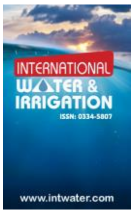

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Analysis of Ecological Compensation Effects in the Beijing-Tianjin-Hebei Region: Focusing on Water Resource Compensation

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Abstract: In promoting regional coordinated development, ecological compensation has become a key means to achieve sustainable development goals. This study takes the Beijing-Tianjin-Hebei region as the research object and introduces a novel ecological compensation method - the emergy-based ecological footprint analysis method - to calculate the ecological compensation amount from 2000 to 2022. This method reflects the accuracy of sustainable development levels and overcomes the limitations of previous methods. By collecting and analyzing data on ecological compensation practices in the Beijing-Tianjin-Hebei region, it was found that the region's ecological compensation practices are currently mainly centered around water resources ecological compensation. By comparing the theoretical ecological compensation amount with the actual payment of the river basin ecological compensation amount, the study evaluated the effectiveness of ecological compensation in the Beijing-Tianjin-Hebei region and identified the main problems with the current ecological compensation mechanism: the significant disparity between theoretical compensation and actual payments, the overly singular compensation model, the inconsistency in compensation standards, and the inadequacy of the legal framework. The results show that although the Beijing-Tianjin-Hebei region has made some progress in river basin ecological compensation, the compensation mechanism still needs to be optimized to improve its effectiveness. This study provides scientific evidence for improving the ecological compensation mechanism in the Beijing-Tianjin-Hebei region and serves as a reference for ecological compensation practices in other regions.

Keywords- Beijing-Tianjin-Hebei region, ecological footprint, ecological carrying capacity, ecological compensation, water resource compensation, emergy ecological footprint method.

1. Introduction

Human beings exploit resources from the ecological environment while also releasing waste into it. These human activities result in resource depletion and environmental pollution, causing severe damage to the ecological environment, and it can be said that the price humans pay for economic development. Nowadays, countries around the world attach great importance to ecological issues and sustainability. Similarly, China's economic development historically followed a "pollution first, governance later" model, while now conserving resources and protecting the environment have become China's basic national policies.

The coordinated development of ecological civilization in the Beijing-Tianjin-Hebei (BTH) remains a hot topic of research. The economic aggregate of the BTH region exceeded 10 trillion CNY, 1.8 times that of 2013 in 2022. This shows that the first phase of BTH coordinated development has achieved remarkable results. This is a topic of pivotal importance in examining changes in the ecological environment while experiencing rapid economic development to ensure sustainable growth. The BTH's ecological environments are under tremendous strain due to the region's rapid urbanization, and the ecological problems have been shown complex and systematic. Eco-environmental protection is the top priority for BTH's coordinated development. BTH insists on joint pollution control and carries out extensive cooperation in regional air pollution prevention and water quality improvement, and has achieved remarkable results, with the ecological environment quality greatly improved.

In recent years, the BTH horizontal ecological compensation (EC) mechanism has played a positive role. Some specific compensation practices, such as the diversion of the Luan River into Tianjin and the ecological protection in the upper reaches of Miyun Reservoir, have provided useful exploration for regional EC. However, at present, the EC standards in the BTH region have not yet been clarified. There are only scattered and case-by-case compensations, and there is a lack of systematic and region-wide compensation programs. Therefore, it is necessary to further perfect the EC mechanism and clarify the compensation standards to better achieve ecological environment protection and sustainable development in the BTH region. This paper proposes an EC model based on the emergy ecological footprint (EF) and conducts quantitative research to formulate the amount of EC in the BTH region. It is expected that the EC will play an important role in regulating the ecological environment protection and economic development, and promote the realization of the coordinated development in BTH.

2. Literature Review

Setting EC's standards is the most challenging and fundamental part, and it is also a commonly studied issue in the academic community. EC's standards reflect its feasibility, scientific accuracy, and implementation impact. In the accounting EC standards, the calculation of ecological benefits is mainly relying on the ecosystem service values. And there are some common methods for assessing the economic value of assets and the environment: the opportunity cost approach, ecological value estimation method, market value method, willingness to pay method, and traditional EF method.

Nevertheless, (1) the opportunity cost approach's data source is biased and may lead to erroneous conclusions. (2) The ecological value estimation method is challenging to ascertain the link between ecosystem service function and service value, and the result typically represents the highest level of EC. (3) The market value approach is subject to the diversification of market mechanisms, and the compensation standards calculated are not universal. (4) The willingness-to-pay method is rarely used because of the difficulty of reconciling willingness-to-pay and willingness-to-receive. (5) The traditional EF method is an effective approach for calculating EC. First, it is a thorough, objective model and has strong results comparability. Second, it fully accounts for the variability of geographic space and the degree of social and economic development. Third, it can be applied to both regional and multi-scale comprehensive processes.

However, the traditional EF method cannot accurately represent the actual ecological carrying capacity in the research study because it adopts the global average productivity and equilibrium indicators [1]. Many researchers have modified the traditional EF model in recent years, including the three-dimensional EF approach [2], NPP EF method [3], and the emergy EF methodology[4], The emergy EF approach combines with Odum's emergy analysis theory [5], connecting the material cycle with the energy flow. It can accurately represent the degree of regional sustainable development by implementing more stable indexes like emergy conversion rate and emergy density. Furthermore, this method can separate natural resources from stock resources, makes it easier to analyze the consumption of resources, and provides a basis for EC. For example, Yang et al. [6] established emergy EF model to determine each city's EF and ECC in the middle reaches of the Yangtze River urban agglomeration to quantify each city's EC.

Many researchers also have examined EC in the BTH region, mostly concentrating on water resources [7], air pollution prevention [8], and ecosystem services value [9], etc. Moreover, other academics have attempted to measure EC from different viewpoints. For example, Yang et al. [10] took the BTH as the research region and established a quantitative model of the total amount of EC on the basis of ecological resources and county-level economic development. Du et al. [11] calculated the value of ecosystem services in the BTH region and built an EC model according to ecosystem service flow. However, the EC standards in the BTH from the perspective of emergy EF have not been studied.

Given the review of previous research, this paper presents the following innovations: (1) This study develops an emergy EF model to calculate the ECC and EF in the BTH region. This approach mitigates biases inherent in traditional EF models and enhances the accuracy of results. (2) This research refines the EC model by incorporating ecological resource conversion efficiency and willingness-to-pay indicators, which effectively reflect economic and social impacts. The findings can serve as a reference for BTH and other urban agglomerations with similar characteristics worldwide in establishing a reasonable EC mechanism.

3. Materials and methods

3.1 Emergy EF Model

The ecological economist Rees [12] first proposed the concept of the EF in 1992 as a way to quantify the effects of human activity on the environment. He claimed that the EF is the total area of ecologically productive land required to produce all the resources consumed and to absorb all the wastes by those populations. Ecologically productive land is specifically divided into six categories: cropland, grassland, forest land, water land, fossil energy land, and built-up land.

3.1.1 Emergy ecological carrying capacity (ECC)

Natural resources can be categorized into two main types: renewable resources and non-renewable resources. Renewable resources include solar energy, wind energy, geothermal energy, rainwater chemical energy, runoff potential energy, and runoff chemical energy. Non-renewable resources contain coal, oil, etc, and their regeneration is not feasible in the long term. For this reason, we consider the emergy of renewable resources as ECC of the region. Thus, we all know, that the only way to achieve sustainable development is to satisfy human needs by fully utilizing renewable resources [13]. According to the research of others [14], the emergy ECC can be calculated as follows (Table 1):

3.1.2 Emergy EF

The emergy EF can be calculated in two parts - biological resources and energy production, and the results can accurately reflect the environmental burden on the region. Biological resources are classified as renewable resources while energy resources as non-renewable. The biological account contains products from ecologically productive land except for built-up land, while energy consumption comes from built-up land. In the same way, we add primary industrial products into energy account, shown in Table 2 for details, this is because the production of primary industrial products will consume a large amount of non-renewable resources [15], when China's industry is in the stage of transformation and upgrading, generating a large number of primary industrial products.

The following are the formulas:

$$EF = \sum_{n=1}^{6} (B_i \times ECR_i) / RED; \quad (1)$$

$$RED = Ere / S; \quad (2)$$

$$\mathrm{ef} = EF / N; \quad (3)$$

Where EF is the gross ecological footprint of the region, Bi refers to the emergy or mass belonging to type n, ECRi represents the emergy conversion rate of item I; RED is the regional emergy density, and ef is per capita EF.

3.1.3 Ecological surplus and deficit

The ecological surplus and deficit is the difference between the ECC and the EF, and it may be calculated using the following formula:

$$ED = EC - EF; \tag{4}$$

Measuring the results, an ecological surplus (ED > 0) indicates that society's economic development is sustainable; an ecological deficit (ED < 0) reveals that the ecosystem is dangerous and that economic development is not sustainable. When ED=0, the ecosystem is secure, meaning demand and supply are balanced, and economic growth is sustainable.

Table 1 Methods of measuring ECC

Indicators	Formula	Parameter description
Solar emergy (Es)	$Es = S \times SRa \times ECRs \times (1 - r)$	S is the study area; SR_a is the annual solar radiation energy of the area, ECR_S is the solar energy conversion rate, and r is the albedo.
Earth cycle emergy (Eec)	$Eec = S \times HF \times CE \times ECRec$	HF is the heat flux, CE is the Carnot efficiency, and ECR_{ec} is the earth cycle emergy conversion rate.
Wind emergy (E_w)	$Ew = S \times \rho_{air} \times DC \times (\bar{v}/0.6)^3 \times (365.25 \times 24 \times 3600) \times ECRw$	ρ_{air} is the air density, DC is the drag coefficient, and v is the average wind speed in the area. ECR_w is the conversion rate of wind emergy.
Rainwater chemical emergy (E_{rc})	$Erc = S \times PREa \times TC \times \rho_w \times GFE \times ECR_{t1}$	PRE_a is the annual precipitation, TC is the transpiration coefficient, ρ_w is the water density, GFE is the Gibbs free energy, and ECR_{t1} is the conversion rate of rainwater chemical emergy.
Rainwater potential emergy (Erp)	$Erp = S \times PREa \times (1 - TC) \times H \times \rho_w \times G \times ECR_{t2}$	H is the regional average elevation, G is the gravitational acceleration, and ECR_{t2} is the conversion rate of rainwater potential emergy.
Renewable emergy (Ere)	$Ere = Es + Eec + \text{Max}\{Ew, Erc, Erp\}$	E_{re} is renewable emergy, including solar emergy, earth cycle emergy, and a maximum of E_w, Er_c, and E_{rp}, because these three types of emergy belong to different conversion forms of the same energy.
Ecological carrying capacity (ECC)	$ECC = (Ere / GED) \times (1 - 0.12)$	GED is global emergy density, and the coefficient of 0.12 indicates that 12 percent of the area is reserved for the conservation of biological diversity.
per capita emergy ECC (ecc)	$ecc = ECC / N$	N is the sum of the regional population.

3.2 EC Model

To establish the EC model needs to consider the environmental system integrity, match the specific circumstances of the study areas, and combine with equitable distribution of environmental benefits. Then, we use emergy EF model proposed before, introduce economic and social indicators like willingness to pay and ecological resource conversion efficiency, and choose total investment in the environmental pollution control index to construct EC model. The following are the formulas:

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Table 2 EF indicators

Items	Indicators	Land type
Biological account	Cereals, wheat, maize, pulses, yams, vegetables, cotton, oil seeds, sugar, vegetables	cropland
	Fruits	forest land
	Meat, milk, eggs	grassland
	Aquatic products	water
Energy account	Crude steel, chemical fiber, cardboard, cement, chemical fertilizer, sulfuric Acid, pesticides, plastic film, raw coal, coke, crude oil, petrol, paraffin, diesel, Fuel oil, LPG, natural gas	fossil energy land
	Hydroelectricity Thermal power generation	Build-up Land

3.2.1 Willingness to pay (WTP)

People's willingness to pay for EC will keep rising as society develops [16]. The development stage coefficient is a measure of how much people's WTP for EC differs depending on their living standards. Thus, the development stage coefficient is used to adjust the amount of EC. The development stage coefficient variation is very similar to the biological growth process, thus we can use a Peel growth curve (S-curve) model to depict this trend [17].

$$Wi = \frac{P_i \times l_i}{\overline{P}}; \tag{5}$$

$$l_i = \frac{1}{1+e^{-t}}; \tag{6}$$

$$t = \frac{1}{n} \times \frac{In_i}{\sum_{i=1}^{n} In_i}; \tag{7}$$

Wi is the willingness to pay; Pi is the population of city i; $\overline{P}$ is the average population of cities; li is the development stage coefficient; Ini is the per capita income; t is the income correction coefficient.

3.2.2 Ecological resource conversion efficiency

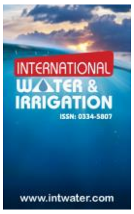
The EF per 10,000 CNY GDP, namely ecological resource conversion efficiency, measures how well natural resources are used in a certain location. The EF inversely correlates with the efficiency of resource consumption. As a result, it has been used to measure how economic development and environmental impact are related, with lower numbers indicating more effective resource use.

$$U_i = \frac{EF_i}{GDP_i}; \tag{8}$$

Where Ui is the ecological resource conversion efficiency of city i, that is, the EF of each 10,000 CYN GDP; EFi is the emergy EF of city i, and GDP is the gross domestic product;

3.2.3 Supplied coefficient of ecological sefervices

A city's ability to supply ecological services to other cities in the region increases with its ECC, which is a key factor in regional economic development.



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$$\beta_i = \frac{EC_i}{\sum_{i=1}^{n} EC_i}; \tag{9}$$

Where βi is the supplied coefficient of ecological services. ECi is the emergy ECC.

3.2.4 Consumption coefficient of ecological services

When assessing the compensation status of various cities in the area, it makes sense that a city with a larger EF would also consume more resources and generate more waste, therefore it should be responsible for paying for ecological compensation. We refer to it as the consumption coefficient of ecological services. We use the comprehensive correction coefficient to revise the consumption coefficient of ecological services, making it more accurately reflect the current situation, where we consider the pulling influence of the regional economy.

$$Rec_i = \frac{U_i \times Wi}{(\frac{1}{n} \times \sum_{i=1}^{n} U_i) \times (\frac{1}{n} \times \sum_{i=1}^{n} W_i)}; \tag{10}$$

$$\partial_i = \frac{EF_i \times Rec_i}{\sum_{i=1}^{n} (EF_i \times Rec_i)}; \tag{11}$$

Reci is the comprehensive correction coefficient; αi is the consumption coefficient of ecological services.

3.2.5 The amount of EC

The principle of EC is that whoever pollutes will be charged. Therefore, we calculate the amount of EC on the ground of the pollution treatment cost spent by the city to restore the ecological environment. We separately calculate the benefits that cities receive from providing ecological services and the costs that cities pay for consuming them, and subtract them. If the result is positive, the city should receive compensation; or the city should pay.

$$V_i = M \times \beta_i; \tag{12}$$

$$F_i = M \times \partial_i; \tag{13}$$

$$X_i = V_i - F_i; \tag{14}$$

Vi is what the city receives for providing ecological services; M is the total investment in environmental pollution control; Fi is what the city should give for the consumption of ecological services; Xi is the EC that should receive. If Xi is positive, it means that the EC is the net inflow; If it is negative, it is a net outflow.

3.3 Collection of Research Data

The BTH region, also known as China's capital economic circle, is the largest and most dynamic region in northern China, and it is increasingly attracting national attention. It is situated in the northern portion of the North China Plain, between 114°30' and 119°30' east longitude and 37°20' to 42°40' north latitude (Figure 1). Data such as output of various products, wind speed, rainfall, and total investment in environmental pollution control are derived from the China Environmental Statistical Yearbook, Beijing Statistical Yearbook, Tianjin Statistical Yearbook, Hebei Statistical Yearbook, Water Resources Bulletin and National Bureau of Statistics (www.stats.gov.cn) from 2000 to 2022. The mean elevation data are processed by ArcGIS software from the spatial distribution data of Chinese DEM. The solar radiation data are obtained from the Geographical Remote Sensing Ecological network (www. gisrs. cn) and processed by ArcGIS software. Some of the indicators had missing data in individual years, which were filled in by interpolation. The emergy conversion coefficient comes from the study of [18], and the emergy conversion rate comes from the study of [19] and [20], which is processed according to the latest emergy baseline (12×1024sej·a-1).

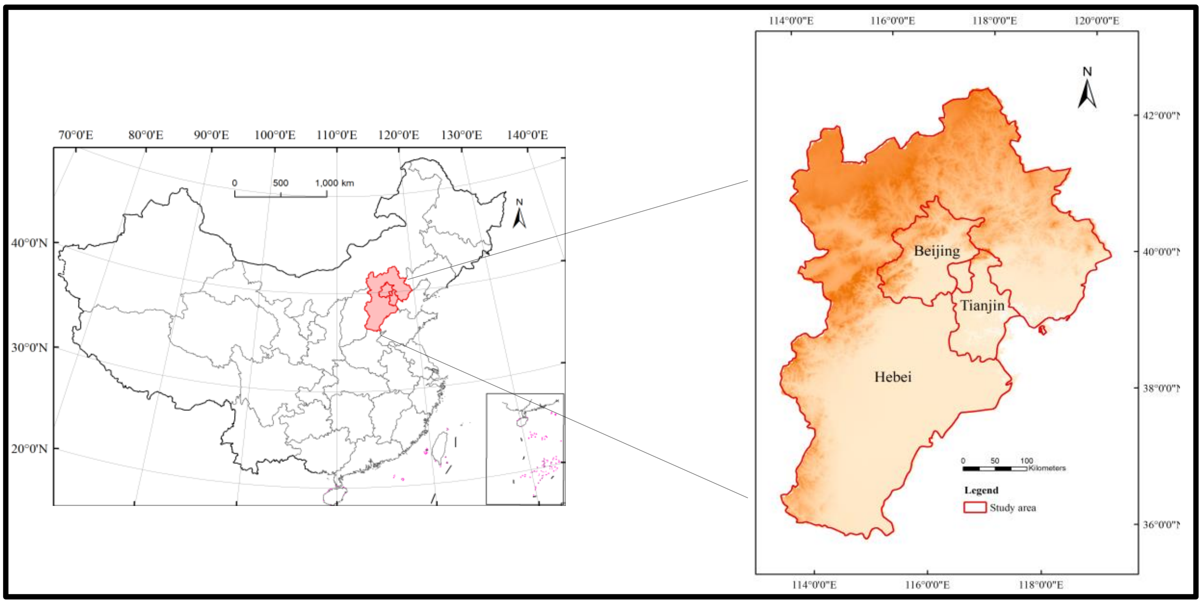

Figure 1. Study area location

4. Results

4.1 Emergy ECC of Beijing-Tianjin-Hebei Analysis

The results indicated significant temporal fluctuations in the ECC of the BTH region, demonstrating an overall increasing trend. The annual growth rate fluctuated within a wide range (-40%, 50%) with substantial variation (Figure 2). Notably, Tianjin and Hebei reached their peak ECC in 2021, leading to the highest level for the total BTH region.

In terms of spatial dimension, the ranking of ECC was Hebei > Beijing > Tianjin, with Hebei having the highest average ECC (3.52×107ha), followed by Beijing (2.64×106ha) and Tianjin (2.03×106ha). This ranking is closely related to the calculation method based on emergy theory which integrates various natural energies such as solar energy, wind energy and earth rotation energy. The specific value for each year is influenced by natural factors like rainfall, wind speed and sunshine intensity in that year's region. It is worth noting that Hebei achieved its highest ECC in 2021 due to historic rainfall of 861.2 mm during that year significantly improving its ECC.

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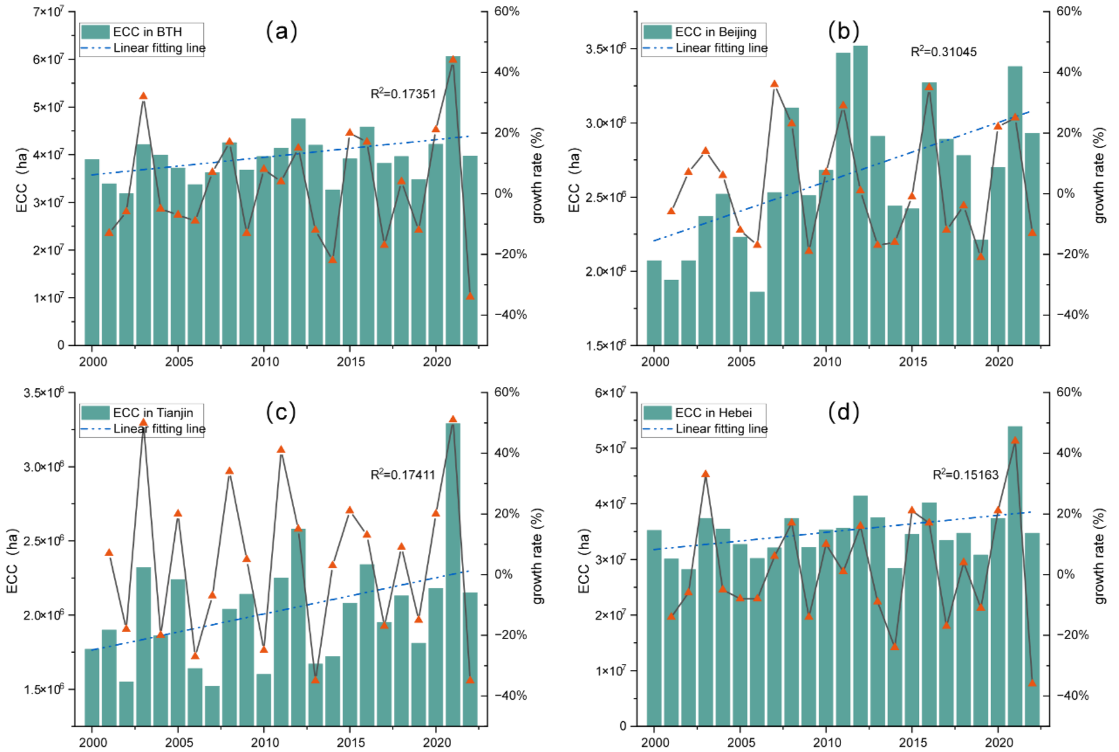

Figure 2. Changes of ECC and growth rate in BTH, 2000-2022 ((a) total ECC and growth rate in BTH. (b)ECC and growth rate in Beijing. (c) ECC and growth rate in Tianjin. (d) ECC and growth rate in Hebei)

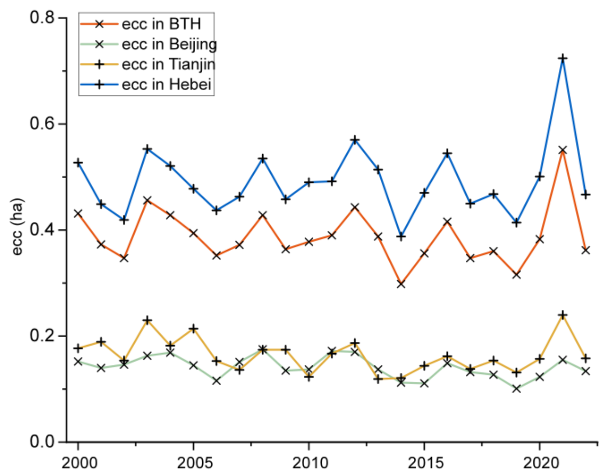

Figure 3. Changes in ecc in BTH, 2000-2022

As a crucial indicator for assessing the ecological sustainability of a region, ecc reflects the relative balance between ecological resources and population within the region. Over time, ecc in the BTH region has exhibited a relatively consistent trend with fluctuations, reaching its peak in 2021 (Figure 3). This trend signifies the dynamic equilibrium between ecological resource utilization and population distribution in the region. In terms of spatial scale, Hebei ranked highest in ecc followed by total BTH, Tianjin, and Beijing in both 2000 and 2022 respectively. Specifically, Hebei's annual average ecc reached 0.493ha, indicating relatively abundant ecological resources and low population density within the region. In contrast, Tianjin and Beijing had lower values at 0.165ha and 0.141ha

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respectively. Despite similar ecc values for Beijing and Tianjin, Beijing's smaller ecc is attributed to its larger population size - a difference primarily influenced by uneven distribution of population and ecological resources.

4.2 Spatial and Temporal Variations in the Emergy EF of Beijing-Tianjin-Hebei

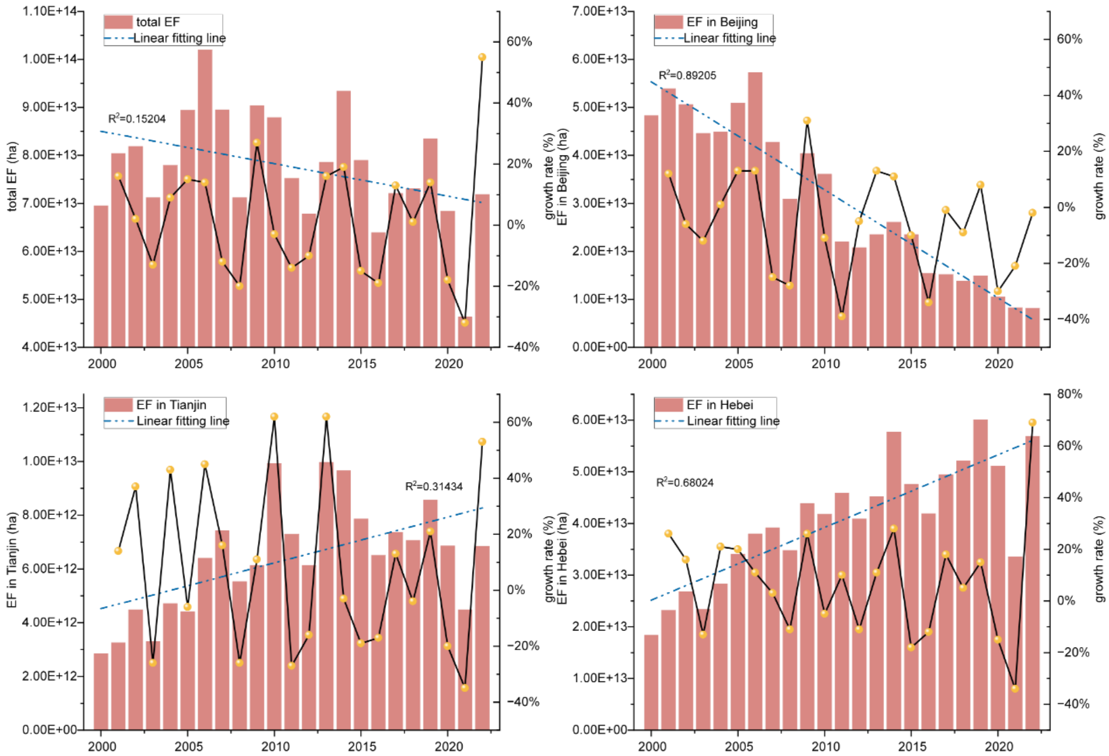

Figure 4. Changes of EF in BTH, 2000 to 2022((a) total EF and growth rate in BTH. (b) EF and growth rate in Beijing. (c) EF and growth rate in Tianjin. (d) EF and growth rate in Hebei)

The results indicated (Figure 4) significant spatiotemporal characteristics in the changes of EF. While the EF of the total BTH region and Beijing exhibited a fluctuating downward trend, Tianjin and Hebei showed an increasing trend.

Spatially, there were substantial regional disparities in EF change rates ranging from -30% to 60%. Beijing's EF decreased for 16 years over the past two decades with a maximum annual decline of 30%, reflecting effective control measures possibly attributed to stringent environmental policies and resource management practices. Tianjin's EF displayed alternating increases and decreases with an overall slow upward trajectory, potentially linked to its economic structure and industrial development model requiring further investigation. In contrast, Hebei experienced a growth in its EF for 12 years with a notable increase of 69% in 2022. Given its already substantial ecological pressure, this rapid growth exacerbates regional environmental concerns likely influenced by factors such as industrialization process, population growth, and resource utilization methods warranting attention.

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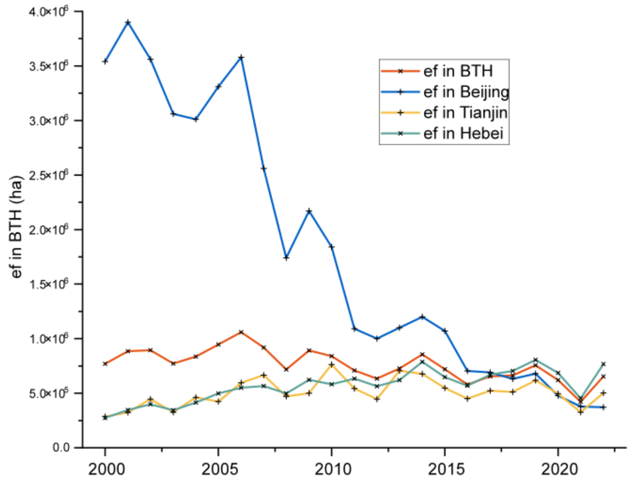
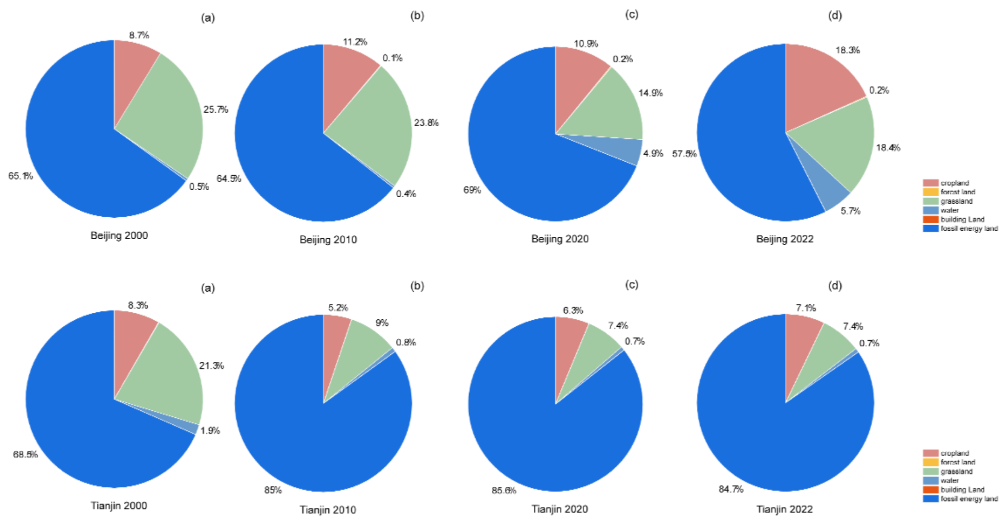


Figure 5. Changes of ef in BTH, 2000-2022

Per capita ecological footprint (ef) is a crucial indicator for measuring the per capita ecological resource consumption in a region, reflecting the amount of resources consumed and waste discharged by each individual. As depicted in Figure 5, over time, the ef of the total BTH region has fluctuated overall, with a gradual decline as the predominant trend. Notably, Beijing's ef experienced a significant decrease of 89.50 percent from 2000 to 2022. In contrast, Tianjin and Hebei witnessed an upward trend in their ef during this period. Particularly noteworthy is Hebei's substantial increase of 178.53 percent, while Tianjin's increased by 53.50 percent.

From a spatial perspective, there have been significant changes in the ranking of ef across the BTH region between 2000 and 2022. In 2000, Beijing had the highest ef followed by the total BTH and then Tianjin and Hebei respectively. However, by 2022, Hebei's ef surpassed that of the total BTH region with Tianjin and Beijing following as third and fourth respectively. This shift reflects variations in utilization of ecological resources and environmental protection efforts across different regions.

4.3 EF Emergy of the Six Ecologically Productive Land Types



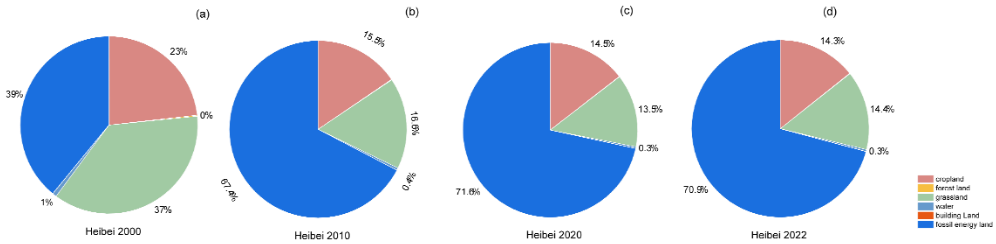


Figure 6. Changes in the EF emergy of six ecologically productive land types in BTH, 2000-2022

The calculation of EF is based on six types of productive land. By analyzing the proportion of each type of land in the EF, we can gain insight into the evolution of energy structure and land use. Using the breakpoint analysis method, this study selected data from 2000, 2010, 2020, and 2022 for in-depth analysis. As shown in Figure 6: (1) From the perspective of the contribution rate of productive land, fossil energy land dominates all regions' EF, accounting for more than 50%. This may be attributed to a large number of primary industrial products and continuous dependence on traditional energy during economic development. However, Beijing, Tianjin and Hebei showed significant differences in this aspect: The proportion of fossil energy land decreased by 7.6% in Beijing but increased by 16.2% in Tianjin and even more significantly by reaching 31.9% in Hebei. (2) The proportion of water land is almost negligible due to natural geographical conditions. (3) The relatively small proportions of construction land and forest land indicate limited contributions to the EF. (4) Cultivated land increased in Beijing and Tianjin but decreased in Hebei possibly due to agricultural policies and economic development patterns. (5) Grassland proportions decreased across Beijing, Tianjin, and Hebei likely due to urbanization processes and changes in land use.

From a spatial perspective, Beijing reduced its proportion of fossil energy lands while increasing water and cultivated lands. In contrast, there is cause for concern regarding an increase in fossil energy lands at Tianjin's expense as well as decreases in cultivate lands and grasslands. The high proportion of fossil energy lands at Hebei's expense also raises concerns about reduced grasslands.

4.4 Ecological Surplus and Deficit in Beijing-Tianjin-Hebei

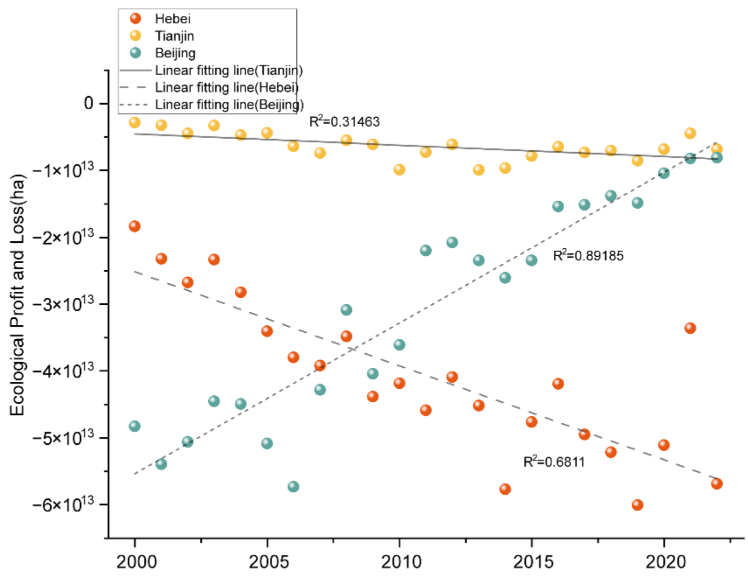


Figure 7. Changes in ecological surplus and deficit in BTH, 2000-2022

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During 2000-2022, the ecological surplus of BTH was negative (Figure 7), that is, there was always an ecological deficit. This suggests that the EF in the BTH region exceeds the ECC, putting pressure on and damaging the ecosystem. From the perspective of time, the ecological deficit of Beijing decreases at a faster rate every year, while that of Hebei increases at a faster rate every year, and that of Tianjin increases at a slower rate. These changes show that due to economic and social development, the ecological environment and natural resources are facing increasing pressure, and the renewable resources of the earth are far from meeting the current resource needs of mankind.

4.5 The Amount of EC in Beijing-Tianjin-Hebei

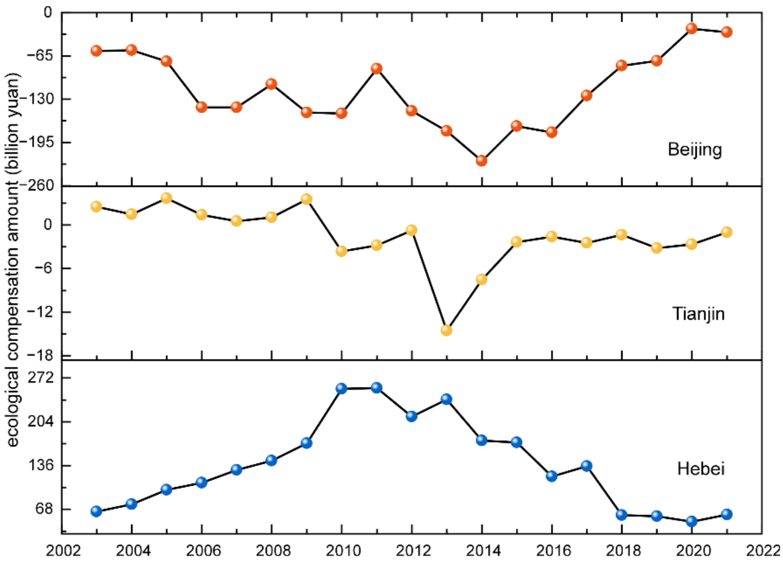
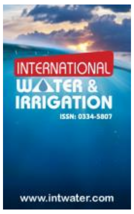


Figure 8. Changes of EC in BTH, 2003 - 2021

The amount of EC comprehensively considers population, economy, resource utilization and pollution control, reflecting the coupling relationship between economic development and environmental protection between regions. Beijing occupies the compensation side and Hebei belongs to the compensated side (Figure 8), with an average annual compensation of 115.62 billion CNY in Beijing and 135.57 billion CNY in Hebei. Tianjin was designated as a compensation area for payment from 2003 to 2009 and as a compensation area for acceptance from 2010 to 2021, with an annual average payment of 1.57 billion CNY. This shows that Beijing's economy develops faster and enjoys the spillover of ecological services brought by Hebei, especially after the transfer of polluting industries to Hebei, the industrial structure is optimized and environmental pollution is less. Tianjin is more affected by its own economic development, but it also enjoys the ecological service spillover brought by Hebei in general. Relatively speaking, Hebei is the party that suffers from ecological resources and environmental quality, which needs to be compensated.

From the perspective of time dimension, the EC in Beijing first increases and then decreases, reaching the highest value in 2014. The trend of change in Tianjin is similar to that in Beijing, for the party who is compensated first, the amount of compensation is getting smaller and smaller. In 2010, it became the compensation party, and the compensation reached the highest value in 2013, and then declined all the way. Contrary to the previous two, the amount of ecological compensation in Hebei is positive, indicating that Hebei is the party in need of compensation, and the amount of compensation first increases and then decreases, and then decreases after reaching the highest value in 2010 and 2011. This is because Beijing Shougang Company moved to Tangshan city, Hebei Province, resulting in increased investment in pollution remediation in the following year, investing 62.39 billion CNY in pollution. However, after the BTH coordinated development was proposed in 2014, the GDP and industrial structure of Hebei province have become increasingly reasonable, alleviating the imbalance between cities.



5. Practice of Ecological Compensation in the BTH Region

At the theoretical level, the practice of ecological compensation in the BTH region has been derived through ecological footprint calculations. In practice, the BTH region has long attempted ecological compensation and achieved certain results, especially in the area of water resource ecological compensation.

5.1 Related Events, Compensation Amounts, and Effectiveness

The cross-regional ecological compensation practice between Beijing and Hebei began in 2001, marked by the release of the "Plan for the Sustainable Use of Capital Water Resources in the Early 21st Century." Here are specific practice cases:

Eco-Clean Small Watershed Management Project: From 1996 to 2004, Beijing annually provided 500,000 to 1,000,000 CNY to Chengde and Zhangjiakou for small watershed management. From 2005 to 2006, the two cities, in collaboration with Beijing, established a water environment ecological protection working group, with Beijing investing 20 million CNY annually to protect water resource projects in Hebei.

Rice-to-Dryland Conversion Project: In 2006, Beijing reached an agreement with Chicheng, Luanping, and Fengning in Hebei to implement "rice-to-dryland conversion" compensation in the early black river and Chaobai river basins. By the end of 2013, the cumulative compensation fund reached 400 million CNY, effectively reducing water resource consumption and environmental pollution, and protecting the ecological environment of the water source area.

Inter-regional Horizontal Ecological Compensation System: In 2013, the "Decision of the Central Committee of the Communist Party of China on Some Major Issues Concerning Comprehensively Deepening Reforms" first proposed the establishment of an inter-regional horizontal ecological compensation system.

Luanhe River Water Environment Compensation Fund: In 2016, Hebei and Tianjin signed an agreement to jointly fund the Luanhe River Water Environment Compensation Fund. By the end of the pilot period in 2019, the two provinces and cities each contributed 100 million CNY from 2016 to 2018, totaling 600 million CNY, with the central finance subsidizing 900 million CNY.

Miyun Reservoir Upper Watershed Water Environmental Protection: In 2017, Beijing and Hebei initiated a compensation mechanism for the protection of the ecological environment in the water source conservation area to protect the upper watershed of the Miyun Reservoir.

Chaobai River Basin Water Source Conservation Horizontal Ecological Protection Compensation Agreement: In 2018, Beijing and Hebei signed an agreement with water quality and quantity as the core assessment indicators.

Luanhe River Upstream and Downstream Horizontal Ecological Compensation Agreement (Phase II): In 2020, Hebei and Tianjin signed an agreement to promote breakthroughs and innovations in four aspects, including the improvement of water quality assessment targets and the establishment of floating reward and punishment funds.

Miyun Reservoir Upper Chaobai River Basin Water Source Conservation Horizontal Ecological Protection Compensation Agreement: In August 2022, the new agreement proposed to increase the number of monitored rivers and expand the scope of compensation monitoring.

Guanting Reservoir Upper Yongding River Basin Water Source Protection Horizontal Ecological Compensation Agreement: In August 2023, Beijing and Hebei signed an agreement to achieve full coverage of ecological compensation in the upstream areas of the Chaobai River, Luanhe River, and Yongding River, which are the sources of water for Beijing and Tianjin.

5.2 Effectiveness

The BTH regional cooperation has implemented the Miyun Reservoir Project and the Luanhe River Project, and has carried out ecological compensation in the Chaobai River Basin and the Luanhe River Basin upstream and downstream, initially forming a cross-regional river basin ecological compensation mechanism oriented towards water quality improvement. Since its implementation, the water quality compliance rate in the three regions has improved, but the pressure on upstream management remains high. There is a need to explore long-term mechanisms, optimize ecological compensation methods, and achieve continuous water quality improvement.

6. Discussion

6.1 EF and Ecological Security in BTH

The EF of Tianjin and Hebei have increased, and the common reasons may be as follows: First, the process of economic development in these cities still heavily relies on conventional energy sources like oil, gasoline, and kerosene. Second, a significant amount of primary industrial products are produced throughout the production process, like raw steel, chemical fiber, cement, and fertilizers. Third, the increasing population may also lead to the result. But for Hebei, there are also unique factors behind the rapid growth of its EF, (1)It saw tremendous expansion between 2000 and 2013. This is because Hebei, being a major industrial province, used a lot of fossil fuels in its production, had rather outdated production technology, and generated a significant amount of primary industrial products. After 2010, Hebei notably participated in Beijing's industrial migration, and its EF dramatically expanded. (2) Then Hebei's growth was modest between 2014 and 2022. This is due to Hebei's active introduction of advanced technology and management experience from Beijing and Tianjin to support technical advancement and industrial upgrading, which is motivated by the coordinated development of BTH.

On the contrary, there are reasons for Beijing's continuous decreasing EF. First, it is due to the adjustment of Beijing's industrial structure. Since 2005, Beijing has actively promoted the development of high-tech and tertiary industries. Some high-energy-consuming factories were relocated from Beijing to Hebei, such as Beijing Shougang Corporation. Second, Beijing's land use structure was constantly being optimized, as a result to reduce EF. A suitable example is that Beijing built vegetable bases in the Tianjin-Hebei region to support its consumption. Third, Beijing has adopted a series of low-carbon and green policies. During the "Eleventh Five-Year Plan" period, Beijing vigorously adjusted the coal industry and closed many small coal mines. In 2014, it began to implement a catalog of prohibited and restricted industries. In 2017, Beijing's power generation entered the coal-free era. All these factors have caused Beijing's EF to decline rapidly.

There has long been an ecological deficit in Tianjin and Hebei, even becoming worse. Renewable energy is far from meeting the needs of urban development. Non-renewable resources need to be extracted from the ecosystem all the time. Currently, the ecology is struggling to survive. We must pay close attention to this trend since it is unsustainable. The ecological deficit in Beijing is still declining, but this is not a reflection of ecological sustainability; rather, it is the result of relocating industries to other places like Hebei.

6.2 EC in BTH

Beijing and Tianjin have taken advantage of their political and economic advantages to absorb and utilize a significant amount of talent, labor, and high-quality ecological resources in Hebei. Meanwhile, Beijing relocated some high-energy-consuming and high-polluting enterprises to Hebei in order to evacuate the non-capital functions and promote the transfer of industrial optimization and upgrading. These both aggravate the problems of environmental pollution in Hebei, where the city has fallen into the trap of sacrificing the environment to develop the economy. Overall, Hebei bears more protection and opportunity costs. In turn, it should be compensated accordingly and receive the corresponding policy inclination.

EC is a favorable measure to solve the imbalance between urban economic development and natural resource consumption in regional economic development, and rationally using EC funds can affect the city's development process. On the one hand, EC ought to be partly used for the investment and construction of Hebei to promote economic transformation and upgrading. On the other hand, it should be used for pollution control, including the construction and updating of infrastructures and the control of industrial pollution. These measures are designed to promote the upgrading of the industrial and energy structures in Hebei, and at the ecological level, to expand ecological capacity and space.

6.3 Issues in Ecological Compensation Practices in the BTH Region

(1)While the BTH region has achieved certain results in water resource ecological compensation, there is still a significant gap between theoretical compensation and actual compensation amounts. According to theoretical calculations, Beijing needs to pay Hebei an average of 13.557 billion CNY in ecological compensation annually, while Tianjin needs to pay 157 million CNY, and Hebei expects an average of 11.552 billion CNY in compensation annually. However, the actual compensation paid is far lower than these theoretical values, affecting the actual effectiveness and sustainable development of ecological compensation.

(2) The ecological compensation mechanism in the BTH region is currently mainly focused on water resources. However, this singular compensation model overlooks other important ecological issues such as air pollution and grassland degradation. As environmental pressures intensify, these issues pose a severe challenge to the regional ecological balance. Therefore, the BTH region urgently needs to broaden the scope of ecological compensation, incorporating more ecological elements into the compensation category to form a more comprehensive and scientific ecological protection network.

(3) The ecological compensation standards in the BTH region are inconsistent, mainly due to differences in economic development levels, ecological protection needs, and governance costs across regions. As a water source area, Hebei requires sufficient compensation to support water body protection, while Beijing and Tianjin have higher water quality requirements, increasing the governance burden on Hebei. The compensation amount is often insufficient to cover Hebei's governance costs, leading to economic pressure on its ecological protection work. Therefore, the BTH region needs to establish a unified ecological compensation standard system to ensure that compensation amounts match governance costs and to strengthen regional cooperation to jointly promote ecological protection.

(4) There are still deficiencies in the legal framework for ecological compensation in the BTH region. Currently, there is a lack of clear legal norms and quantification standards, making the implementation of ecological compensation lack stability and predictability. At the same time, the absence of regulatory mechanisms and assessment systems also limits the effectiveness of ecological compensation. Therefore, the BTH region should accelerate the improvement of the legal system for ecological compensation, clarify the main body, object, standard, and procedures of compensation, and establish effective regulatory and assessment mechanisms to ensure the smooth implementation and continuous effectiveness of ecological compensation work.

6.4 Limitations and Outlook

There are some limitations of this study. (1) Scale-related queries. The BTH consists of a large province (Hebei) and two very special cities (Beijing and Tianjin) and this combination makes the three cities significantly different in magnitude. Therefore, follow-up research can consider exploring different scales to more accurately assess the development balance issue in the BTH. (2) Regarding the connotation of ECC. Economic development has also expanded the connotation of ECC. For example, technological progress and optimization of industrial structure can improve the efficiency of resource use, reduce waste emissions, and thereby expand ECC. Therefore, subsequent research can consider economic development as an important factor when calculating ECC. (3) The calculation of EC in this article is based on the total investment in environmental pollution control. Although this method has a certain reference value, it is relatively one-sided. Follow-up research can consider combining multiple factors for comprehensive assessment, such as ecological service value, environmental quality improvement, etc.

6.5 Suggestions

There are obvious differences in the socioeconomic development of BTH, with varying degrees of consumption of natural resources, especially in Hebei, which provides resources, population, and other essential elements of economic development for Beijing's advancement. It further results in larger differences in the geographical natural resource allocation and consumption patterns. Hence it is necessary to strengthen the adjustment of industrial structure and the transformation of energy structure.

To accomplish sustainable development, we can start with the following: First, we should change the traditional energy structure and switch to clean energy. The BTH has a massive energy requirement as one of China's main economic zones. Resource strain can be efficiently alleviated by actively developing and exploiting renewable energy sources, such as photovoltaic power generation. Second, we need to quicken the pace of technical advancement and raise the rate at which natural resources are used. The EF can be efficiently reduced by technological advancement. Enterprises should increase investment in the development of energy-saving and emission-reduction technologies, and introduce advanced production processes and management methods. Third, it is necessary to raise the share of tertiary industry in the country's GDP. As one of China's heavy industrial bases, the BTH has a large percentage of secondary industry, and adjusting the industrial structure will assist in lowering the EF.

To address the discrepancies in ecological compensation standards and the gap between theoretical and actual values in the BTH region, it is essential to establish a unified ecological compensation standard system that takes into account the economic development levels, ecological protection demands, and governance costs of different areas, ensuring that compensation amounts are commensurate with the costs of management. Concurrently, there is a need to expedite the improvement of the legal and regulatory framework for ecological compensation, clarifying the entities, targets, standards, and procedures involved, and to establish effective supervision and assessment mechanisms to ensure the smooth implementation and sustained effectiveness of ecological compensation efforts. Furthermore, the BTH region should broaden its perspective on ecological compensation to include ecological issues such as air pollution and grassland degradation, forming a more comprehensive ecological protection network. Strengthening regional cooperation is crucial, defining the responsibilities of the three jurisdictions in planning alignment, project collaboration, and the equalization of public services to resolve administrative barriers and conflicts of interest. Establishing cross-regional collaborative protection mechanisms is essential for jointly protecting the ecological environment of river basins like the Chaobai River. Efforts should be made to promote ecological restoration and management, signing horizontal ecological protection compensation agreements, deepening and expanding the mechanisms for ecological protection compensation, and exploring new forms and methods of compensation. Lastly, increasing the compensation efforts for key ecological functional areas and improving the ecological protection compensation mechanisms for forests, grasslands, wetlands, and other key domains are necessary to achieve regional ecological protection and sustainable development.

7. Conclusion

First, we constructed an EF model using energy theory and investigated the EF and ECC in the BTH region between 2000 and 2022. Research results show that the ECC of the BTH region is relatively stable, while the EF changes in different ways. Specifically, the EF of Tianjin and Hebei is always in an increasing trend, with a slower growth rate in Tianjin, while Hebei's growth was rapid between 2000 and 2014, and became slow between 2015 and 2022. On the contrary, Beijing's EF has decreased over the years at a rapid rate. In 2008, Hebei's EF surpassed that of Beijing, making it the city with the highest EF in the BTH region.

Second, we computed the ecological surplus of the BTH region from 2000 to 2022 and discovered a rising ecological deficit in Hebei and Tianjin. This indicates a very serious ecological problem and we must pay great attention to the ecological security of the BTH region.

Third, we modified the EC model by introducing social and economic indicators and studied the EC in the BTH region from 2003 to 2021. The results demonstrate that the supply of ecological services in Hebei exceeds its consumption, so it should be compensated accordingly. In contrast, Tianjin and Beijing consume ecological services more than they supply, so they ought to pay the compensation correspondingly. In addition, the amount of EC increases initially and then decreases. The study also revealed that the ecological resource conversion coefficient, an economic indicator, is on the rise, which indicates that the EF required to achieve 10,000 CNY of GDP is decreasing.

Last, in the context of ecological compensation in the BTH region, several issues have been identified, including a significant discrepancy between theoretical compensation amounts and actual payments, a singular focus on water resources compensation, inconsistencies in compensation standards, and a lack of a robust legal framework. These challenges have led to suboptimal ecological compensation outcomes and hindered sustainable development in the region. To address these issues, it is imperative to establish a unified ecological compensation standard system, broaden the scope of compensation to encompass a wider range of ecological elements, enhance regional cooperation, and improve the legal and regulatory framework to ensure the smooth implementation and ongoing effectiveness of ecological compensation efforts.

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