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The Valuation of China's Environmental Degradation from 2004 to 2017

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Foreword »

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Since its opening-up and reform, China has been in the process of rapid economic development with its people enjoying an increasingly improved standard of life. Meanwhile accompanying this dramatic economic growth is the degradation of environment which has, to some extent, damaged the gains of the opening-up and reform and prevented the economy from a healthy and sustainable development. The Chinese government is increasingly aware of that without addressing the environmental issues it is facing now, it will jeopardize its long term goal of the great rejuvenation of the Chinese nation. Given the magnitude and complexity of the environmental issues in China, there is no easy way in addressing them and the solution to them entails an equal priority being given to environmental protection, ecological conservation and economic development or even higher than the latter by mainstreaming the former into the overall socio-economic decision-making

process. As a matter of fact, China has been in the struggle against environmental pollution since the very beginning of its economic take-off and trying to explore a pathway that could help address China's environmental issues in the way most suitable to China's specific circumstances.

In recent years, especially since the 12th Five-Year Plan period, the enhanced measures including legislation, policy, regulatory and economic means have been taken by the Chinese government in dealing with environmental problems, of which environmental policies have played an important role in this regard. China has established Xi Jinping's ecological civilization thought, with the concept of green development deeply rooted in the hearts of Chinese people, and now is moving towards the goal of Beautiful China by 2050.

Corresponding to this situation and in

meeting the demand of governments at different levels for environmental policy tools, the environmental policy research projects on topics of a wide range have been conducted by some Chinese environmental research institutions including the Chinese Academy of Environmental Planning (CAEP).

CAEP founded in 2001, is a research advisory body supporting governments in the development of key environmental planning, national environmental policies, and major environmental engineering projects. In the past more than 10 years, CAEP has accomplished the development of the overall planning of national environmental protection for the 10th, 11th, 12th and 13th Five-Year Plan periods; water pollution prevention and control planning for key river basins; air pollution prevention and control planning for key regions; soil pollution prevention and control planning; and some regional environmental protection plans. We are now engaged in national eco-environmental protection plan for the 14th Five-Year Plan. In the same period of time, CAEP also actively engaged in research on such topics as green GDP, environmental taxation, emission trading, ecological compensation, green financing, etc. By undertaking these activities, CAEP has become an indispensable advisory body in the environmental decision-making in mainland China. According to *2019 Global Go To Think Tank Index Report* published by University of Pennsylvania, CAEP was ranked 25 in the field of Environment Policy

in the world. Many of CAEP's research results and project outcomes regarding environmental policies have drawn great attention of decision makers and international institutions, and have been utilized to contribute to the formulation of national environmental policies concerned.

The Chinese Environmental Policy Research Working Paper (CEPRWP) is a new internal publication produced by CAEP for the purpose of facilitating the academic exchange with foreign colleagues in this field, in which the selected research papers on environmental policies from CAEP are set out on the irregular basis. It is expected that this publication will not only make CAEP's research results on environmental policies be known by foreign colleagues but also serve as a catalyst for creating opportunity of international cooperation in the field of environmental policies, and environmental economics in particular, with a view of both the academic research and practical policy needs.

This paper aims to evaluate the cost of environmental degradation by adopting the conventional environmental economic methodology in China from 2004 to 2017 and summarize the change in both the causes and costs of China's environmental degradation. We came up with the following results: i. The environmental degradation cost in China increased from 511 billion yuan to 1,892 billion yuan from 2004 to 2017, and its share in the GDP decreased from 3.05% to 2.23%; ii. The environmental degradation cost growth rate was lower than the GDP growth rate. The

environmental degradation cost growth rate decreased sharply, by dropping from 10% in 2014 to 2% in 2017. The environmental benefits of industrial transformation have emerged; iii. The provinces of Shandong, Hebei, Jiangsu, Henan, and Guangdong had highest environmental degradation

costs. The annual average growth rate of the environmental degradation costs in Jiangsu, Guangdong, and Zhejiang were lower than their growth rate of the GDP respectively; iv. Consideration of environmental degradation cost in decision-making could contribute to the high-quality development of China.



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1. INTRODUCTION

As gross domestic product (GDP) does not include the resource and environmental costs of economic growth, it cannot precisely measure the impact of such costs on the reduction of real national welfare^[1-3]. The international green national accounting system, was established during the 1970s, rectifies this by subtracting the costs of natural resource depletion and environmental degradation from GDP in order to measure national economic welfare more accurately. The United Nations Statistics Division (UNSD) issued and revised the Integrated Environmental and Economic Accounting System (SEEA) in 1993^[4], 2003^[5], and 2012^[6], providing a basic framework for the establishment of green national accounting. In 1993, Pearce and Atkinson (1993)^[7] first used the green national accounting system in a study of 18 countries and found that economic development in 8 countries was unsustainable. Hamilton et al. (2000)^[8] found that resource losses in low-income countries accounted for 7.8% of GDP, 5.6% of GDP in middle-income countries, and 0.8% of GDP in developed countries, with resources and environmental costs in the Middle East and North African countries with the highest costs at 20.7% of GDP.

Since the 1990s, the Chinese government has paid great attention to the resource and environmental costs of economic development. Guo and Zhang (1990)^[9] first calculated the environmental degradation cost and ecological damage in China and

concluded that the annual average loss accounted for 6.75% of gross national product (GNP) during the period 1981–1985. Zheng et al.(1999)^[10], Li(1995)^[11], World Bank(1997)^[12], Xia(1998)^[13], and Lei(2000)^[14] evaluated the environmental degradation cost in China, and found that the cost amounted to 3–10% of China's GDP. Since then the research on environmental degradation cost and ecological deterioration loss has risen interests and there are some studies carried out at the regional level, such as Cheng and Li (2018)^[15], Wang et al. (2019)^[16], Wang et al. (2019)^[17], Chang et al. (2019)^[18]. During the Chinese Central Population, Resources and Environmental Conference the former Chinese President Hu Jintao proposed the study of the green national accounting method and indicated in the report of the 17th National Congress of the Communist Party of China that the most serious problem of China's social and economic development is that "the resource and environmental costs of economic growth are too large."

In order to continuously and quantitatively measure the resource and environmental costs of China's economic development, a technical team, led by the Chinese Academy of Environmental Planning, developed China's environmental and economic accounting system based on the Green GDP accounting, which was jointly conducted by the former State Environmental Protection Administration and the National Bureau of



Statistics in 2004^[19]. The accounting system basically followed the SEEA guideline, including the environmental degradation cost and ecological deterioration cost. The environmental degradation cost included the physical quantity of environmental pollution and its monetized value. The latter uses the abatement cost and pollution damage methods to obtain the pollution's imputed abatement costs and environmental degradation costs, respectively. The team continuously researched China's environmental economic accounting for 14 years (2004 to 2017). The results show that the cost of environmental

degradation in China increased from 511.82 billion yuan in 2004 to 1,892.42 billion yuan in 2017; while its share of GDP fell from 3.05% to 2.23%^[20-23]. In order to measure the efficacy of recent pollution prevention and control, and the effects of various ecological and environmental protection measures, we analyzed China's national and regional environmental degradation costs during the period of 2004–2017 to summarize the changes in the cost of environmental degradation in China, based on the accounting results of the Chinese Academy of Environmental Planning.





2. DATA AND METHODS

The environmental degradation cost mainly includes the costs caused by air pollution, water pollution, and land occupation of solid waste. Air pollution costs include four components: damage to human health, loss of crop production, corrosion loss of building materials exposed to the outdoor environment, and increased cost of cleaning. Water pollution costs include human health loss, agricultural loss caused by sewage irrigation, additional treatment cost of industrial polluted water, economic loss of urban residents, and water shortage due to water pollution.

2.1 Data and Sources

The environmental degradation cost accounting requires two kinds of data. One is conventional statistical or monitoring data, which includes the quality monitoring data of the atmospheric and water environment during the period of 2004-2017 (obtained from China National Environmental Monitoring Center), the data of solid waste storage and discharges (obtained from the Annual Statistic Report on Environment in China (2004–2017)), the GDP, urban population, rural population, household number, major agricultural output, water resources, water consumption, and other social and economic data (obtained from the China Statistical Yearbook (2005–2018)), the hospital admissions (obtained from the China Health Statistical Yearbook (2005–2018)), and the number of standard operating

vehicles, number of taxis, road areas, built-up areas, and safety disposal amount of domestic garbage (obtained from China's Urban Construction Statistical Yearbook (2005–2018)). The technical parameters are mainly from surveys, statistical yearbooks, and the Technical Guide for China Environmental and Economic Accounting ^[19], as shown in Table 1.

2.2 Environmental degradation cost caused by water pollution

2.2.1 Human health damage

Water pollution assessment values human health damage due to inaccessible tap water. The hazard endpoints include the health damage caused by biological pollutants (i.e., four types of water-borne infectious diseases including hepatitis, dysentery, typhoid fever, and cholera) and by chemical pollutants (i.e., cancer of the circulatory system and digestive system, including gastric, liver, esophageal, colon, and bladder cancers). Currently, there were no studies on the dose-response relationship between water pollution and health. We analyzed the results of the China Environmental Cost Model (ECM/VEHR) conducted by the World Bank and the former State Environmental Protection Administration ^[24].

(1) Economic losses caused by the incidence of water-borne infectious diseases by drinking polluted water

Due to the lack of reliable studies about



the relationship between the water intake methods and the incidence of water-borne infectious diseases, it was difficult to estimate the number of incidence cases. We instead calculated the reduction in the number of cases caused by clean water engineering (i.e., the benefits from clean water engineering represented the possible loss due to a lack of safe drinking water). The calculation model for the economic loss (EC_{wl}) caused by the incidence of water-borne infectious diseases resulting from drinking water pollution is^[19]:

$$EC_{wl} = \sum_{i=1}^{31} \text{Rural population of each province} \times \text{tap water penetration rate} \\ \times \text{per capita income}$$

(2) Economic losses caused by death from malignant tumors due to drinking water pollution

$$P_{edw} = (f_p - f_t) \cdot P_e$$

$$f_p = f_t \cdot OR$$

$$P_{edw} = ((OR - 1) / OR) \cdot f_p \cdot P_e$$

$$EC_{w2} = P_{ed} \cdot HC_{mr} = P_{ed} \cdot \sum_{i=1}^t GDP_{pci}^{pv}$$

P_{edw} is the number of premature deaths from malignant tumors caused by current water pollution; f_p is the current mortality rate of malignant tumors under polluted water conditions; f_t is the mortality rate of malignant tumors under clean conditions; OR is the relative risk of malignant tumor caused by drinking water pollution (the hazard odds ratio); and t is the average years of life lost from malignant tumors caused by water

pollution. The average years of life lost from malignant tumors is 21 years. HC_{mr} is the per capita human capital of the rural population. GDP_{pci}^{pv} is the i -year rural per capita GDP.

2.2.2 Agricultural losses by sewage irrigation

We estimated the agricultural economic losses caused by water pollution using the agricultural water consumption of the “Inferior to Grade V Water” and the shadow price of agricultural water^[19].

$$EC_c = Q_c \cdot P_c$$

EC_c is the agricultural economic loss caused by water pollution; Q_c is the water consumption of the Inferior to Grade V Water; and P_c is the shadow price of agricultural water.

2.2.3 Additional treatment costs of industrial water

The additional treatment cost of industrial water indicated that, due to the excessive amount of pollutants in the water supply, some industries (e.g. food processing and manufacturing, pharmaceutical manufacturing, textile printing and dyeing, and chemical manufacturing) that required a higher water quality need the additional pre-treatment facilities installation or additional treatment costs for special reagents. If the source water was severely polluted, the regular water treatment process of the water plant could not produce tap water that met the water quality standards, and additional water treatment facilities, chemicals, or



water purifiers will be needed. The additional cost of the processing facilities or increased processing costs was a direct economic loss due to water pollution:

$$EC_i = Q_{ie} \cdot P_i$$

EC_i is the additional treatment cost of industrial water caused by water pollution; Q_{ie} is the industrial water consumption of the Inferior to Grade IV Water; and P_i is the average additional treatment cost of industrial water.

2.2.4 Economic loss of urban residents caused by water pollution

This loss is the protection cost of the household's pure water and tap water purification equipment for urban residents who worry about water pollution^[19]:

$$EC_h = \sum_{i=1}^3 P_i \cdot H \cdot C_i \cdot \alpha$$

EC_h is the household protection cost of using clean water alternatives; i includes three types of household clean water alternatives: barreled water, integrated water purifier and dispensers, and tap water filters; P_i is the average cost of the 3 alternatives; and H is the city's total number of households; C_i is the proportion of the 3 types of devices used in urban households; and α is the proportion of households that use clean water instead of alternatives for health and sanitation reasons.

2.2.5 Economic loss of water shortage

In southern China where refers to the area located in southern side of Qinling-Huaihe,

due to abundant water resources, there should be no water shortages. If there are water shortages, they are most likely a pollution-type water shortage. For the watersheds in the northern region, it is necessary to distinguish between a pollution-type and a resource-based water shortage. For watersheds with a water resource abstraction and utilization rate less than 40%¹, all water shortages were counted as pollution-type water shortages. For watersheds with a utilization rate of more than 40%, the pollution-type water shortage was the product of water shortages to the ratio of contaminated water exceeding the grade-type standards^[19].

For the watersheds with the abstraction and utilization rate less than 40% in the southern and northern regions, we calculated the loss of water shortage by pollution with:

$$EC_{ps} = (Q_{Ri} - Q_{Si}) \cdot P_s$$

For the watersheds with the abstraction and utilization rate greater than 40% in the northern regions, we calculated the loss of water shortage by pollution with:

$$EC_{pn} = (Q_{Ri} - Q_{Si}) \cdot R_w \cdot P_s$$

EC_{pn} is the pollution-type water shortage; Q_{Ri} is the water required; Q_{Si} is the water supply, R_w is the ratio of contaminated water exceeding the standards, and P_s is the shadow price of the water resources.

2.3 Environmental degradation cost caused by air pollution

The cost of environmental degradation caused by air pollution includes four parts: damage

¹ 40% is the internationally recognized reasonable development limit of water resources.



to human health; loss of the crop production; corrosion loss of outdoor building materials; and increased cost of living due to extra cleaning.

2.3.1 Human health damage

The impact of air pollution on human health is very complex, many studies find air pollution caused both acute and chronic mortality effects such as Ebenstein et al.(2015)^[25], Ebenstein et al.(2017)^[26], Liu et al.(2019)^[27], Ding et al.(2019)^[28]. Currently, the main pollutants in the urban air pollution in China are inhalable particulate matter (PM₁₀), fine particulate matter (PM_{2.5}), sulfur dioxide (SO₂), and nitrogen dioxide (NO₂). The study only calculate the loss of human health from particulate matter as the representative indicator, and the PM₁₀ data were used before 2014 and the PM_{2.5} data were used after 2014. The calculation range only covers the urban area.

There were three main losses to human health caused by PM₁₀ and PM_{2.5} accounted for in the calculation: i. The losses by all-causes of death related to atmospheric pollution: PM₁₀ and PM_{2.5}, (EC_{a1}) are evaluated by the revised human capital method. This method applies the per capita GDP as the value of human capital (i.e. the contribution of a statistical life year to GDP). ii. The hospitalization losses of patients with respiratory and circulatory diseases associated with atmospheric pollution PM₁₀ and PM_{2.5} and the loss of workday (EC_{a2}) using the disease cost method. iii. The disability loss of chronic bronchitis caused by the atmospheric

pollution: PM₁₀ and PM_{2.5}, (EC_{a3}) with 40% of the human capital loss accounted as the disability loss^[19].

(1) The economic loss of premature death from all-causes deaths by air -pollution:

$$EC_{a1} = P_{eda} \cdot GDP_{pc0} \cdot \sum_{i=1}^t \frac{(1+\alpha)^i}{(1+r)^i}$$

$$P_{eda} = ((RR - 1) / RR) \cdot f_p \cdot P_e$$

$$RR = [(C+1) / 16]^{0.07217}$$

P_{eda} is the number of premature deaths caused by the current atmospheric pollution; GDP_{pc0} is the per capita GDP of the base year; t is the average years of life lost; α is the growth rate of per capita GDP; and r is the social discount rate. In this study, t was set as 18 years, α was 7.3%, and r was 8%; f_p is all-causes mortality at a given air pollution level; p_e is the urban exposed population; RR is the relative risk of all-causes death; and C is the concentration of PM₁₀ and/or PM_{2.5}.

(2) The economic losses caused by air pollution that resulted in hospitalization and workday loss:

$$EC_{a2} = P_{eh} \cdot (C_h + WD \cdot C_{wd})$$

$$P_{eh} = \sum_{i=1}^n f_{pi} \frac{\Delta c_i \beta_i / 100}{1 + \Delta c_i \beta_i / 100}$$

P_{eh} is the extra hospitalization level at the current air pollution level; C_h is the cost of hospitalization for the disease; WD is the workday losses for the disease; C_{wd} is the cost of workday losses evaluated with per capita GDP; n is the air-pollution-related diseases; f_{pi} is the patient days of hospitalizations at the



current air pollution level; β_i is the regression coefficient, which is the percentage change of the health hazard i caused by the unit change of the pollutant concentration; and Δc_i is the difference between the actual pollutant concentration and the health hazard concentration threshold.

2.3.2 Crop yield reductions

Between the Sixth Five-Years Plan (1981-1985) to the Eighth Five-Years Plan (1991-1995), China contributed much to the scientific research on acid rain which was supported by the Key Scientific and Technological Research Program. The dose-response relationship between acid rain and SO₂ on crops, forests, and materials was studied through pot-plant experiments. The experimental results showed that the pH threshold for a 5% reduction in the yield of several crops induced by acid rain in southern China was 3.6; while the pH threshold for a 5% reduction in the yield induced by acid rain combined with 0.1 mg/m³ SO₂ was 4.6. A combination of pH 5.6 and 0.1 mg/m³ SO₂ produced an effect similar to SO₂ alone. The specific dose-response relationship is shown in Table 2^[29].

$$L = \sum_{i=1}^i \alpha_i \cdot P_i \cdot S_i \cdot Q_i$$

L is the value of the crop yield loss caused by environmental pollution; P_i is the price of the i type of crop, S_i is the area planted with the i type of crop; Q_i is the yield per unit area of the i type of crop in the control area; and α_i is the percentage of the i type of crop reduction caused by environmental pollution.

2.3.3 Material losses due to acid rain and SO₂ pollution

Various outdoor materials are exposed and affected by both natural and atmospheric pollution. Air pollution factors including acid rain and SO₂ further exacerbate material damage. Based on the study of the relationship between acid rain and material destruction, we determined the material damage thresholds of SO₂ and acid rain, which are pH=5.6 and SO₂=0.015 mg/m³, respectively.

$$C_{pi} = \left(\frac{1}{L_{pi}} - \frac{1}{L_{0i}} \right) \cdot C_{0i}$$

C_{pi} is the material loss from acid rain and SO₂ pollution; L_{pi} is the life-span of the i type of material under the pollution condition; L_{0i} is the life span of the i type of material under the non-pollution condition; and C_{0i} is the one-time cost of repairing or replacing the i type of material.

2.3.4 Cleaning costs by air pollution

The cleaning cost of air pollution refers to the increase of cleaning manpower, material resources and cleaning frequency caused by air pollution. The cleaning and labor costs generally increase as the smoke and dust air pollution deteriorates^[19].

$$P = S \cdot C_s + B \cdot C_b + T \cdot C_t + H \cdot C_h$$

P is the cleaning costs under pollution conditions; S is the added street area to be cleaned under the pollution condition; B is the number of buses to be cleaned under the pollution condition; T is the amount of taxis



to be cleaned under the pollution condition; and H is the building area to be cleaned under the pollution condition.

2.4 Solid waste and land occupation loss

Land used for planting crops, afforestation or business provides certain benefits every year, while stacking solid waste on this land causes it to lose such benefits. This part of the economic loss was accounted by adopting the opportunity cost method (i.e., the benefits from having crops on the land were used as the economic losses caused by land occupied

by solid waste).

$$L = \frac{1}{1-\alpha} \cdot \sum_{i=1}^n E_i \cdot S_i$$

L is the economic loss caused by the land occupation of solid waste (10,000 yuan); E_i is the economic value of the annual crop production of the i land type (10,000 yuan/ha); S_i is the area of the i land type occupied by the solid waste storage and discharge in that year; and α is the social discount rate.





3. DISCUSSION

3.1 Overall environmental degradation costs

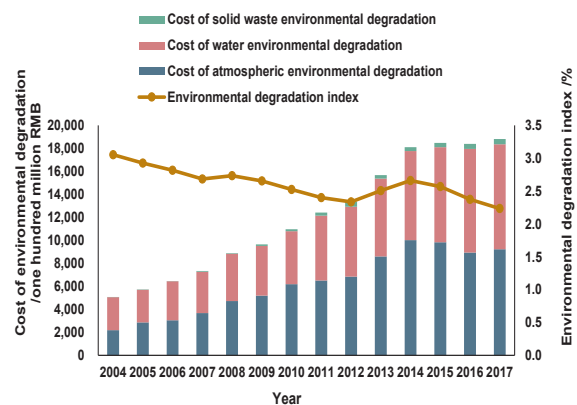
The water environment quality improved during the period of 2004–2017. During this period, the proportion of surface water in Grade I–III in the country increased by 26.1%, and the proportion of the Inferior to Grade IV Water decreased by 19.6%. The proportion of the Inferior to Grade-IV Water decreased only slightly, compared to the proportion of the Grade I–III water. Especially in the Haihe River Basin, in 2017 the proportion of Inferior to Grade IV Water was as high as 32.9%, while the proportion of Inferior to Grade IV Water in the Liaohe River Basin was 18.9%. Consequently, the cost of the water environment degradation in Hebei, Shandong, and Liaoning provinces was high in 2017, accounting for 16%, 11.3%, and 3.5% of the national water environment degradation cost, respectively.

The annual average concentration of SO₂ in China decreased from 60 µg/m³ in 2004 to 18 µg/m³ in 2017. However, since 2015, 338 prefecture-level cities in China are monitored and evaluated by adopting the new air quality standards, and the national urban air quality compliance ratio was only between 20% and 30%. The average concentration of PM_{2.5} in China was 43 µg/m³ in 2017, which was higher than the national air quality Grade II standard (35 µg/m³) and 4.3 times the safety level of 10 µg/m³ proposed by the World

Health Organization. The impact of pollution on human health remains very large.

The cost of environmental degradation in China increased continuously from 2004 to 2017, from 511 billion yuan to 1,892 billion yuan, with an average annual growth rate of 10.6%. From 2014 to 2017, it has gradually stabilized. The annual average growth rate of the atmospheric environmental degradation costs was 11.7% and the annual cost growth rate of water environment degradation was 9.3%. The environmental degradation index² was calculated to assess the impact of the environmental degradation costs on the economy. The environmental degradation index from 2004 to 2017 decreased from 3.05% to 2.23% (Figure 1), indicating that China's economic development has become greener in the most recent five years.

■ **Figure 1. Environmental degradation costs from 2004 to 2017**



² The environmental degradation index is the ratio of environmental degradation cost to GDP.

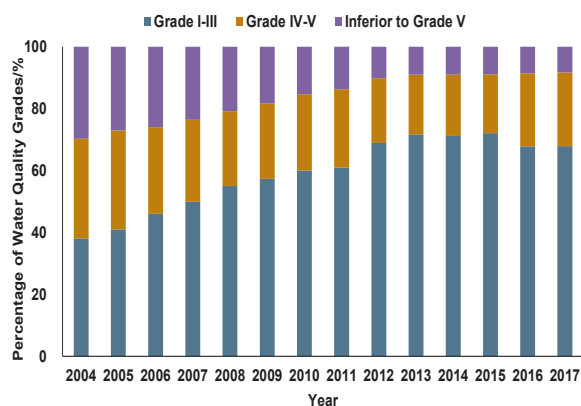


3.2 Water environment degradation costs

From 2004 to 2017, China's water pollution control and prevention has made progress. The reduction in the total amount of major pollutants and the revision of the 'Action Plan on the Prevention and Control of Water Pollution' led to a decrease in the discharge of pollutants such as chemical oxygen demand (COD) and ammonia nitrogen. This improvement is impressive. The water quality of the main river basins such as the Yangtze and the Yellow Rivers was improved till 2017. The water quality of the mainstream of the Pearl River and Songhua River was good, but the water of the tributaries of the Yellow River remains in moderately polluted. The Huaihe, Haihe and Liaohe Rivers were all heavily polluted. From 2004 to 2013, the proportion of high-quality water (Grade I–III) in the major river basins in China gradually increased. After 2014, the proportion of high-quality water (Grade I–III) decreased, and the proportion of water with inferior quality remained stable (Figure 2). There was no Grade I water in the Huaihe River Basin from 2014 to 2017 and the proportion of Grade I–III water decreased by 10.3%. The proportion of Grade I water in the Haihe River Basin decreased by 2.8%, and the proportion of Inferior to Grade IV Water was still high (32.9% in 2017). Overall, although the total amount of water pollution decreased and the water quality of the mainstream increased, the water quality of the tributaries in some river basins was still poor. Therefore, the cost of water environmental degradation

continued to rise from 2004 to 2017, from 286.08 billion yuan to 912.85 billion yuan.

■ **Figure 2. Water quality in major river basins from 2004 to 2017**

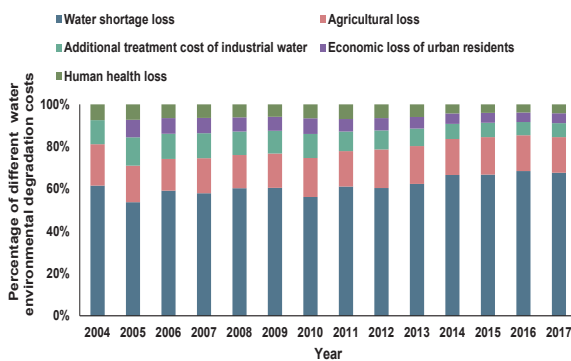


Water shortage caused by pollution largely contributed to the water environment degradation cost. From 2004 to 2017, the proportion of pollution originated water shortage in the water environmental degradation cost increased from 51.7% to 67.5%, and the agricultural loss caused by sewage irrigation accounted for approximately 17%. The cost of the other three types of water degradation accounted for approximately 20% of overall water environment degradation cost (Figure 3). The amount of polluted water was initially increased, then decreased. It increased annually from 2004 to 2016 and reached its highest value of 114.91 billion m³ in 2016. Hebei, Shandong, and Henan, which are the main provinces flowed through by the Haihe and Huaihe Rivers, also suffered severe pollution. In Hebei, Shandong, and Henan



the water shortages due to pollution in 2017 accounted for 10.8%, 7.9%, and 6.4% of the total water shortage in these provinces, respectively.

■ **Figure 3. Proportion of different water environmental degradation costs from 2004 to 2017**



3.3 Atmospheric environmental degradation costs

From 2004 to 2017, China's air pollution prevention and control experienced three stages of development: i. From 2004 to 2010, the total amount of major air pollutants was controlled and SO₂ emissions decrease, while the *Air Pollutant Emission Standards for Thermal Power Plants and Boiler Air Pollution Emission Standards* was revised; ii. After 2010, new air quality standards were implemented, and the control target since then focused on coordinating the total pollutants control and environmental quality improvements; iii. Since the implementation of *the Action Plan of Air Pollution Prevention and Control* in 2013, the following measures have been proposed:

intensify comprehensive management, adjust and optimize the industrial structure, accelerate the technological transformation of enterprises, adjust the energy structure, optimize the industrial layout, improve environmental economic policies, enhance laws and regulations, coordinate regional environmental governance, establish monitoring and early warning response systems, and clarify the responsibilities of government, enterprises and society. The implementation of the action plan has significantly improved the quality of the atmospheric environment. From 2004 to 2012, the proportion of cities above the prefecture level compliant with the air quality standards increased by 52.8%. After the implementation of the new air quality standards in 2013, the annual average concentration of PM_{2.5} decreased by 40.3%, the annual average concentration of PM₁₀ decreased by 36.4%, and the annual concentration of SO₂ decreased by 55%. The average annual concentration of PM_{2.5} in the key areas of air pollution control, including the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta regions, decreased by 39.6%, 34.3%, and 27.7%, respectively.

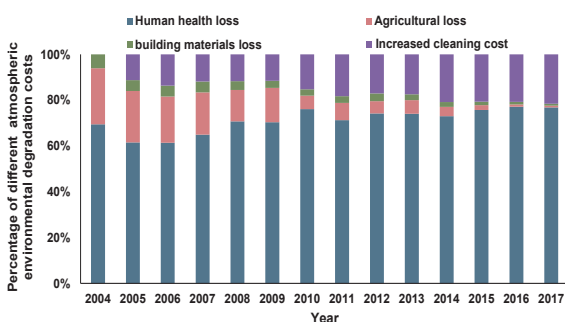
Between 2004 and 2017, the atmospheric environmental degradation cost increased from 219.8 billion yuan to 923.27 billion yuan, an average annual increase of 11.7%. The atmospheric environmental degradation cost reached a peak in 2014 with 1,001.19 billion yuan, then decreased slightly (Figure 1). Human health losses account for the



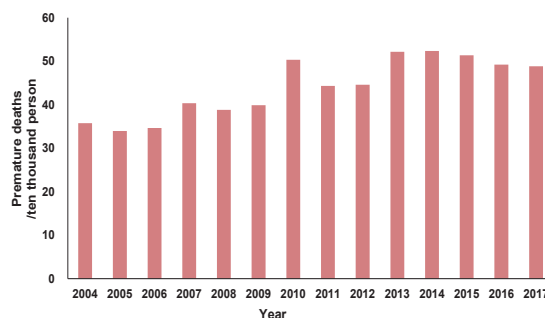
major part of the atmospheric environmental degradation costs which increased from 69.5% in 2004 to 76.9% in 2017 (Figure 4). The probability of premature death due to environmental pollution initially increased from 358,000 to 524,000 but then decreased to 488,000 (Figure 5). The frequency of acid rain in China decreased from 56.5% to 10.8%

during the period of 2004–2017. The loss of agricultural and building materials due to acid rain and SO₂ pollution also decreased. The ratio of the two losses to the cost of atmospheric environmental degradation decreased from 30.5% in 2004 to 1.6% in 2017.

■ **Figure 4. Proportion of different atmospheric environmental degradation costs from 2004 to 2017**



■ **Figure 5. Probability of premature deaths due to atmospheric pollution from 2004 to 2017**



3.4 Spatial distribution of environmental degradation cost

The average annual growth rate of the environmental degradation costs in the eastern, central, and western regions were 10.1%, 10.4%, and 12.4%, respectively from 2004 to 2017, in which the western region had the fastest growth rate. The annual average growth rate of the atmospheric environmental degradation costs in the eastern, central, and western regions were 10.9%, 12.1%, and 13.5%, respectively. The annual average growth rate of the water environment degradation costs in each region

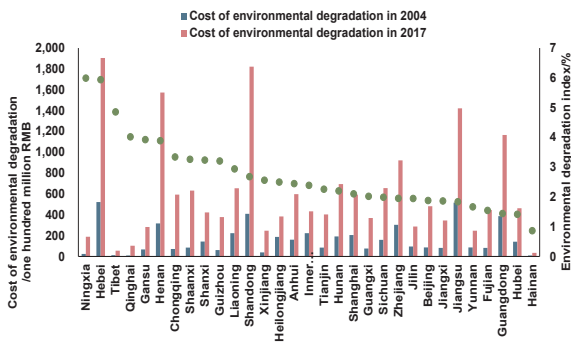
were 9%, 8.4%, and 11.2%, respectively. The provinces of Shandong, Hebei, Jiangsu, Henan, and Guangdong all had higher environmental degradation costs. In 2017, the environmental degradation cost was more than 100 billion yuan (Figure 6). From 2004 to 2017, the annual average growth rates of the environmental degradation costs in each of these five provinces were 10.5%, 12.2%, 13.1%, 8.1%, and 8.8% respectively. The five provinces with the fastest-growing environmental degradation costs were Qinghai, Chongqing, Ningxia, Shaanxi, and Xinjiang, which were all located in the western region (Figure 7). The five provinces



with a high environmental degradation index in 2017 were Ningxia, Hebei, Qinghai, Gansu, Henan which accounted for 6%, 5.9%, 4%, 3.9%, and 3.9% of the total, respectively. Compared to 2014, the environmental

degradation index in Hebei, Gansu, and Henan was unchanged, and the environmental degradation index in Ningxia and Qinghai increased.

■ Figure 6. Regional environmental degradation costs from 2004 to 2017



■ Figure 7. Comparison of the regional environmental degradation cost growth rate and economic growth rate from 2004 to 2017

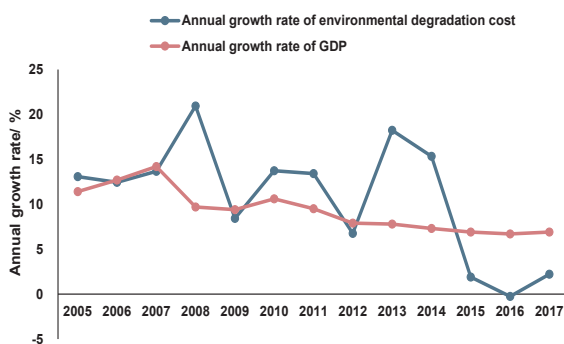




4. CONCLUSIONS

From 2004 to 2017, China's GDP growth rate decreased from 10.1% to 6.9%. In the same period, the environmental degradation cost growth rate decreased from 13.1% to 2.2%. After 2014, the national environmental degradation cost growth rate accelerated downward. The growth rate in 2017 was only 2%, which was much lower than the GDP growth rate in the same period (Figure 8). This relationship indicates that the nationwide promotion of the ecological civilization development strategy and the increased investment in ecological and environmental protection and management are constantly paying off the debt of economic development. The environmental degradation index was used to characterize the greenness of China's economic development. The environmental degradation index decreased from 3.05% to 2.23% from 2004 to 2017, indicating that China's economic development has become greener over the recent years.

■ **Figure 8. growth rate of the environmental degradation cost and GDP**



The effect of the industrial structure adjustment has become evident, and the growth rate of environmental degradation costs in most provinces has slowed. From 2004 to 2017, the annual average growth rate of environmental degradation costs in 25 provinces was lower than the GDP growth. The annual growth rate of the environmental degradation costs in Qinghai, Chongqing, Ningxia, Shaanxi, and Xinjiang was faster than their GDP growth. Among the provinces with higher environmental degradation costs as Henan, Shandong, and Hebei, the annual average growth rate of their environmental degradation cost was basically as same as their GDP average annual growth rate, but the growth rate of the environmental degradation costs in Jiangsu, Guangdong, and Zhejiang was lower than the average annual growth rate of their GDP by 6.3%, 3.9%, and 3.2%, respectively. The environmental benefits of industrial transformation have emerged.

The environmental management capacity has significantly improved, but the task of environmental pollution prevention and control is still arduous. The introduction of the ecological civilization development strategy resulted in the yearly launch of a number of reform measures of ecological and environmental protections. The laws of environmental protection, air pollution prevention and control, water pollution prevention and control, environmental impact assessment, and environmental protection taxes were developed and revised. The development of central environmental protection inspections has solved many outstanding environmental problems. The prevention and control of atmospheric



environmental pollution is still at a crucial stage. The air quality compliance rate of major cities in China is not high, and the water quality of the main river basins is low. Spatial simulation of remote sensing retrieved $PM_{2.5}$ concentration and grid exposed population finds that in China, only 24.6% of the population was in regions with a $PM_{2.5}$ concentration of less than $35\mu g/m^3$ - the National Grade II standard. The environmental degradation cost in China is still high and has not shown a decreasing trend. The environmental degradation cost in the western region has increased rapidly. The economic growth of Qinghai, Chongqing, Ningxia, Shaanxi, and Xinjiang is still highly dependent on the ecology and environment.

The method of Statistical Life-Year Value assessment has a great impact on the accounting of environmental health degradation costs. The life value assessment mainly includes the human capital method and the contingent value method. The former is widely used in China, while the latter is mainly used in foreign countries. According to the Organization for Economic Co-operation and Development^[30], which recommended that member states use the value of a statistical life between \$1.5 million and \$4.5 million. The United States has a value of a statistical life between \$200,000 and \$13 million which, depends on the cause of death.

The Chinese Academy of Environmental Planning's environmental economic accounting project team surveyed the willingness to pay (WTP) for air pollution control in the Chengyu District in 2018. Using the single-boundary dichotomous model of the conditional value method,

the value of statistical life (VSL) of China was 3.95 million yuan. The environmental degradation cost accounting results introduced in this paper all adopted the human capital method. If, instead, the calculation of the VSL was calculated by WTP, the environmental degradation cost would be higher than that calculated by the human capital method. By using the Statistical Life-Year Value of 3.95 million yuan, we found that the environmental degradation cost was 3,202.28 billion yuan in 2017, which was 1.69 times that calculated using the human capital method.

Environmental degradation cost is the major component of environmental-economic accounting system, a powerful tool when it is taken into policy consideration. In China, GDP-oriented performance assessment system is undergoing a transformation which leads to a more comprehensive system taken resource depletion, environmental degradation and ecological benefit into account. Green GDP as an integrated product of environmental-economic accounting provides an environmental sound indicator for governmental performance assessment, and generates driving forces for industrial structure upgrading in heavily polluted regions and promotion of green and high-quality development. Exploration on development of regional-based environmental-economic accounting and realization of accounting system from theory to practice become the prioritized emerging issue. Environmental-economic accounting could also support cost-benefit analysis of various environmental plannings, policies, regulations and projects for reasonable decision-making. Chinese government urgently need to take action to formalize the environmental-economic accounting for enhancing ecological civilization process.



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APPENDICES A: TABLES

 **Table 1 Main parameters of environmental degradation cost accounting**

No.	Data description	Data source
1	Mortality rates at various ages and diseases of urban residents	China Health Statistical Yearbook (2005–2018)
2	Prices of major agricultural products	Data Collection of National Agricultural Product Incomes (2005–2018)
3	Hospitalizations due to respiratory diseases and circulatory diseases	Fourth National Health Service Survey Analysis Report
4	Consumer price index, building material stock increase index, personal goods and service consumer price index, and industrial producer purchase price index	China Statistical Yearbook (2005–2018)
5	All-cause mortality at “clean” concentrations, relative hazard ratio of all causes of death resulting from air pollution, percentage change in the health hazard caused by the change in the unit pollutant concentration, loss coefficient of chronic bronchitis disability, average number of lost years due to chronic bronchitis, percentage of crop yield reduction caused by environmental pollution, life span of materials in the clean control area, mortality of 5 kinds of polluted-water-caused cancer (gastric cancer, liver cancer, esophageal cancer, colon cancer, and bladder cancer), shadow price of water resources, 3 types of household clean water replacements (average cost and the proportion of water, water purifier, and tap water filter)	Technical Guide for China Environmental and Economic Accounting
6	Hospitalization cost and patient days of diseases	The Third National Health Service Survey
7	Average additional treatment cost of domestic water	Technical Guide for China Environmental and Economic Accounting
8	Discount rate	Research on Economic Evaluation Parameters of Construction Projects



 **Table 2. Dose-response relationships of the effects of SO₂ and acid rain, alone and combined, on crop yield**

Crops	Reduction percentage (%)		
	SO ₂ pollution (mg/m ³)	Acid rain pollution (pH value)	SO ₂ and acid rain combined pollution
Rice	10.96 X_1		2.92+17.93 X_1 -0.182 X_2
Wheat	26.91 X_1	27.59-4.93 X_2	24.61+30.17 X_1 -4.3949 X_2
Barley	35.83 X_1	24.13-4.31 X_2	24.90+45.08 X_1 -4.4466 X_2
Cotton	25.16 X_1	22.67-4.05 X_2	29.06+28.31 X_1 -5.1886 X_2
Soybean	28.78 X_1	15.32-2.73 X_2	26.32+31.91 X_1 -4.7 X_2
Rapeseed	50.80 X_1	47.39-8.46 X_2	34.57+43.92 X_1 -6.1724 X_2
Carrot	53.96 X_1	49.63-8.86 X_2	29.16+41.71 X_1 -5.2064 X_2
Tomato	37.40 X_1	22.52-4.02 X_2	16.64+36.52 X_1 -2.9711 X_2
Bean	68.99 X_1	79.90-14.27 X_2	42.40+75.74 X_1 -7.5712 X_2
Vegetables	53.45 X_1	48.1-9.05 X_2	29.4+51.32 X_1 -5.25 X_2

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Center of Eco-environment of the Yangtze
river economic belt

Center of Eco-Civilization of
the Yellow River

Center of Eco-Environment Compensation

Center of Total Quantity Control and
Emissions Trading

Center of Environment and Health

Center of Eco-Environmental Zoning

Center of Environmental PPP

Center of Tax on Environmental Protection

Center of Environmental Investment
Performance Management

Center of Environment Audit

Center of Eco-Environment and Economic
Accounting





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