounting Technical Guide" published by our research team (Yu et al., 2009).

$$PDC = APDC + WPDC + SPDC \tag{2}$$

Table 1
The methods of pollution damage cost.

Indexes		Physical value	Monetary Value
Air pollution	Human health damage	Exposure-response model	Adjusted human capital method
	Crop production damage	Exposure-response model	Market value method
	Outdoor building materials corrosion	Exposure-response model	Defensive expenditures method
	Increased cost of cleaning	Statistical survey method	Market value method
Water pollution	Human health damage	Exposure-response model	Adjusted human capital method
	Crop production damage	Statistical survey method	Market value method
	Additional treatment costs	Statistical survey method	Defensive expenditures method
	Economic loss of urban life quality	Statistical survey method	Defensive expenditures method
	Water shortage	Supply and demand balance method	Shadow price method
Land occupation of solid waste		Statistical survey method	Opportunity cost approach

PDC is pollution damage cost, *APDC* is air pollution damage cost, *WPDC* is water pollution damage cost, and *SPDC* is solid pollution damage cost.

2.3.1.2. The cost of ecological degradation. Ecological degradation refers to the degradation of ecological service functions caused by irrational use of human beings, which can be explained by the loss of ecological regulating services (Ma et al., 2019). Due to the unreasonable use of forests, grasslands and wetlands, the loss of ecological regulating services is a product of ecosystem regulating services and the rate of destruction of different ecosystems. The forest over-exploitation rate is adopted as the destruction rate of the forest ecosystem, which is the ratio of forest over-exploitation to forest accumulation. The wetland destruction rate is the proportion of the wetland severely threatened area to the total wetland area. The destruction rate of grassland is calculated according to the average livestock overload rate on the national key natural grassland from the 2017 National Grassland Monitoring Report.

$$EDC = ERV_f \times HR_f + ERV_g \times HR_g + ERV_w \times \mathrm{HR}_w \quad (3)$$

$$HR_f = \frac{FO}{FGS} = \frac{DV - FCQ}{FGS} \quad (4)$$

$$HR_W = \frac{STA}{WA} \quad (5)$$

$$HR_g = \frac{1.0}{1.0 + 29.875*0.143^x} \quad (6)$$

EDC is ecological degradation cost, ERV_f, ERV_g, ERV_w are the ecosystem regulating the value of the forest, grassland, and wetland, HR_f *is* forest over-exploitation rate, *FGS* is forest growing stock, *FO* is forest over-exploitation, *DV* is deforestation volume, *FCQ* is forest cutting quota, HR_w is human destruction rate of wetland. *STA* is severe threat area of wetland; WA is wetland area. HR_g is human destruction rate of grassland. *x* is a grassland overloading rate.

2.3.2. Gross Ecosystem Product

Ecosystems provide various ecological values which benefit for human economic activities, it includes three kinds of services: ecosystem provisioning service, ecosystem regulating service, and ecosystem cultural service. To avoid overlap, GEEP only considers the value of ecosystem-adjusted services provided by ecosystems to economic systems, as ecosystem provisioning services and ecosystem cultural services are included in GDP. Based on the summary of ecosystem service accounting indicators proposed from Costanza et al., (1997), Millennium Ecosystem Assessment (2005), System of Environmental-Economic Accounting 2012-Experimental Ecosystem Accounting(United Nations, 2014), Ouyang et al., (2013), Specification for Assessment of Forest Ecosystem Services in China(China National Forestry Administration, 2008), and combined with data availability, we propose that ecosystem regulating services mainly include climate regulation, water flow regulation, carbon fixation and oxygen release, water & air purification, soil conservation, wind and sand fixation, etc. About the accounting methods of these indexes(Table 2), please refer to the supplementary materials.

$$\mathrm{GEP} = EPV + ERV + ECV \quad (7)$$

$$\mathrm{ERV} = ARV + WFRV + SSV + SFV + CFORV + WPV + APV + PDCV \quad (8)$$

EPV is ecosystem provisioning value, which is the market value of eco-products in China Statistical Yearbook. *ECV* is ecosystem cultural value, which is the tourism income of natural landscape coming from *Yearbook of China Tourism Statistics. ERV* is ecosystem regulating value, *ARV* is atmospheric regulating value, *WFRV* is water flow regulating value, *SSV* is soil stabilization value, *SFV* is sand fixation value, *CFORV* is carbon fixation and oxygen release value, *WPV* is water purification value, *APV* is air purification value, *PDCV* is pest and disease control value.

2.3.3. Data sources

The data for calculating ecosystem regulating service comes from *China Statistical Yearbook in 2017*, *China's Annals of Agricultural Statistics in 2017*, *Statistical Yearbook of Animal Husbandry in China in 2017*, *China Forestry Statistics Yearbook in 2017*, *Compilation of Cost and Benefit of National Agricultural Products in 2017*, *China Energy Statistics Yearbook in 2017*. And remote sensing data include the land-use map in 2016 and DEM data provided by Resource Science Data Center of the Chinese Academy of Sciences(http://www.resdc.cn/), NDVI of MOD13A3 in 2016, NPP of MOD17A3(http://e4ftl01.cr.usgs.gov/), soil type data from The Institute of Soil Science, Chinese Academy of Sciences(http://www.resdc.cn/data.aspx?DATAID=145) Meteorological data come from China Meteorological Data Network(http://data.cma.cn/). Other data come from *2006 IPCC Guidelines for National Greenhouse Gas Inventories*(IPCC, 2006), *Study on greenhouse gas inventory in China in 2008* (Department of Climate Change of National Development and Reform Commission, 2014), *Specification for Assessment of Forest Ecosystem Services in China*(China National Forestry Administration, 2008), *Guideline for Chinese Environmental and Economic Accounting*(Yu et al., 2009).

The index of human destruction rate in the cost of ecological degradation mainly comes from Eighth National Forest Resources Inventory (2009–2013), Second National Wetland Resources Survey (2009–2013) and *The National Grassland Monitoring Report in 2017* (Ministry of Agriculture of the People's Republic of China, 2017). The accounting data of pollution damage costs mainly come from *China Statistical Yearbook (2017)*, *China Environmental Statistics Annual Report 2016*, *China Urban Construction Statistical Yearbook 2016*, *Chinese Health Statistics Yearbook 2017*, *2008 China health Service Investigation and Research Report*, *The China Environmental Status Bulletin 2016*. The environmental quality data and the environmental statistics data are provided by the China National Environmental Monitoring Center (CNEMC).

Table 2
The methods of GEP.

Indexes		Physical value	Monetary Value
Provisioning service		Statistical survey method	Market Value Method
Regulating service	atmospheric regulation	Evapotranspiration model	Shadow Project Method
	carbon fixation	Carbon sequestration mechanism model	Carbon Transaction Cost Method
	oxygen release	Oxygen release mechanism model	Industrial Oxygen Production Method
	water purification	Water environmental capacity	Method for Pollution Control Cost
	air purification	Air environmental capacity	Method for Pollution Control Cost
	water flow regulating value	Water balance method	Replace cost method
	pest and disease control	Statistical survey method	Protection Cost Method
	soil stabilization	RUSLE model	Replace Cost Method
	sand fixation	REWQ model	Recovery Expense Method
Cultural service		Statistical survey method	Market Value Method

3. Gross Economic-Ecological Product accounting in China in 2016

3.1. The results of Green Gross Domestic Product

GGDP is the deduction of ecological degradation costs and pollution damage costs based on GDP. In 2016, China's GGDP was 75.2 trillion RMB, accounting for 96.4% of GDP in the same year. In particular, the cost of pollution damage was 2117.5 billion RMB, and the cost of ecological degradation was 688. billion RMB. Among the cost of pollution damage in China, the cost of water pollution damage was 900.5 billion RMB, the cost of air pollution damage was 1172.4 billion RMB, and the land damage caused by solid waste occupation was 39.7 billion RMB. The cost of air and water pollution damage was the main component, accounting for 55.1% and 42.3% of the total pollution cost respectively. In the ecological damage costs, the value of the forest, grassland, and wetland ecosystem degradation was 98.9billion RMB, 135.7billion RMB, and 454.1 billion RMB, accounting for 14.4%, 19.7%, and 65.9% of the total ecological degradation costs, respectively (see Table 3). The results of the Second National Wetland Resource Survey showed that although the wetland area in China has increased, the proportion of wetlands that have been seriously threatened has almost doubled since the first national wetland resource survey, indicating that China's wetland ecosystem is seriously affected.

Eastern region[1] of China contributed most GGDP. In 2016, the GGDP was 41.9 trillion RMB, and the central region accounted for 18.4 trillion RMB, and there was only 14.9 trillion RMB from the western region, which accounted for 56%, 24%, and 20% respectively. The proportion of environmental damage and ecological degradation on GDP in the western region was higher than that in the central and eastern regions. The ecological environment degradation index in the western region is 5.2%, 3.6%, in the central region, and 3.0% in the eastern region, therefore, if the cost of ecological environment degradation is deducted from regional GDP, the economic development gap in the western region will further expand in the eastern region.

3.2. The results of Gross Ecosystem Product

In 2016, China's total Gross Ecosystem Product (GEP) was 73.15 trillion RMB, which was 0.94 times GDP. The value of ecosystem provisioning services was 13.9 trillion RMB, the value of ecosystem regulating services was 51.4 trillion RMB, and the value of ecosystem cultural services was 7.8 trillion RMB, accounting for 19%, 70.3% and 10.7% respectively. Among the ecosystem regulating services, climate regulation services contributed the most, accounting for 65.7%, followed by water flow regulation, accounting for 20.0%, solid carbon and oxygen emissions of 6.5%, and soil retention of 4.4%. In climate regulation services, the value of wetland ecosystems is 29.5 trillion yuan, accounting for 45.4% of climate regulation services. Followed by forests and grasslands, accounting for 25.6% and 17.6% respectively (Table 4).

The provinces with higher GEP were Inner Mongolia in North China, Heilongjiang in Northeast China, Tibet in Qinghai-Tibet Plateau, Sichuan in Southwest China and Guangdong Province in South China. In addition, Yunnan in the southwest, Guangxi, and Jiangxi in southern China, Hunan and Hubei in central China, and Qinghai in the Qinghai-Tibet Plateau which was also with the relatively high value of GEP. Ningxia in the northwest, Beijing, Tianjin, and Shanxi in North China, Shanghai in East China, and Hainan in South China had relatively low GEP(Fig. 2).

Table 3
The cost of pollution damage and ecologcal degradation in 2016 (billion RMB).

Indexes			Monetary Value
Pollution damage	Air pollution	Human health damage	968.1
		Crop production damage	8.8
		Outdoor building materials corrosion	9.9
		Increased cost of cleaning	185.6
	Water pollution	Human health damage	34.7
		Crop production damage	152.4
		Additional treatment costs	41.5
		Economic loss of urban life quality	56.7
		Water shortage	615.3
	Land occupation of solid waste		44.6
Ecological degradation	Grassland		135.7
	Forest		98.9
	Wetland		454.1

[1] Eastern Region includes the provinces of Beijing, Tianjin, Hebei, Liaoning, Jiangsu, Shanghai, Zhejiang, Shandong, Fujian, Guangdong, and Hainan. Central Region includes the provinces of Jilin, Heilongjiang, Anhui, Henan, Hubei, Hunan, Shanxi, and Jiangxi. Western Region includes the provinces of Qinghai, Gansu, Xinjiang, Chongqing, Shaanxi, Ningxia, Inner Mongolia, Sichuan, Guizhou, Guangxi, Yunnan and Tibet.

3.3. The results of Gross Economic-Ecological Product

In 2016, China's GEEP was 126.64 trillion RMB, GEEP per unit area was 13.19 million RMB/km^2, and GEEP per capita was 92,000 RMB/person, which was 1.6 times of GDP per capita. Tibet, Qinghai, Inner Mongolia, Heilongjiang, and Xinjiang were the provinces with the highest GEEP per capita in China, and the GEEP per capita in these five provinces exceeded 141,657 RMB/person (Fig. 3). The GEEP per capita in these five provinces was 2.9 times that of per capita GDP, especially in Tibet and Qinghai, where the per capita GEEP was about 14 times the per capita GDP. Except for Heilongjiang, the other four provinces were in the western part of China. They belonged to areas with abundant population and sparse ecological functions, but the ecological environment was quite fragile and sensitive. Qinghai and Tibet are the main parts of the Qinghai-Tibet Plateau in China, known as the third pole of the world. They are the source of rivers of China and Asia, and wetlands are widespread. There are various vegetation types and rich biodiversity, which is an important ecological security barrier for China to conserve and regulate climate in water sources. At the same time, Qinghai and Tibet also belong to China's backward regions, with a large area and a sparse population. Therefore, per capita GEEP is much higher than per capita GDP.

In 2016, the GDP of eastern, central and western region in China were 55.4%, 24.5% and 20.1%, respectively, while GEEP accounted for 40.7%, 26.5% and 32.8%. Gini coefficient is a way to measure equity and is derived from the Lorenz curve, which is defined as a ratio with values between 0 and 1(Yitzhaki, S. 1983). Based on the GDP and population of 31 provinces, the regional Gini coefficient was 0.51 in 2016, but the regional Gini coefficient based on GEEP became 0.44, so the regional gap calculated by GEEP tends to shrink. According to China's "Nineteenth National Peoples' Congress Report" the main contradictions in our society are the people's growing needs for a better life and the development of an inadequate imbalances. The GEEP accounting framework system is formed and developed to resolve this contradiction between the growing needs of the people and the uneven development in China.

The GEEP rankings of China's 31 provinces differ greatly from the GDP rankings. In addition to Guangdong, Jiangsu and Shandong, the rankings of all other provinces have also changed (Fig. 4). The provinces with a lower GEEP ranking than the GDP rankings were mainly Beijing, Shanghai, Hebei, Tianjin, Shaanxi, Henan. Beijing dropped from the 12th in GDP ranking to 24th in GEEP ranking, Shanghai dropped from 11th in GDP to 22nd in GEEP, and Tianjin dropped from 19th in GDP to 27th in GEEP, while Hebei ranked 8th in GDP, 17th in GEEP, and Shaanxi dropped from the 15th in GDP to 23rd in GEEP. Inner Mongolia, Heilongjiang, Yunnan, Qinghai and Tibet in GEEP ranking was much higher than its ranking in GDP. Inner Mongolia rose from the 18th in GDP ranking to the 9th in GEEP, Heilongjiang rose from 21st in GDP to 8th in GEEP, Yunnan rose from 22nd in GDP to 14th in GEEP, and Qinghai ranked 30th in GDP rose to the 19th place in GEEP, and Tibet rose from the 31st in GDP to the 10th in GEEP.

Set averages of the population, GDP, and GEEP of 31 provinces across the country for illustrating the distribution of scattering points for GDP, GEEP and relative populations (Figs. 5 and 6). Except that Hebei changed from the first quadrant of Fig. 5 to the second quadrant of Fig. 6 and Guangxi changed from the second quadrant of Fig. 5 to the second quadrant of Fig. 6, the GEEP of other provinces in the first quadrant of Fig. 5, was still higher than the national average. This shows that these provinces with high GDP still have high GEEP. The GEEP in Hebei province is lower than the national average because of its high cost of eco-environmental cost and relatively low ecological benefits. The GEEP in Guangxi has become the first quadrant because its ecological benefits have prominent contribution to GEEP. In Fig. 5 GDP of Tibet, Heilongjiang, Inner Mongolia, Guangxi, and Yunnan are lower than the national GDP average, but their GEEP was higher than the national average due to outstanding contribution of ecological benefits in Fig. 6.

Table 4
The accounting results of Gross Ecosystem Product in Chinese ecosystems in 2016 (billion Renminbi).

Index		Forest	Grassland	Wetland	Farmland	Urban	Desert	Total
Provisioning service		117.7	3033.4	5085.7	5661.7	–	–	13898.5
Regulating service	atmospheric regulation	8028.7	5261.9	20014.9	×	×	×	33305.6
	carbon fixation	38.9	22.9	1.8	×	×	×	63.6
	oxygen release	2012.5	1184.3	93.1	×	×	×	3290.0
	water purification	–	–	231.6	–	–	–	231.6
	air purification	20.2	10.2	2.5	20.0	4.0	4.5	61.3
	water flow regulating value	4317.7	1253.4	4820.3	–	–	–	10391.4
	pest and disease control	7.2	×	×	–	–	–	7.2
	soil stabilization	2070.8	476.9	61.7	560.2		✓	3169.5
	sand fixation	11.8	185.9	8.4	10.0	1.3	315.1	532.3
Cultural service		–	–	–	–	–	–	7815.9

Note: Cultural service cannot be decomposed to different ecosystem, and only have total. √ assessment, × no assessment, - Unsuitable for assessment.

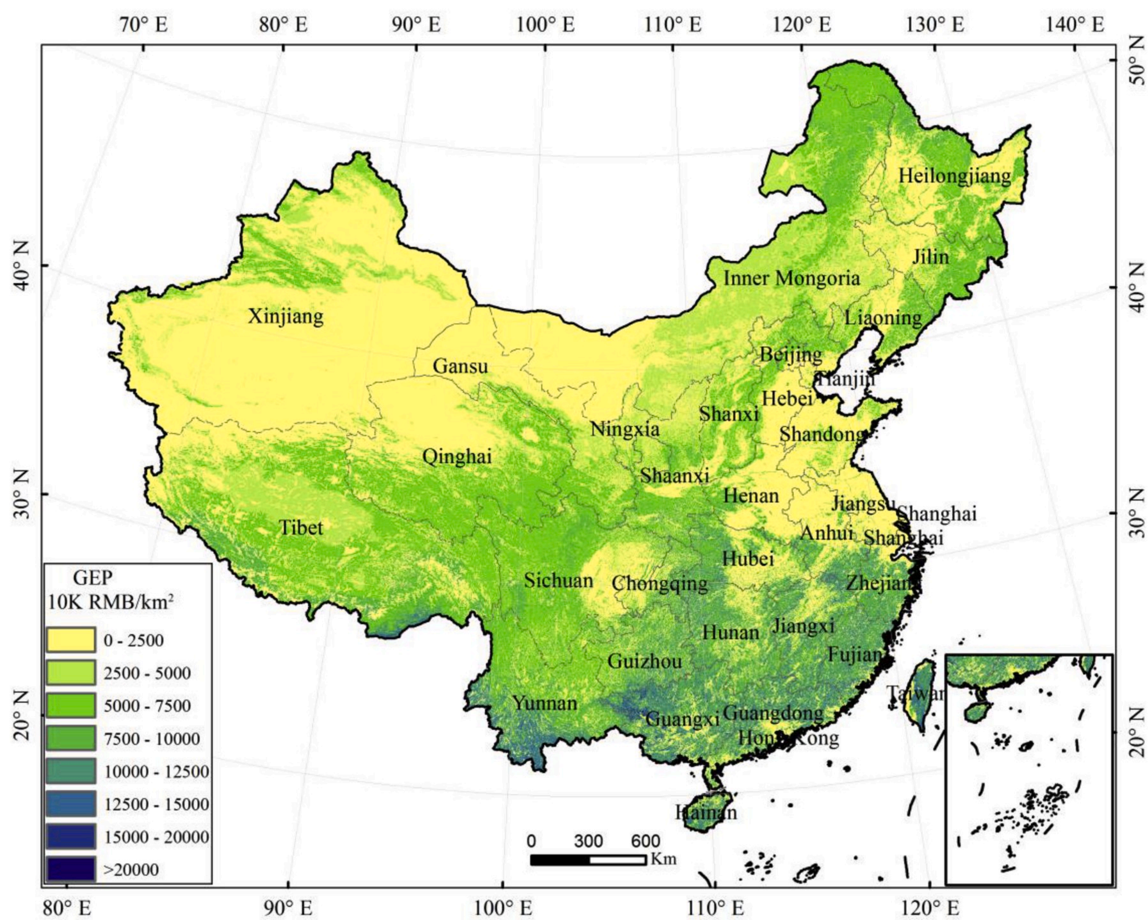

Fig. 2. The distribution of GEP in China in 2016 (1 × 1 km^2).

The GDP of Beijing and Shanghai exceeded the national average, but their GEEP was lower than the national average.

4. Results and Discussion

1) GEEP is an integrated economic-environment accounting system based on weak sustainable development theory and welfare economics. GEEP has similar accounting principle, methodological matrix and technical approach of GDP, and it considers both the value of the final products of ecological and economic systems and services provided by the ecosystem's flow amount. GEEP is calculated based on the GDP of the economic system, meanwhile taking into account the damage caused by human beings in economic activities and the contribution of ecosystems to the economic system. SEEA and green GDP only deduct the ecological and environmental costs caused by human irrational use from GDP, which only reflects invaluable assets. GEP separately calculates the ecological benefit value provided by the ecosystem to the economic system, reflecting the value of lucid waters and lush mountains. GEEP is a comprehensive indicator of prosperity that corrects the one-sidedness of considering only the human economic contributions or ecological contribution. Using GEEP accounting system, it can reflect the level of eco-economic development of a region more comprehensively, and reflect the sustainability of a region.
2) GEEP in China was 126.64 trillion RMB, 1.6 times GDP in 2016. In which the cost of ecological degradation was 0.69 trillion RMB, the cost of pollution damage was 2.1 trillion RMB, and the ecosystem regulating services was 51.4 trillion RMB, accounting for 40.6% of

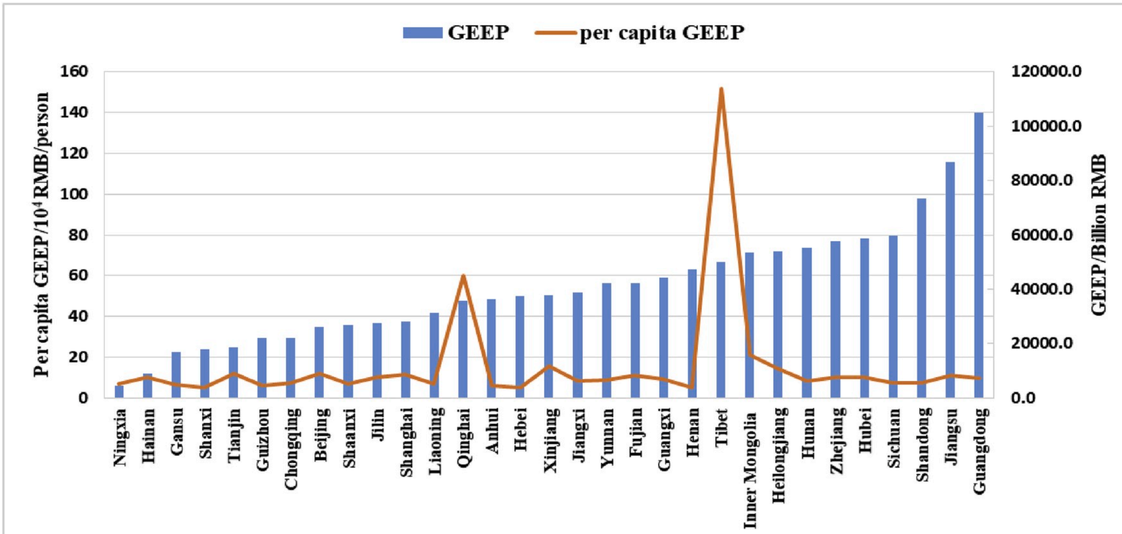

Fig. 3. China's GEEP by provinces and per capita in 2016.

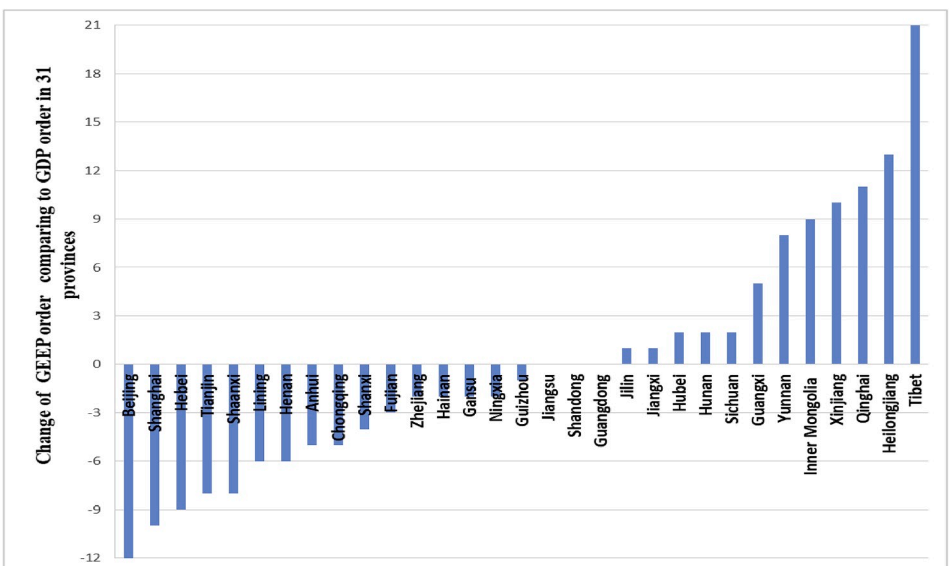

Fig. 4. Changes of relative gross domestic product by gross economic-ecological product in 31 provinces ranking in 2016.

GEEP. The regional Gini-coefficient based on GEEP calculation is 0.44, which was 0.07 smaller than GDP based calculation, indicating that the regional imbalance of the GEEP measuring system is smaller than GDP measuring system. The less-developed areas of Tibet, Qinghai, Inner Mongolia, Yunnan, Heilongjiang, and Guangxi are all important ecological function areas in China, and the value of ecosystem services are bigger than other provinces. Based on green GDP, GEEP consider the ecological benefits to narrow the regional gap.

3) The GEEP rankings of 31 provinces, in China, had a significantly difference than their GDP ranking. Inner Mongolia, Heilongjiang, Yunnan, Qinghai, Tibet and other provinces with large ecological services value had increased by more than 10 ranks in GEEP ranking compared with the GDP ranking. The provinces with weak ecological services and serious environmental pollution such as Beijing, Shanghai, Tianjin, Hebei had dropped their GEEP rankings also by more than 10 ranks compare to GDP ranking. The results indicated that Northwest provinces have large potential of the overall human well-being rather than economic prosperous provinces located in east coast region. The region performance assessment takes GDP as the hero in China, which leads to the excessive pursuit of the high speed of economic growth. However, if all regions pursue high economic growth rate, some ecological barriers and ecological sensitive areas are easy to cause ecological degradation, resource overconsumption. GEEP accounting system considers the contributions of economic system and ecosystem, which helps us to protect the Eco-functional areas, such as Inner Mongolia, Yunnan, Qinghai, and Tibet.
4) GEEP is a relatively complex accounting system in which ecosystem regulating services, ecological degradation costs, and pollution damage costs unified under the same measurement system and included many accounting indicators, each of them involves both measurable physical quantity and monetarize value, in the meanwhile accounting methods, are quite diverse caused various accounting results. The UNSC adopted the SEEA Central Framework as an initial international statistical standard for environmental-economic accounting in 2012, but SEEA Experimental Ecosystem Accounting does not constitute an international statistical standard,

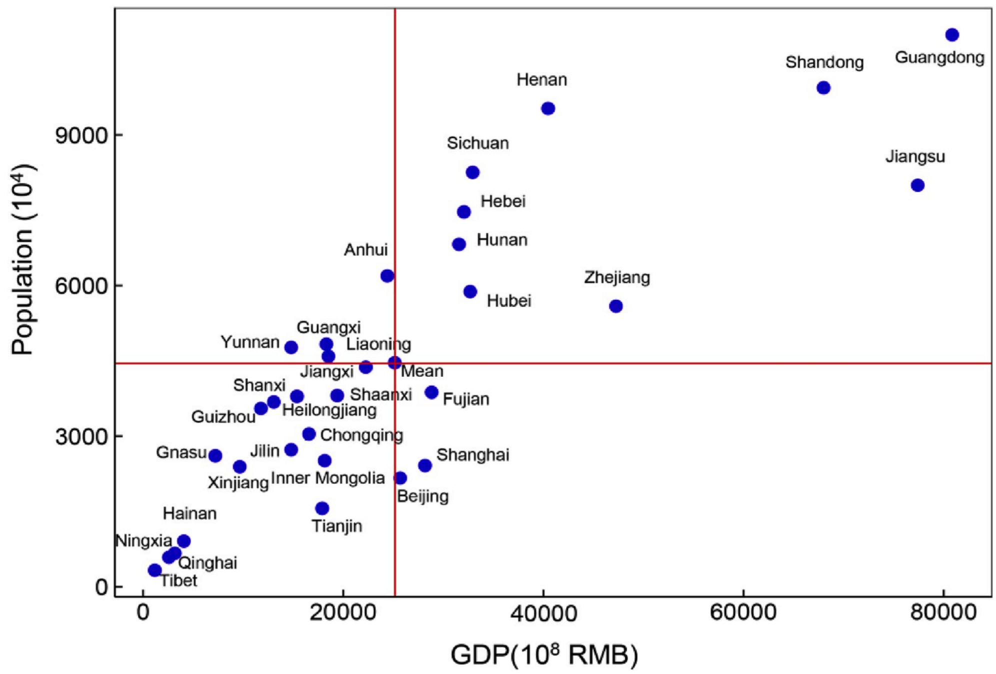

Fig. 5. Distribution of Population and GDP in four Quadrants in 31 Provinces in 2016.

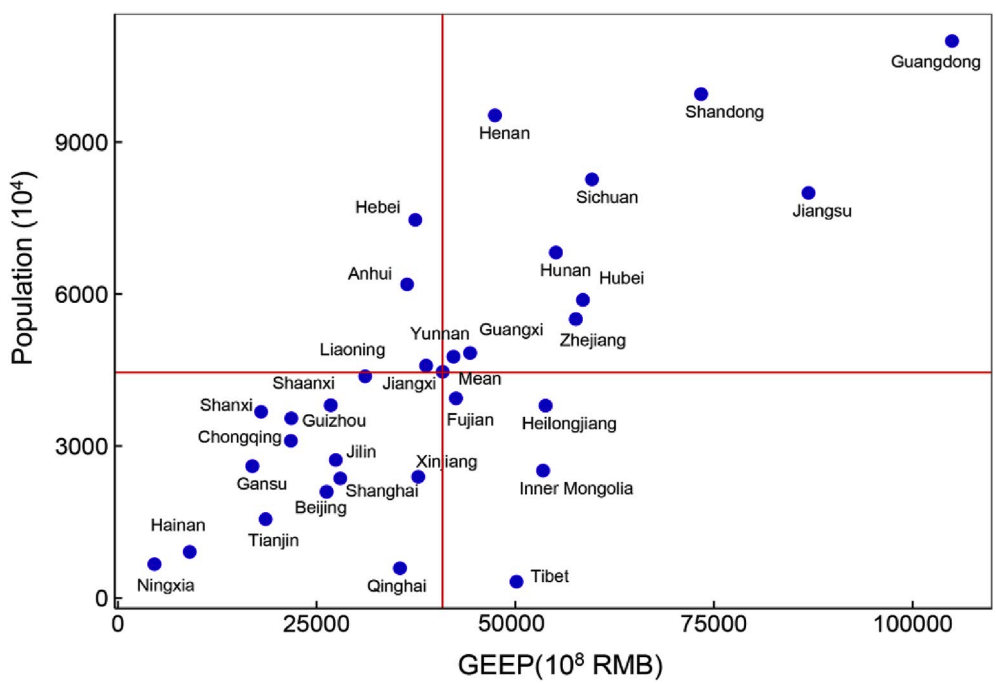

Fig. 6. Distribution of Population and GEEP in four Quadrants in 31 Provinces in 2016.

provided an accounting framework for multi-disciplinary research and testing on ecosystems and their relationship to economic and other human activity. Since the 1990s, China has begun to implement ecosystem service accounting, however due to the differences in accounting methods, key parameters, accounting scope, index system and accounting contents, the results of ecosystem service value are quite different by different scholars. Therefore, it is necessary to develop a GEEP accounting technical guideline to standardize GEEP accounting methods, key parameters, accounting scope, and indicator systems to achieve the accounting system in standardization for accounting, assessing and monitoring reginal development performance.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.109852.

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