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Health Assessment and Improvement Path of the Beijing-Tianjin-Hebei Ecological-Economic System from the Perspective of Emergy

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Abstract: As a crucial economic growth pole in China, the health of the Beijing-Tianjin-Hebei (BTH) ecological-economic system is key to regional sustainable development. Based on emergy theory, this study constructs an emergy analysis index system for the BTH ecological-economic system and comprehensively evaluates the health status of the region's ecological-economic system from 2015 to 2022. The study first converts energy inputs, economic activities, and waste emissions within the BTH ecological-economic system into emergy values and calculates the Emergy Loading Ratio (ELR) and the Emergy Sustainability Index (ESI). The results show that the ELR exhibits a decreasing trend, reflecting a gradual reduction in environmental pressure. The ESI value shows an increasing trend, reflecting its advantages in economic structure optimization and environmental protection. Therefore, based on the perspective of emergy optimization, this study proposes that, under the condition of a fixed total regional emergy, continuous promotion of green economic transformation, improvement of the level of sustainable development, driving the overall development of the region, and realization of a virtuous cycle of the regional ecological economy.

Keywords: Emergy; Sustainability; Ecological Economy

1 INTRODUCTION

2024 marks the 10th anniversary of the implementation of the Beijing-Tianjin-Hebei coordinated development strategy. The BTH region is one of the areas with the fastest economic development, the most comprehensive functions, and the highest comprehensive value in China. However, it is also one of the regions with a relatively severe environmental situation in China. Water resources and environmental capacity are extremely scarce, which has constrained regional economic and social development to varying degrees. Therefore, how to find a new model for ecological environment and economic development and achieve sustainability is a key issue that must be resolved in the BTH region.

In 2019, President Xi Jinping emphasized at the symposium on coordinated development of the BTH region that coordinated development is a systematic project, and it is necessary to play an important role in leading high-quality development and strengthen joint construction, joint prevention, and joint control of the ecological environment. The ecological-economic system of the BTH region is a complex symbiotic organic system, which is an organic functional body formed by the long-term adaptation of the cities of Beijing, Tianjin, and Hebei Province to the external environment and in the process of mutual communication, coordination, and mutual adaptation. The cities within the region are by no means independent and unaffected by each other, but rather a network-like cross-sectional structural relationship. Ecological economy, as an inevitable choice to transform the traditional industrialization growth mode and achieve coordinated and sustainable development of the economy, society, and ecological environment, has attracted much attention (Chen Wen, 2018). Therefore, adopting appropriate research methods to identify and evaluate the current development status of the BTH ecological-economic system is an important component of achieving high-quality development in the BTH region and an important guarantee for ecological civilization construction to promote regional sustainable development.

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2 Literature Review

2.1 Ecological-Economic System Health Assessment

Previous studies have mainly evaluated the health of ecological-economic systems from the aspects of ecosystem service functions, environmental quality, resource utilization, economic development, and social development. Li et al. (2020) evaluated the ecosystem service functions of the BTH region, and the results showed that there was a certain degradation trend in ecosystem service functions. Wang et al. (2019) evaluated the environmental quality of the BTH region and proved that environmental pollution is the main threat to the health of the ecological-economic system in the BTH region.

2.2 Research On Improving The Ecological-Economic System

Researchers have mainly explored ways to improve the ecological-economic system from the aspects of ecosystem protection and restoration, environmental pollution control, resource conservation and recycling, economic restructuring, and social development. Zhang et al. (2018) proposed strategies for ecosystem protection and restoration in the BTH region, including establishing ecological reserves and restoring ecosystem service functions. Liu et al. (2019) conducted research on environmental pollution control in the BTH region, and the results showed that strengthening environmental pollution control is key to improving the health of the ecological-economic system in the BTH region.

2.3 Research From The Emergy Perspective

Emergy analysis plays an important role in ecosystem assessment and economic system analysis, used to assess the health of natural ecosystems and guide the sustainable development of human economic activities. By quantifying the energy flow and transformation processes of ecosystems, it reveals the structural and functional characteristics of ecosystems and assesses the health status and sustainable development capabilities of ecosystems. Chen et al. (2020) evaluated the health of the ecological-economic system in the BTH region from the emergy perspective, and the results showed that there was a certain degradation trend in the health of the ecological-economic system in the BTH region. Xu et al. (2019) studied the path to improve the health of the ecological-economic system in the BTH region from the emergy perspective, and the results showed that strengthening ecosystem protection and restoration, environmental pollution control, and resource conservation and recycling are key to improving the health of the ecological-economic system in the BTH region.

3 Health Evaluation Of The Beijing-Tianjin-Hebei Ecological-Economic System From The Emergy Perspective

3.1 Construction Of Emergy Analysis Framework

Emergy analysis is a method to evaluate the efficiency and environmental impact of an economic system by converting economic activities and resource consumption into energy units, used to evaluate the impact and sustainability of a system (such as an economy, an industry, or a product) on natural resources and the environment. Ecological-economic emergy analysis mainly converts indicators such as green GDP, emergy input rate, and environmental load rate within the ecological-economic system into unified emergy indicators through emergy conversion rates and establishes a tourism ecological emergy evaluation index system (Table 1) for quantitative analysis of the sustainable development level of the study area.

3.2 Ecological-Economic Emergy Indicators

Emergy-based GDP (Green GDP): A revised value of traditional GDP after deducting the costs caused by resource consumption and environmental pollution, reflecting the true sustainability of economic activities, and is used to measure the true environmental costs of economic activities.

Calculation formula: Green GDP = Traditional GDP - Environmental Damage Cost - Resource Consumption Cost

Energy Input Ratio (EIR): The amount of energy consumed per unit of economic output, reflecting the energy efficiency of economic activities.

Calculation formula: EIR = Total Energy Consumption/Economic Output (GDP)

Environmental Loading Rate (ELR): The amount of environmental load per unit of economic output, expressed as carbon dioxide emissions in this article.

Calculation formula: ELR = CO_2 emissions/Economic Output (GDP)

Emergy Self-Sufficiency Ratio (ESSR): The ratio of local emergy input to total emergy input, reflecting the system's self-sufficiency ability. The higher the ESSR, the lower the dependence on external resources.

Calculation formula: ESSR = Local Emergy Input/Total Emergy Input

Emergy Sustainability Index (ESI): The ratio of emergy yield ratio to environmental loading rate, which comprehensively reflects the environmental and economic benefits of the system. The higher the ESI, the stronger the sustainability.

Calculation formula: ESI = Emergy Yield Ratio/Environmental Loading Rate (or ESI = EIR/ELR)

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TABLE 1. DATA SOURCES AND PROCESSING METHODS

Indicator	Data Source	Data Processing Method
Green GDP	National/Regional Statistical Yearbooks, Environmental Statistics Bulletins, Related Research Reports	1. Obtain traditional GDP data. 2. Obtain data on environmental resource consumption and environmental pollution. 3. Determine the emergy conversion rate for environmental resource consumption and environmental pollution. 4. Calculate emergy environmental costs. 5. Deduct emergy environmental costs from traditional GDP.
Emergy Input Ratio	Statistical Yearbooks, Enterprise Financial Statements, Industry Reports	1. Obtain data on all emergy inputs, including natural resources and economic inputs. 2. Determine the emergy conversion rate for various inputs. 3. Calculate total emergy input. 4. Obtain total output (monetary value) data. 5. Calculate EIR.
Environmental Loading Rate	Statistical Yearbooks, Environmental Monitoring Reports, Related Research Reports	1. Obtain data on the emergy of renewable and non-renewable resources. 2. Calculate ELR.
Emergy Conversion Rate	Emergy conversion rate table by Brown & Ulgiati (2004, 2016), or other related research. Estimate using the energy hierarchy transfer theory when a corresponding conversion rate cannot be found.	1. Prioritize using published emergy conversion rates for similar systems. 2. Carefully record the sources and estimation methods of all emergy conversion rates. 3. Conduct sensitivity analysis to assess the impact of changes in emergy conversion rates on the results.

4 ANALYSIS OF THE BEIJING-TIANJIN-HEBEI EMERGY ECOLOGICAL-ECONOMIC INDICATOR SYSTEM

4.1 EMERGY INPUT ANALYSIS

The emergy input ratio (also known as energy consumption intensity or energy utilization efficiency) refers to the amount of energy consumed per unit of GDP. As can be seen from Figure 1, the emergy input ratio of Beijing-Tianjin-Hebei from 2015 to 2022 shows a significant downward trend, indicating a reduction in overall energy consumption. The green GDP of the Beijing-Tianjin-Hebei region shows a year-on-year upward trend from 2016 to 2022, indicating that the region has made progress in reducing environmental damage and resource consumption costs, and the green economic transformation has begun to take effect.

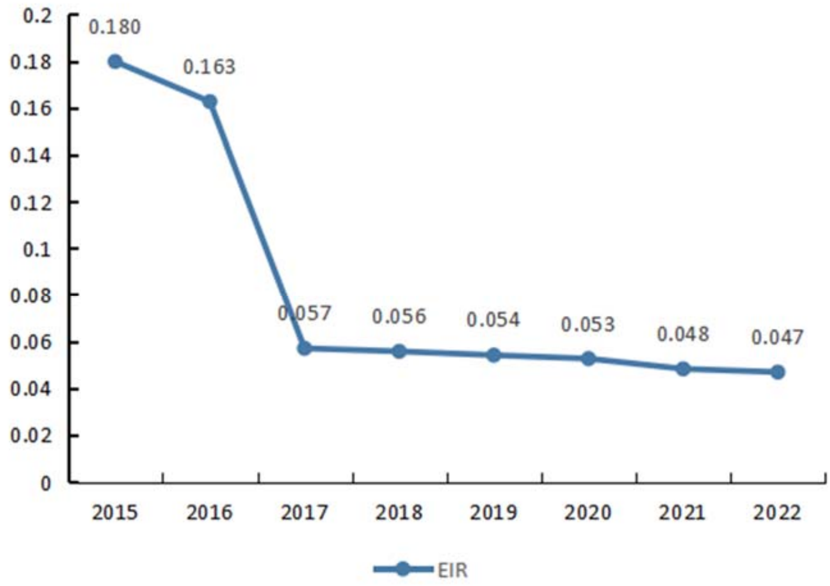

FIGURE 1: TREND OF EMERGY INPUT RATE IN BEIJING-TIANJIN-HEBEI FROM 2015 TO 2022

4.2 *ENVIRONMENTAL LOAD RATE ANALYSIS*

The level of the environmental load rate reflects the level of ecological environment carrying capacity of a region. The higher the environmental load rate, the lower the index of ecological and economic sustainable development, and the relatively lower level of sustainable development of the ecological economy. Conversely, the level of sustainable development is higher. The average environmental load rate of Beijing-Tianjin-Hebei from 2015 to 2022 is 1.334, which is lower than the environmental load rate of Yulin City of 1.49 (Li Xiaoge, 2022), indicating that the current ecological environment of Beijing-Tianjin-Hebei is at a relatively good level.

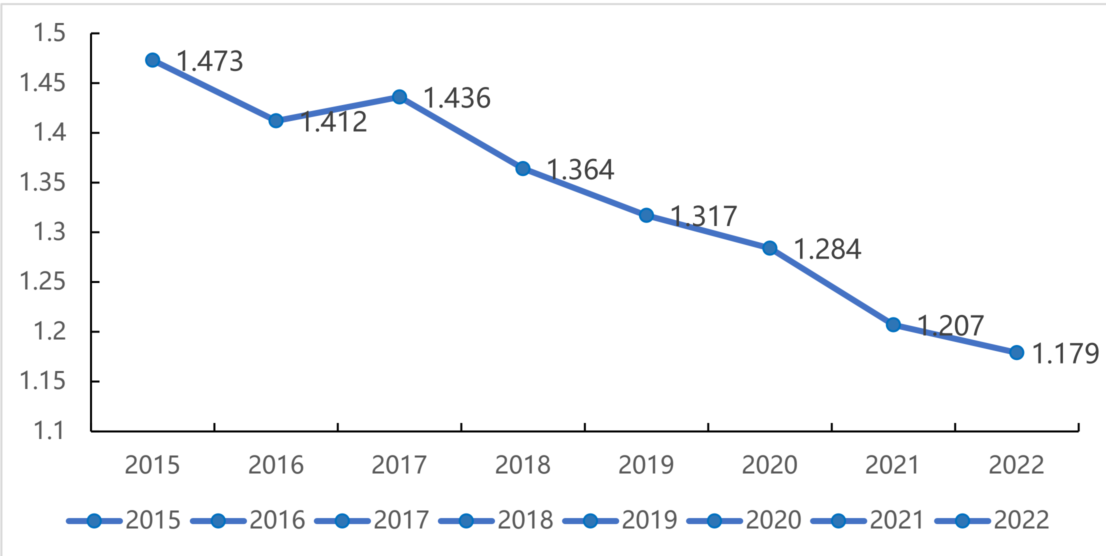

FIGURE 2: CHANGES IN ENVIRONMENTAL LOADING RATE(ELR) IN BEIJING-TIANJIN-HEBEI FROM 2016 TO 2022

4.3 *ECOLOGICAL AND ECONOMIC SUSTAINABLE DEVELOPMENT EMERGY INDICATOR ANALYSIS*

The sustainable development emergy indicator is a comprehensive indicator for evaluating regional sustainable development, and the level of its value reflects the level of sustainable development. As can be seen from Figure 3, the sustainable development emergy indicator of Beijing-Tianjin-

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Hebei shows an upward trend, with an average value of 1.65, indicating the improvement of emergy utilization efficiency and the reduction of environmental pressure in the region, and the ecological economy of Beijing-Tianjin-Hebei is in a sustainable development stage.

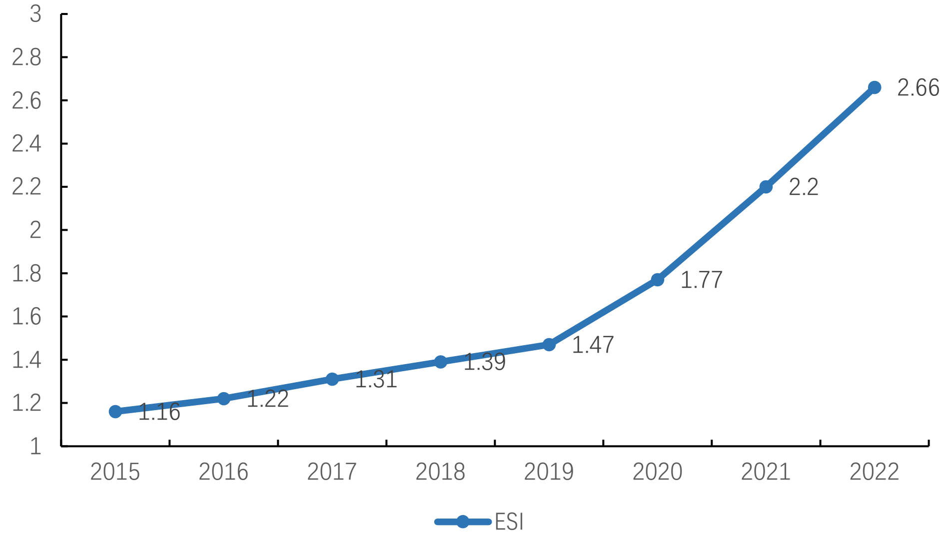

FIGURE 3: EMERGY SUSTAINABILITY INDEX (ESI) IN BEIJING-TIANJIN-HEBEI FROM 2016 TO 2022

5 RECOMMENDATIONS FOR IMPROVING THE HEALTH OF THE BEIJING-TIANJIN-HEBEI ECOLOGICAL-ECONOMIC SYSTEM

The improvement of the health of the ecological and economic system in Beijing-Tianjin-Hebei faces many challenges, but through the coordinated promotion of industrial structure optimization and technological innovation, and policy coordination and regional cooperation, the quality of the ecological environment can be effectively improved and sustainable economic development can be promoted.

5.1 INDUSTRIAL STRUCTURE OPTIMIZATION AND TECHNOLOGICAL INNOVATION

The Beijing-Tianjin-Hebei region faces problems such as tightening resource constraints, squeezed ecological space, and degraded ecosystem functions. These problems not only affect the sustainable development of the region, but also pose a serious threat to environmental quality and ecological security. Therefore, improving resource utilization efficiency and reducing pollutant emissions are effective paths that the Beijing-Tianjin-Hebei region needs to adhere to for a long time. First, it is crucial to promote the manufacturing industry towards high-end, intelligent, and green development. By encouraging companies to adopt green design and green manufacturing processes to produce green products, the consumption of resources and the emission of pollutants during the production process can be significantly reduced. This can not only enhance the market competitiveness of enterprises, but also promote a win-win situation between economic and ecological benefits. Second, actively developing new energy sources such as wind energy, solar energy, and biomass energy, and building a clean energy supply system are important ways to achieve sustainable development. By promoting the development of the new energy industry, dependence on traditional fossil energy can be reduced, carbon emissions can be reduced, and air quality can be improved. At the same time, the development of the new energy industry can also drive the development of related industrial chains, creating more job opportunities and economic increments. Finally, promoting resource sharing and recycling between enterprises and industries, and building a regional circular economy system are also important means to improve resource utilization efficiency. Through resource sharing and recycling, resource consumption and waste generation can be reduced, and limited resources can be utilized to the maximum extent, achieving efficient resource utilization and environmental protection. This circular economic model not only helps to reduce environmental pollution, but also promotes the sustainable development of the regional economy.

5.2 POLICY COORDINATION AND REGIONAL COOPERATION

The Beijing-Tianjin-Hebei region is divided by administrative divisions, and there are policy differences. The efficiency of environmental governance needs to be improved. It is necessary to strengthen policy coordination and regional cooperation to effectively improve the quality of the ecological environment. First, the establishment of an ecological compensation system can effectively mobilize the enthusiasm of local governments to protect the ecological environment and avoid local governments sacrificing environmental benefits in pursuit of economic development. This compensation mechanism can ensure that ecological protection areas are effectively maintained, thereby ensuring regional ecological security. Second, it is essential to establish a regional environmental information sharing platform. By achieving interconnection and interoperability of environmental monitoring data, pollution source information, environmental risk assessment, and other information, the ability to monitor and warn of environmental pollution can be effectively improved, providing data support for scientific decision-making. Information sharing platforms can help governments at all levels better understand regional environmental conditions and promptly identify and deal with environmental problems. Finally, jointly carrying out ecological restoration projects can effectively improve ecosystem functions and improve the quality of the regional ecological environment by implementing measures such as afforestation, wetland restoration, and returning farmland to forests. These ecological restoration projects can not only increase green space area, but also improve soil and water loss conditions, improve biodiversity, and provide ecological security for regional sustainable development.

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