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Research Article

Accounting and Prediction of Carbon Emissions from Land Use in Nine Provinces of the Yellow River Basin Based on a System Dynamics Model

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Abstract

As the Yellow River Basin is an important region for China's future economic development and environmental protection, the relevant provinces and regions are under relatively high pressure to reduce carbon dioxide emissions, and exploring carbon emissions in the Yellow River Basin is of great significance for the ecological protection and high-quality development of the Yellow River Basin. This paper accounts for land use carbon emissions and carbon footprint indices, etc., based on 1990-2018 panel data, and constructs a system dynamics prediction model to explore and predict the change pattern of land use carbon emissions through land use, population, energy and economic data. The results show that: (1) Net carbon emissions in the study area have shown an upward trend over the last 30 years. The carbon footprint pressure index and carbon emission risk index show a simultaneous increasing trend. (2) Grey correlation analysis shows that the influence of each land type on net carbon emissions in the study area is in the following order: construction land > water area > forest land > cropland > unused land > grassland. (3) Using a system dynamics model, scenario prediction and simulation were conducted on the research area. By 2035, the projected net carbon emissions (cumulative) will be 280.4 million tons under the existing development pattern; 230.7 million tons under the ecological priority development scenario; 280.4 million tons under the status quo continuation development scenario; and 356.1 million tons under the high economic development scenario in the study area.

INTRODUCTION

With the increase in extreme weather and natural disasters, the issue of global warming has received widespread attention. Since 2006, China has led the world in car-bon emissions for 16 consecutive years, attracting widespread international attention and enormous pressure to reduce carbon emissions [1]. China is currently in a bottleneck period of economic and social development and needs to consume a large amount of energy, further aggravating the pressure on carbon emission reduction [2]. In 2020, Xi Jinping, General Secretary of the United Nations, proposed at the Joint 75th Session that China's carbon dioxide emissions will peak by 2030 and strive to achieve carbon neutrality by 2060, making clear the country's goal of reducing carbon emissions [3]. The Yellow River Basin has been a major food production area in China, and its land use changes also significantly affect carbon emissions [4].Therefore, it is of great significance to study the future development trend of carbon emissions in the relevant provinces and regions within the Yellow River Basin, as well as the peak value of carbon emissions under different scenarios, in order to realize carbon peaking in the basin at an early date, and then to achieve the country's carbon neutrality strategic goal [5].

Many scholars at home and abroad have conducted in-depth and detailed research on various aspects, such as the study of the effect of carbon emission from land use, the study of the factors influencing carbon emission from land use, and the prediction of carbon emission from land use, by using different data and methods. Pei J, et al. used remote sensing estimation methods to observe the carbon fluxes and analyzed the overall carbon effect from land cover in Shenzhen from 2005 to 2013 [6]. From 2001 to 2011, Dong Jie utilized the IPCC carbon emission inventory method to account for carbon emissions in Hubei Province during the past 10 years [7]. Ang, et al. comprehensively analyzed the changes in total carbon intensity across countries and the main drivers behind ACI reduction [8]. Michele, et al. incorporated a regression analysis model to assess the factors affecting land use carbon emissions within the study area [9]. In the study area, Tong, et al. used a metacell model to analyze the factors influencing carbon emissions and predict future land use [10]. Chen Wenying, et al. combined the MARKAL model with the MACRO model depending on energy service demand to develop the MARKAL-MACRO model for China.

It was observed that a continuous increase characterizes carbon emissions in China until 2050 [11]. Yang Kun and other scholars classified the regional land into six major categories on

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the erdas platform depending on remote sensing data from the Lhasa region for two periods in 2000 and 2010. They utilized Markov models to predict future land use changes and carbon emissions within the study area [12]. An intelligent body model was used by Mainak Bandyopadhyay, et al. to project future land use carbon emissions within the study area [13]. Zhang, et al. combined Monte Carlo simulations with scenario simulations to predict carbon emissions in 2030 within the study site [14]. Tan, et al. utilized the GM (1,1), model in 2020 to predict the carbon emissions of Chongqing [15]. Zhang, et al. used Baoding city as the study target and determined the peak CO2 emission time via scenario prediction [16]. In general, domestic and foreign studies focus on the accounting of carbon sinks and sources of land use in the study area, and analyze the temporal changes and spatial distribution of carbon emissions from land use in the study area based on the results of the accounting, which is relatively comprehensive, but there is a lack of discussion of the social, economic and ecological effects, which fails to comprehensively and profoundly reveal the principles of the impact of land use changes on carbon emissions, and fails to explore in depth the main factors leading to the changes, and there are fewer predictions of future carbon emissions.

The Yellow River Basin is an important area for economic development and ecological protection in China, as well as an important energy basin in China [17], which occupies an important position in China's economic development and ecological security. Based on the land use, population, energy and economic data of nine provinces and districts in the Yellow River Basin from 1990 to 2018, this study utilizes the carbon emission coefficient method in the IPCC inventory method, combines the energy consumption data, accounts and analyzes the land-use carbon emissions from multiple perspectives, and constructs system dynamics prediction models to predict the land-use carbon emissions of relevant provinces and districts in the Yellow River Basin under different scenarios, respectively, with the aim of providing key regional It is expected to provide theoretical references for the key provinces and regions in the region to realize the goal of carbon peaking at an early date.

MATERIALS AND METHODS

Overview of the Study Area

The Yellow River is the mother river of the Chinese nation. It is the second largest river in China after the Yangtze River, originating from the Qinghai-Tibet Plateau. It has a 5,464 km total length and about 750,000 km^2 of the basin area. The Yellow River basin spans three significant steps of east-west China. It accounts for about 1/12th of the country's total land area. The river begins from Qinghai in the west and reaches Shandong in the east, with nine provinces and regions: Qinghai, Sichuan, Gansu, Ningxia, Shaanxi, Shanxi, Inner Mongolia, Henan and Shandong [18]. Significant climatic differences, a fragile ecological environment, and a relatively complex topography characterize the basin. The basin has a large population, which will be 421,604,100 by the end of 2020, accounting for 30% of the national population. The regional GDP is RMB 2,538,661 billion. Traditional industries dominate the industrial structure compared with the Yangtze River basin. However, its transformation and upgrading of endogenous power are insufficient. The level of economic development within the basin varies greatly, requiring further improvement of the development quality [19]. This study takes the natural flowing area of the Yellow River as the primary objective. Finally, nine provinces and districts in the basin were selected as the study area depending on the availability and accuracy of relevant research data.

Data Sources

This study used the land use monitoring data from the Chinese Academy of Sciences, having an average resolution of 30 m×30 m. where 2000, 2005, and 2010 data were pro-cured using Landsat TM/ETM remote sensing images of each period as the primary data source. Moreover, the 2018 data were updated depending on previous data, combined with the Landsat 8 remote sensing images. The final annual land use remote sensing monitoring data from the manual analysis was 90% accurate. The energy consumption data of Qinghai, Sichuan, Gansu, Shaanxi, Ningxia, Inner Mongolia, Shanxi, Henan, and Shandong provinces and other data necessary for assessing carbon emissions from various energy sources were obtained from 1991, 2001, 2011, and 2019 China Energy Statistical Yearbook. The GDP data, the output value of the three industries, fixed asset in-vestment, primary, secondary, and tertiary industry investment, and total and residential energy consumption were procured from the Statistical Yearbook of each province.

RESEARCH METHODOLOGY

Estimation of Land Use Carbon Emissions

Accounting for the Direct Land Use Carbon Emissions: It can be observed that direct land use carbon emission is the generation of carbon emission during direct land use. This involves five land use types: arable, forest, grassland, water, and unused lands. Based on the outcomes of the study by Yang Kai [20], and combined with the actual situation of the study area, the specific calculation formula is:

$$E = \sum ei = \sum Si \times Qi$$

Where: land use type is depicted by i, total land use carbon emissions in the region are characterized by E, the carbon emissions from different land types are expressed as, the area of different land types is represented by Si, and the carbon emission factors for varying land types are represented by Qi. The carbon emission factors for non-construction land are shown in (Table 1).

Table 1: Table of carbon emission factors for non-building land.

Land type	Carbon emission factor t/(hm^2·a)	Reference Sources
Arable land	0.497	Cai Zuchong, He Yong [21,22]
Forest land	-0.6125	Shi Hongxin, Xiao Hongyan [23,24]
Grassland	-0.021	Fang Jingyun [25]
Waters	-0.253	Lai Li, Duan Xiaonan [26-27]
unused land	-0.005	Liu Xiya [28]

Accounting for the Indirect Land Use Carbon Emissions: The carbon emissions of people are determined based on the energy consumed by them in production and living when they use the land as a carrier for socio-economic activities. Construction land is the most crucial carbon source, while combustion dominates carbon emissions from fossil fuels. Based on the standard coal conversion and carbon emission factors from the IPCC Guidelines for National Greenhouse Gas Inventories, depending on the results from relevant studies [29], along with the energy consumption within the region, we selected eight different types of energy sources.

$$E_c = \sum_{i=1}^{8} E_{ci} = \sum_{i=1}^{8} (E_{mi} \times b_i \times f_i)$$

Where: E_c is the carbon emission from the construction land, E_{ci} is the energy consumption, b_i depicts the standard coal conversion factor and f_i represents the carbon emission factor of different fossil energy sources. The current paper selects eight major energy sources: raw coal, coke, crude oil, fuel oil, gasoline, paraffin, diesel, and natural gas. The standard coal conversion and carbon emission factors for different energy sources are represented in (Table 2).

Carbon Foot printing and Risk Accounting: The impact of human and economic activities on regional ecosystems was indirectly represented by the carbon footprint pressure index [30,31]. It indicates the ratio of carbon sources to carbon sinks in the land-use state based on the formula:

$$C_P = \frac{C_o}{C_q}$$

Where: C_P indicates the carbon footprint pressure index, C_o represents the carbon sources from the different land use practices and C_q denotes the carbon sinks from the different land use practices. A carbon risk index could measure the riskiness of carbon emissions to explore the impact of land use carbon emissions.

$$C_{RI} = \frac{\sum_{i=1}^{n} (S_i \times P_i)}{S}$$

Where: C_{RI} depicts the carbon emission risk index, S_i represents the area of the ith land use type, s denotes the total land area of the region, and P_i indicates the carbon emission factor of the ith type.

Grey Correlation Theory

The grey correlation theory analyzes the relationship between the elements inside the system. There is a relative lack of information because of the relatively small amount of data between land use types and carbon emissions. Thus, the grey system theory is selected to determine the correlation [32,33]. The models are:

The assumption is that s analysis area contains w original sequences using the area of each class within the study area as a subsequence:

$$\left\{x_1^{(0)}(s), x_2^{(0)}(s), \ldots, x_w^{(0)}(s)\right\}$$

We assume that there are z original parent series within s analysis areas using carbon emissions from different land use types within the study area as parent series.

$$\left\{y_1^{(0)}(s), y_2^{(0)}(s), \ldots, y_z^{(0)}(s)\right\}$$

The averaging process could eliminate the data magnitude and obtain an entirely new series because of the different degrees of quantification of the above series. It will compare the data series with the reference series for the absolute value difference, determined as follows.

$$\Delta m(q) = \left| y_i^{(0)}(s) - x_i^{(0)}(s) \right|$$

The relative difference between the comparison and the reference series is represented as the number of correlation coefficients at point k and is assessed as follows.

$$\xi_i(k) = \frac{\min_i \min_k \left| y(k) - x_i(k) \right| + \alpha \max_i \max_k \left| y(k) - x_i(k) \right|}{\left| y(k) - x_i(k) \right| + \alpha \max_i \max_k \left| y(k) - x_i(k) \right|}$$

α∈(0, ∞) is the discrimination coefficient, and the range of values of α is (0,1). In this study, α has a value of 0.5. The correlation degree is the average of the relationship coefficients of the comparison series and the reference data. The calculation formula is.

$$ri = \frac{1}{q} \sum_{k=1}^{q} \xi_i(k)$$

System Dynamics Model

The system dynamics model is a dynamic feedback system depending on multi-factor interaction and causality. It is guided by system theory to emphasize the overall behavior and understand integrated problems from multiple perspectives, levels, and aspects [34]. System dynamics models can predict future land use carbon emissions by simulating evolution, and changes in total land use carbon emissions under different scenarios within the study area [35]. In this study, a system dynamics model is used to combine the factors influencing land use carbon emissions in previous studies, and a carbon emission prediction model is constructed for the study area. Using 2010-2020 as the simulation test period and 2020-2035 as the prediction simulation period, the four subsystems of land, economy, population and energy are used to predict and simulate the future land use carbon sources, carbon sinks and cumulative net carbon emissions of the study area based on the 2010 base period.

Subsystem construction: Depending on the actual development of land use within the study area and the results from previous studies, the carbon emission system is divided into four subsystems: population, economy, land, and energy [36]. The Vensim software helps construct a dynamics model of the land-use carbon emission system in the study area. Moreover, it explores the causal relationships among the land-use carbon emission system subsystems. Additionally, predictions were made on the future land-use carbon emission efficiency of the study area depending on testing the validity of the model.

Population Subsystem: The population size determines the total amount of energy consumption and carbon emissions. The

Table 2: Carbon emission coefficients of various energy sources.

Type of energy	Raw Coal	Coke	Crude Oil	Fuel oil	Gasoline	Kerosene	Diese	Natural gas
Carbon emission factor (tC•t-1 Standard coal)	0.7559	0.8550	0.5857	0.5538	0.5714	0.5921	0.6185	0.4483
Standard coal factor (t standard coal))	0.7143	0.9714	1.4286	1.4286	1.4714	1.4714	1.4571	1.2143

variables of the population subsystem mainly include the total population of the region and the number of people employed in the primary, secondary, and tertiary industries combined with the results of the above decomposition analysis.

Economic Subsystem: The decomposition of factors affecting carbon emissions indicates that factors such as GDP and GDP per capita affect the change in total carbon emissions. Therefore, the main economic subsystems are GDP, primary, secondary, and tertiary industry output, fixed asset investment, and primary, secondary, and tertiary industry investment.

Land Subsystem: The land is an essential carrier of human socio-economic activities and directly or indirectly affects the growth and absorption of carbon emissions. In this study, arable land, forest land, grassland, construction land, unused land, and residential land became system variables.

Energy Subsystem: The energy subsystem primarily deciphers the influence of energy consumption on carbon emissions. The variables of the energy subsystem include total and residential living energy consumption.

Subsystem Circuit Analysis: A causal diagram of land use carbon emissions within the study area (Figure 1) was constructed from the four subsystems of population, economy, land, and energy to analyze the interrelationships among the variables within each subsystem depending on the principles of system dynamics and following the results of the above analysis.

The Typical Circuit of the Population Subsystem: The total regional population → + residential land use → + residential energy consumption → + residential land use carbon emissions → + carbon source → - GDP.

The total regional population → + number of people employed in the primary industries → + output value of the primary industries → + GDP.

The Typical Circuit of the Economic Subsystem: GDP → + fixed asset investment → + investment in the three industries → + land for construction → + output value of the three industries → + GDP.

GDP → + the total energy consumption → + carbon sources → + net carbon emissions → + carbon emission intensity → - GDP.

The Typical Circuit of the Land Subsystem: Arable land → + carbon sequestration from the arable land → + carbon sink → - net carbon emission → + carbon emission intensity → - GDP → +

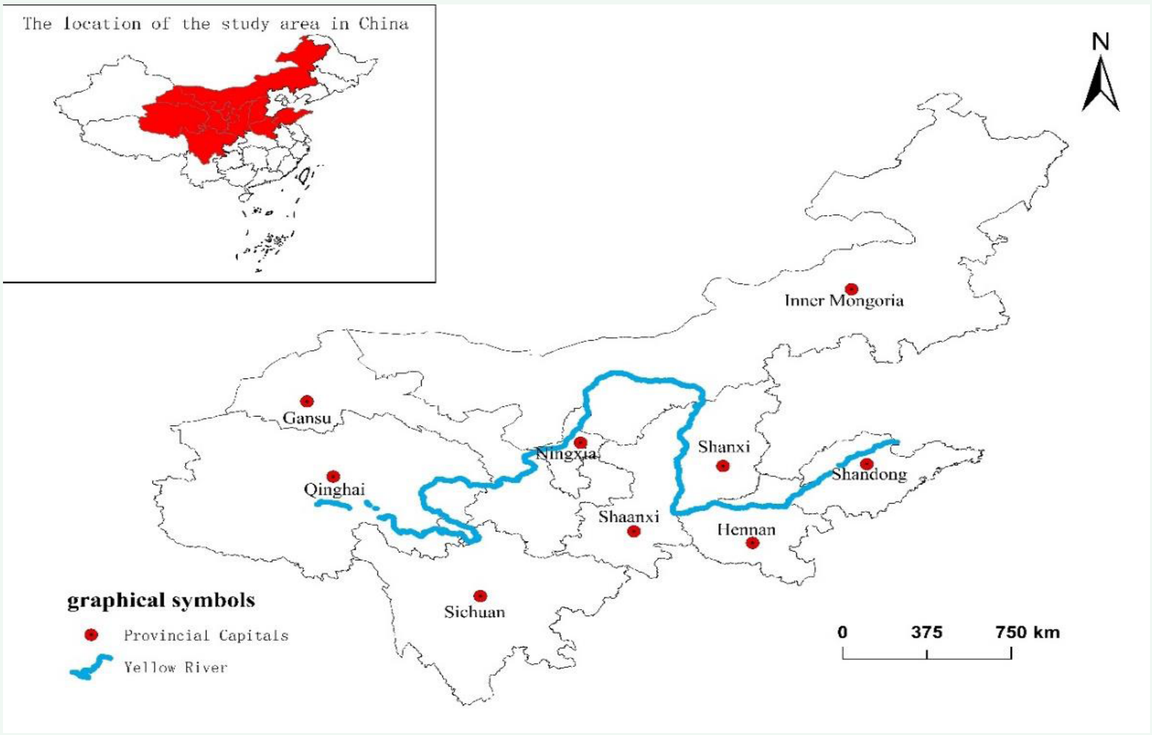

Figure 1 Administrative division map of the study area.

fixed asset investment → + investment in the primary production → + arable land.

Forest land → + output value of the primary production → + GDP → + total energy consumption → + carbon source → - GDP → + fixed asset investment → + investment in the primary production → + forest land.

The Typical Circuit of the Energy Subsystem: The total energy consumption → + carbon sources → + net carbon emissions → + carbon emission intensity → - GDP → + the total energy consumption.

The total energy consumption → + carbon source → - GDP → + fixed asset investment → + investment amount in the secondary assets → + construction land → + output value of the tertiary production → + GDP → + the total energy consumption.

Construction of the System Equations: The system equation is a description of the logical quantitative relationship that exists between the variables, (Figure 2) shows the main equations of the system for constructing a model land use carbon emission stock flow diagram for this study as follows.

1. GDP = output of the primary production + output of the secondary production + output of the tertiary production
2. Increase in the GDP of the primary sector = (natural rate of increase of the primary sector + additional rate of increase of the primary sector) * output value of the primary sector
3. Number of people employed in the primary sector = –2.1136* total regional population + 95738
4. Value of primary production = INTEG (Increase in the primary GDP, 12,234.9)
5. The amount of investment in the primary industry assets = investment in fixed assets * proportion of investment in the primary industry assets
6. An additional increase rate of primary production = the amount of investment in primary production assets/1.5e+007 + the number of people employed in primary production/1e+007 + area of (area grassland + forest land + cultivated land)/2.5e+007
7. Increase rate of GDP of the tertiary sector = additional increase rate of the tertiary sector + natural increase rate of the tertiary sector
8. Number of people employed in the tertiary sector = 2.0968* total regional population - 78629
9. Value of tertiary output = INTEG (Increase in value from tertiary production, 40056.7)
10. Increase in the output value of the tertiary industries = output value of the tertiary industries * increase rate of GDP of the tertiary industries
11. The amount of investment in assets of the three industries = investment in fixed assets * ratio of investment in assets from the three industries
12. An additional increase rate of the tertiary industries = number of people employed in the tertiary industries/1e+007+construction land/800000
13. Number of people employed in the secondary industries = –0.3826*Total regional population + 21954
14. Output of secondary production = INTEG (Increase in the output of the secondary production, 55119.3)
15. Increase in the output value of the secondary production = (natural rate of increase in the secondary production +

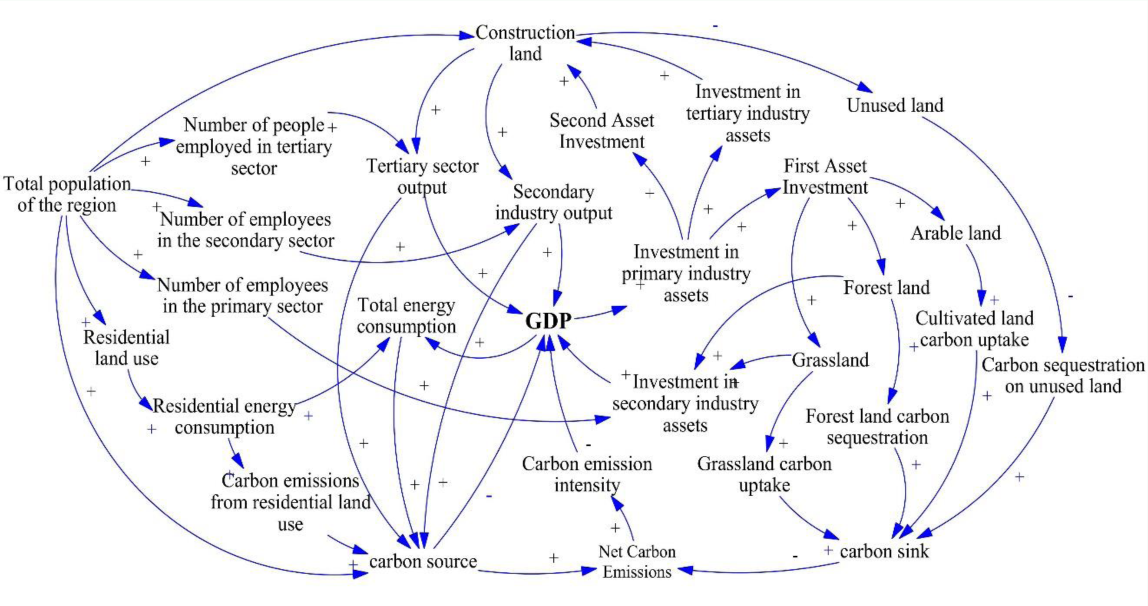

Figure 2 The causal relationship diagram of land use carbon emissions in the study area.

additional rate of increase in the secondary production) * output value of the secondary production

16. Amount of investment in secondary assets = investment in fixed assets * ratio of investment in secondary assets
17. Additional increase rate of secondary production = number of employees in secondary industry/6e+006+construction land/800000
18. Population increase = total regional population * population growth rate
19. Construction land area per capita = construction land/ total regional population
20. Energy consumption per capita = total energy consumption/total regional population
21. Net carbon emissions = INTEG (carbon emissions increase - carbon emissions decrease, 0)
22. Total regional population = INTEG (increase in population, 40566.7)
23. Energy consumption per unit of GDP = total energy consumption/GDP
24. Investment in fixed assets = 1.2818*GDP - 63117
25. Residential land use = INTEG (change in residential land use, 249.083)
26. Residential land use change = 0.1 + population increase/500
27. Residential domestic carbon emissions = carbon emission factor for coal consumption * residential domestic energy consumption
28. Residential energy consumption = 156.65*Residential land use - 28328
29. Construction land = INTEG (new construction land, 830.277)
30. New construction land = 15.8 + (amount of investment in secondary assets + amount of investment in tertiary assets)/300000 + increase in population/200
31. Unexploited land = total area - residential land - forest area - arable land area - grassland area
32. Utilized land carbon sequestration = Utilized land * Utilized land carbon emission factor
33. Change in forest land = 0.0001*investment in primary assets - new construction land*0.33
34. Forest land carbon sequestration = Forest land area * Forest land carbon sequestration factor
35. Woodland area = INTEG (Woodland change, 5463.1)
36. Carbon emission factor for coal consumption = 0.7476/100
37. Carbon intensity = net carbon emissions/GDP
38. Carbon sink = carbon sequestration on unused land + carbon emission sequestration on forest land + carbon emission sequestration on grassland
39. Carbon source = (output value of secondary production + output value of tertiary production) * carbon emission factor of coal consumption * energy consumption per unit of GDP + total carbon emission from arable land + carbon emission from residential life
40. Total carbon emission from cultivated land = area of cultivated land * carbon emission coefficient of cultivated land (0.497)
41. Cropland area = INTEG (Amount of change in cropland area, 6652.11)
42. Change in arable land area = -0.6 * new construction land + investment in primary assets * 0.0001
43. Total energy consumption = 0.2814*GDP + 91908
44. Change in grassland = investment in primary assets * 2.5e-005 - new land for construction * 0.035
45. Grassland carbon emission absorption = Grassland area * Grassland carbon emission absorption factor
46. Grassland area = INTEG (Grassland change, 13423.5)

RESULTS AND DISCUSSION

Analysis of Land Use Carbon Emissions

The net carbon emissions of the study region from 1990–2018 were 253,493,700 tons, 351,427,000 tons, 112,451,636,300 tons, and 157,499,420 tons. There was a continuously increasing trend, from 97,909,000 tons or 38.62% in 1990–2000 to 77,311,360 tons or 220.00% in 2000–2010 and 450,477,900 tons or 40.06% in 2010—2018 (Table 3). Among them, 2000 and 2010 have the biggest difference in the amount of change, with a rate of change of 40.06%, which is related to the rapid economic development of China in this period.

The carbon emissions from arable land were 32,813,200 tons, 33,414,800 tons, 33,061,000 tons, and 32,660,000 tons, respectively, between 1990–2018. There was an in-crease and a decrease; however, the overall change was insignificant, with a rate of 2%, –1%, and –1% in the three time periods, respectively. Carbon emissions from construction land were 256.3756, 353.3912, 112.812.09, and 157.889.20 million tons, respectively. These emissions showed an upward trend with a significant change, at 37.84%, 219.23%, and 39.96% in the three periods. Moreover, there was an overall change of 132.25164 million tons, with a 515.85% rate of change. Additionally, the overall change in woodland and grassland was not significant. The carbon sequestration within water areas was 1,585,800 tons, 1,595,300 tons, 1,713,300 tons, and 1,816,900 tons. It had an increasing trend, with a 0.6%, 7.39%, and 6.05% rate of change in the three periods, respectively, and an overall change of 231,100 tons, or 14.57%. For the three time periods, the rate of change was –0.2%, 1.47%, and –1.03%, with an overall change of 0.09 million tons or 0.22%.

The net carbon emissions of the relevant provinces and regions from 1990 to 2018 within the Yellow River Basin are in a state of constant growth. The carbon sources are elevating yearly, and carbon sink capacity indicates a yearly downward trend. This causes a synchronous upward trend in the carbon footprint pressure index and emission risk index of the provinces within the study area. Moreover, there are increasingly severe urban carbon emission problems and environmental pressure. The carbon footprint pressure index enhanced from 225.81 in 1990 to 1339.48 in 2018. It witnessed an average annual increase of 47.84 and $C_q>1$. Furthermore, the carbon emission risk coefficient enhanced from 0.74 in 1990 to 0.82 in 2018, with an annual increase of around 0.03 (Table 4). This indicates that the overall carbon emissions from energy consumption on construction land in the provinces along the Yellow River region during the study period continued to enhance the carbon sink capacity of woodlands, grasslands, and watersheds. The overall ratio of carbon sources and sinks is unbalanced, providing more significant pressure on the ecological environment.

The carbon footprint pressure and emission risk index vary due to the dynamic economic and social development conditions of the provinces. Ningxia, Shandong, and Henan are important cities from the yellow provinces with extensive economic activities and larger populations. They have a more significant carbon footprint pressure and emission risk index than the rest of the provinces. In 2018, it accounted for 84% of the total index within the study area. The carbon footprint pressure index has an overall increasing trend greater than 50%. The remaining five provinces and regions had a high carbon footprint pressure index of less than 20%, with slight variations in the carbon emission risk index. Due to its location in the northern grassland region, Inner Mongolia maintains a stable carbon footprint pressure index and emission risk index with no significant fluctuations.

Analysis of the Correlation between Land Use Types and Carbon Emissions

(Table 5) indicates a linear relationship between all the land use types and net carbon emissions. Most provinces along the Yellow River are heavily populated and industrial-ized. Thus, the demand for energy, transport facilities, and industrial or residential lands is greater. Therefore, it causes land expansion for construction and dominantly affects carbon emissions. It is followed by water having net carbon emissions of 0.718, and woodland, with net carbon emissions of 0.698. Woodland decreases CO2 emissions by absorbing CO2 from the atmosphere and fixing it in the soil [37]. The correlation between cropland and unused land is similar. In contrast, the average correlation between grass-land is the smallest. However, the protection of cropland and grassland should be strengthened. Moreover, forest land is the primary carbon source, and its utilization for construction should be strictly controlled.

Therefore, the degree of influence of different land types on net carbon emissions within the study area is ranked as follows:

Table 3: Carbon emissions of various land use types in the study area (104t).

Year	Arable land	Forest land	Grassland	Waters	Construction land	unused land	Net emissions
1990	3281.32	-3077.77	-294.38	-158.58	25637.56	-38.78	25349.37
2000	3341.48	-3050.00	-292.10	-159.53	35339.12	-38.70	35140.27
2010	3306.10	-3174.06	-281.89	-171.33	112812.09	-39.27	112451.63
2018	3266.60	-3153.59	-282.22	-181.69	157889.20	-38.87	157499.42

Table 4: Table of carbon footprint pressure index and carbon emission risk index for nine provinces and regions in the Yellow River Basin, in China.

Province	Carbon Footprint Stress Index				Carbon Emission Risk Index			
	1990s	2000s	2010s	2018s	1990s	2000s	2010s	2018s
Inner Mongolia	0.73	0.87	1.45	1.87	-0.05	-0.04	-0.04	-0.04
Gansu	17.74	14.76	36.31	34.33	0.02	0.02	0.02	0.03
Shanxi	7.03	10.25	18.86	22.96	0.04	0.04	0.05	0.05
Shaanxi	3.10	3.68	13.35	30.09	0.04	0.04	0.03	0.04
Qinghai	7.48	11.37	51.24	88.84	-0.04	-0.04	-0.04	-0.04
Ningxia	83.09	111.55	406.00	631.22	0.13	0.15	0.15	0.16
Shandong	73.73	124.41	262.16	398.51	0.38	0.38	0.41	0.40
Henan	26.65	38.53	104.56	90.25	0.30	0.30	0.30	0.31
Sichuan	6.26	7.87	30.31	41.42	-0.08	-0.08	-0.08	-0.08
Total	225.81	323.28	924.24	1339.48	0.74	0.79	0.81	0.82

Table 5: Table of correlations between land use type and net carbon emissions.

Land type	Arable land	Forest land	Grassland	Waters	Construction land	unused land
Average correlation	0.691	0.698	0.674	0.718	0.811	0.685

construction land > water > forest land > cropland > unused land > grassland. Every year, the correlation coefficients between different land types and carbon emissions within the study area fluctuate and vary significantly (Figure 3). There is an overall trend of increasing and then decreasing, with 2010 being the inflection point. Moreover, the correlation coefficients between carbon source-dominated land types and emissions vary more than carbon sink-dominated ones. Therefore, the provinces and regions across the Yellow River have been actively responding to the energy conservation and emission reduction policies proposed during the National 11th Five-Year Plan. This policy has transformed the economic development mode, adjusted the industrial structure, and developed the ecological economy, facilitating economic development.

Land Use Carbon Emission Projections

Model Validity Tests: Building land is strongly associated with land use carbon emissions [38]. The two indicators of total regional population and GDP from 2010 to 2020 were selected as test variables based on the leading evaluation indicators of construction land. We tested the historical data from 2010 to 2020 against the model simulation values. The test results are represented in (Table 6).

Prediction Results and Stimulability Analysis: The simulation results and trends of land use carbon sources, carbon sinks, and net carbon emissions (cumulative) in the study area from 2010 to 2035 were obtained by simulating the land use carbon emission system in the study area. The results are characterized in (Figure 4).

The projected carbon sources depict a continuous upward trend, with 44.81 million tons in 2020, 46.37 million tons in 2025, 49.17 million tons in 2030, and 53.39 million tons in 2035, based on the forecast results. The projected carbon sinks were 34.69 million tons in 2020, 34.59 in 2025, 34.49 in 2030, and 34.41 in 2035. In addition, net carbon emissions (cumulative) were 82.25 million tons in 2020, 134.9 in 2025, 199.1 in 2030, and 280.4 in 2035, indicating a continuous upward trend.

Land Use Carbon Emissions Scenario Simulation Analysis: The current study focuses on the trends in net carbon emissions (cumulative) under different economic development rate scenarios because of the high GDP output of the relevant

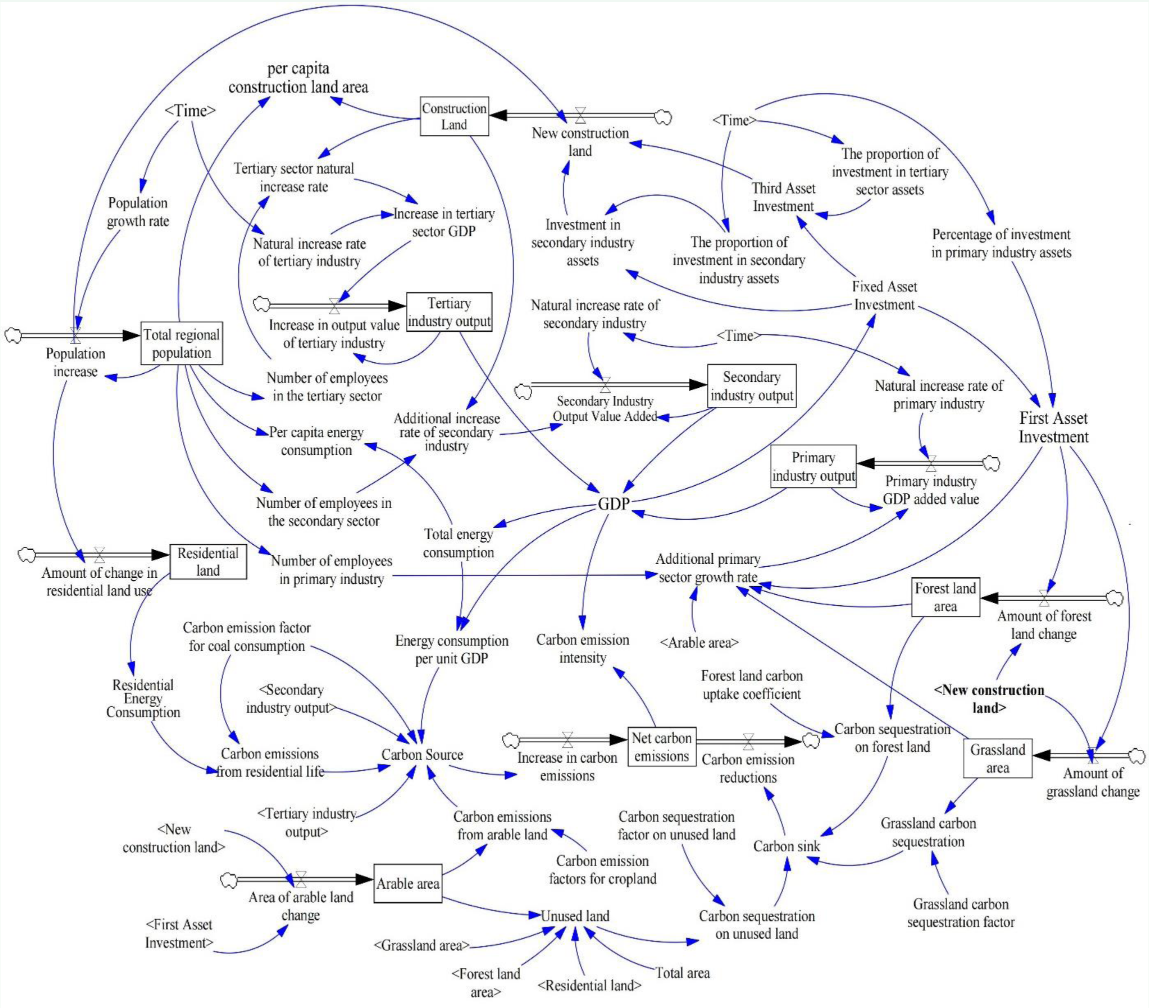

Figure 3 Land use carbon emission stock flow map in the study area.

Table 6: Simulation relative error.

Year	Total regional population				GDP			
	True value	Predicted value	Difference	Error rate (%)	True value	Predicted value	Difference	Error rate (%)
2010	40567	40570	3	0.0081	107411	107400	-11	-0.0101
2011	40755	40760	5	0.0115	127081	126600	-481	-0.3787
2012	40907	40910	3	0.0084	141190	141700	510	0.3613
2013	41004	41000	-4	-0.0087	154835	156200	1365	0.8813
2014	32361	32360	-1	-0.0037	166736	170200	3464	2.0773
2015	41363	41360	-3	-0.0077	176546	183600	7054	3.9955
2016	41635	41630	-5	-0.0117	188879	197100	8221	4.3524
2017	41824	41820	-4	-0.0105	209600	219400	9800	4.6755
2018	41946	41950	4	0.0107	229890	240300	10410	4.5283
2019	42048	42050	2	0.0049	245997	256500	10503	4.2695
2020	42160	42160	0	-0.0010	253862	263300	9438	3.7179

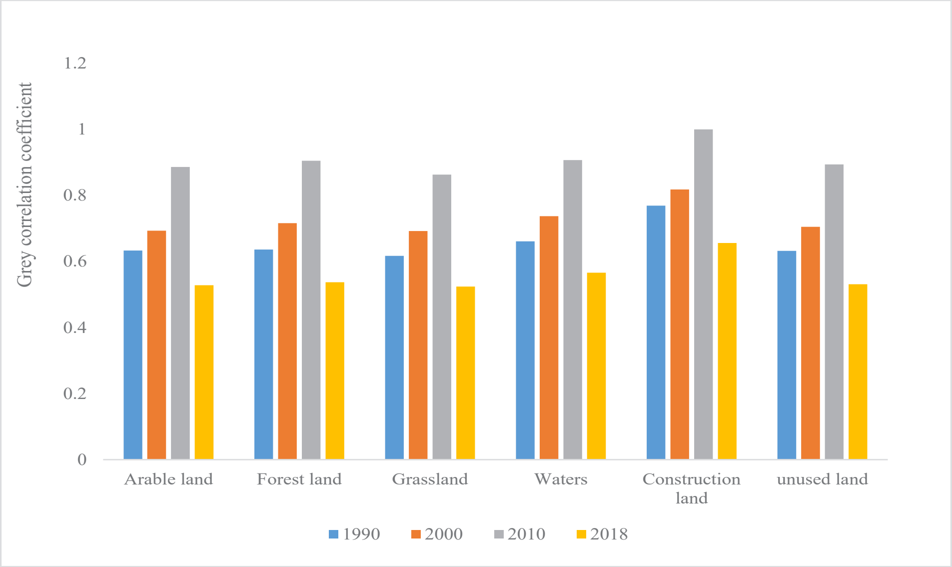

Figure 4 Trends in the association between land use types and net carbon emissions.

Table 7: Economic subsystem scenario simulation.

Scenario	Simulation programs
Eco-first development	Reduce the natural growth rate of primary, secondary and tertiary GDP by 30% each
The status quo continues to develop	Simulation without changing any variables, following existing trends
High economic growth	Increase the natural growth rate of primary, secondary and tertiary GDP by 30% each

provinces and regions in the Yellow River Basin. This study divides economic development into three simulation scenarios: ecological priority development, status quo continuation development, and rapid economic development. The specific simulation scenarios are shown in (Table 7) to study the impact on land use carbon emissions under different levels of economic growth.

Net carbon emissions (cumulative) indicate an upward trend, irrespective of eco-logical priority, the continuation of the status quo, or rapid economic development, as shown in (Figure 5). The increase in net carbon emissions (cumulative) depends on the rate of economic development. (Table 8) shows that the net carbon emissions (cumulative) under ecological priority development in 2035 are 230.7 million tons, 280.4 under status quo continuation development, and 356.1 under rapid economic development. In 2035, the net carbon emissions (cumulative) under rapid economic development are 75.7 and 125.4 million tons more than under steady development and low development, respectively (Figure 6). Therefore, it indicates the significance of the impact of economic development on land use carbon emissions.

CONCLUSION

From 1990 to 2018, the current study utilizes the area, energy

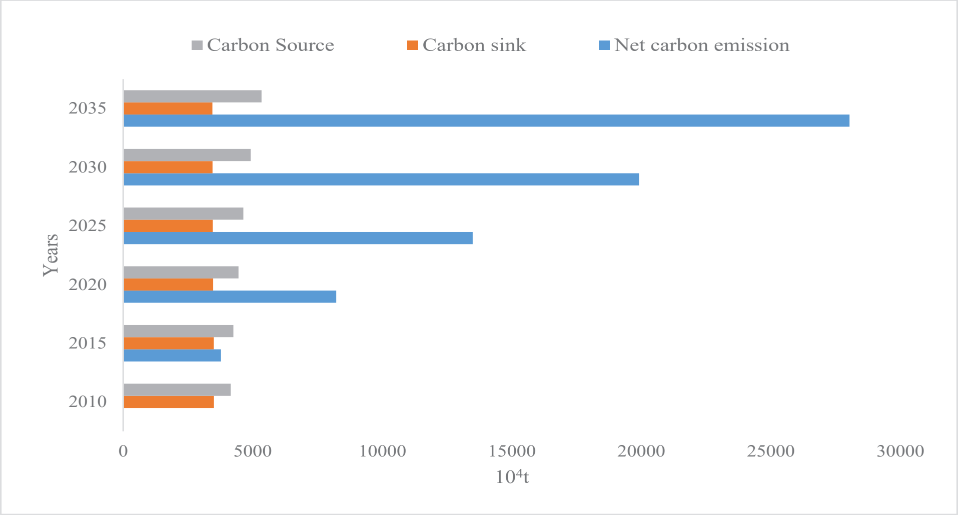

Figure 5 Projected land use carbon emissions (cumulative) in the study area.

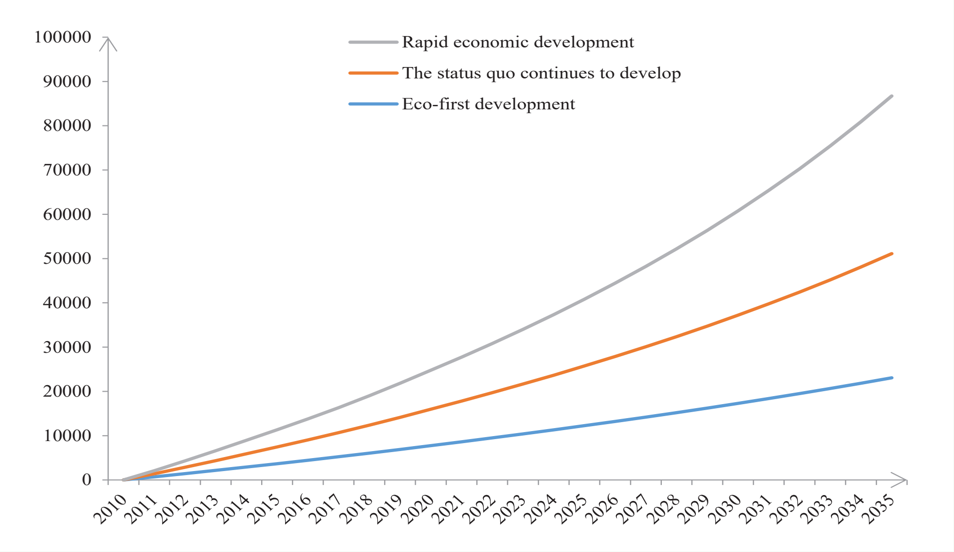

Figure 6 Economic subsystem simulation of net carbon emissions.

consumption data, population, and economic data of different land usage types in the relevant provinces and regions of the Yellow River Basin. We analyzed the land use carbon emissions in the study area through multiple perspectives based on relevant research. Then, a grey correlation model was constructed to explore the dominant influencing factors across the different land types. Finally, we applied the system dynamics model in the study area to simulate and forecast future carbon emissions, leading to the following outcomes.

From 1990–2018, the net carbon emissions increased in the study region, with a more significant increase between 2000–2010. Carbon sinks are relatively stable, while carbon sources continuously increase, leading to a much higher number of carbon sources than carbon sinks. In the study area, the carbon footprint pressure and emission risk index depict a synchronous upward trend. The Yellow River provinces have different economic and social development conditions, with specific spatial heterogeneity of the carbon footprint pressure and emission risk index.

Every year, the correlation coefficients across each category and carbon emissions within the nine Yellow River Basin provinces vary significantly. With 2010 being the in-flection point, they fluctuate and indicate an overall increasing and decreasing trend. Moreover, the correlation coefficients of carbon source-oriented land categories and carbon emissions vary more than carbon sink-oriented ones. The average correlation between construction land and carbon emissions is the highest, followed by watershed, arable, and forest land. However, grassland has the most negligible average correlation.

The future carbon emissions from land use within the study area would be 53.39 million tons of carbon sources, 34.41 carbon sinks, and 280.4 net carbon emissions (cumulative) by

Table 8: Economic subsystem scenario simulation.

Year	Eco-first development	The status quo continues to develop	High economic growth
2010	0	0	0
2011	695.8	695.8	695.8
2012	1422	1435	1448
2013	2163	2198	2233
2014	2920	2986	3054
2015	3672	3775	3886
2016	4443	4591	4752
2017	5231	5434	5660
2018	6045	6323	6638
2019	6885	7257	7690
2020	7743	8225	8797
2021	8606	9203	9923
2022	9487	10220	11110
2023	10390	11260	12360
2024	11310	12350	13680
2025	12250	13490	15080
2026	13210	14660	16570
2027	14190	15890	18150
2028	15200	17170	19830
2029	16230	18510	21630
2030	17300	19910	23560
2031	18390	21380	25620
2032	19510	22920	27840
2033	20660	24540	30230
2034	21840	26240	32810
2035	23070	28040	35610

Note: Net carbon emissions here are cumulative for the 2010 base period

2035 using a system dynamics model. Moreover, the net carbon emissions are projected to be 230.7, 280.4, and 356.1 million tons under the low economic growth, stable economic growth, and low economic growth scenario, respectively.

DISCUSSION

With global warming and frequent natural disasters, the normal production and life of human beings have been seriously affected, and the land as the carrier of human pro-duction and life as well as the carbon emission during its utilization has become a hotspot of concern, and at the same time the relevant research results are also more and more [39-40], based on the results of the predecessors, this paper mainly focuses on the study of the overall region of the Yellow River Basin related provinces and districts on a large scale, because of the some detailed data are missing, the paper has the following deficiencies.

Carbon emission accounting has certain accuracy problems, and does not take into account the problem of the large span of the study area, where the same accounting formula and conversion coefficients are used throughout the entire study area, and the results of the accounting may be somewhat different from the actual carbon emission situation. In the process of accounting for carbon emissions from construction land, only carbon emissions from fossil energy fuels are taken into account, however, construction land also carries human life and production activities, and carbon emissions from popu-lation respiration and urban buildings are not taken into account in the accounting. Therefore, it is necessary to adjust and complete the inventory of carbon emissions in the study area in the future research, so that the results will be closer to the real value.

Different provinces have different social, economic and natural conditions, and their carbon emissions may vary. This study takes the provinces involved in the study area as an overall research object, without considering the interrelationships between different provinces. Therefore, in the future, we should conduct an in-depth comparative study of the carbon emission changes in the provinces in the region, consider the interprovincial effects, adopt differentiated control and implement carbon emission reduction policies, which will be conducive to grasping the impacts of land-use changes on carbon emissions at a deeper level.

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REFERENCES

1. ZiZi Z. Research on the estimation of tax rate and its impact of carbon tax in China [D]. Huazhong University of Science and Technology. 2014.
2. Yixuan X, Rui Z, Xinjun W. Analysis of the influencing factors of energy consumption of fisheries in Dongmen Island, Zhejiang Province. Journal of Fudan (Natural Science Edition). 2014; 53: 752-757+763.
3. Rongjiao Y. Research on the construction of the rule of law of ecological civilization in the new era. Northeast Normal University, 2020.
4. Qiangxiang M, Yanna Zheng, Qi L, Baolu L, Hejie W. Analysis of Spatiotemporal Variation and Influencing Factors of Land-Use Carbon Emissions in Nine Provinces of the Yellow River Basin Based on the LMDI Model. Land. 2023; 12: 437.
5. Nan H, Xinyu L. Projections of carbon emission peaks and emission reduction potential in Beijing, Tianjin and Hebei from a multi-scenario perspective. Journal of Natural Resources. 2022; 37: 1277-1288.
6. Jie P, Li W, Ziwei C, Qinghua Fu, Zheng Niu. Analysis of land use/cover change and carbon effect in Shenzhen City based on RS and GIS. Soil and water conservation research. 2017; 24: 227-233.
7. Dong J, Yuan KQ. Total land use carbon emission and its efficiency in Hubei Province. Soil and Water Conservation Bul-letin. 2016; 36: 337-342+348.
8. Ang BW, Su B. Carbon emission intensity in electricity production: A global analysis. Energy Policy. 2016; 94: 56-63.
9. Michele FV, Srinath P. Parametric embodied carbon prediction model for early stage estimating. Energy & Buildings, 2018; 168: 106-119.
10. Xiaohua Tong, Yongjiu Feng. A review of assessment methods for cellular automatamodels of land-use change and urban growth. Int J Geogr Inf Sci. 2019; 34: 866-898.
11. Chen H, Chen WY, He JK. A synergistic governance path to achieve peak carbon emissions and air quality standards. China Population-Resources and Environment. 2020; 30: 12-18.
12. Kai Y, Hu X, Shi Y. Analysis of the current situation and prediction of carbon emissions from land use change based on RS and GIS. Journal of the Changjiang Academy of Sciences. 2016; 33: 137-141.
13. Bandyopadhyay M, Singh V. Development of agentbased model for predicting emergency response time. Perspect Sci. 2016; 8: 138-141.
14. Yiqing Z, Chuangeng Liu, Lei Chen, Xiaofei Wang, Xiaoqian Song, Ke Li. Energy-related CO2 emission peaking target and pathways for china's city: a case study of baoding city. J Clean Prod. 2019; 226: 471-481.
15. Tan XC, Dong LL, Chen DX, Baihe Gu, Yuan Zeng. China's regional CO2 emissions reduction potential: A study of Chongqing city. Applied Energy. 2015; 162: 1345-1354.
16. Yiqing Z, Chuangeng Liu, Lei Chen, Xiaofei Wang, Xiaoqian Song, Ke Li. Energy-related CO2 emission peaking target and pathways for china's city: a case study of baoding city. J Clean Prod. 2019; 226: 471-481.
17. Ma L, Tian HZ, Kang L. Ecological and environmental impacts and spatial control paths of mineral resources develop-ment in the Yellow River city. Resource Science. 2020; 42: 137-149.
18. Ali W, Abdullah A, Azam M. The dynamic linkage between technological Innovation and carbon dioxide emissions in Malaysia: An autoregressive distributed lagged bound approach. IJEEP. 2016; 6: 389-400.
19. Panpan C. Evaluation of the effectiveness and potential of carbon emission reduction from energy consumption in the Yellow River Basin. Nanjing Normal University. 2021.
20. Kang Y. Study on the carbon emission effect of land use change in Hunan Province. South China University. 2021.
21. Cai ZC, Kang GD. Tsuruta H, Mosier A. Estimate of ch4 emissions from year-round flooded rice fields during rice growing season in china. Pedosphere. 2005; 15: 66-71.
22. Yong H. Climate and carbon cycle of terrestrial ecosystems in China. Meteorological Press. 2006.
23. Hongxin S, Xingming M, Yinglong Z, et al. Study on carbon emission effects of different land use types in Guangyuan City, Si-chuan Province. Soil and Water Conservation Bulletin. 2012; 32: 101-106.
24. Hongyan X, Xingzhong Y, Bo L, et al. Study on the effect of land use change on carbon emissions in Chongqing. Journal of Chongqing Normal University (Natural Science Edition). 2012; 29: 38-42.
25. Jingyun F, Zhaodi G, Shilong P, et al. Estimation of terrestrial vegetation carbon sinks in China from 1981 to 2000. China Science (D: Earth Science). 2007; 06: 804-812.
26. Li L. Study on the carbon emission effect of land use in China. Nanjing University Press. 2010.
27. Xiaonan D, Kexiao W, Fei Lu, et al. Current status and potential of carbon sequestration in wetland ecosystems in China. Journal of

Ecology. 2008; 02: 463-469.

28. Xiya L, Yufei W, Jiaoqi S, et al. Sources of carbon emissions in the urbanization process. China Population Resources and Environment. 2015; 25: 61-66.

29. Yuan M, Zhenzhen L. Spatial and temporal evolution of carbon emissions from land use in the Yellow River Basin and the influencing factors. Ecological Economics. 2021; 37: 35-43.

30. Jing Y, Lingli Z, Wenfu P. Analysis of spatial and temporal changes in land use carbon emissions in northwestern Sichuan basin: the case of Mianyang city. Environmental Science and Technology. 2021; 44: 172-185.

31. Yunjie K, Guozhang Z, Jianping Y. Research on sustainable land use in Shanxi Province based on carbon footprint ap-proach. Journal of Shanxi Normal University (Natural Science Edition). 2021; 35: 23-28.

32. Yuan W, Xiaoyu J. Evolution and prediction of land-use carbon emissions in Guizhou Province based on carbon peaking and carbon neutrality. Ecological Economics. 2022; 38: 108-114.

33. Zhuangzhuan Y, Changsheng Y, Huidan L. Analysis of carbon emission effects in Nanchang City based on land use change. Journal of Natural Sciences, Hunan Normal University. 2021; 44: 30-39.

34. Qingfan W. System dynamics. Tsinghua University Press. 1995; 12-22.

35. Huogen W, Lixiang X, Bing L. A system dynamics-based simulation of carbon reduction pathways in China. Journal of Natural Resources. 2022; 37: 1352-1369.

36. Yuanyuan L, Wei W, Junjv Z, Ruijun H, Dibo C. Changes in land use carbon emissions and coordinated zoning in Chi-na. Huan Jing Ke Xue. 2023; 44: 1267-1276.

37. Ge W, Huizhong D, Hui Z. Simulation of carbon emission evolution pattern and low carbon economic development strategy in Shandong Province based on ArcGIS and SD. Science and Technology Management Re-search. 2017; 37: 249-256.

38. Meng W, Li R, Yinrong C. Simulation study on the dynamics of urban land use carbon emission system--Wuhan city as an example. China Land Science. 2017; 31: 29-39.

39. Zhongxiu Z, Yunfeng Y, Jiwen L. Study on the realization path of “double carbon” target in nine provinces of the Yellow River Basin. Journal of Xi’an Jiaotong University (Social Science Edition). 2022; 1-15.

40. Xincai G, Xue H. Study on the spatial differentiation of carbon emissions in the Yellow River Basin and the influencing fac-tors. Economics. 2022; 39: 13-23.