

Article

How to Realize Synergistic Emission Reduction in Future Urban Agglomerations: Spatial Planning Approaches to Reducing Carbon Emissions from Land Use: A Case Study of the Beijing–Tianjin–Hebei Region

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Abstract: Land use changes in rapidly urbanizing regions around the world constitute a principal anthropogenic element fueling the surge in carbon emissions. Here, land use patterns within the Beijing–Tianjin–Hebei (BTH) urban agglomeration under low-carbon development (LCD) scenarios were simulated. Additionally, social network analysis was employed to formulate carbon balance planning guidelines for various administrative regions. (1) In the ecological protection scenario, carbon emissions from land use were 643.42×10^4 tons lower compared to the natural development scenario. Counties with high ecological support coefficients accounted for 22%, making them better suited for predicting outcomes related to low-carbon-oriented land use. (2) The spatial connections of carbon emissions in BTH were closely related, forming the three main carbon emission spatial linkage areas. (3) A carbon balance zoning plan for the BTH in 2035 under the LCD scenario was formulated. Furthermore, key areas for the implementation of carbon peak and carbon neutrality projects were delineated, and targeted measures for carbon reduction and sink increase were proposed. This study provides a new perspective for implementing territorial spatial planning in Chinese urban agglomerations and can aid the government in formulating a reasonable low-carbon-oriented regional planning policy.

Keywords: land use simulation; CO₂ emissions; spatial connection; social network analysis; carbon balance planning



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1. Introduction

Global warming is a growing concern and has become one of the major environmental challenges confronting the world presently. Carbon dioxide (CO₂) is a greenhouse gas that is sourced mainly from man-made emissions, and its excessive emissions put significant pressure on the ecological environment [1,2]. Cities are densely populated and have become hot spots for CO₂ emissions, with China's urban areas accounting for 75% of the country's overall carbon emissions [3]. Urban agglomeration is a key factor for promoting urban–rural integration and coordinated regional development [4]. In the process of achieving a low-carbon transformation of urban and rural areas, it is crucial to formulate sink increase and emission reduction strategies at the urban agglomeration level.

Carbon emissions are limited by land use change, which can affect global climate change and the carbon cycle by altering the surface carbon process and the intensity of human energy consumption [5]. Carbon emissions resulting from land use/cover changes (LUCCs) surpass 30% of global man-made carbon emissions [6,7]. Therefore, scientifically

simulating LUCCs and exploring land use patterns under future low-carbon development (LCD) scenarios both aid in finding ways to reduce carbon emissions.

Land use carbon emissions can be calculated in several ways. Many scholars have characterized CO₂ emissions by calculating the carbon emissions from energy consumption [8]. This method has some limitations, however. The calculation results of this method can only be expressed numerically, making it difficult to locate specific geographic spaces and to demonstrate the similarities and differences in the spatial distribution of carbon emissions. Some studies have used a combination of land use layout and carbon emission factors to compute carbon emissions [9]. This method can effectively express the spatial differences in carbon emissions and provide a planning basis for carbon reduction measures in different regions, filling the gap in calculating carbon emissions based on energy. The future land use layout in different scenarios can be used to guide the use of various methods, including the cellular automata (CA) model [10,11], CLUE-S model [12], FLUS model [13], and PLUS model [14]. Among these methods, the PLUS model provides benefits of high simulation accuracy and rapid data processing speed. By introducing land expansion analysis strategies and multitype random patch-seed generation mechanisms, it effectively simulates the intricate evolution process of multiple land types. At present, multiple studies have made notable contributions to carbon reduction in Chinese urban agglomerations from the perspective of emission reduction technologies. Although the development space for technology emission reduction is constrained, the importance of a top-down systematic planning methodology is gradually becoming prominent [15]. As a hot spot for greenhouse gas emissions, urban agglomerations exhibit the uneven distribution of CO₂ because of their imbalanced socioeconomic factors [16]. Exploring collaborative approaches to emission reduction in urban agglomerations can better demonstrate the importance of the urban network structure in reducing CO₂ emissions in the process of urbanization, thereby better guiding emission reduction planning. The economic development levels and natural environments of different cities and counties vary, and as a result, their carbon emissions also vary. These differences directly affect different regions' ability to achieve carbon peak targets. Therefore, policy makers must develop different carbon reduction strategies based on specific circumstances and the inherent emission differences of each city and county [17]. The economic and population mobility relationships among counties are complex. The carbon emissions of each county within the urban cluster are greatly affected by surrounding counties, making it difficult to separate a county from the urban cluster and address its carbon issues separately. Therefore, when studying carbon emission reduction issues in urban agglomerations, considering the connections of carbon emissions between cities is essential. Social network analysis (SNA) serves as an effective methodology for examining the spatial structure of urban agglomerations and the spatial connections among cities. SNA can be employed to explore the spatial correlation characteristics of carbon emissions in urban agglomerations and the specificity of different cities and counties in carbon emission networks. Lately, numerous scholars have utilized SNA to examine spatial coupling, spatial correlation, and dynamic evolution of the spatiotemporal patterns of carbon emissions among regions in terms of the spatial scale [18,19].

Still, many gaps exist in current research on carbon emissions within urban agglomerations. Because of a lack of data, most studies can focus only on the carbon emissions of some large cities with recorded data, and the research locations are individual, not universal. In addition, due to limited interannual records of historical data, the data analysis results are applicable only to the policies and economic conditions at that time, making it difficult to align with recent carbon emission reduction governance policies. Moreover, most carbon emission simulations focus only on simulating future land use patterns or providing macro-policy recommendations to reduce emissions and enhance foreign exchange in the research area as a whole [20]. Few studies have simulated the land use patterns of LCD scenarios or formulated detailed and feasible planning guidelines for different administrative regions informed by the location and socioeconomic attributes of cities [21]. The classification types and methods of carbon balance zoning, as well as the planning guidelines for different

regions to undertake the functions of increasing emissions and reducing emissions, remain unclear, and the theoretical basis needs to be improved.

Combining the PLUS model with the SNA method can compensate for this lack of data and can simulate the spatial carbon emission linkage in the context of formulating LCD policies in the future. Therefore, these methods can be used to more effectively formulate planning strategies and achieve the goal of increasing foreign exchange and reducing emissions.

The Beijing–Tianjin–Hebei (BTH) urban amalgamation stands as one of China’s four national-level urban agglomerations, and it has a high proportion of heavy industry and significant deterioration of ecological functions [22], which puts significant pressure on economic development, industrial upgrading, and integrated development. The significant energy consumption and exhaust emissions in the BTH urban agglomeration have caused serious air pollution [23]. Thus, coordinating the development of the BTH integration is of overriding significance to plan for carbon balance zoning and formulate a scientific linkage emission reduction scheme. Given this imperative, our study delved into the land use pattern under the future LCD scenario and the spatial association of carbon emissions. We also developed a low-carbon-oriented carbon balance zoning planning and management scheme.

2. Study area and Materials

2.1. Study Area

The BTH includes 13 cities ($113^{\circ}27'–119^{\circ}50' E$, $36^{\circ}05'–42^{\circ}40' N$) (Figure 1). Its total area spans 21.5 million km^2 and is situated in the northeastern coastal plain of China. As the BTH is one of four national urban agglomerations, its coordinated and integrated development can effectively improve the layout and form of urban agglomerations and contribute to the construction of an environmentally friendly society. In 2015, the state released the *Outline for Coordinated Development of the Beijing–Tianjin–Hebei Region*, which clarifies the significance of ecological environmental protection and the synergy between emission reduction and sink increase.

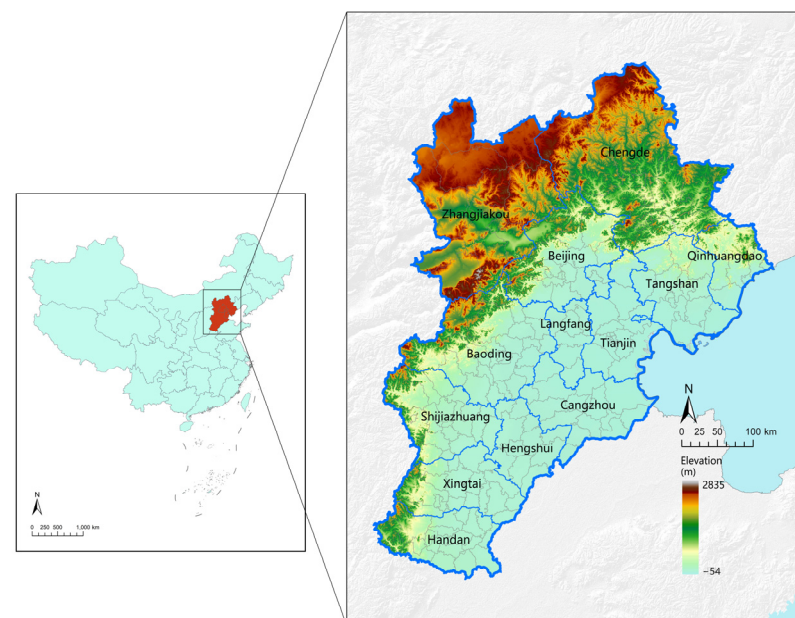


Figure 1. Geographical location of the study area.

2.2. Data Sources

The data utilized in this study comprise land use data, soil type data, annual mean temperature data, annual mean precipitation data, DEM data, nighttime light data, GDP

data, population data, railway data, highway data, national highway data, river water data, national nature reserve data, and carbon emission calculation data (Table 1).

Table 1. Details of the datasets.

Data Types	Data	Years	Spatial Resolution (m)	Sources
Land use datasets	Land use	2000, 2010, 2020	30	Jie Yang and Xin Huang (2022). The 30 m annual land-cover dataset and its dynamics in China from 1990 to 2021 [Dataset]. In <i>Earth System Science Data</i> (1.0.1, Vol. 13, Number 1, pp. 3907–3925). Zenodo. https://doi.org/10.5281/zenodo.5816591 [24]
Climate environmental datasets	Soil type	2018	30	Resource and Environmental Sciences Data Center, Chinese Academy of Sciences
	Annual mean temperature	2020	30	National Tibetan Plateau Data Center
	Annual mean precipitation	2020	30	National Tibetan Plateau Data Center
	DEM	2020	30	Geospatial Data Cloud
	Slope	2020	30	Generated from DEM data using ArcGIS
Socioeconomic datasets	GDP	2019	1000	Resource and Environmental Sciences Data Center, Chinese Academy of Sciences
	POP	2019	1000	Resource and Environmental Sciences Data Center, Chinese Academy of Sciences
	Proximity to railway	2020	30	Open street map
	Proximity to motorway	2020	30	Open street map
	Proximity to national highway	2020	30	Open street map
	Proximity to river water	2020	30	Open street map
	Nighttime light data	2020	1000	Chinese Long Time Series Nighttime Light Dataset of China (2000–2020) https://doi.org/10.3974/geodb.2022.06.01.V1 [25]
Future driver dataset	National nature reserves	/	/	China Nature Reserve Specimen Resource Sharing

3. Methodology

The proposed planning simulation framework in this study consists of three main components (Figure 2).

1. Land use pattern under the future LCD scenario: We used the PLUS model to import a dataset that includes land use data spanning three periods from 2010 to 2020, as well as climate, environment, and future driving factors to investigate the land use pattern under both the natural development (ND) scenario and ecological protection (EP) scenario in the BTH in 2035. We analyzed the carbon emission characteristics under the different scenarios and used the carbon emission and ecological support coefficient (ESC) as the criteria to screen the development scenarios that are more conducive to LCD scenarios.
2. Spatial connection analysis of carbon emissions under the LCD scenario: We introduced the carbon emission and socioeconomic data into the gravity model to formulate the carbon emission gravity matrix for the BTH region. We used SNA to assess the spatial network characteristics of carbon emissions in the BTH in 2035 under the LCD scenario.
3. Carbon balance zoning planning under the 2035 LCD scenario in the BTH: Drawing from the land use pattern under the LCD scenario and the spatial network characteristics of future carbon emissions, we analyzed the status and role of each region in increasing sinks and reducing emissions. On this basis, we formulated a future

carbon balance zoning plan for the BTH to pinpoint critical areas for implementing the emission peak and carbon neutrality projects.

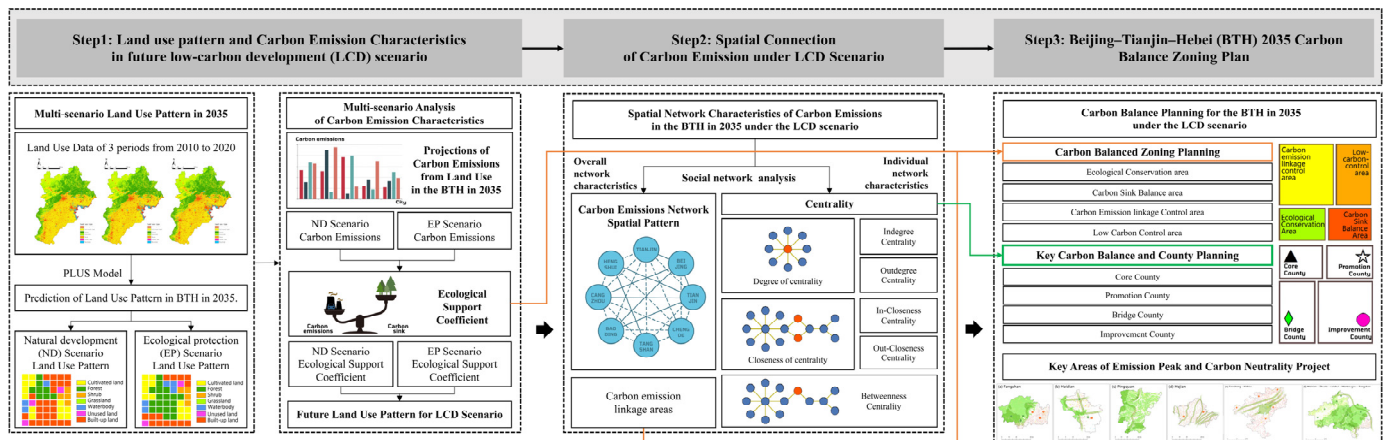


Figure 2. Workflow of this study.

3.1. Multi-Scenario Land Use Pattern Projections

The PLUS model was derived from the FLUS model [26]. Drawing from the prediction of land use demand, the Markov module developed two modules: (1) land expansion strategy analysis (LEAS) and (2) the CA model of multitype random patch seeds (CARS). CARS can be used for refined land use simulation and prediction and can be coupled with a multi-objective optimization algorithm. The simulation outcomes can provide enhanced support for formulating planning policies to attain sustainable development goals.

To explore the land use patterns under various development scenarios, in the PLUS model, we established two development scenarios (ND and EP) to simulate the land use patterns in the BTH region for the year 2035. The ND scenario continued the development trend from 2010 to 2020 and maintained the transfer probability and neighborhood weight of the original land use types. Under the EP scenario, the primary goal orientation was the protection of the ecological environment. It aimed to curb the unordered expansion of urban areas, decrease the likelihood of converting forest land, shrub, grassland, and water bodies into built-up land by 20%, elevate the likelihood of converting cultivated land into forest land by 60%, and augment the likelihood of converting cultivated land into shrub and grassland by 50% when setting the neighborhood weight [27]. These two scenarios both took the national nature reserves as the limited expansion area.

3.2. Carbon Emissions Accounting

3.2.1. Carbon Emission Calculation Model

Carbon emissions from the BTH region were computed based on land use patterns under various scenarios derived from the PLUS simulation. Built-up land and cultivated land served as the primary carbon sources in the urban agglomeration, whereas forest land, grassland, water bodies, and unused land acted as the primary carbon sinks in the urban agglomeration [28–33]. Based on the China carbon emission inventory coefficient, and a coefficient from the relevant literature [29], we formulated the carbon emission coefficient of land use in the BTH region, as presented in Table 2. The formula for the land use carbon emission estimation model is as follows [9]:

$$C_e = \sum e_i = \sum_{i=1}^n A_i \times a_i, \quad (1)$$

where C_e is carbon emissions, e_i is carbon emissions from a specific land use type, A_i indicates the area of the i th land use type, and a_i is the carbon emission coefficient of the i th land use type.

Table 2. Carbon emission coefficients of different land use types.

Land Use Types	Coefficient (ton CO ₂ /hm ²)	References
Cultivated land	0.42	Fang et al., 2007 [29], She et al., 2017 [31]
Forest	−0.62	Fang et al., 2007 [29], Cui et al., 2019 [28]
Grassland	−0.14	Fang et al., 2007 [29], Cui et al., 2019 [28]
Shrub	−0.23	Tang et al., 2018 [32], Cui et al., 2019 [28]
Waterbody	−0.03	Fang et al., 2007 [29], Cui et al., 2019 [28]
Built-up land	120.37	Liu et al., 2023 [30], Yan et al., 2022 [33]
Unused land	−0.05	Cui et al., 2019 [28]

3.2.2. Ecological Support Coefficient

We used the ecological support coefficient (ESC) to assess the carbon sink capacity under different development scenarios [34,35]. ESC can gauge the ecological capacity's contribution to carbon balance in each region, and its calculation formula is as follows:

$$ESC = \frac{CA_i}{CA} \bigg/ \frac{C_i}{C}, \quad (2)$$

where C_i and C represent the carbon emissions from each county-level unit and the entire region, respectively, and CA_i and CA are the carbon sequestration values of each county-level unit and the entire region, respectively. If $ESC > 1$, the contribution rate of carbon absorption exceeds the contribution rate of carbon emissions, and this indicates a robust ecological carrying capacity for the county. If $ESC < 1$, the region's ecological carrying capacity is considered weak. Taking ESC as one of the evaluation bases, we selected the low-carbon-oriented development scenario in the multi-scenario land use pattern prediction study described in Sections 4.1.3 and 4.1.4, which encompassed a higher proportion of counties with lower carbon emissions and ESC values > 1 , as the LCD scenario. Then, we analyzed the spatial connection of carbon emissions under the subsequent low-carbon scenario.

3.3. Spatial Correlation Analysis of Carbon Emissions Based on SNA

In this study, we employed the gravity model to measure the economic and social links between regions. GDP, POP size, and carbon emissions were also incorporated into the gravity model to adjust and measure the intensity of the carbon emissions linkage between the counties in the BTH [36]. The calculation formula is as follows:

$$R_{ij} = k_{ij} \times \frac{\sqrt[3]{G_i P_i C_i} \times \sqrt[3]{G_j P_j C_j}}{d_{ij}^2}, k = \frac{C_i}{C_i + C_j}, \quad (3)$$

where R is the gravitational value; d is the spherical geographical distance between counties; G , P , and C are GDP, POP, and total carbon emissions, respectively; k is the adjustment factor of the carbon emission ratio of a county in the two-way relationship; and i and j represent two different counties.

The GDP and POP data for 2035 were predicted using the gray (1, 1) model (GM). As the growth and change trends of the GDP and POP data are complex and uncertain, GM is suitable for predicting the GDP and POP data for 2035 [37,38]. We selected the GDP data and population data from 2014 to 2020 for prediction. We obtained the GDP data from a previous study [39] and the population data from the LandScan population dataset. The LandScan population data produced by the U.S. Department of Energy at Oak Ridge National Laboratory (ORNL) represents ambient population count (averaged over 24 h) at approximately 1 km² resolution.

The main characteristics of the spatial network were the network spatial pattern and the centrality of each county. The network spatial pattern was used primarily to visualize the overall structure of the network, indicating the ability to achieve coordinated development among regions. Centrality was employed to examine the individual roles of each

county in collaborative emission reduction within the network. It reflects the significance of carbon emission exchange between counties for the coordinated development of the entire network. As a result, we clarified the key counties with different carbon emission reduction attributes. The centrality selection indicators are given in Table 3 [17].

Table 3. Spatial network indicators of carbon emissions.

Network Characteristics		Formula	Symbolic Meaning	Role
Degree of Centrality	Outdegree Centrality	$C'_{od}(i) = \sum_{j=1}^n X_{ij} / (n-1)$	X indicates whether there is a direct connection between counties, where 1 indicates a direct connection and 0 indicates no connection; n is the number of cities in the network	Directly reflects the status of nodes in the network
	Indegree Centrality	$C'_{id}(i) = \sum_{j=1}^n X_{ji} / (n-1)$		
Closeness of Centrality	In-closeness Centrality	$C'_{ic}(i) = (n-1) / \sum_{j=1}^n d(j,i)$	$d(i,j)$ denotes the shortest spherical distance from county i to county j	Reflects the degree to which each city in the entire network is not dominated by the other cities
	Out-closeness Centrality	$C'_{oc}(i) = (n-1) / \sum_{j=1}^n d(i,j)$		
Betweenness Centrality		$C'_b(i) = \frac{\sum_{j < k} g_{jk}(i) / g_{jk}}{(n-1)(n-2)}$	g_{jk} represents the total number of shortest paths from county j to county k that generate links; $g_{jk}(i)$ is the number of shortest paths from county j to county k that generate links through county i	Reflects the extent to which a node can control the relationships between other nodes

3.4. Carbon Balance Planning for the BTH Urban Agglomeration in 2035 under the LCD Scenario

3.4.1. Carbon Balance Zoning Planning

Based on the simulation results of land use under the future LCD scenario, a carbon balance zoning plan for the BTH region in 2035 was developed. ESC was used to characterize the carbon sink potential of a region, while carbon emission linkage regions were used to characterize the potential for regional collaborative emission reduction. We believe that when $ESC > 1$, the region exhibits carbon-sink-oriented characteristics; when $ESC < 1$, the region exhibits carbon-emission-oriented characteristics. When the county is in a carbon emission linkage zone, the correlation between networks is high, making it easy to carry out regional collaborative emission reduction work; when the county is not in the carbon emission linkage zone, the correlation between networks is low, making it difficult to carry out regional collaborative emission reduction work. Utilizing the calculated spatial distribution of ESC and the three major carbon emission linkage zones, we divided the carbon balance zoning according to this standard.

3.4.2. Key Carbon Balance and County Planning

Based on carbon balance zoning planning, the centrality of each county was calculated. The study identified the characteristics of each county in the carbon emission network. Building upon the centrality analysis of each county within the carbon emission network outlined in Section 3.3, four key counties were determined based on the scores of urban agglomerations in the above four indicators: core county, promotion county, bridge county, and improvement county. Among them, counties with higher indegree centrality were designated as core counties, counties with higher in-closeness centrality were designated as promotion counties, counties with higher betweenness centrality were designated as bridge counties, and counties with higher outdegree centrality were designated as improvement counties.

4. Results

4.1. Multi-Scenario Carbon Emission Analysis of the BTH Urban Agglomeration in 2035

4.1.1. Simulation Accuracy Verification

Ensuring the precision of land use model simulation, according to BTH land use in 2010 and 2015, we conducted simulations and compared the expected results of land use in 2020 with the real land use distribution in the same year. The results are displayed in Table 4. Regarding the accuracy validation of the PLUS model, the kappa coefficient stood at 0.9149,

with the overall simulation accuracy reaching 0.9402. This outcome indicates that the land use predictions generated by the model in this study had high accuracy [27,40]. Consequently, the model could be extended for simulating land use types and their distributions in 2035 in future studies.

Table 4. Comparison between the simulated land use types and the actual land use types in 2020 at pixel level.

	Cultivated Land	Forest	Shrub	Grassland	Waterbody	Unused Land	Built-Up Land
Real (2020)	472,275	265,462	3252	160,055	15,016	265	160,376
Simulation results (2020)	472,401	265,338	3226	159,874	14,225	282	161,355

4.1.2. Land Use Distribution Pattern

The land use distribution results for 2035 under the two scenarios obtained from the simulation are shown in Figure 3 and Table 5. According to the simulation results, in comparison to land use in 2020, forest land, water bodies, and built-up land would continue to increase, while cultivated land, shrub, grassland, and unused land would decrease in 2035 under the ND scenario. Under the EP scenario, in contrast to the ND scenario, built-up land and cultivated land would decrease by 52,284 ha and 175,628 ha, respectively. The area of ecological land (forest land, shrub, and grassland) would increase by 223,247 ha. Therefore, under the constraints of the EP policy, the disorderly expansion of built-up land in the BTH urban agglomeration in 2035 could be effectively restricted, while the area of ecological land could be augmented.

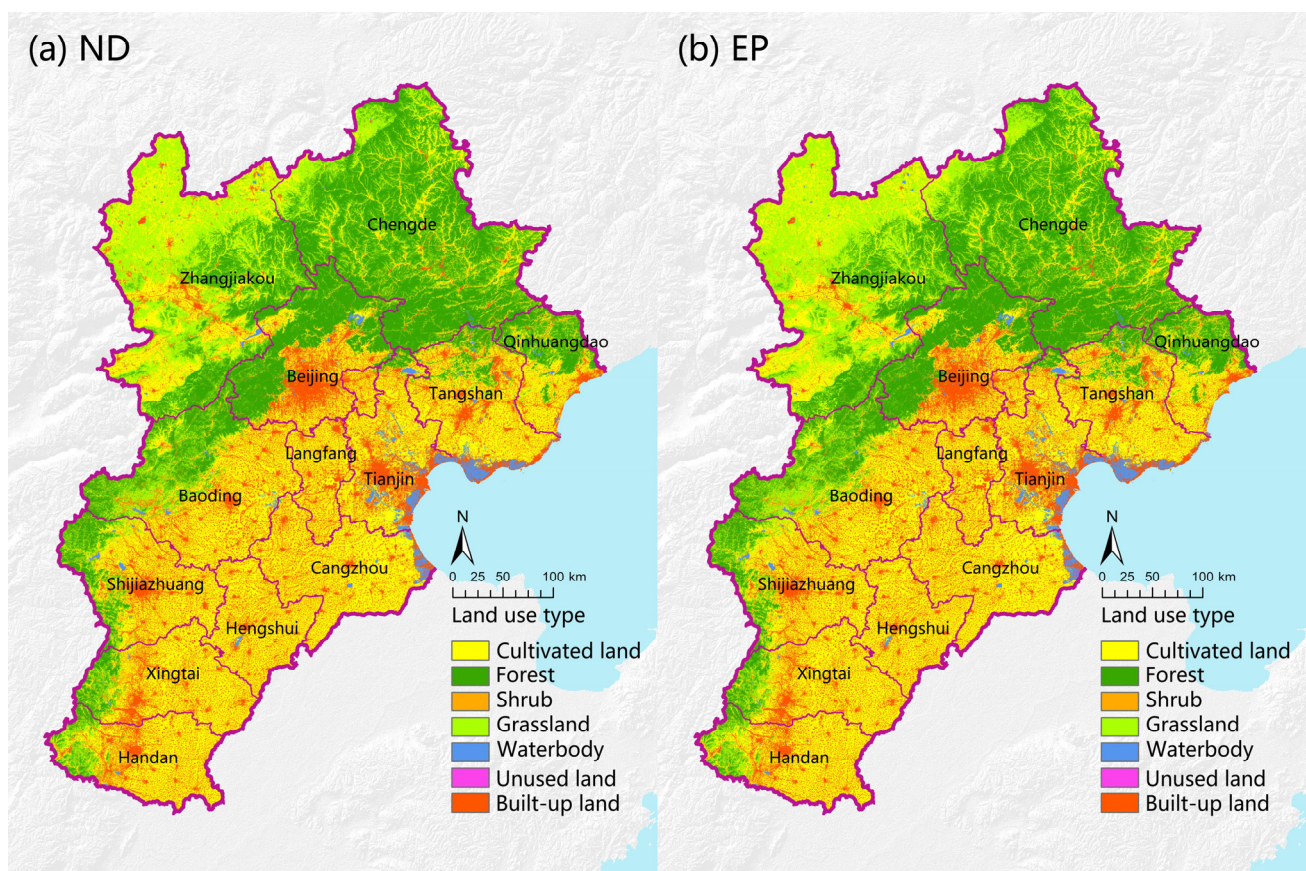


Figure 3. Land use patterns under the (a) ND scenario and (b) EP scenario in 2035.

Table 5. Changes in the regional area under different scenarios in 2020–2025 (ha).

Year	Scenario Analysis	Cultivated Land	Forest	Shrub	Grassland	Waterbody	Unused Land	Built-Up Land
2020		9,433,128	5,314,139	63,930	3,189,193	281,330	4652	3,224,288
2035	ND	9,236,893	5,565,082	58,023	2,909,005	299,492	2086	3,440,079
	EP	9,061,265	5,639,408	56,856	3,059,093	303,338	2905	3,387,795
2020–2035	ND	−196,235	250,943	−5907	−280,188	18,162	−2566	215,791
	EP	−371,863	325,269	−7074	−130,100	22,008	−1747	163,507

4.1.3. Spatial Distribution of Carbon Emissions

We calculated future carbon emissions in 2035 based on land use patterns under different scenarios (Figure 4 and Table 6). Carbon emissions in 2035 would be $41,408.18 \times 10^4$ tons under the ND scenario and $40,774.76 \times 10^4$ tons under the EP scenario. In comparison to the ND scenario, the EP scenario would reduce the emission of greenhouse gases by 643.42×10^4 tons. The net carbon sink was larger, leading to lower overall carbon emissions and reduced net carbon emissions.

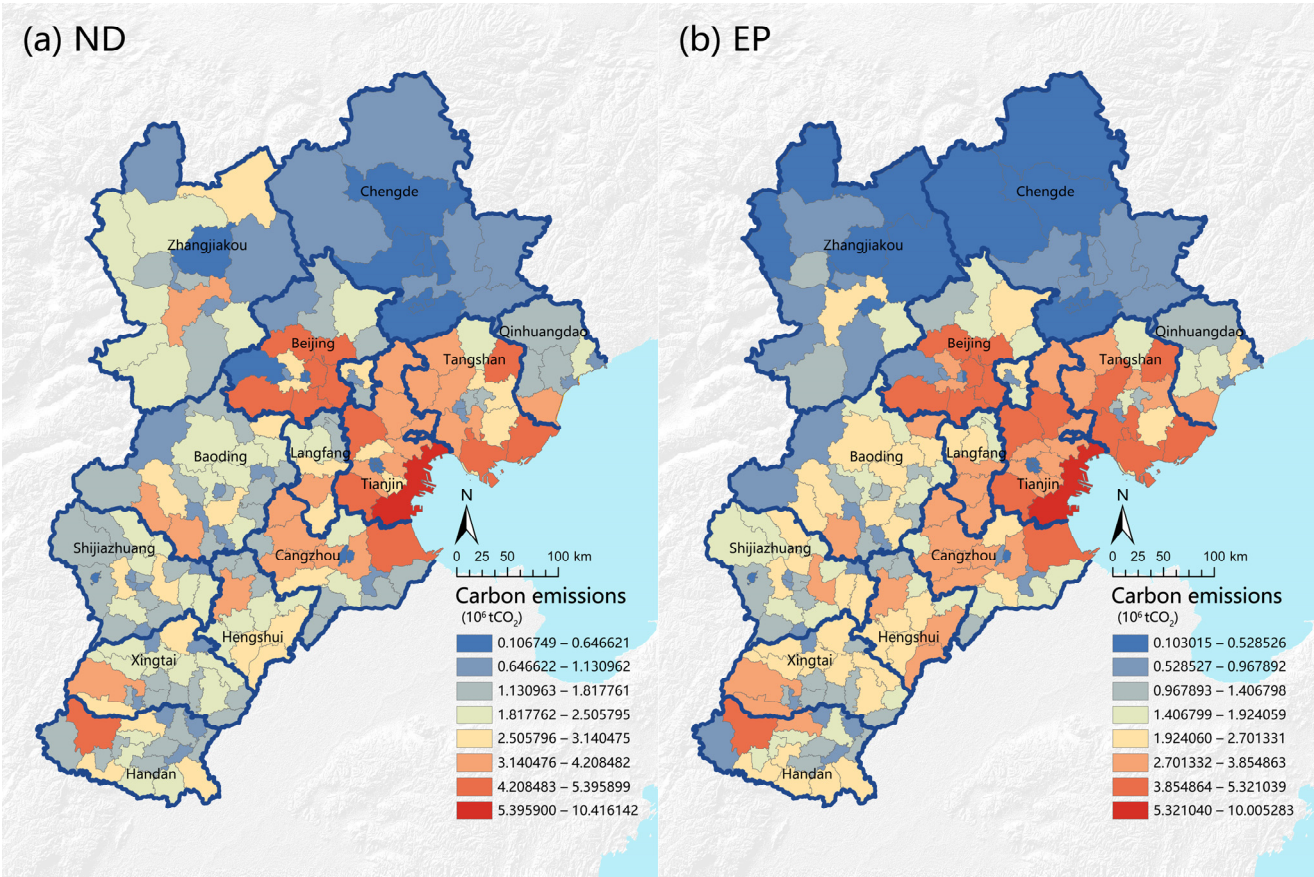


Figure 4. Spatial distributions of carbon emissions under the (a) ND scenario and (b) EP scenario in 2035.

Table 6. Carbon emissions under the ND scenario and EP scenario in 2035 (10^4 t).

Scenario Analysis	Cultivated Land	Forest	Shrub	Grassland	Waterbody	Unused Land	Built-Up Land
ND	387.95	−345.04	−1.33	−40.73	−0.90	−0.01	41,408.23
EP	380.57	−349.64	−1.31	−42.83	−0.91	−0.01	40,778.89

The spatial distributions of the carbon emissions under the two scenarios exhibited higher concentrations in the central and eastern regions, while they were lower in the

western and northern regions. The main areas of carbon emission accumulation included Beijing, Tianjin, Tangshan, Cangzhou, and the Binhai New Area. These accumulation areas are characterized by developed industries, high-density population distributions, highly concentrated distributions of built-up land, and a relatively small proportion of ecological land (forest land and grassland) retaining the same characteristics of carbon emission agglomeration observed in 2020.

4.1.4. Ecological Support Coefficient

ESC was employed to assess the carbon sink capacity under the different development scenarios (Figure 5). The spatial distribution trends of ESC under the two development scenarios were similar, and the overall characteristics were as follows: High ESC values were observed in the northwest, while lower ESC values were noted in the central, southern, and eastern regions. Under the ND scenario, 39 counties had an ESC > 1, accounting for 19.5%. Under the EP scenario, 44 counties had an ESC > 1, accounting for 22%.

We selected the development scenarios with lower carbon emissions and more counties with higher ESC values for the land use prediction results for the LCD scenarios.

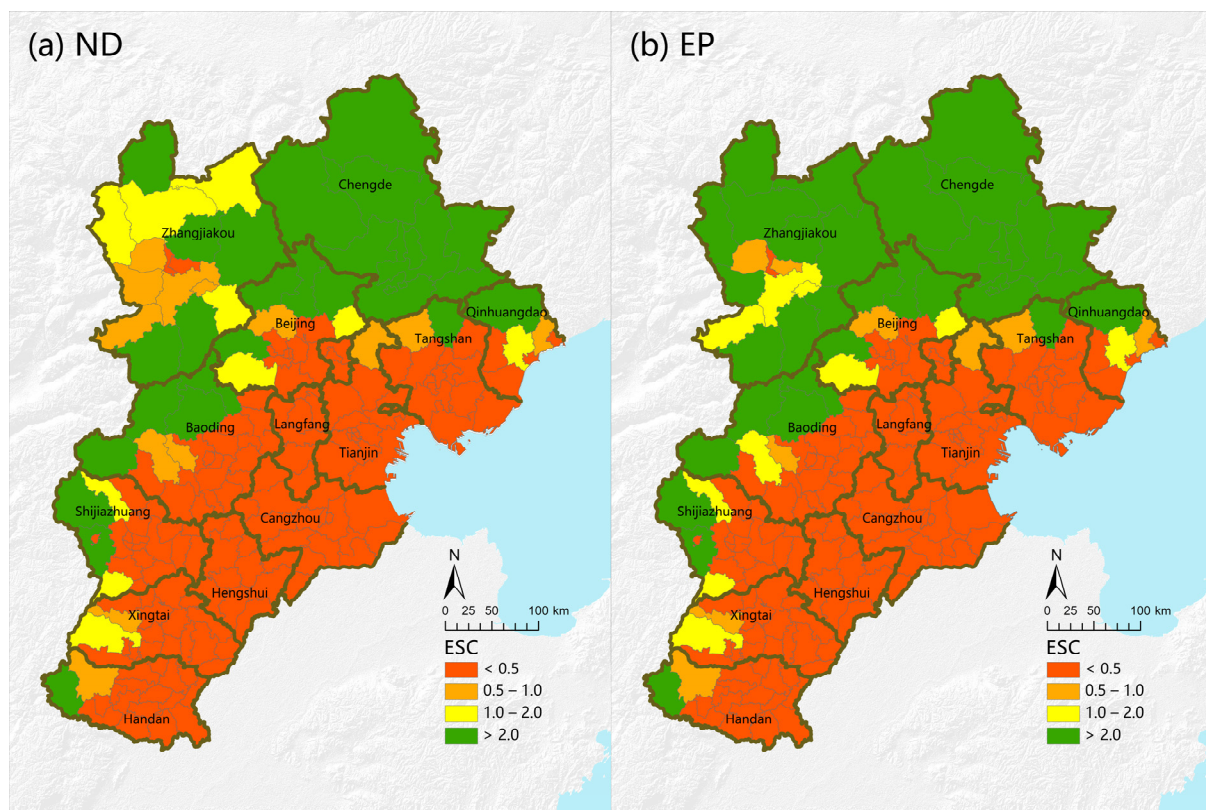


Figure 5. ESC under the (a) ND scenario and (b) EP scenario in 2035.

4.2. Spatial Correlation Analysis of Carbon Emissions in the BTH Urban Agglomeration under the LCD Scenario

4.2.1. Carbon Emission Network in the BTH Urban Agglomeration

We used the gravity model to draw a carbon emission correlation intensity map of the BTH under the LCD scenario in 2035 (Figure 6). To illustrate the network structure more clearly, we opted to map the carbon emission correlations corresponding to the top 1% of the gravity values [41]. Under the LCD scenario, a distinct spatial correlation pattern of carbon emissions emerged in the BTH region. Beijing, Tianjin, and the neighboring counties of Langfang, Baoding, Tangshan, and Cangzhou in the central area of the study region exhibited close relationships. Conversely, the carbon emission network in the southwestern part of the study area was mainly concentrated in Shijiazhuang and displayed

less connectivity with other regions. In the southern region of the study area, the spatial network of carbon emissions was composed mainly of Xingtai and Handan.

According to the gravity values (threshold gravity value = 153,000), the counties with close carbon emission spatial correlations were clustered. We obtained the linkage areas of carbon emissions. Under the LCD scenario, in 2035, the BTH region formed three main groups of carbon emission spatial correlation networks: (1) the Beijing–Tianjin–Tangshan–Baoding–Cangzhou carbon emission aggregation network, with Beijing and Tianjin serving as the dual core hubs; (2) the Shijiazhuang carbon emission aggregation network, which was concentrated in Shijiazhuang Province; and (3) the Xingtai–Handan carbon emission aggregation network, which was composed primarily of Xingtai and Handan. These three carbon emission networks were grouped into three carbon emission linkage areas.

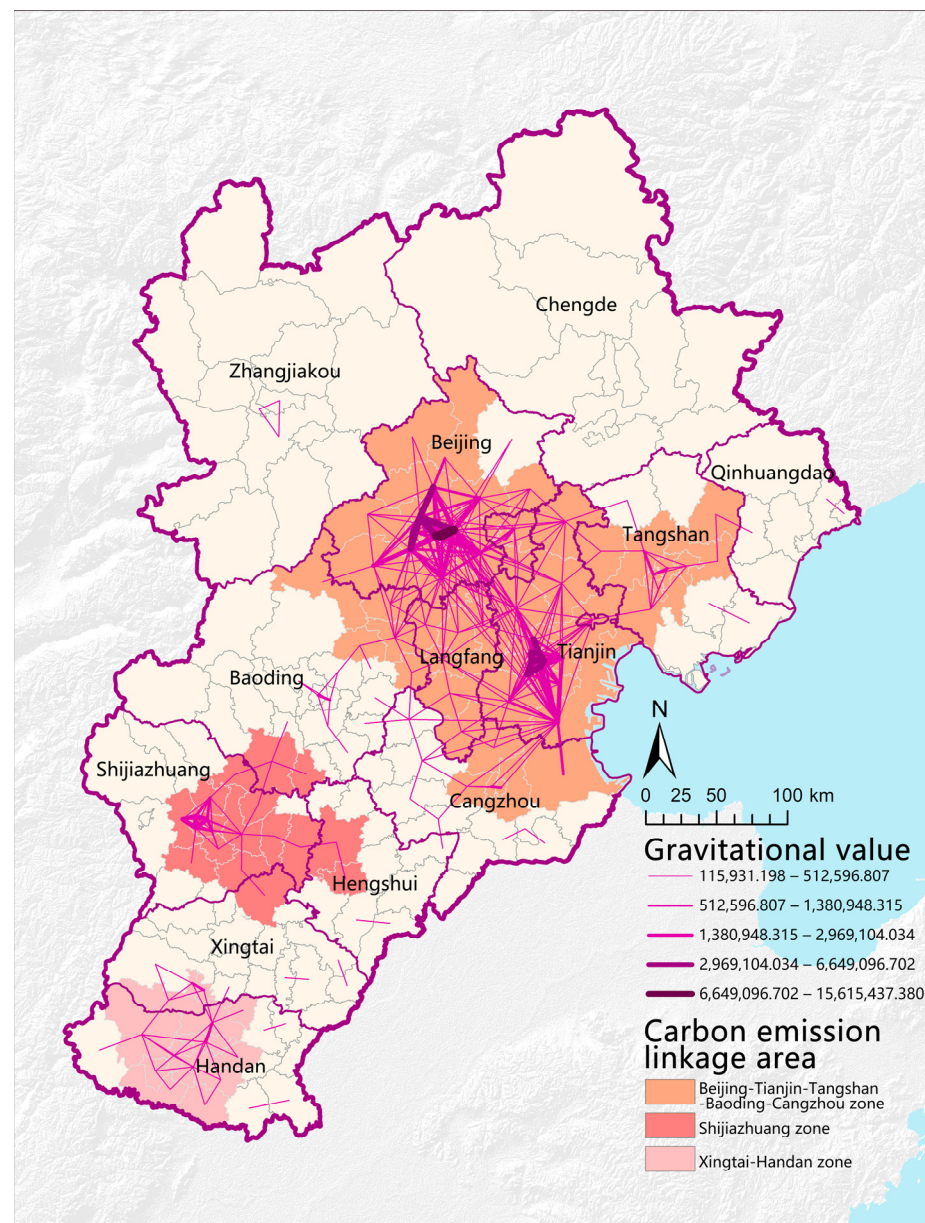


Figure 6. Carbon emission networks under the LCD scenario in the BTH urban agglomeration.

4.2.2. Analysis of the Centrality of Counties in the Carbon Emission Networks

Analyzing and visualizing the centrality of the counties in the networks further clarifies the key counties in the carbon emission networks in the BTH urban agglomeration and

4.3. Carbon Balance Planning for the BTH Urban Agglomeration in 2035 under the LCD Scenario

Based on the multi-scenario carbon emission simulation, we selected the EP scenario with lower carbon emissions and more counties with high ESC values as the LCD scenario for the BTH urban agglomeration in 2035. Utilizing the ESC analysis, carbon emission spatial network characteristics, and network centrality of each county under this scenario, we formulated low-carbon-oriented carbon balance zoning planning and carbon balance key county planning.

4.3.1. Carbon Balance Zoning Planning

The carbon balance zoning planning was based mainly on the ESC results discussed in Section 4.1.4 and the carbon emission linkage area summarized in the carbon emission network within the urban agglomeration discussed in Section 4.2.1. According to the planning method of carbon balance zoning plan in Section 3.4.1, we divided the zones into four types of zones, and the division process is shown in Figure 8. We divided the BTH urban agglomeration into 33 carbon sink balance areas, six ecological conservation areas, 88 carbon emission linkage control areas, and 74 low-carbon control areas (Table 8).

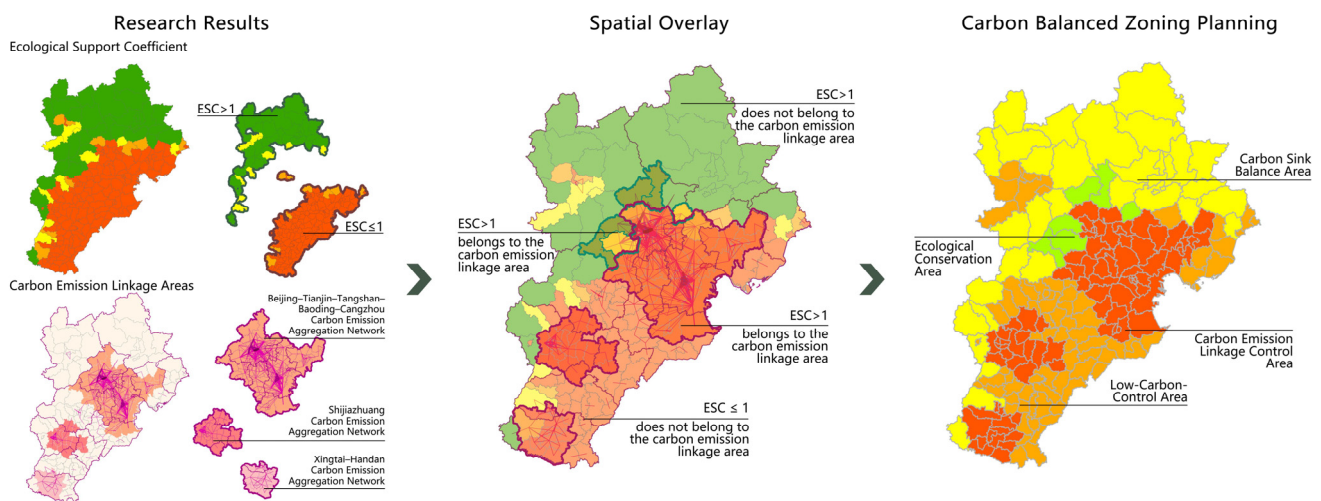


Figure 8. Flowchart of carbon balance zoning planning.

Table 8. Carbon balance zoning planning for the BTH urban agglomeration in 2035 under the LCD scenario.

Carbon-Balance Zoning	Division Criteria	Functional Features
Ecological conservation area	ESC > 1, belongs to the carbon emission linkage area	The ecological conservation area primarily resided in the northwestern region of the Beijing–Tianjin–Tangshan–Baoding–Cangzhou carbon emission linkage area. It accounted for 4.699% of the urban agglomeration area. The region has strong carbon sink capacity and is situated within the carbon emission linkage area, so it can give full play to the carbon sink regulation capacity of the ecological region and drive the overall coordinated emission reduction within the carbon emission network.
Carbon sink balance area	ESC > 1, does not belong to the carbon emission linkage area	The carbon sink balance area was located mainly in the northwestern part of Hebei Province. It accounted for 43.322% of the urban agglomeration area and was composed mainly of 33 counties. The region has a strong ecological function, high carbon sink benefit, and low carbon emissions, so it is suitable to introduce economically developed county industries appropriately and continue to carry out ecological environmental construction.

Table 8. Cont.

Carbon-Balance Zoning	Division Criteria	Functional Features
Carbon emission linkage control area	$ESC \leq 1$, belongs to the carbon emission linkage area	The carbon emission linkage control area was composed mainly of counties in three carbon emission linkage areas. It accounted for 22.207% of the urban agglomeration area and was composed mainly of 87 counties. The region exhibits significant carbon emissions and is integrated into the carbon emission network, enabling it to effectively utilize the influence mechanism of the carbon emission network and establish a regional carbon emission reduction linkage system [20].
Low-carbon control area	$ESC \leq 1$, does not belong to the carbon emission linkage area	The low-carbon control area was located mainly in the central and southern parts of the urban agglomeration. It accounted for 25.369% of the urban agglomeration area and was composed of 74 counties. The region has high carbon emissions, but it has less contact with other counties in the BTH region and is difficult for the other counties to affect. It is necessary to strengthen communication with other regions and gradually carry out project cooperation and technical exchanges with provinces and cities.

4.3.2. Key Carbon Balance and County Planning

Based on the centrality analysis of each county in the carbon emission network described in Section 4.2.2, we divided four types of counties according to the planning method of Key Carbon Balance and County Planning in Section 3.4.2. The division process is shown in Figure 9. Based on indegree centrality, outdegree centrality, in-closeness centrality, and betweenness centrality, we identified four types of key counties: core counties, promotion counties, bridge counties, and improvement counties (Table 9 and Figure 10).

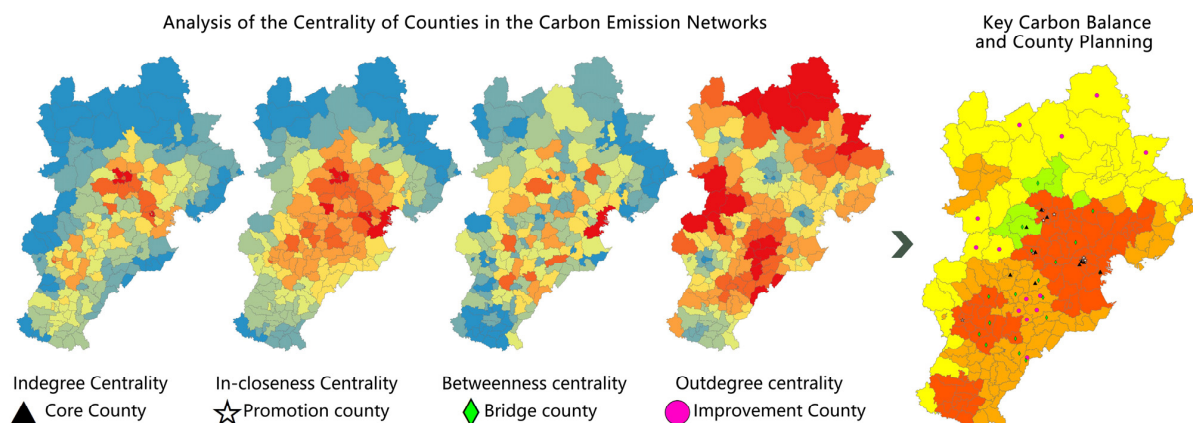


Figure 9. Flowchart of key carbon balance and county planning.

Table 9. Planning of key counties for carbon balance in 2035 under the LCD scenario in the BTH urban agglomeration.

County Type	Division Criteria	Functional Features
Core county	Counties with higher indegree centrality	These counties dominate the central position within the carbon emission network, deserving top priority in shaping regional policies for carbon emission reduction. The optimization of socioeconomic development and energy development top-level design in these core counties is essential. The construction of a carbon emission trading market should be strengthened with market-oriented low-carbon mechanisms.
Promotion county	Counties with higher in-closeness centrality	Counties that are more connected to other counties can change their carbon emission behaviors and the carbon emission behaviors of their neighboring counties more quickly, so they should be used as promotion counties for carbon emission reduction and sink increase, further promoting emission peak and carbon neutrality policies according to local conditions. The government can learn from the experience of advanced cities to promote the effective implementation of coordinated emission reduction planning.

Table 9. Cont.

County Type	Division Criteria	Functional Features
Bridge county	Counties with higher betweenness centrality	Counties that play a communication role in the network can control the coordinated emission reduction process in other cities in a planned manner. These counties provide network communication and can carry out key planning control. By limiting some functions, the government can minimize the exchange of ineffective carbon emissions, impede unnecessary carbon emission connections.
Improvement county	Counties with higher outdegree centrality	These counties exhibit a greater number of spatial spillover relationships within the carbon emission network and bear a higher burden of carbon emissions. Their ecological conservation function is strong, and their spillover effect can be used to carry out ecological environmental construction and avoid ecological degradation caused by overurbanization and industrial development.

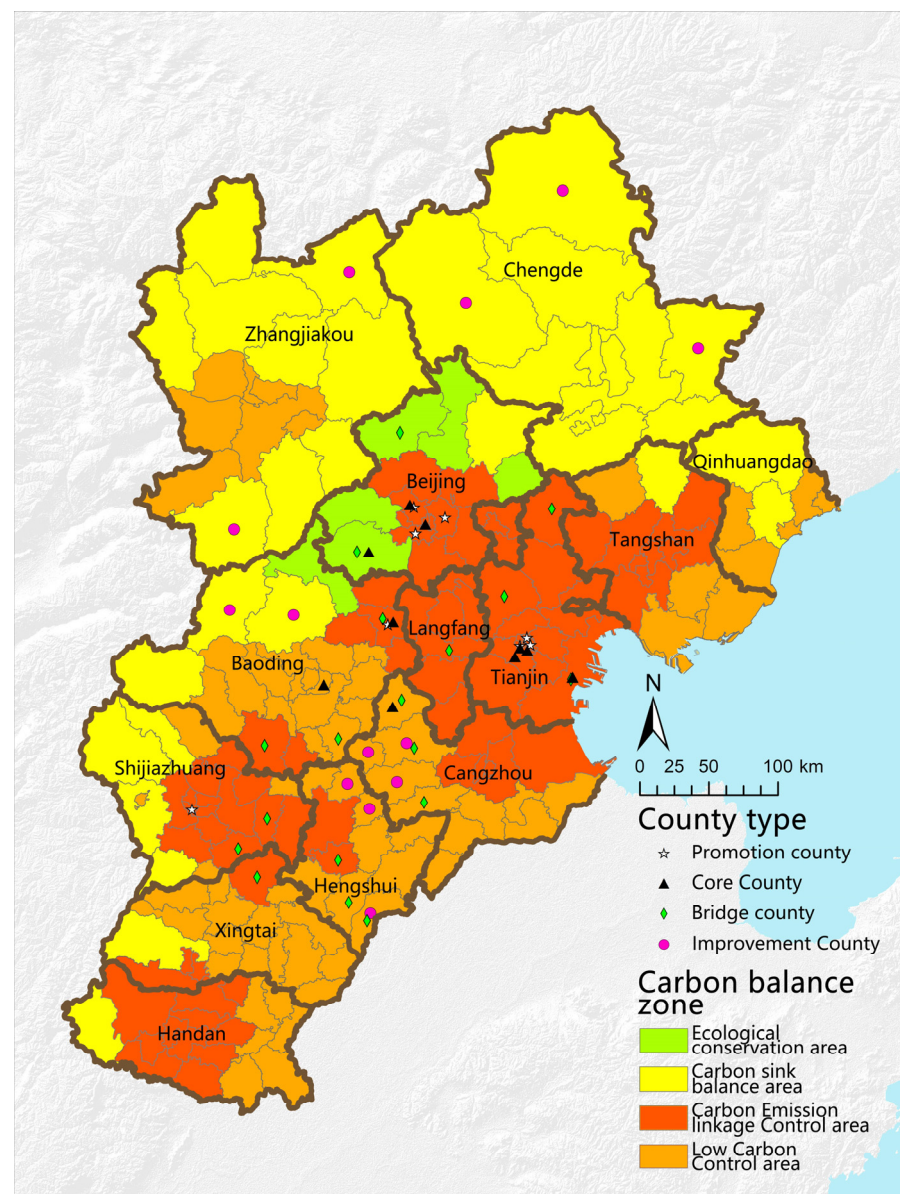


Figure 10. Carbon balance zoning and key county planning for the BTH urban agglomeration in 2035 under the LCD scenario.

5. Discussion

5.1. Multi-Scenario Simulation of Land Use

By setting different constraints, we conducted simulations of the land use patterns within the BTH urban agglomeration in 2035 under different scenarios. In comparison to the ND scenario, the EP scenario saw a transformation of built-up land in Zhangjiakou and Baoding into forest land and grassland, leading to an increase in their carbon sinks and a reduction in their carbon emissions. In addition, under the EP scenario, carbon emissions were low, and the counties with $ESC > 1$ accounted for a higher percentage of these counties. Carbon emissions in Zhangjiakou and Hengshui decreased significantly. The ecological carrying capacity of the western region of Zhangjiakou improved, transforming from a low-carbon-emission contribution and low-carbon-sink contribution area to a low-carbon-sink contribution and high-carbon-sink contribution area. After comparing the two simulated scenarios, it is evident that the EP scenario imposed stricter limitations on the expansion of built-up land; retained more ecological land, including forest land, shrub, and grassland; produced fewer carbon emissions; eased the problem of the gathering situation of high-carbon-emission areas in spatial patterns, and had stronger carbon sink benefits and ecological benefits. Therefore, we selected the EP scenario as the prediction result for the LCD scenario in the BTH in 2035 for further research and analysis. These research findings demonstrate that through the preservation of ecological functional spaces, controlling unplanned construction land expansion, and execution of policies promoting low-carbon environmental protection development, it is possible to effectively decrease carbon emission intensity and enhance regional carbon sink efficiency. In future planning and construction, these cities will be more conducive to carrying out EP planning actions and maintaining the carbon sequestration benefits of existing forests and grasslands.

We found that carbon emissions were concentrated primarily in the central and eastern counties of the BTH urban agglomeration under the LCD scenario. These findings align with earlier research [42,43]. The ecological support coefficient exhibited higher values in the northwestern region and lower values in the central, southern, and eastern regions. The distribution trend of the overall evaluation results was consistent with the results of a previous study [41], but there were some differences in the distribution of the counties with an $ESC < 1$. Zhang et al. used the Comprehensive Environmental Data Archive's (CEDA) database as the source of carbon emission data to calculate the ESCs of Beijing, Tianjin, and Hebei from 2005 to 2017. In this study, we calculated carbon emissions by setting multiple development scenarios, which was more conducive to evaluating carbon balance under different development scenarios and providing suggestions for the zoning planning of low-carbon transformation and development in BTH urban agglomerations.

5.2. Characteristics of Carbon Emission Spatial Networks

In this study, we utilized SNA to analyze the carbon emission network of the BTH urban agglomeration. The use of SNA to analyze the spatial association of carbon emissions can break through traditional geographic restrictions and identify the intricate spatial network connections in each region [19]. The spatial connections of carbon emissions revealed a network structure with Beijing, Tianjin, Tangshan, Baoding, and Cangzhou at its core, alongside clusters located in Shijiazhuang, as well as in Xingtai and Handan. The spatial arrangement of this clustering aligned with findings from prior research [41]. This network of carbon emission spatial clusters exhibited denser connections compared to other urban areas. The collaborative ability of carbon emission networks could be expressed by the number of network connections. Clustered areas with a large number of connections had stronger collaborative capabilities. Further analysis of typical cities that share the characteristics of this network, as well as exploration of the degree of centralization and its characteristics, could help identify the factors that affect the coordinated emission reduction of urban agglomerations. As a result, it would be possible to better formulate low-carbon plans with different goal orientations based on these characteristics.

The centrality degree indicated the crucial role of the nodes within the network. The top 10% of counties in terms of indegree centrality were located mainly in Beijing and Tianjin, where the economy is more developed. These counties had the following characteristics: they undertook a large number of external carbon emission relationships, their industrial structure was more advanced, and their dependence on basic raw materials and energy imports was strong. Furthermore, these counties reside within the core of the spatial network of carbon emissions, situated centrally within the Beijing–Tianjin–Tangshan–Baoding–Cangzhou carbon emission aggregation network. These findings indicate that augmenting the node count in counties in terms of indegree centrality helped promote carbon emission network collaboration. The focus of coordinating carbon emission networks should be on counties with high indegree centrality. The top 10% of the counties in terms of outdegree centrality were all located in Hebei, and these counties had small carbon emissions and strong ecological conservation functions. This result may have been due to the ecological resource advantages of these counties, but the technology level was low and the energy utilization rate was low. Although the core position of the network in these counties was higher than that of other resource-based cities with better ecological benefits, it was still in the middle to low end of the value range in the carbon emission network. These results prove that remote geographical locations, underdeveloped economies, and population levels acted as impediments to the coordinated development of carbon emission networks. Therefore, special consideration should be given to these counties when devising policies, given their relatively passive position in the carbon emission network. As it would be difficult for these counties to achieve positive cooperative effects, more policy support should be given to them.

The closeness of centrality primarily characterized the spatial transfer distance of carbon emissions from counties and determined whether or not carbon transfer links with other counties could be produced more quickly. The top 10% of counties with in-closeness centrality are located in Beijing, Tianjin, and Baoding. These counties shared the following characteristics: they were highly involved in the spatial network of carbon emission integration and established extensive carbon emission links with the surrounding counties, thus becoming central actors in the network. It remains crucial to enhance the connection between hub cities and surrounding cities, enhance their communication, and enhance the synergy of carbon emission networks, thus enabling them to quickly take advantage of regional linkage mechanisms. The top 10% of counties with out-closeness centrality were concentrated in Hengshui, Baoding, and Cangzhou in Hebei Province. These counties occupied a subordinate position in the network and were easily influenced by other regions to make corresponding changes.

Betweenness centrality represented the communication function of one county with other counties. The top 10% of counties are located primarily in Baoding, Beijing, Cangzhou, Hengshui, and Tianjin. The distribution of these counties was relatively scattered and these counties were located in the outskirts areas of key cities. Counties with higher betweenness centrality were more likely to establish carbon emission networks, which meant that carbon emissions between provinces could be exchanged mainly through these cities. This result proved that enhancing the centrality of betweenness could strengthen the transfer of carbon emissions between provinces and promote regional collaboration in carbon emission networks. The counties with high betweenness centrality formed the central relationships connecting surrounding counties, served as good communication bridges, and held great significance in improving the carbon emission network structure.

In summary, fostering collaboration within the carbon emission network in the BTH urban agglomeration requires boosting the centrality of county nodes and internal connectivity. In counties with higher centrality of entry, key policies should be implemented to increase foreign exchange and reduce emissions. Cities with higher inward proximity should be used as policy pilots to strengthen the connections between counties with higher centrality of intermediaries to drive carbon exchange between provinces. Counties with higher centrality of entry should be given more policy assistance. To optimize coordinated

regional emission reduction planning, it is essential to comprehensively manage the spatial structure characteristics of urban agglomerations, regulate the association mode, internal groups, and regional status of carbon emissions, and align with the principles of social and economic development [18].

5.3. Recommendations for Key Areas for the Implementation of Emission Peak and Carbon Neutrality Projects

In crafting and executing carbon emission reduction policies, our attention was directed towards the spatial interconnection impact of carbon emissions within the urban agglomeration. We devised a low-carbon-centric carbon balance zoning strategy, leveraging insights from the ESC, spatial network properties of carbon emissions, and network centrality assessment. On this basis, we could further adopt differentiated development strategies for different counties according to the specifics of carbon balance zoning across various regions of the BTH and the functions of key counties in carbon balance. Taking four characteristic counties and two groups of cross-regional cooperation counties as examples, we propose the suggestions given in Table 10 and shown in Figure 11.

The Fangshan District, located in Beijing, is in the ecological conservation area and undertakes the functions of promoting counties and bridge counties. The eastern part of the region is projected to experience a rise in built-up land, while the western part is anticipated to witness an expansion of forest land and grassland. In terms of carbon reduction, we should concentrate on the construction of three high-tech groups in the east and advocate for the development direction of low carbon. To foster compact urban development, efforts will be intensified to promote the construction of bus lanes and dedicated roads [44–46]. In terms of increasing foreign exchange, we should construct a recreational and cultural green belt in the plain area [47–49].

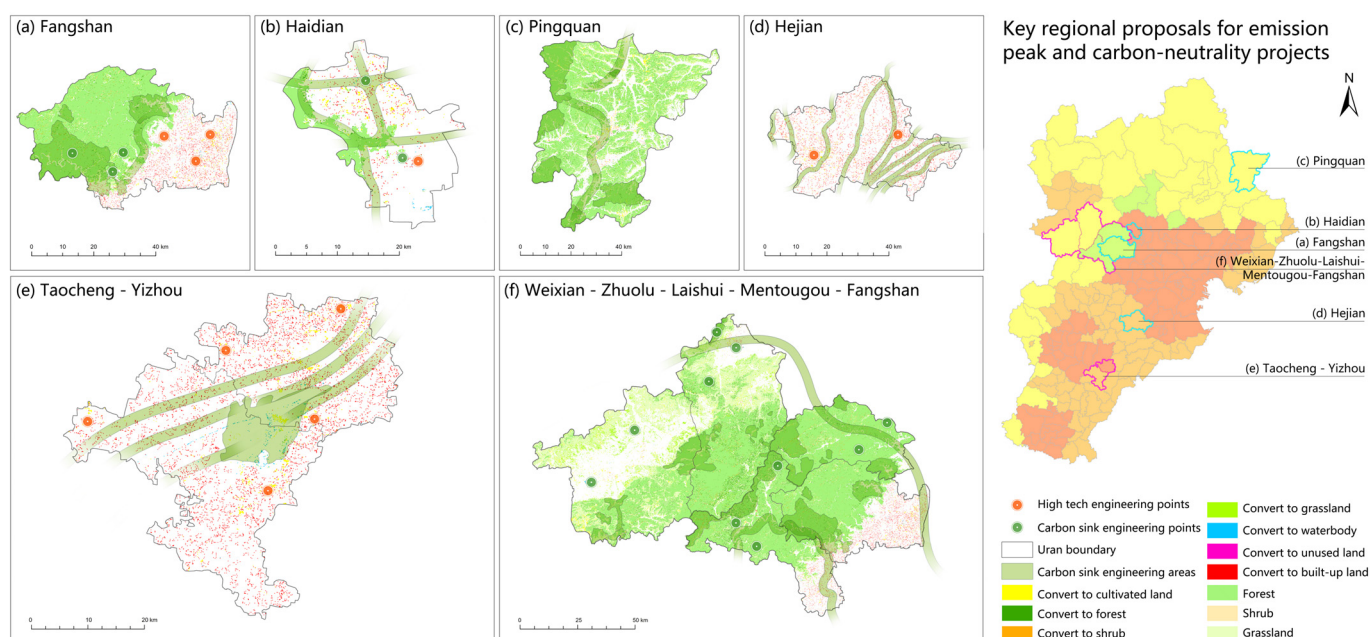


Figure 11. Key regional proposals for emission peak and carbon neutrality engineering for the BTH urban agglomeration in 2035 under the LCD scenario.

The Haidian District, located in Beijing, is in the carbon emission linkage control area and serves the functions of core counties and promotion counties. In the forthcoming years, the northern region is expected to witness an augmentation in both built-up and cultivated land, while forest land is projected to expand in the northwest. For carbon reduction endeavors, our focal point should center on Zhongguancun Science City situated in the southern region. It will spearhead the synchronized advancement of low-carbon

technology across the carbon emission linkage area [50–52] and promote active and public transportation by improving street connectivity [53–55]. In terms of increasing sinks, in the future, we should establish the ecological barrier of Xishan Mountain in the northwest as the core position [56–58].

Table 10. Key regional proposals for emission peak and carbon neutrality projects in the BTH urban agglomeration in 2035 under LCD scenarios.

Region Type	Prefecture -Level City	County	Carbon Balance Zoning	County Type	Key Areas for Emission Peak and Carbon Neutrality Projects
Single County	Beijing	Fangshan District	Ecological Conservation Area	Extension County, Bridge County	Carbon reduction: Yanfang, Liangxiang, Doudian, three high-tech clusters Sink enhancement: Juma River Basin, Shidu Scenic Spot, Shihua Cave Scenic Spot, Baicao Riverside Scenic Spot, Yongding River Forest Wetland Leisure Belt.
	Beijing	Haidian District	Carbon Emission Linkage Control Area	Core County, Promotion County	Carbon reduction: Zhongguancun Science City Sink enhancement: Xishan Ecological Barrier, Green Heart of Three Hills and Five Gardens, Green Heart of Ecological Science and Technology.
	Chengde	Pingquan City	Carbon Sink Balance Area	Improvement County	Sink enhancement: ecological protection of Liaoheyuan Forest Ecological Reserve, Shihu Forest Park, Qinghe Forest Park, Yamenzi Forest Park, Shuangfengshan Forest Park, Shanwanzi Forest Park, Longtanshan Forest Park, Pu River Waterfront Ecological Corridor.
	Cangzhou	Hejian City	Low-Carbon Control Area	Improvement County, Bridge County	Carbon reduction: central urban area and eastern cluster Sink enhancement: Nine River System (referring to the nine main rivers in the city, including east branch of Xiaobai River, Yujia River, Guyang River, east branch of Ren River, west branch of Ren River, Ziya River, Beipai River, and west branch of Heilonggang River).
Cross-Regional Cooperation	Hengshui	Taocheng District, Jizhou District	Carbon Emission Linkage Control Area, Low-Carbon Control Area	Bridge County	Carbon reduction: National Demonstration Zone for Transformation of Scientific and Technological Achievements to the south of Beijing, Hengshui High-Tech Industry Development Zone, Taocheng High-Tech Industry Development Zone, and Jizhou High-Tech Industry Development Zone Sink enhancement: Hengshui Lake National Nature Reserve, Fuyang River Water Ecological Comprehensive Renovation Area, Taocheng Urban Area–Binhu New Area and Jizhou Urban Area Blue and Green Space System, Fuyang New River–Fudong Pai River Flood Discharge Corridor, Fuyang River, and Yanhe Old Course.
	Zhangjiakou–Baoding–Beijing	Yu county, Zhuolu County, Laishui County, Mentougou District, Fangshan District	Carbon Sink Balance Area, Ecological Conservation Area	Bridge County, Promotion County, Improvement County	Sink enhancement: Important water ecological corridor: Mentougou District–Fangshan District–Yu County–Zhuolu County: Yongding River Basin (Zhangjiakou Section) Laishui County–Fangshan District: Water Source Protection Area of Juma River Basin Important nature reserves: Yu County–Zhuolu County: Xiaowutai Mountain National Forest Ecological Reserve in Hebei Province Zhuolu County–Laishui County: Jinhua Mountain–Henglingzi Crossoptilon Mantchuricum Nature Reserve Mentougou District–Fangshan District: Beijing Baihuashan National Forest Ecological Reserve.

Pingquan City, located in Chengde, is in the carbon sink balance area and serves as an improvement county. In the forthcoming years, we anticipate a rise in forest land, grassland, and cultivated land across the entire region. It is crucial to take advantage of these additional regional ecological benefits. In terms of carbon reduction, we should strengthen Pingquan’s support of Beijing’s noncapital functions and actively accept carbon emission spillover within the Beijing–Tianjin region [59–61]. In terms of increasing sinks, we should cooperate with the BTH and Liaoning–Inner Mongolia regions to carry out ecological protection [62–65].

Hejian City, located in Cangzhou, is in the low-carbon control area and serves as an improvement country and bridge country. In the future, there will be a trend of growth in both built-up and cultivated land across the entire region. Therefore, it is essential to prioritize efforts towards promoting carbon reduction initiatives. In terms of carbon reduction, we should decrease reliance on fossil fuels while concurrently elevating the utilization of nuclear and renewable energy sources [66,67]. To augment sinks, it is imperative to establish an ecological security pattern grounded in agriculture, forestry, and water networks. Improve agricultural technology [68], advocate for improving the dietary structure of residents [69–71], and reduce the indiscriminate use of fertilizers, organic fertilizers, and chemical fertilizers [72].

The Taocheng District and Jizhou District, located in Hengshui, are in the carbon emission linkage control area and the low-carbon control area, respectively, and serve as bridge counties. In the future, there will be a surge in built-up land on the periphery of the region and an expansion of water bodies in the central area and cultivated land. To advance carbon reduction, fostering interregional collaboration and establishing a national demonstration zone for the conversion of scientific and technological advancements in the southern part of Beijing is crucial [73,74]. We should conform to the expansion trend of the central waterbody in the aspect of increasing the sinks and should carry out ecological restoration in the Fuyang River water ecological comprehensive renovation area around the regional central Hengshui Lake National Nature Reserve [75,76]. We should also promote scientific planning and the construction of tourist areas [77,78].

Yu County and Zhuolu County are located in Zhangjiakou, Laishui County is located in Baoding, and the Mentougou District and Fangshan District are located in Beijing. These counties are in the carbon sink balance area and ecological conservation area. In the future, they will follow a trend of increasing forest land, grassland, and cultivated land. In terms of increasing sinks, we should establish a way of putting regional coordinated ecological restoration planning into action; take advantage of the characteristic county role of bridge, promotion, and improvement counties [79,80]; carry out industry structure adjustment; and coordinate the implementation of emission peak and carbon neutrality policy projects. For the important nature reserves, we should carry out regional coordinated habitat protection optimization and ecological corridor construction. We should also increase the number of nature reserves [81,82].

5.4. A Low-Carbon-Oriented Urban Agglomeration Planning Framework

Numerous studies have consistently demonstrated the pivotal role of regional spatial planning in mitigating regional carbon emissions and attaining climate objectives [83–85]. First, spatial planning is comprehensive and can regulate the spatial division of urban agglomerations on a macroscopic scale [86]. Second, spatial planning helps determine the characteristics of cities and formulate differentiated development policies based on the social and economic disparities within the urban agglomeration [87]. Additionally, spatial planning assists in reorganizing spatial relationships within the region, ensuring the balanced and coordinated development of spaces, including residential, commercial, transportation, service, and ecological areas [84]. Given the significance of spatial planning in reducing regional carbon emissions, this study proposes a low-carbon-oriented carbon balance spatial planning method for future urban agglomerations (Figure 12). The overall planning method can be split into four steps:

- (1) By simulating multiple scenarios of land use, we calculated the carbon emissions of urban agglomerations under different scenarios for the future, selected development scenarios align more favorably with low-carbon principles, and optimized the overall spatial scale of regional carbon emissions from the standpoint of urban agglomerations. This approach has been validated in most urban studies [88–90], demonstrating that this top-down carbon reduction strategy can be used to adjust future urban land demand, formulate urban expansion plans with minimal ecological losses, and promote compact and green urban development.

- (2) Taking into account the carbon emission characteristics and spatial correlation of urban agglomerations, we utilized carbon balance zoning planning to delineate four distinct carbon balance-oriented zones at the internal spatial correlation level of urban agglomerations. This approach clarifies the spatial development pattern of carbon emissions within urban agglomerations and addresses the question of how to perceive spatial carbon effects. Regional planning with different orientations helps divide the “zoning entities” under the concept of functional control of the main body. The “zoning” control emphasizes respecting and balancing the different roles played by different zoning entities in regulating regional carbon balance, to better protect ecological space and coordinate urban spatial development [43,91].
- (3) Through the analysis of individual network characteristics in social network analysis, we developed the key carbon balance and county planning based on the centrality indicators of each county and analyzed their position within the carbon emission network. Clear guidance and development goals for carbon reduction actions in different counties were established. In the field of urban planning, the literature has shown that governments and policymakers worldwide intend to utilize various data and measurement methods to ascertain urban characteristics; summarize regional political, economic, and social characteristics; and plan cities based on these factors to better address the needs of people regarding housing, economic opportunities, and social system changes [87].
- (4) Finally, we developed key areas for the implementation of emission peak and carbon neutrality projects by analyzing the land features within the county. By scaling down from the level of urban agglomerations, we analyzed the composition of land parcel elements within the county. By optimizing the structure of industrial land, energy land, ecological land, agricultural land, and transportation land, we further optimized the structure of the carbon-source and carbon-sink land and implemented urban spatial planning accordingly. We guided the practice of county-level urban spatial planning in terms of low-carbon layout, low-carbon industries, low-carbon transportation, low-carbon human settlements, and ecological green spaces to better regulate carbon spatial layout and formulate a carbon intensity design. Urban and transportation planners have conducted various studies on achieving carbon neutrality goals at this level, and combined with the low-carbon planning tasks of county-level urban spaces, they have screened and extracted planning and control elements from both qualitative and quantitative perspectives, and implemented them in practice [45,92–94].

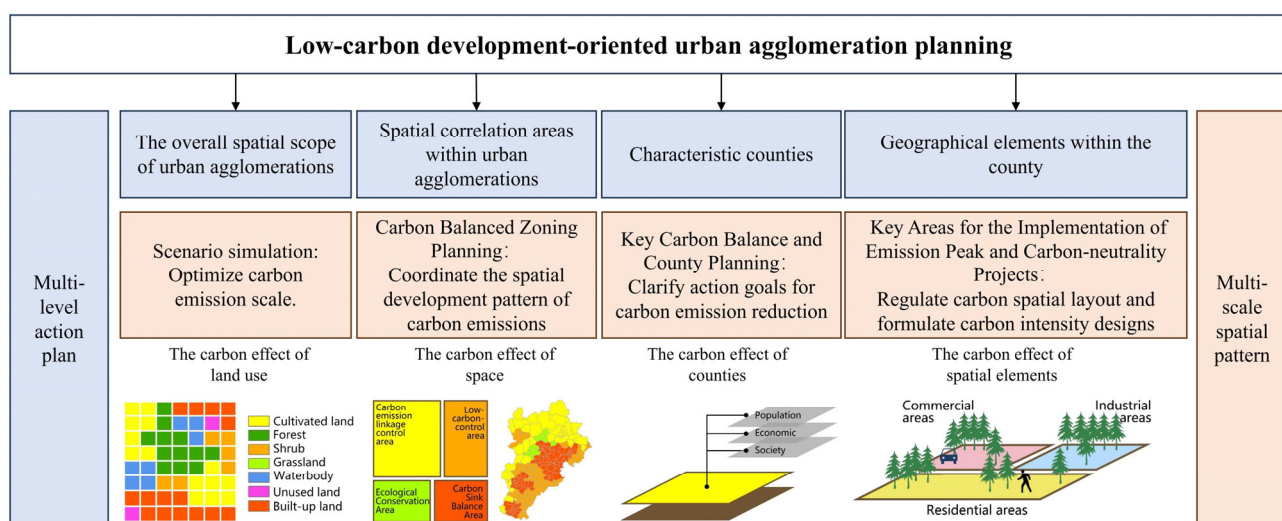


Figure 12. A low-carbon-oriented urban agglomeration planning framework.

In summary, we started from four levels: the overall space of the urban agglomeration, the spatial correlation areas within the urban agglomeration, each county, and the internal

land features within the county. We optimized the carbon emission scale through scenario simulation, coordinated the carbon emission spatial development pattern through carbon balance zoning planning, clarified the carbon emission action goals through key carbon balance and county planning, and finally, established key areas for the implementation of emission peak and carbon neutrality projects to regulate the carbon spatial layout and formulate carbon intensity designs in response to the carbon effects of land types, space, urban areas, and spatial elements. By starting from a multi-scale spatial pattern, developing multilevel action plans, constructing a planning policy framework, and integrating carbon reduction and sink enhancement goals into multilevel and multi-class spatial planning, we aim to achieve the leading, comprehensive, and fundamental nature of regional carbon reduction policies, thereby more widely guiding their application in major urban agglomerations around the world.

5.5. Limitations

While this study examined the interplay between future land use changes and social networks within spatial planning, it is important to acknowledge certain limitations. Specifically, during the process of simulating land use carbon emissions, variations in carbon emission intensities across different land use types and years might have existed, particularly concerning built-up land. In the process of comparing future development scenarios, however, this research method can still effectively screen more low-carbon simulation results, and these results can be used as an optimization guide to build a carbon-neutral territorial spatial pattern system. Additionally, although this study developed a multi-scale and multilevel research framework through calculations and references to articles from various planning fields worldwide, it has not yet been validated through virtual simulation models to evaluate the feasibility of planning policies. In future research, it would be valuable to conduct additional evaluation studies to assess the effectiveness of carbon emission reduction planning initiatives.

6. Conclusions and Contribution

In this study, we focused on the urban agglomeration comprising BTH county-level units as our research subject. We established a theoretical framework for carbon balance planning from the standpoint of low-carbon development. Future land use patterns were simulated under different development scenarios, and we selected low-carbon-oriented development models. On this basis, we introduced the socioeconomic factors of the urban agglomeration and constructed a spatial association network of the carbon emissions in the BTH urban agglomeration under LCD scenarios. Based on the spatial network characteristics and centrality characteristics, we carried out carbon balance zoning planning, clarified the functional characteristics of the different zoning areas and key counties, delineated the key areas for carbon neutrality projects, and proposed suggestions. The primary findings of the research are outlined below:

1. We simulated land use patterns under the ND and EP scenarios in the BTH in 2035. Carbon emissions from land use under the EP scenario decreased by 643.42×10^4 t. The spatial distribution was characterized by lower carbon emission and higher ESC values in the northwest and higher carbon emissions and lower ESC values in the central, southern, and eastern regions. We selected the EP scenario as the prediction result of the LCD scenario for the BTH in 2035 for further analysis;
2. Carbon emissions within the BTH were closely related, forming three major carbon emission linkage areas: Beijing–Tianjin–Tangshan–Baoding–Cangzhou, Shijiazhuang, and Xingtai–Handan. The counties of Beijing, Tianjin, Baoding, Hengshui, and Cangzhou and other cities in the central region had different levels of individual centrality.
3. Based on the characteristics of the ESC and carbon emission network, we formulated a carbon balance zoning plan for the BTH urban agglomeration in 2035 under the LCD scenario. The urban agglomeration underwent division into four areas: eco-

logical conservation, carbon sink balance, carbon emission control, and low-carbon control areas. Furthermore, we selected the core counties, promotion counties, bridge counties, and improvement counties according to the characteristics of the network centrality. We pinpointed critical zones for the execution of emission peak and carbon neutrality projects within the distinctive counties. Furthermore, we put forth tailored recommendations aimed at mitigating carbon emissions and augmenting carbon sinks based on the prevailing characteristics of the study area.

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References

1. Masson-Delmotte, V.; Zhai, P.; Pirani, A.; Connors, S.L.; Péan, C.; Berger, S.; Caud, N.; Chen, Y.; Goldfarb, L.; Gomis, M. Climate change 2021: The physical science basis. In *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; 2021; Volume 2, p. 2391. Available online: <https://www.ipcc.ch/report/ar6/wg1/> (accessed on 15 April 2024).
2. Pachauri, R.K.; Gomez-Echeverri, L.; Riahi, K. *Synthesis Report: Summary for Policy Makers*, 2014; pp. 1–30.
3. Meng, L.; Graus, W.; Worrell, E.; Huang, B. Estimating CO₂ (carbon dioxide) emissions at urban scales by DMSP/OLS (Defense Meteorological Satellite Program’s Operational Linescan System) nighttime light imagery: Methodological challenges and a case study for China. *Energy* **2014**, *71*, 468–478. [\[CrossRef\]](#)
4. Li, L.; Ma, S.; Zheng, Y.; Xiao, X. Integrated regional development: Comparison of urban agglomeration policies in China. *Land Use Policy* **2022**, *114*, 105939. [\[CrossRef\]](#)
5. Lin, Q.; Zhang, L.; Qiu, B.; Zhao, Y.; Wei, C. Spatiotemporal analysis of land-use patterns on carbon emissions in China. *Land* **2021**, *10*, 141. [\[CrossRef\]](#)
6. Li, W.; Ciais, P.; Peng, S.; Yue, C.; Wang, Y.; Thurner, M.; Saatchi, S.S.; Arneeth, A.; Avitabile, V.; Carvalhais, N. Land-use and land-cover change carbon emissions between 1901 and 2012 constrained by biomass observations. *Biogeosciences* **2017**, *14*, 5053–5067. [\[CrossRef\]](#)
7. Zhao, J.; Cohen, J.B.; Chen, Y.; Cui, W.; Cao, Q.; Yang, T.; Li, G. High-resolution spatiotemporal patterns of China’s FFCO₂ emissions under the impact of LUCC from 2000 to 2015. *Environ. Res. Lett.* **2020**, *15*, 044007. [\[CrossRef\]](#)
8. Jing, Q.; Bai, H.; Luo, W.; Cai, B.; Xu, H. A top-bottom method for city-scale energy-related CO₂ emissions estimation: A case study of 41 Chinese cities. *J. Clean. Prod.* **2018**, *202*, 444–455. [\[CrossRef\]](#)
9. Yang, S.; Fu, W.; Hu, S.; Ran, P. Watershed carbon compensation based on land use change: Evidence from the Yangtze River Economic Belt. *Habitat Int.* **2022**, *126*, 102613. [\[CrossRef\]](#)
10. Basse, R.M.; Omrani, H.; Charif, O.; Gerber, P.; Bódis, K. Land use changes modelling using advanced methods: Cellular automata and artificial neural networks. The spatial and explicit representation of land cover dynamics at the cross-border region scale. *Appl. Geogr.* **2014**, *53*, 160–171. [\[CrossRef\]](#)
11. Ku, C.-A. Incorporating spatial regression model into cellular automata for simulating land use change. *Appl. Geogr.* **2016**, *69*, 1–9. [\[CrossRef\]](#)
12. Verburg, P.H.; Soepboer, W.; Veldkamp, A.; Limpiada, R.; Espaldon, V.; Mastura, S.S. Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environ. Manag.* **2002**, *30*, 391–405. [\[CrossRef\]](#)
13. Liu, X.; Liang, X.; Li, X.; Xu, X.; Ou, J.; Chen, Y.; Li, S.; Wang, S.; Pei, F. A future land use simulation model (FLUS) for simulating multiple land use scenarios by coupling human and natural effects. *Landsc. Urban Plan.* **2017**, *168*, 94–116. [\[CrossRef\]](#)
14. Xie, L.; Bai, Z.; Yang, B.; Fu, S. Simulation Analysis of Land-Use Pattern Evolution and Valuation of Terrestrial Ecosystem Carbon Storage of Changzhi City, China. *Land* **2022**, *11*, 1270. [\[CrossRef\]](#)
15. Dong, L.; Liang, H.; Zhang, L.; Liu, Z.; Gao, Z.; Hu, M. Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China. *Ecol. Model.* **2017**, *361*, 164–176. [\[CrossRef\]](#)

16. Qian, Y.; Wang, H.; Wu, J. Spatiotemporal association of carbon dioxide emissions in China's urban agglomerations. *J. Environ. Manag.* **2022**, *323*, 116109. [[CrossRef](#)] [[PubMed](#)]
17. Shen, W.; Liang, H.; Dong, L.; Ren, J.; Wang, G. Synergistic CO₂ reduction effects in Chinese urban agglomerations: Perspectives from social network analysis. *Sci. Total Environ.* **2021**, *798*, 149352. [[CrossRef](#)]
18. Dong, J.; Li, C. Structure characteristics and influencing factors of China's carbon emission spatial correlation network: A study based on the dimension of urban agglomerations. *Sci. Total Environ.* **2022**, *853*, 158613. [[CrossRef](#)]
19. Yu, Z.; Chen, L.; Tong, H.; Chen, L.; Zhang, T.; Li, L.; Yuan, L.; Xiao, J.; Wu, R.; Bai, L. Spatial correlations of land-use carbon emissions in the Yangtze River Delta region: A perspective from social network analysis. *Ecol. Indic.* **2022**, *142*, 109147. [[CrossRef](#)]
20. Wang, C.; Zhan, J.; Zhang, F.; Liu, W.; Twumasi-Ankrah, M.J. Analysis of urban carbon balance based on land use dynamics in the Beijing-Tianjin-Hebei region, China. *J. Clean. Prod.* **2021**, *281*, 125138. [[CrossRef](#)]
21. Hurlimann, A.; Moosavi, S.; Browne, G.R. Urban planning policy must do more to integrate climate change adaptation and mitigation actions. *Land Use Policy* **2021**, *101*, 105188. [[CrossRef](#)]
22. Haas, J.; Ban, Y. Urban growth and environmental impacts in jing-jin-ji, the yangtze, river delta and the pearl river delta. *Int. J. Appl. Earth Obs. Geoinf.* **2014**, *30*, 42–55. [[CrossRef](#)]
23. Gu, R.; Li, C.; Li, D.; Yang, Y.; Gu, S. The impact of rationalization and upgrading of industrial structure on carbon emissions in the Beijing-Tianjin-Hebei urban agglomeration. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7997. [[CrossRef](#)] [[PubMed](#)]
24. Yang, J.; Huang, X. The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019. *Earth Syst. Sci. Data* **2021**, *13*, 3907–3925. [[CrossRef](#)]
25. Zhong, X.; Yan, Q.; Li, G. Development of the Long Time Series Nighttime Light Dataset of China (2000–2020). *J. Glob. Chang. Data Discov.* **2022**, *3*, 420–428.
26. Li, X.; Liu, Z.; Li, S.; Li, Y. Multi-scenario simulation analysis of land use impacts on habitat quality in Tianjin based on the PLUS model coupled with the InVEST model. *Sustainability* **2022**, *14*, 6923. [[CrossRef](#)]
27. Luo, S.; Hu, X.; Sun, Y.; Yan, C.; Zhang, X. Multi-scenario land use change and its impact on carbon storage based on coupled Plus-Invest model. *Chin. J. Eco-Agric.* **2023**, *31*, 300–314.
28. Cui, X.; Wei, X.; Liu, W.; Zhang, F.; Li, Z. Spatial and temporal analysis of carbon sources and sinks through land use/cover changes in the Beijing-Tianjin-Hebei urban agglomeration region. *Phys. Chem. Earth Parts A/B/C* **2019**, *110*, 61–70. [[CrossRef](#)]
29. Fang, J.; Guo, Z.; Piao, S.; Chen, A. Terrestrial vegetation carbon sinks in China, 1981–2000. *Sci. China Ser. D Earth Sci.* **2007**, *50*, 1341–1350. [[CrossRef](#)]
30. Liu, C.; Xu, R.; Xu, K.; Lin, Y.; Cao, Y. Carbon Emission Effects of Land Use in Chaobai River Region of Beijing–Tianjin–Hebei, China. *Land* **2023**, *12*, 1168. [[CrossRef](#)]
31. She, W.; Wu, Y.; Huang, H.; Chen, Z.; Cui, G.; Zheng, H.; Guan, C.; Chen, F. Integrative analysis of carbon structure and carbon sink function for major crop production in China's typical agriculture regions. *J. Clean. Prod.* **2017**, *162*, 702–708. [[CrossRef](#)]
32. Tang, X.; Zhao, X.; Bai, Y.; Tang, Z.; Wang, W.; Zhao, Y.; Wan, H.; Xie, Z.; Shi, X.; Wu, B. Carbon pools in China's terrestrial ecosystems: New estimates based on an intensive field survey. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 4021–4026. [[CrossRef](#)]
33. Yan, H.; Guo, X.; Zhao, S.; Yang, H. Variation of net carbon emissions from land use change in the Beijing-Tianjin-Hebei region during 1990–2020. *Land* **2022**, *11*, 997. [[CrossRef](#)]
34. Huang, H.; Zhou, J. Study on the spatial and temporal differentiation pattern of carbon emission and carbon compensation in China's provincial areas. *Sustainability* **2022**, *14*, 7627. [[CrossRef](#)]
35. Rong, T.; Zhang, P.; Jing, W.; Zhang, Y.; Li, Y.; Yang, D.; Yang, J.; Chang, H.; Ge, L. Carbon dioxide emissions and their driving forces of land use change based on Economic Contributive Coefficient (ECC) and Ecological Support Coefficient (ESC) in the lower Yellow river region (1995–2018). *Energies* **2020**, *13*, 2600. [[CrossRef](#)]
36. Wang, F.; Gao, M.; Liu, J.; Fan, W. The spatial network structure of China's regional carbon emissions and its network effect. *Energies* **2018**, *11*, 2706. [[CrossRef](#)]
37. Ho, H.-X.T. Forecasting of CO₂ emissions, renewable energy consumption and economic growth in vietnam using grey models. In Proceedings of the 2018 4th International Conference on Green Technology and Sustainable Development (GTSD), Ho Chi Minh City, Vietnam, 23–24 November 2018; pp. 452–455.
38. Wang, B.; Ge, Y. Predicting the influence of Guangfo Metro on the economic level of Foshan City Based on the GM (1, 1) model. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *634*, 012013. [[CrossRef](#)]
39. Zhao, N.; Liu, Y.; Cao, G.; Samson, E.L.; Zhang, J. Forecasting China's GDP at the pixel level using nighttime lights time series and population images. *GIScience Remote Sens.* **2017**, *54*, 407–425. [[CrossRef](#)]
40. Wang, Z.; Li, X.; Mao, Y.; Li, L.; Wang, X.; Lin, Q. Dynamic simulation of land use change and assessment of carbon storage based on climate change scenarios at the city level: A case study of Bortala, China. *Ecol. Indic.* **2022**, *134*, 108499. [[CrossRef](#)]
41. Zhang, Z.; Zhang, D. Spatial connection of CO₂ emission and carbon balance zoning in Beijing Tianjin Hebei counties based on social network analysis. *China Environ. Sci.* **2023**, *43*, 2057–2068. [[CrossRef](#)]
42. Fu, H.; Zhao, S.; Liao, C. Spatial governance of Beijing-Tianjin-Hebei urban agglomeration towards low-carbon transition. *China Agric. Econ. Rev.* **2022**, *14*, 774–798. [[CrossRef](#)]
43. Liu, G.; Zhang, F. Land Zoning Management to Achieve Carbon Neutrality: A Case Study of the Beijing–Tianjin–Hebei Urban Agglomeration, China. *Land* **2022**, *11*, 551. [[CrossRef](#)]

44. Ewing, R.; Cervero, R. "Does compact development make people drive less?" The answer is yes. *J. Am. Plan. Assoc.* **2017**, *83*, 19–25. [\[CrossRef\]](#)
45. Gao, S.; Zhang, H. Urban planning for low-carbon sustainable development. *Sustain. Comput. Inform. Syst.* **2020**, *28*, 100398. [\[CrossRef\]](#)
46. Malambo, P.; Kengne, A.P.; De Villiers, A.; Lambert, E.V.; Puoane, T. Built environment, selected risk factors and major cardiovascular disease outcomes: A systematic review. *PLoS ONE* **2016**, *11*, e0166846. [\[CrossRef\]](#) [\[PubMed\]](#)
47. Bastin, J.-F.; Finegold, Y.; Garcia, C.; Mollicone, D.; Rezende, M.; Routh, D.; Zohner, C.M.; Crowther, T.W. The global tree restoration potential. *Science* **2019**, *365*, 76–79. [\[CrossRef\]](#) [\[PubMed\]](#)
48. Yang, J. Strategies for low-carbon green growth and urban management in Korea. *J. Urban Manag.* **2013**, *2*, 85–101. [\[CrossRef\]](#)
49. Ye, Y.; Wang, C.; Zhang, Y.; Wu, K.; Wu, Q.; Su, Y. Low-carbon transportation oriented urban spatial structure: Theory, model and case study. *Sustainability* **2017**, *10*, 19. [\[CrossRef\]](#)
50. Cifuentes, L.; Borja-Aburto, V.H.; Gouveia, N.; Thurston, G.; Davis, D.L. Assessing the health benefits of urban air pollution reductions associated with climate change mitigation (2000–2020): Santiago, São Paulo, México City, and New York City. *Environ. Health Perspect.* **2001**, *109*, 419–425.
51. Dudek, D.; Golub, A.; Strukova, E. Ancillary benefits of reducing greenhouse gas emissions in transitional economies. *World Dev.* **2003**, *31*, 1759–1769. [\[CrossRef\]](#)
52. Wang, X.; Smith, K.R. Secondary Benefits of Greenhouse Gas Control: Health Impacts in China. *Environ. Sci. Technol.* **1999**, *33*, 3056–3061. [\[CrossRef\]](#)
53. Djurhuus, S.; Hansen, H.S.; Aadahl, M.; Glümer, C. The association between access to public transportation and self-reported active commuting. *Int. J. Environ. Res. Public Health* **2014**, *11*, 12632–12651. [\[CrossRef\]](#)
54. Florindo, A.A.; Barrozo, L.V.; Turrell, G.; Barbosa, J.P.d.A.S.; Cabral-Miranda, W.; Cesar, C.L.G.; Goldbaum, M. Cycling for transportation in Sao Paulo City: Associations with bike paths, train and subway stations. *Int. J. Environ. Res. Public Health* **2018**, *15*, 562. [\[CrossRef\]](#) [\[PubMed\]](#)
55. Pucher, J.; Dill, J.; Handy, S. Infrastructure, programs, and policies to increase bicycling: An international review. *Prev. Med.* **2010**, *50*, S106–S125. [\[CrossRef\]](#) [\[PubMed\]](#)
56. Bustamante, M.M.; Silva, J.S.; Scariot, A.; Sampaio, A.B.; Mascia, D.L.; Garcia, E.; Sano, E.; Fernandes, G.W.; Durigan, G.; Roitman, I. Ecological restoration as a strategy for mitigating and adapting to climate change: Lessons and challenges from Brazil. *Mitig. Adapt. Strateg. Glob. Chang.* **2019**, *24*, 1249–1270. [\[CrossRef\]](#)
57. Galatowitsch, S.M. Carbon offsets as ecological restorations. *Restor. Ecol.* **2009**, *17*, 563–570. [\[CrossRef\]](#)
58. Lim, C.H.; Lim, B.S.; Kim, A.R.; Kim, D.U.; Seol, J.W.; Pi, J.H.; Lee, H.; Lee, C.S. Climate change adaptation through ecological restoration. In *Natural Resources Conservation and Advances for Sustainability*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 151–172.
59. Chen, Y. Does a regional greenhouse gas policy make sense? A case study of carbon leakage and emissions spillover. *Energy Econ.* **2009**, *31*, 667–675. [\[CrossRef\]](#)
60. Gu, G.; Wang, Z.; Wu, L. Carbon emission reductions under global low-carbon technology transfer and its policy mix with R&D improvement. *Energy* **2021**, *216*, 119300.
61. Zhang, Y. *Spillover and Feedback Effects in Low Carbon Development*; Springer: Singapore; Prime Minister's Office: Singapore, 2021.
62. Cao, S.; Li, C. The exploration of concepts and methods for low-carbon eco-city planning. *Procedia Environ. Sci.* **2011**, *5*, 199–207. [\[CrossRef\]](#)
63. Li, D.; Fan, K.; Lu, J.; Wu, S.; Xie, X. Research on Spatio-Temporal Pattern Evolution and the Coupling Coordination Relationship of Land-Use Benefit from a Low-Carbon Perspective: A Case Study of Fujian Province. *Land* **2022**, *11*, 1498. [\[CrossRef\]](#)
64. Wang, C.; Zhan, J.; Xin, Z. Comparative analysis of urban ecological management models incorporating low-carbon transformation. *Technol. Forecast. Soc. Chang.* **2020**, *159*, 120190. [\[CrossRef\]](#)
65. Wang, Z. Coordinated development of regional resources, environment, and economic growth under the background of low-carbon economy. *Front. Ecol. Evol.* **2023**, *11*, 1181990. [\[CrossRef\]](#)
66. He, K.; Lei, Y.; Pan, X.; Zhang, Y.; Zhang, Q.; Chen, D. Co-benefits from energy policies in China. *Energy* **2010**, *35*, 4265–4272. [\[CrossRef\]](#)
67. Markandya, A.; Armstrong, B.G.; Hales, S.; Chiabai, A.; Criqui, P.; Mima, S.; Tonne, C.; Wilkinson, P. Public health benefits of strategies to reduce greenhouse-gas emissions: Low-carbon electricity generation. *Lancet* **2009**, *374*, 2006–2015. [\[CrossRef\]](#)
68. Friel, S.; Dangour, A.D.; Garnett, T.; Lock, K.; Chalabi, Z.; Roberts, I.; Butler, A.; Butler, C.D.; Waage, J.; McMichael, A.J. Public health benefits of strategies to reduce greenhouse-gas emissions: Food and agriculture. *Lancet* **2009**, *374*, 2016–2025. [\[CrossRef\]](#)
69. Biesbroek, S.; Bueno-de-Mesquita, H.B.; Peeters, P.H.; Verschuren, W.M.; Van Der Schouw, Y.T.; Kramer, G.F.; Tyszler, M.; Temme, E.H. Reducing our environmental footprint and improving our health: Greenhouse gas emission and land use of usual diet and mortality in EPIC-NL: A prospective cohort study. *Environ. Health* **2014**, *13*, 1–9. [\[CrossRef\]](#) [\[PubMed\]](#)
70. Milner, J.; Green, R.; Dangour, A.D.; Haines, A.; Chalabi, Z.; Spadaro, J.; Markandya, A.; Wilkinson, P. Health effects of adopting low greenhouse gas emission diets in the UK. *BMJ Open* **2015**, *5*, e007364. [\[CrossRef\]](#)
71. Springmann, M.; Godfray, H.C.J.; Rayner, M.; Scarborough, P. Analysis and valuation of the health and climate change cobenefits of dietary change. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 4146–4151. [\[CrossRef\]](#)

72. Xiong, C.; Wang, G.; Su, W.; Gao, Q. Selecting low-carbon technologies and measures for high agricultural carbon productivity in Taihu Lake Basin, China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 49913–49920. [\[CrossRef\]](#)
73. Rogge, K.S.; Pfluger, B.; Geels, F.W. Transformative policy mixes in socio-technical scenarios: The case of the low-carbon transition of the German electricity system (2010–2050). *Technol. Forecast. Soc. Chang.* **2020**, *151*, 119259. [\[CrossRef\]](#)
74. Wang, Y.; Ren, H.; Dong, L.; Park, H.-S.; Zhang, Y.; Xu, Y. Smart solutions shape for sustainable low-carbon future: A review on smart cities and industrial parks in China. *Technol. Forecast. Soc. Chang.* **2019**, *144*, 103–117. [\[CrossRef\]](#)
75. Cheng, Q.; Su, B.; Tan, J. Developing an evaluation index system for low-carbon tourist attractions in China—A case study examining the Xixi wetland. *Tour. Manag.* **2013**, *36*, 314–320. [\[CrossRef\]](#)
76. Cheshmehzangi, A.; Xie, L.; Tan-Mullins, M. The role of international actors in low-carbon transitions of Shenzhen’s International Low Carbon City in China. *Cities* **2018**, *74*, 64–74. [\[CrossRef\]](#)
77. Li, J.H.; Sia, R.; Yang, L. Study on low-carbon development in the eco-tourism area: Taking Qinghai Lake of China as an example. *Adv. Mater. Res.* **2012**, *524*, 2442–2447. [\[CrossRef\]](#)
78. Qing, L. Study on Poyang Lake Tourism Plan under the Low-Carbon Ecology. *Appl. Mech. Mater.* **2013**, *368*, 369–374. [\[CrossRef\]](#)
79. Heinen, D. Growth management for low-carbon development patterns—leverages in state planning enabling legislation. *Urban Res. Pract.* **2022**, *15*, 71–93. [\[CrossRef\]](#)
80. Song, Q.; Liu, T.; Qi, Y. Policy innovation in low carbon pilot cities: Lessons learned from China. *Urban Clim.* **2021**, *39*, 100936. [\[CrossRef\]](#)
81. Chen, J.; Wang, Z. Low-Carbon Rural Landscape Optimization Strategy Based on Green Infrastructure Evaluation. *J. Simul.* **2021**, *9*, 125.
82. Khanna, N.; Fridley, D.; Hong, L. China’s pilot low-carbon city initiative: A comparative assessment of national goals and local plans. *Sustain. Cities Soc.* **2014**, *12*, 110–121. [\[CrossRef\]](#)
83. Gao, J.; Kovats, S.; Vardoulakis, S.; Wilkinson, P.; Woodward, A.; Li, J.; Gu, S.; Liu, X.; Wu, H.; Wang, J. Public health co-benefits of greenhouse gas emissions reduction: A systematic review. *Sci. Total Environ.* **2018**, *627*, 388–402. [\[CrossRef\]](#)
84. Mueller, N.; Daher, C.; Rojas-Rueda, D.; Delgado, L.; Vicioso, H.; Gascon, M.; Marquet, O.; Vert, C.; Martin, I.; Nieuwenhuijsen, M. Integrating health indicators into urban and transport planning: A narrative literature review and participatory process. *Int. J. Hyg. Environ. Health* **2021**, *235*, 113772. [\[CrossRef\]](#)
85. Nieuwenhuijsen, M.J. Urban and transport planning pathways to carbon neutral, liveable and healthy cities; A review of the current evidence. *Environ. Int.* **2020**, *140*, 105661. [\[CrossRef\]](#)
86. Biesbroek, G.R.; Swart, R.J.; Van der Knaap, W.G. The mitigation–adaptation dichotomy and the role of spatial planning. *Habitat Int.* **2009**, *33*, 230–237. [\[CrossRef\]](#)
87. Wang, S.-H.; Huang, S.-L.; Huang, P.-J. Can spatial planning really mitigate carbon dioxide emissions in urban areas? A case study in Taipei, Taiwan. *Landsc. Urban Plan.* **2018**, *169*, 22–36. [\[CrossRef\]](#)
88. Ning, X.; He, Y.; Zhang, J.; Wu, C.; Zhang, Y. Analysis of Carbon Emission Projections and Reduction Potential of Resource-Dependent Urban Agglomerations from the Perspective of Multiple Scenarios—A Case Study of Hu-Bao-O-Yu Urban Agglomeration. *Int. J. Environ. Res. Public Health* **2023**, *20*, 4250. [\[CrossRef\]](#) [\[PubMed\]](#)
89. Wu, W.; Xu, L.; Zheng, H.; Zhang, X. How much carbon storage will the ecological space leave in a rapid urbanization area? Scenario analysis from Beijing-Tianjin-Hebei Urban Agglomeration. *Resour. Conserv. Recycl.* **2023**, *189*, 106774. [\[CrossRef\]](#)
90. Zhang, Y.; Liu, Y.; Wang, Y.; Liu, D.; Xia, C.; Wang, Z.; Wang, H.; Liu, Y. Urban expansion simulation towards low-carbon development: A case study of Wuhan, China. *Sustain. Cities Soc.* **2020**, *63*, 102455. [\[CrossRef\]](#)
91. NCCS Singapore’s Climate Action Plan. *Take Action Today, for a Carbon-Efficient Singapore*; National Climate Change Secretariat Prime Minister’s Office: Singapore, 2016.
92. Damsø, T.; Kjær, T.; Christensen, T.B. Implementation of local climate action plans: Copenhagen—Towards a carbon-neutral capital. *J. Clean. Prod.* **2017**, *167*, 406–415. [\[CrossRef\]](#)
93. Pacheco-Torres, R.; Roldán, J.; Gago, E.; Ordóñez, J. Assessing the relationship between urban planning options and carbon emissions at the use stage of new urbanized areas: A case study in a warm climate location. *Energy Build.* **2017**, *136*, 73–85. [\[CrossRef\]](#)
94. Toh, C.K. Tokyo’s city sustainability: Strategy and plans for net zero emissions by 2050. *IET Smart Cities* **2022**, *4*, 81–91. [\[CrossRef\]](#)

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