Research on Ecological Production and Sustainable Development of Population Based on Ecological Footprint Analysis

Yi Dong

This paper takes Beijing-Tianjin-Hebei urban agglomeration as the study area, and constructs a multi-dimensional sustainable development evaluation system based on the three-dimensional ecological footprint of "sustainability-efficiency-equity". On this basis, different scenarios of population, carbon emission and land use are set to predict the sustainable development of the Beijing-Tianjin-Hebei urban agglomeration in 2025 under the continuation of the current situation. The impact of different scenarios on the sustainable development status of the Beijing-Tianjin-Hebei urban agglomeration is investigated, and the right and choice of sustainable development strategies for the future Beijing-Tianjin-Hebei urban agglomeration is made.

Keywords: Ecological footprint, Beijing-Tianjin-Hebei urban agglomeration, Sustainable development
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INTRODUCTION

Since the industrial revolution, the rate of urbanization has accelerated. While urbanization represents the progress of human civilization, it also leads to the massive depletion of natural resources, concentrated consumption of energy and concentrated release of pollutants in the surrounding areas, which has a huge negative impact on resources, environment and ecosystems. In the study of sustainable development, how to incorporate the multidimensional connotation of sustainable development into the sustainable development evaluation framework in order to reasonably and effectively diagnose regional sustainable development is the core problem facing sustainable development science. Therefore, it is of great theoretical significance and practical value to conduct sustainable development evaluation and scenario analysis of urban cluster areas, diagnose the impact of urbanization on the ecosystems of urban clusters, and select differentiated ecological control measures to ensure the sustainable development of urban clusters. The Beijing-Tianjin-Hebei urban agglomeration is the political and cultural center of China, but the unbalanced economic development of Beijing-Tianjin-Hebei has formed a "siphon effect" on Hebei. In order to solve the imbalance of the scale and structure of the Beijing-Tianjin-Hebei urban agglomeration, it is necessary to consider the development situation of the Beijing-Tianjin-Hebei urban agglomeration and to reasonably coordinate the allocation of population, resources and environment.

The term "sustainable development" is defined differently depending on the field of study. Among them, the Brundtland Report [1] published by the World Commission on Environment and Development1 proposed a definition of sustainable development as development that meets the needs of the present without jeopardizing the ability of future generations to meet their needs. Daly[2] proposed the scale, equal distribution and effective distribution of sustainable development in Population Economics. KerK and others [3] construct a definition of sustainable development that expands on the Brundtland Report's definition of sustainable development by adding the description of "the opportunity for everyone to develop themselves freely in a fair and harmonious society". Hoekstra [4] also proposed the framework of sustainable development and the concept of ecological footprint. In recent years, more and more researchers have turned their attention to the use of ecological footprint analysis methods on the distribution of resources among different regions and populations, focusing more on equity in the spatial and temporal dimensions.Brelsford [5] reveals the inhibitory nature of resource use in developing countries and regions. Niu Wenyuan [6] proposed that (1) only when human claims on nature are balanced with human returns to nature; (2) only when human efforts in the present are equal to their contributions to future generations; and (3) only when human thinking about the development of the region

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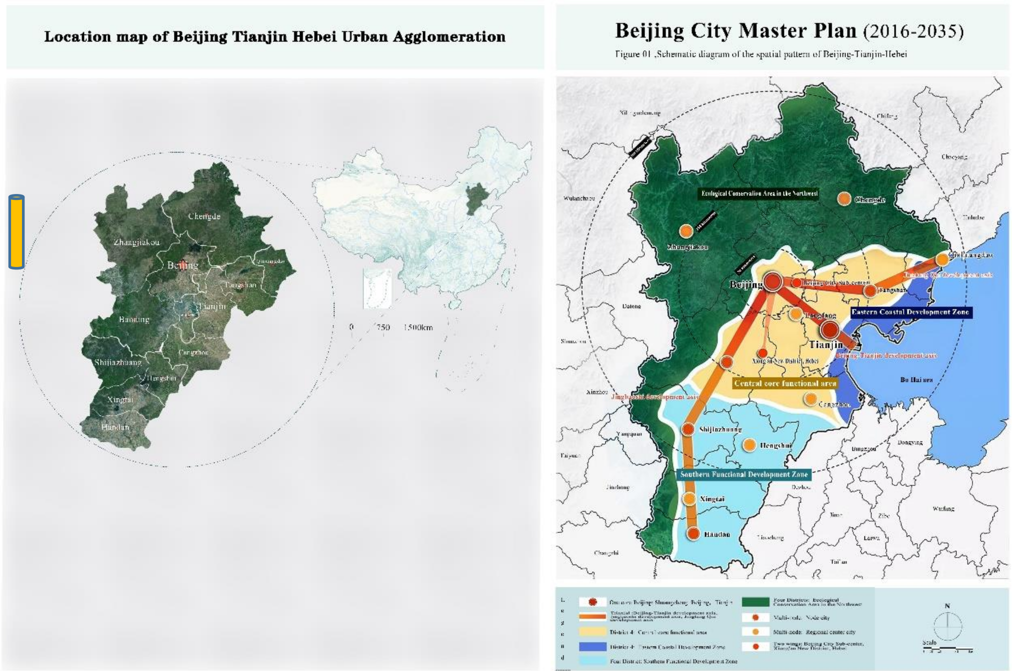
can simultaneously take into account the interests of other regions and even the globe, it makes the theory of sustainable development have a solid foundation. The concept of ecological footprint was first proposed by the ecological economist William and his PhD student Wackemagel in 1992 and refers to the area of ecologically productive land needed to produce the resources consumed by a certain population and to absorb the waste produced by the consumption of these populations [7]. Niccolucci and others [8-9] pioneered the development of an area-based two-dimensional model into a three-dimensional spatio-temporal model with volume, and introduced two indicators of the breadth and depth of the ecological footprint as a way of expressing the level of human use of the stock and flow of natural capital. The three-dimensional ecological footprint model realizes the measurement of natural capital stock and flow in a disaggregated manner, focuses on the asynchrony between resource consumption and resource recycling, increases the comparability between different regions in different periods, and is advanced in the evaluation of sustainable development.

RESEARCH METHODS

Research Area

Figure 1. Schematic diagram of spatial pattern of Beijing-Tianjin-Hebei region



The study area of this paper is the Beijing-Tianjin-Hebei city cluster. The Beijing-Tianjin-Hebei region is the "Capital Economic Circle" of China, which includes Beijing, Tianjin and 11 prefecture-level cities in Hebei Province, including Baoding, Langfang, Tangshan, Shijiazhuang, Handan, Qinhuangdao, Zhangjiakou, Chengde, Cangzhou, Xingtai and Hengshui, as well as two provincial cities directly under the control of Dingzhou and Xinji. The total area of the region is 218,000 square kilometers with a total population of 112.7 million people. The Beijing-Tianjin-Hebei urban agglomeration, the largest economic region in northern China, had a combined regional gross domestic product of 8,458,008 billion yuan in 2019, accounting for 8.5% of the country.

Research Methods

Three-dimensional ecological footprint model

The three-dimensional ecological footprint model is obtained by multiplying the footprint breadth and footprint depth.The calculation formula is:

$$EF_{size,region} = \sum_{i=1}^{n}\{EF, BC\} \quad (1)$$

$$EF_{depth,region} = 1 + \frac{\sum_{i=1}^{n} \max\{EF_i - BC_i, 0\}}{\sum_{i=1}^{n} BC_i} \quad (2)$$

$$EF_{3D,region} = EF_{size,region} \times EF_{depth,region} \quad (3)$$

Footprint breadth Gini coefficient calculation

Footprint breadth Gini coefficient is an indicator to measure the fairness of per capita natural capital flow in a region. It is generally calculated by the rectangular area method, and its calculation formula is:

(4)

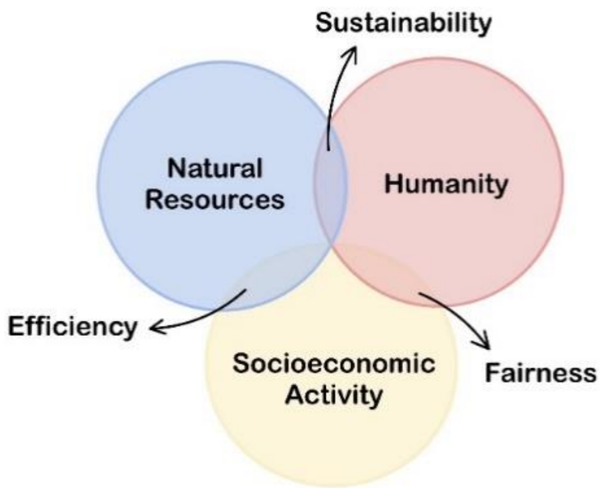
2.2.3. Markov Model

This paper uses Markov model to successfully predict the land use in 2025 under different scenarios in the Beijing-Tianjin-Hebei urban agglomeration. The model can be represented by the following matrix:

$$P = \begin{pmatrix} P_{11} & K & P_{1n} \\ M & O & M \end{pmatrix} (0 \le P \le 1, \sum^{n} P = 1)$$

2.3.4. Regression Model

This paper uses regression model ... gglomeration in 2025, and uses linear regression model and least s...



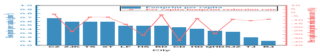
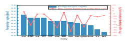
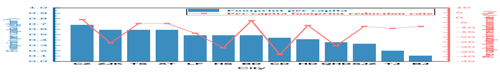
CONSTRUCTION OF ... TION SYSTEM AND SCENARIO SETTING

Construction of Sustainabl...

Fi... rk

Urban system is an integrated system formed by the interaction of natural environment and social economy with human as the main body. Sustainability reflects the relationship between human and nature, requiring human claims on nature to be within the carrying capacity of natural resources and the like. Efficiency reflects the relationship between natural resources and socio-economic activities, requiring the maximization of social and economic benefits per unit of natural resource consumption and the minimization of environmental pollution. Equity reflects the relationship between human and socio-economic activities, and seeks to rationalize the distribution of natural resources in socio-economic activities. Based on the conceptual framework of urban system and the three-dimensional ecological footprint model, this study constructs a sustainable development evaluation index system. As shown in Table 1:

Table 1. Sustainable Development Evaluation Index System Based on Three-dimensional Ecological Footprint

Index	Dimensionality	Calculation formula	Unit
Footprint Per Capita	Sustainable	Footprint breadth per capita = Footprint breadth/population	
Footprint Depth	Sustainable		
Ecological Use Efficiency	Efficiency	Ecological use efficiency = GDP/Three-dimensional ecological footprint	
Footprint Breadth Gini Coefficient	equity		
Footprint Depth Gini Coefficient	equity	Footprint depth variation coefficient = Footprint depth standard deviation/footprint depth average	

when $G_{EF} \le 0.2$, it means highly balanced; when $0.2 < G_{EF} \le 0.3$, it means more balanced; when $0.3 < G_{EF} \le 0.4$, it means relatively reasonable; when $0.4 < G_{EF} \le 0.5$, it means more uneven; when $G_{EF} \ge 0.5$, it means highly unbalanced.

Scenario Setting of Beijing-Tianjin-Hebei Urban Agglomeration

This study aims to investigate the performance of Beijing-Tianjin-Hebei cities on the above three dimensions (sustainability, efficiency, and equity) under different development scenarios, and make policy choices under the trade-offs, which are necessary for building a healthy world-class city cluster.

Based on the current population policy orientation, this study sets the following two population scenarios:

1. Status quo continuation scenario: The cities in the Beijing-Tianjin-Hebei city cluster continue the current population growth trend.

2. Population regulation scenario: According to the Beijing Master Plan (2016-2035), Beijing adopts a population regulation policy, and the resident population in Beijing is stabilized at 23 million in the long term after 2020, with Tianjin and Hebei as the centralized hosts for population deconstruction. By plotting the scatter diagram of the resident population of each city in the Beijing-Tianjin-Hebei city cluster from 2000 to 2020, it is found that the population growth of Beijing and Tianjin shows an "S" shape, while the population of other cities shows a linear growth. Therefore, this study uses the Logistic model to predict the resident population of Beijing and Tianjin under the status quo continuation scenario, while the other cities use the linear regression model to predict. In the population control scenario, the portion of Beijing's population exceeding 23 million in the status quo continuation scenario is weighted according to the straight-line distance from Beijing to other cities.

Table 2. Permanent population forecast of cities in The Beijing-Tianjin-Hebei urban agglomeration in 2025 under different scenarios

Population (ten thousand))	Beijing	Tianjin	Shiiazhuang	Tangshan	Qinhuangdao	Handan	Xingtai	Baoding	Zhangjiakou	Chengde	Cangzhou	Langfang	Hengshui

The status quo continue	2679	1755	1181	831	337	1020	780	1214	489	400	789	504	463
Population control	2300	1771	1221	854	377	1082	833	1235	513	426	817	511	502

According to the current land use policy orientation of Beijing-Tianjin-Hebei city cluster, the following three land use scenarios are set:

1. Status quo continuation scenario: The land use demand of each city in the Beijing-Tianjin-Hebei urban agglomeration will not be affected by large-scale policy adjustments, and the rate of land use change from 2000 to 2020 will be used as the rate of future land use change to simulate the future land use scenario.
2. Food security scenario: focus on protecting arable land and strictly control the transformation of arable land to other land.
3. Ecological protection scenario: Strictly protect ecological land such as forest land, grassland and water area, and at the same time strengthen the transformation of arable land and unused land to ecological land.

Based on Markov theory, this study constructs the land use transfer probability matrix under the above three scenarios and simulates the land use situation of each city in the Beijing-Tianjin-Hebei urban agglomeration under different scenarios.

Table 3. Prediction of the land use situation of each city in the Beijing-Tianjin-Hebei urban agglomeration in 2025 under the continuation of the status quo

hm^2	Beijing	Tianjin	Shijiazhuang	Tangshan	Qinhuangdao	Handan	Xingtai	Baoding	Zhangjiakou	Chengde	Cangzhou	Langfang	Hengshui
arable land	404790	678210	677003	704390	268209	758315	795865	952030	1781099	768653	1108552	466776	727142
woodland	727097	31804	157965	120367	287363	13862	88883	340571	725847	1868461	1629	6418	11
grassland	109496	10202	281010	120413	106440	179271	110132	521409	900949	1227898	69	1472	716
territorial waters	31449	178728	19159	50866	33015	13764	5530	46998	43477	49372	125631	4667	2876
Construction land	406186	326178	289519	419048	108965	256342	256663	3992	219255	123717	200474	178124	170908
Unused land	197	1762	3590	1242	1324	62	8630	1329	66910	8982	10525	0	0

Table 4. Prediction of Land Use Situation of Beijing-Tianjin-Hebei Urban Agglomeration in 2025 under Food Security Scenario

hm^2	Beijing	Tianjian	Shijiazhuang	Tangshan	Qinhuangdao	Handan	Xingtai	Baoding	Zhangjiakou	Chengde	Cangzhou	Langfang	Hengshui
arable land	417390	683657	683911	710964	273312	762519	800097	964505	1800666	801145	1111559	468319	728695
woodland	723947	31689	156618	118753	285999	13217	88304	337508	720470	1857766	1591	6365	11

grassland	106346	10080	278508	118799	105077	178571	109552	516768	895571	1217203	69	1443	693
territorial waters	28299	176425	18655	49251	32064	13709	5228	46869	42893	49001	124492	4644	2853
Construction land	403037	323876	287018	417434	107604	253538	253983	394570	213878	113022	199325	176688	169401
Unused land	196	1157	3536	1124	1260	62	8540	1327	64058	8947	9843	0	0

Table 5. Prediction of land use in each city in the Beijing-Tianjin-Hebei urban agglomeration in 2025 under the scenario of ecological protection

hm^2	Beijing	Tianjin	Shijiazhuang	Tangshan	Qinhuangdao	Handan	Xingtai	Baoding	Zhangjiakou	Chengde	Cangzhou	Langfang	Hengshui
arable land	401494	674080	673799	701787	266325	753609	793111	946433	1772494	756174	1096597	465045	719658
woodland	723802	31689	154828	117765	285479	13217	86197	334973	717243	1855982	1591	4688	11
grassland	6200	10080	277806	117810	104556	174565	107446	515811	892344	1215419	69	1443	693
territorial waters	28153	174598	16798	48263	31543	13709	5228	44334	39666	47217	125148	2966	2853
Construction land	419369	335281	301492	429576	116152	266455	267288	418671	254958	163344	212976	183316	178438
Unused land	193	1747	3590	1226	130	62	8630	1320	66142	8805	10498	0	0

According to the commitments made by the Chinese government to address global climate change in the Paris Agreement, the following two carbon emission scenarios are set:

1. Status quo continuation scenario: the carbon intensity level of each city in the Beijing-Tianjin-Hebei city cluster in 2025 remains the same as that in 2020.
2. Energy saving and emission reduction scenario: the carbon intensity level of each city in the Beijing-Tianjin-Hebei city cluster in 2025 is reduced by 45% compared with that in 2020.

Where, carbon intensity refers to carbon dioxide emissions per unit of GDP. The carbon intensity × total GDP in 2025 will give the total carbon emission in that year. In this study, the trend extrapolation method is used to predict the total GDP of each city in the Beijing-Tianjin-Hebei urban agglomeration in 2025, and the GDP in the study adopts the constant price in 2005.

Table 6. Carbon emissions of cities in the Beijing-Tianjin-Hebei urban agglomeration in 2025 under different scenarios

Ton/Ten thousand yuan	Beijing	Tianjin	Shijiazhuang	Tangshan	Qinhuangdao	Handan	Xingtai	Baoding	Zhangjiakou	Chengde	Cangzhou	Langfang	Hengshui
Status quo continues	0.54	1.03	2.63	3.01	1.93	2.42	2.31	2.94	2.42	3.05	2.63	3.12	2.32
Energy conservation	0.29	0.57	1.45	1.66	1.06	1.33	1.27	1.62	1.33	1.68	1.44	1.72	1.27

THE PREDICTION AND TRADE-OFF OF THE SUSTAINABLE DEVELOPMENT OF THE BEIJING-TIANJIN-HEBEI URBAN AGGLOMERATION UNDER DIFFERENT SCENARIOS

Prediction of the Sustainable Development of the Beijing-Tianjin-Hebei Urban Agglomeration Under the Background of the Continuation of the Status Quo

The per capita footprint breadth of each city in Beijing-Tianjin-Hebei in 2025 and its reduction rate in the context of status quo continuation are shown in Figure 3. According to the trend of the status quo, with population growth and land use conversion, the per capita footprint breadth of each city in the Beijing-Tianjin-Hebei urban agglomeration decreases compared to 2020, and this trend is optimistic for sustainable development. In terms of footprint depth, the 2025 footprint depth of 13 cities in the Beijing-Tianjin-Hebei city cluster under the status quo continuation scenario is shown in Figure 4. Among them, the footprint depths of eight cities increase compared to 2020, and Beijing and Tianjin have the highest footprint depth growth rates of 55.7% and 42.2%, respectively, indicating that the consumption of natural capital stock will still increase sharply if Beijing and Tianjin develop according to the status quo trend. On the contrary, Qinhuangdao, Xingtai, Zhangjiakou, Langfang, and Hengshui rely less on natural capital stock under the status quo continuation scenario. A four-quadrant analysis of footprint depth and per capita footprint breadth reveals (Figure 5) that the average footprint depth increases and the average per capita footprint breadth decreases in the Beijing-Tianjin-Hebei urban agglomeration under the status quo continuation scenario compared with that in 2020. The ecological use efficiency of 13 cities in the Beijing-Tianjin-Hebei urban agglomeration in 2025 under the status quo continuation scenario is shown in Figure 6. Under the current trend, all 13 cities in the Beijing-Tianjin-Hebei urban agglomeration have a significant improvement in ecological use efficiency in 2025, with growth rates above 100%. The Gini coefficient of footprint breadth in 2025 for the Beijing-Tianjin-Hebei urban agglomeration under the status quo continuation scenario is 0.251, which is comparable to the level in 2020 and within the range of 0.2-0.3, indicating a more balanced natural capital flow per capita occupation. The coefficient of variation of the footprint depth of the Beijing-Tianjin-Hebei urban agglomeration in 2025 under the status quo continuation scenario is 0.740, and the dispersion of the footprint depth of the Beijing-Tianjin-Hebei urban agglomeration in 2025 is significantly larger compared with 0.576 in 2020, which indicates that the differences in the consumption of natural capital stock by different cities in the Beijing-Tianjin-Hebei urban agglomeration will gradually increase in the future according to the current trend.

Figure 3. Per capita footprint reduction rate of each city in 2025 under the continuation of the status quo

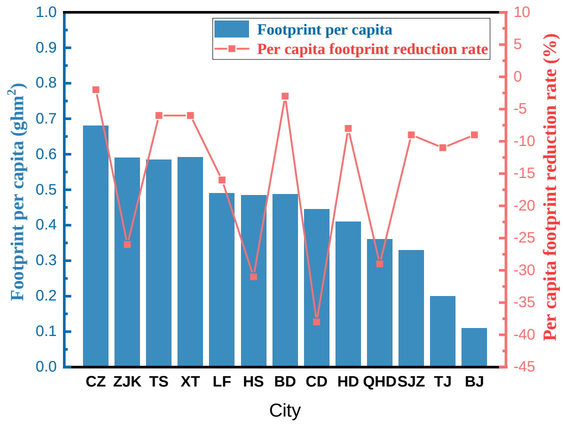


Figure 4. Depth of footprint per capita of each city in 2025 under the current situation continuation scenario

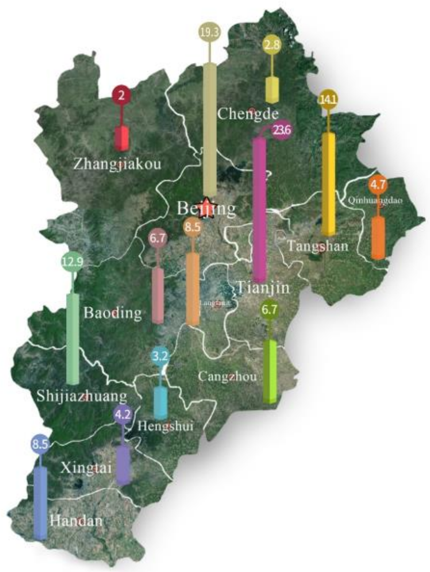


Figure 5. A Four-quadrant Analysis of Footprint Depth and Per Capita Footprint Breadth of Beijing-Tianjin-Hebei Urban Agglomeration in 2025 under the Continuation of Status Quo

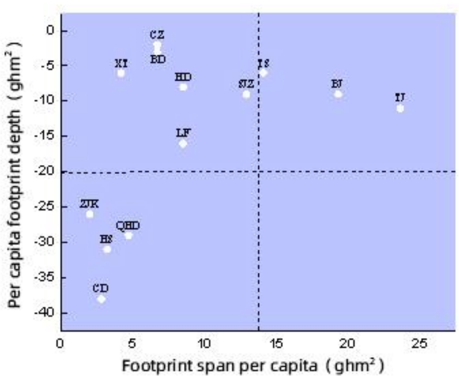
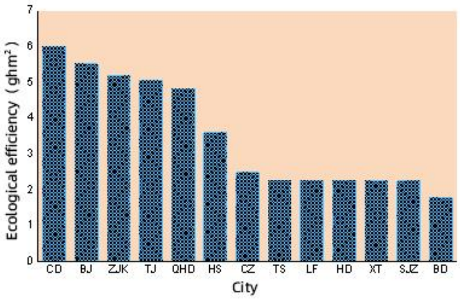


Figure 6. Prediction of Ecological Utilization Efficiency in 2025



The Balance of Sustainable Development Strategies of Beijing-Tianjin-Hebei Urban Agglomeration Under Different Scenarios

Prediction of sustainable development of cities under different scenarios

Table 8. The impact of land use, carbon emissions, and population scenarios on the depth of Beijing-Tianjin-Hebei footprint (change rate of footprint depth)%

City	Food Security	Ecological Protection	Energy saving and emission reduction scenarios	Population control scenario
Beijing	0.77	0.62	-15.25	-8.93
Tianjin	0.30	0.52	-31.1 5	0.28
Shijiazhuang	0.39	0.89	-34.44	0.72
Tangshan	0.38	1.02	-39.98	0.25
Qinhuangdao	0.5	0.76	-35.13	0.11
Handan	0.1 5	0.58	-32.92	1.52
Xingtai	0.19	0.9	-30.72	1.89
Baoding	0.5	1.03	-29.33	0.53
Zhangjiakou	0.25	0.62	-22.16	0
Chengde	0.69	0.52	-29.04	0
Cangzhou	0.11	0.11	-37.68	0.05
Langfang	0.01	0.37	-39.31	0.01
Hengshui		0.13	-30.12	0.13

From Table 8, it can be seen that energy conservation and emission reduction policies will significantly reduce the footprint depth of each city in the Beijing-Tianjin-Hebei urban agglomeration, and energy conservation and emission reduction will have the least impact on the reduction of footprint depth in Beijing, while energy conservation and emission reduction will have the greatest impact on the reduction of footprint depth in Tangshan.

The impact of land use on the reduction of footprint depth is relatively small. The food security land use scenario reduces the footprint depth of all cities except Hengshui, and the food security land use scenario reduces the footprint depth of Beijing most significantly. The ecological conservation land use scenario increases the footprint depth of each city. The population control scenario, which aims to stabilize the population in Beijing and to concentrate the population in Tianjin and Hebei, reduces the footprint depth in Beijing by 8.93%, but also increases the footprint depth in most cities in Tianjin and Hebei.

Table 9. Effects of land emission, carbon emission and population scenarios on eco-use efficiency in Beijing-Tianjin-Hebei Region (change rate of eco-use efficiency),%

City	Food Security	Ecological Protection	Energy saving and emission reduction scenarios	Population control scenario
Beijing	-0.21	0.27	17.99	11.54
Tianjin	0.01	0.01	45.24	-0.28
Shijiazhuang	-0.03	0.19	52.54	-0.78
Tangshan	-0.05	0.29	66.61	-0.28
Qinhuangdao	0.98	0.15	54.16	-7.07
Handan	0.04	0.04	49.07	-1.5
Xingtai	0.05	0.25	44.35	-1.91
Baoding	-0.03	0.38	41.51	-0.56
Zhangjiakou	1.05	2.17	28.47	-3.17
Chengde	3.27	1.42	40.92	-4.41
Cangzhou	0.21	-0.07	60.46	-2.89
Langfang	0.25	-0.21	64.78	-0.97
Hengshui	0.28	-0.15	43.1	-5.62

Table 9 shows the effects of changing one of the land use, carbon emission, and population scenarios on the ecological use efficiency of each city in Beijing, Tianjin, and Hebei. The minimum value of footprint depth and the maximum value of eco-use efficiency in Beijing are in the population scenario with population regulation, while the minimum value of footprint depth and the maximum value of eco-use efficiency in other cities occur in the population scenario with continuation of the status quo. Meanwhile, except for Qinhuangdao, Chengde, Cangzhou, Langfang, and Hengshui, the minimum value of footprint depth and the maximum value of ecological use efficiency do not appear in the same scenario combination. This requires further trade-off analysis in the specific implementation of our strategy.

The balance of sustainable development strategy of Beijing-Tianjin-Hebei urban agglomeration

Figure 7. The balancing process of sustainable development strategy of Beijing-Tianjin-Hebei urban agglomeration

Status quo continuation scenario

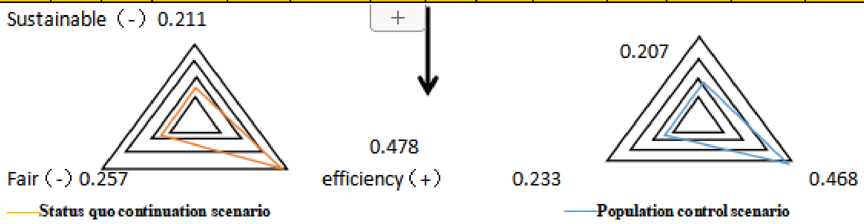
City	footprint depth Minimum	Ecological The most efficient
Beijing	5	6
Tianjin	5	6
Shijiazhuang	5	6
Tangshan	5	6
Qinhuangdao	5	6
Handan	5	6
Xingtai	5	6
Baoding	5	6
Zhangjiakou	5	6
Chengde	5	5
Cangzhou	5	5
Langfang	5	5
Hengshui	5	5

Population control scenario

City	footprint depth Minimum	Ecological The most efficient
Beijing	11	12
Tianjin	11	12
Shijiazhuang	11	12
Tangshan	11	12
Qinhuangdao	11	12
Handan	11	12
Xingtai	11	12
Baoding	11	12
Zhangjiakou	11	12
Chengde	11	11
Cangzhou	11	11
Langfang	11	11
Hengshui	11	11

Highest overall score

The population situation	Beijing	Tianjin	Shijiazhuang	Tangshan	Qinhuangdao	Handan	Xingtai	Baoding	Zhangjiakou	Chengde	Cangzhou	Langfang	Hengshui
The status quo continue	6	5	5	6	5	5	6	6	5	5	5	5	5
Population control	12	11	11	12	11	11	12	12	12	11	11	11	11



Composite scores:

Status quo continuation scenario：0.25*（-0.211）*0.24*（-0.257）+0.52*0.478=0.135
Population control scenario：0.25*（-0.207）+0.24*（0.233）+0.52*0.468=0.136

Under the population scenario of status quo continuation, Qinhuangdao, Chengde, Cangzhou, Langfang, and Hengshui satisfy the minimum footprint depth and the highest ecological use efficiency for scenario 5, and under the population scenario of population regulation, the minimum footprint depth and the highest ecological use efficiency for scenario 11, i.e., scenario 5 and scenario 11 have satisfied the sustainability and efficiency of these five cities under their respective population scenarios. For the remaining eight cities, Scenario 5 meets the minimum footprint depth, Scenario 6 meets the highest eco-use efficiency under the population scenario, and Scenario 10 meets the minimum footprint depth and the highest eco-use efficiency under the population scenario. For the remaining eight cities, scenario 11 meets the minimum footprint depth and scenario 12 meets the maximum eco-efficiency under the population regulation scenario. The data were standardized using the extreme value method, and the overall score of each scenario combination was obtained according to the weights determined by the entropy weighting method, and the combination with the highest overall score was selected as the scenario combination for the remaining eight cities (orange table in Figure 7).

After determining the scenario combinations chosen by each city under the status quo continuation and population regulation scenarios, respectively, the population scenarios were weighed (Figure 7 radar chart). Based on the weights determined by the entropy weighting method, it is obtained that the population regulation scenario scores higher. Therefore, the trade-off results of sustainable development strategies for the Beijing-Tianjin-Hebei urban agglomeration are obtained: for the population scenario, the region chooses the population regulation strategy; for the carbon emission scenario, each city chooses the energy conservation and emission reduction strategy; for the land use scenario, Tianjin, Shijiazhuang, Qinhuangdao, Handan, Chengde, Cangzhou, Langfang, and Hengshui choose the food security strategy, and Beijing, Tangshan, Xingtai, Baoding, and Zhangjiakou choose the ecological protection strategy.

The study shows that energy conservation and emission reduction will significantly reduce the depth of footprint and improve the ecological use efficiency of each city in the Beijing-Tianjin-Hebei urban agglomeration. For land use, the land use strategy of food security is consistent with the role of Shijiazhuang, Handan, Cangzhou, Langfang, and Hengshui as food and cash crop production bases. The land use strategy of ecological conservation will be conducive to ensuring and bringing into play the ecological advantages of Zhangjiakou and Baoding, while Tangshan and Xingtai have a weaker ecological base, and ecological conservation is the key to enhancing the sustainable development status of the local area. The ecological conservation land use strategy is consistent with the current functional positioning of Beijing and is also conducive to the improvement of ecological utilization efficiency in Beijing from the simulation results. According to the current trend, Tianjin will consume the largest amount of natural capital in the future, and the land use strategy of food security will help to relieve the ecological pressure and improve the sustainable development status. Regarding the choice of population strategy, it is found that the optimal scenario of population regulation improves in the regional sustainability dimension and equity dimension and decreases in the efficiency dimension compared with the optimal scenario of status quo continuation, and scores higher in the aggregate. This study suggests that the population control policy accompanying the deconcentration of non-capital functions is conducive to the sustainable development of the capital city of Beijing, while resulting in a more balanced per capita natural capital flow occupation in the Beijing-Tianjin-Hebei urban agglomeration. From the results of this paper, the population deconcentration in Beijing will increase the footprint depth of other cities and reduce the ecological use efficiency of other cities. To achieve the synergistic development of the Beijing-Tianjin-Hebei urban agglomeration, it is also necessary to give full play to the spillover effect of Beijing's science and technology innovation and strengthen the docking and cooperation of advantageous industries between Beijing and these cities, so as to improve the ecological utilization efficiency of other cities in the Beijing-Tianjin-Hebei urban agglomeration, reduce their footprint depth, and further improve the sustainable development.

CONCLUSION

This study takes Beijing-Tianjin-Hebei urban agglomeration as the study area, and evaluates and compares the sustainable development status of Beijing-Tianjin-Hebei urban agglomeration in different years by constructing a multidimensional sustainable development evaluation system based on three-dimensional ecological footprint, and also conducts a cluster analysis based on the evaluation results for the sustainable development status of Beijing-Tianjin-Hebei urban agglomeration. Further, we set different scenarios of population carbon emission and land use to predict the sustainable development of the Beijing-Tianjin-Hebei urban agglomeration in 2025 under the continuation of the status quo scenario, explore the impact of different scenarios on the sustainable development status of the Beijing-Tianjin-Hebei urban agglomeration, and try to make trade-offs and choices on the sustainable development strategy of the Beijing-Tianjin-Hebei urban agglomeration in the future.

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