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Research on the Spatiotemporal Evolution, and Optimized Paths of Carbon Pressure in Northwestern Sichuan under the Carbon Peaking and Carbon Neutrality Goals

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Abstract: Consolidating carbon sink capacity and reducing carbon pressure are important channels to achieve the carbon peaking and carbon neutrality goals actively yet prudently. In order to study the current situation of carbon pressure in the Northwestern Sichuan, we took the carbon pressure of the Aba Tibetan-Qiang autonomous prefecture (Aba prefecture) as an example and used the Intergovernmental Panel on Climate Change (IPCC) approach to measure the carbon emissions, carbon uptake, and the carbon balance index (CBI) of each county-level city in Aba prefecture from 2012 to 2020. The study found that: (a) There was a continuous trend of declining carbon emissions, increased carbon uptake, and decreased CBI in Aba prefecture during the sample period, but there is a large variability among county-level cities; (b) Aba prefecture differs in the spatiotemporal distribution of carbon emissions, carbon uptake, and CBI. Based on the research results, we propose several optimized paths for alleviating the current carbon pressure situation in the Northwestern Sichuan.

Keywords: carbon peaking and carbon neutrality goals, the Northwestern Sichuan, carbon pressure, path

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Introduction

Since the advent of the Industrial Revolution, global warming has become a major problem. According to the Blue Book on Climate Change in China (2021), the average global temperature in 2020 was 1.2 degrees Celsius (2 degrees Fahrenheit) above the pre-industrial (1850–1900) level, making 2020 one of the three warmest years on record since complete meteorological observation records were available; the period 2011–2020 was the warmest decade on record since 1850. Global warming has brought about obvious adverse effects, such as significant changes in global precipitation patterns, accelerating the melting of glacial permafrost, and pushing up sea levels. In addition, global warming not only causes an imbalance in a natural ecosystem but also poses a serious threat to human's normal production and living activities, food supplies, and living environments.

Carbon emissions are an important cause of global warming. As a responsible major country, China has actively addressed global warming and taken the initiative to reduce carbon emissions. On September 22, 2020, Chinese President Xi Jinping, announced at the General Debate of the 75th Session of the United Nations General Assembly that "China will scale up its Intended Nationally Determined Contributions by adopting more vigorous policies and measures. We aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060." On April 22, 2021, Xi reiterated at the Leaders Summit on Climate that "China has committed to moving from carbon peak to carbon neutrality in a much shorter time span than what might take many developed countries, and that requires extraordinarily hard efforts from China." According to the report to the 20th National Congress of the Communist Party of China, we should, "work actively and prudently toward the goals of reaching peak carbon emissions and carbon neutrality. Reaching peak carbon emissions and achieving carbon neutrality will mean a broad and profound systemic socioeconomic transformation. We will improve the statistics and accounting systems and the cap-and-trade system for carbon emissions. The carbon absorption capacity of ecosystems will be boosted." As a developing country, China will complete the highest carbon emission intensity reduction in the world and achieve the goal of moving from carbon peaking to carbon neutrality in the shortest possible time. Therefore, China faces a severe challenge with a tight schedule and heavy tasks. To meet that challenge, the counties, cities, and provinces actively promote a clean and low-carbon transition in industry, buildings, and transportation.

Many studies on carbon peaking and carbon neutrality goals have been conducted. However, most studies only focus on industrial agglomeration areas and coal resource-based cities, while little attention has been paid to the carbon balance in areas with fragile ecosystems, surrounding areas of large river basins, and areas where nature reserves and scenic tourist areas coexist. For this reason, we took Northwestern Sichuan as the research object, and selected Aba Tibetan and Qiang autonomous prefecture (Aba prefecture) in Sichuan province as the case study object.

Northwestern Sichuan is located at the southeast edge of the Qinghai-Tibet Plateau, characterized by complex topography, diverse climate, rich flora and fauna resources, and abundant national nature reserves and scenic tourist areas. At the same time, Northwestern Sichuan is a major tributary of the upper reaches of the Yangtze River and Yellow River. It is also the largest green ecological barrier and major water conservation area in the upper reaches of the Yangtze River and Yellow River. Accordingly, it is of great importance to enhance the carbon sink capacity of Northwestern Sichuan to fully promote the high-quality development of the Yangtze River and Yellow River economic belts, and to promote the realization of carbon peaking and carbon neutrality goals in a holistic manner. Also, it has important implications for the stable carbon sink capacities of other ecological reserves. In this context, it is essential to clarify the basic situation and main characteristics of carbon emissions, carbon uptake, and carbon pressure in Northwestern Sichuan, to identify the problems faced by Northwestern Sichuan in mitigating carbon balance, and to propose a strategic path for the sustainable reduction of carbon pressure in Northwestern Sichuan.

Literature Review

Carbon pressure refers to the ratio between carbon emissions and carbon carrying capacity of regional energy consumption, which can measure the equilibrium relationship between carbon emissions and carbon carrying capacity, and directly reflect the degree of carbon emissions' coercion on the regional ecological environment (Liang & Xu, 2017). Domestic and foreign research on carbon pressure mainly focuses on the following three perspectives:

The first is the research conducted from the perspective of the measurement of carbon emissions and carbon pressure. Domestically, scholars have detailed measurements of carbon emissions and carbon pressure indices in China at the municipal, provincial, and state levels. Liang and Xu (2017) observed the carbon pressure at the provincial level in China and found that China was in a serious state of "carbon overload." Song et al. (2021) studied carbon balance index (CBI) of the middle reaches of the Yangtze River city cluster from 2008 to 2018 and found that this cluster was in a state of carbon overload and showed a typical "N" shaped trend. Tu and Liu (2021) measured the relationship between tourism carbon emissions and tourism carbon carrying capacity in seven provinces in East China during 2004–2018. They concluded that East China showed an overall trend of increases in its current tourism carbon carrying capacity. Jian (2022) analyzed the current land use carbon emission pressure situation in Guizhou province during 2005–2019 and found that the overall net land use carbon emissions fluctuated and increased during the study period. Based on the data on energy consumption and vegetation coverage from 2002–2014, Liu (2017) explored the changing pattern of the carbon footprint and the carbon carrying capacity and other related characterization indicators in Huainan city of Anhui province and then studied the dynamic changes of the carbon footprint and carbon carrying capacity in coal resource-based cities.

The second is the research conducted from the perspective of the spatialtemporal evolution of carbon emissions and the carbon pressure. Wang et al. (2011) conducted an in-depth analysis of the spatiotemporal pattern of carbon emissions and carbon emission types in 30 provinces and regions of China. They found that their carbon emissions showed obvious and consistent stages. Based on the spatial econometric model, Li (2014) studied the spatialtemporal pattern of CO_2 emissions at the provincial level in China and concluded that the spatial pattern of CO_2 emissions per capita in China is relatively stable. There was a clustering effect in the spatial distribution of CO_2 emissions per capita at the provincial level. By introducing the CBI, Qian and Ma (2019) analyzed the spatiotemporal dynamic variation characteristics of carbon pressure in China’s provinces. They concluded that there were significant differences in the spatial distribution of carbon pressure at the provincial level. Based on the spatial autocorrelation and geographically and temporally weighted regression (GTWR) model, Wei and Li (2022) explored the spatiotemporal evolution pattern of carbon emissions in the Chengdu-Chongqing city cluster, and the results showed significant spatial differences in their total carbon emissions and the carbon emissions per region.

The third is the research conducted from the perspective of factors influencing carbon emissions and carbon pressure. By analyzing the Granger Causality Test (GCT) between emissions and income, Coondoo (2002) concluded there were different causality relationships holding for different country groups. York (2003) explored the relationship between population and carbon emissions by refining the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model. Based on the five factors of energy emissions intensity, energy structure, energy efficiency, economic effect, and environmental effect, Wang and Nan (2014) focused on analyzing the role and effects of these factors on carbon pressure in Shaanxi province. Huang and Zhou (2018) computed the carbon footprint and carbon carrying capacity of Zhejiang province during 2000–2015. They held that population, urbanization rates, gross regional product (GRP), the proportion of secondary industries, and the raw coal carbon footprint were the main factors affecting Zhejiang’s carbon carrying capacity. Feng (2018) observed the influence mechanisms of different industrial agglomerations on urban carbon emissions and the impact of city cluster economies on carbon emissions. Ma et al. (2019) explored the effect of environmental regulation and regional innovation on carbon pressure. Wang and Fan (2022) classified the research methods on the influencing factors of carbon emissions of energy consumption into three categories: the IPAT or STIRPAT model, the Kaya identity and the logarithmic mean division index (LMDI) decomposition method, and the geographically weighted regression (GWR) and environmental Kuznets curve (EKC).

The fourth is the research conducted from the perspective of the optimization path of carbon emissions and carbon pressure. After analyzing the problems of low-carbon development in Handan city, Hebei province, Chen (2016) concluded that urban low-carbon development could be realized by improving energy efficiency and promoting low-carbon education. Wang and Yin (2022) measured and predicted carbon emissions in Weifang city, Shandong province, and proposed to seek the regional low-carbon development path from both production and consumption. Taking Quanzhou county in Guangxi Zhuang autonomous region as an example, Zheng and Wen (2022) proposed to optimize the county-level city system through the path of “carbon function classification—carbon function positioning—industry guidance” to help achieve the carbon peaking and carbon neutrality goals.

Existing studies have produced fruitful results from the perspective of carbon pressure, yet the following deficiencies still exist. First, in terms of research content, little attention has been paid to the temporal evolution law and driving factors of carbon balance. There are few studies on the situation and the future path to alleviate the carbon pressure situation. Second, in terms of research perspectives, existing studies on the statistics and accounting of carbon emissions and carbon uptake are mainly conducted at the provincial and state levels, and most of these focus on provincial capitals and developed cities at the city level, with rare statistics and accounting of carbon balance of county-level cities. Third, in terms of research objects, existing studies focus on industrial enterprises and other high-value areas; little attention is paid to the ecological carbon sink capacity and carbon balance in ecologically fragile areas, and less attention is paid to the western region, especially to Northwestern Sichuan Ecological Demonstration Zone. Fourth, in terms of research methods, existing studies focus on analyzing the current situation of carbon balance based on theoretical data. Few field studies have been conducted on the actual situation of the studied region, resulting in a lack of relevance and practicality in the recommendations. Therefore, combined with the results of field research in Aba, Ruoergai, Songpan, and Hongyuan counties, we computed the carbon balance in Aba prefecture ecology in Northwestern Sichuan, analyzed its spatiotemporal evolution patterns, and identified the difficulties in mitigating the current carbon balance to provide a reference for developing effective mitigation strategies. This will help to improve the rationality, systematization, and diversity of research on how to promote the green transformation of the regional economy, which can expand the research fields of regional and environmental economics, and at the same time, accelerate the carbon peaking and carbon neutrality process and the green, low-carbon transformation in Sichuan province and the western region.

Research Methods and Data Source

Research Methods

Statistics and accounting of carbon emissions.

Based on mainstream research methods, the IPCC approach was chosen to conduct statistics and accounting of carbon emissions in this study. The IPCC approach is a top-down method prepared by the United Nations Intergovernmental Panel on Climate Change. Regardless of how energy is allocated and consumed in each sector, the IPCC approach focuses only on the total end-use energy consumption, which is multiplied by the carbon content of different fuels to obtain the total carbon emissions. In this study, the energy sources mainly include raw coal, clean coal, coke, coke oven gas, other gases, other coking products, crude oil, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas (LPG), dry refinery gas, other petroleum products, and natural gas. The formula is as follows:

$$C=\sum_{i=1} m_i \times n_i \times \delta_i, i \in [1,13] \tag{1}$$

Where C denotes the total carbon emissions from construction sites in counties and cities, m_i denotes various energy consumption (10^4t), n_i denotes the conversion factor for converting various energy consumption into standard coal, and δ_i denotes the carbon emission factor of various energy sources (10^4t/10^4t). For the standard coal conversion factor and carbon emission factors, refer to Table 1 and Table 2 below.

Table 1 Carbon emission coefficient of various energy sources

Energy type	Carbon emission factor	Energy type	Carbon emission factor
Raw coal (thousand tons)	0.7559	Fuel oil (thousand tons)	0.6185
Clean coal (thousand tons)	0.7559	Other petroleum products (thousand tons)	0.5857
Coke (thousand tons)	0.8550	LPG (thousand tons)	0.5042
Other coking products (thousand tons)	0.6449	Natural gas (hundred million m³)	0.4483
Crude oil (thousand tons)	0.5857	Coke oven gas (hundred million m³)	0.3548
Gasoline (thousand tons)	0.5538	Refinery dry gas (thousand tons)	0.4602

Energy type	Carbon emission factor	Energy type	Carbon emission factor
Kerosene (thousand tons)	0.5714	Other gas (hundred million m^3)	0.3548
Diesel (thousand tons)	0.5921	-	-

Source: United Nations Intergovernmental Panel on Climate Change (IPCC), same below.

Table 2 Conversion factors of standard coal for various energy sources

Energy type	Conversion coefficient of standard coal	Energy type	Conversion coefficient of standard coal
Raw coal (thousand tons)	0.7143(t/t)	Fuel oil (thousand tons)	1.4286(t/t)
Clean coal (thousand tons)	0.9000(t/t)	Other petroleum products (thousand tons)	1.2000(t/t)
Coke (thousand tons)	0.9714(t/t)	LPG (thousand tons)	1.7143(t/t)
Other coking products (thousand tons)	1.3000(t/t)	Natural gas (hundred million m^3)	13.3000(t/m^3)
Crude oil (thousand tons)	1.4286(t/t)	Coke oven gas (hundred million m^3)	6.143(t/m^3)
Gasoline (thousand tons)	1.4714(t/t)	Refinery dry gas (thousand tons)	1.5714(t/t)
Kerosene (thousand tons)	1.4714(t/t)	Other gas (hundred million m^3)	3.5701(t/m^3)
Diesel (thousand tons)	1.4571(t/t)	-	-

Statistics and accounting of carbon uptake.

Referring to the research of Wu et al. (2022), in this study, the carbon uptake mainly covers forest land, cropland, and grassland, where the carbon uptake of grassland and forest land is calculated using the carbon uptake coefficient. The formula is as follows:

$$CA_i = \sum_{i=1}^{n} C_i S_i \qquad (2)$$

Where CA_i denotes the carbon uptake of the i-th land use type (Unit: t); S_i denotes the area of the i-th land use type (Unit: hm^2); and C_i denotes the carbon uptake coefficient of the i-th land use type. Concerning the current results, the carbon uptake coefficients of forest land and grassland were determined as 5.77t/hm^2 and 0.021t/hm^2, respectively.

Referring to the research of Tang (2016), we estimated the carbon uptake of cropland based on the estimation method of carbon uptake of farmland ecosystems, i.e., based on the crop yield data, economic coefficients, and carbon uptake rate. The formula is as follows:

$$CA_f = \sum_{i=1}^{n} \frac{C_i Y_i}{H_i} \qquad (3)$$

Where CA_f denotes the carbon uptake of arable land of county-level cities (Unit: t); C_i denotes the carbon uptake rate of synthetic organic matter of the ith crop; Y_i denotes the economic yield of the i-th crop (Unit: t); H_i denotes the economic coefficient of the i-th cash crop. Based on the current agricultural development in Aba prefecture, we selected the following crops to estimate the carbon uptake of arable land, as shown in Table 3 below.

Table 3 Carbon uptake rate and economic coefficient of major crops in Aba prefecture

Crop Type	C	H
Wheat	48.35%	0.40
Soybeans	45.00%	0.35
Potatoes	42.26%	0.70
Vegetables	45.00%	9.50
Fruits	45.00%	1.75

Source: United Nations Intergovernmental Panel on Climate Change (IPCC). C represents the carbon uptake rate of organic matter synthesized by crops, and H represents the economic coefficient of crops.

Based on the calculation of carbon uptake of forest land, arable land, and grassland of county-level cities, we calculated the total carbon uptake according to the formula below:

$$CA = CA_i + CA_f \tag{4}$$

Statistics and accounting of carbon balance.

Based on the calculation of carbon emissions and carbon uptake of county-level cities, we constructed the carbon balance index (CBI):

$$CBI = \frac{C}{CA} \tag{5}$$

If $CBI>1$, it means that the county's carbon emission is greater than carbon uptake, and the county is in a state of carbon overload; if $CBI<1$, it means that the county's carbon emission is less than the carbon uptake, and the county is in a state of carbon surplus; if $CBI=1$, it means that the county's carbon emissions are equal to carbon uptake, and the county is at the critical point of carbon overload.

Data Source

The original data of this study, including the energy consumption, the area of various land use types, and the permanent resident population of 13 counties in Aba prefecture, were sourced from the *Sichuan Statistical Yearbook*, *China Energy Statistical Yearbook*, *China Rural Statistical Yearbook*, and *China County Statistical*

Yearbook during 2013–2021. Among these, *China Energy Statistical Yearbook* only shows the energy balance data at the province and state levels, so we estimated the energy consumption of the 13 counties in Aba prefecture based on the per capita energy consumption in Sichuan province. After multiplying the per capita energy consumption by the permanent resident population in each county-level city, we obtained the energy consumption of the 13 counties, which were, however, partially missing and then supplemented through the linear interpolation method. The area data of various land use types were sourced from the second and third national land surveys of Sichuan province, *China Rural Statistical Yearbook*, and *China County Statistical Yearbook,* and the statistical yearbooks of each county-level city, in which the missing data were supplemented through the linear trend approach at nearest-neighbor (NN) points. The energy carbon emission coefficients and conversion coefficient of standard coal were mainly obtained from *the IPCC Guidelines for National Greenhouse Gas Inventories* and the Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC) (2006).

Spatiotemporal Evolution Analysis of Carbon Pressure in Aba Prefecture Ecology in Northwestern Sichuan

Based on the above formula and data sources described in the previous section, we calculated the carbon emissions, carbon uptake, and carbon pressure of each county-level city in Aba prefecture during 2012–2020 and plotted these carbon emissions, carbon uptake, and carbon pressure indices using ArcGIS software and the Jenks natural breaks classification method, as shown in Table 4, Table 5, Table 6 below, respectively.

Table 4 Carbon emissions of Aba prefecture during 2012–2020 (unit: thousand tons)

County	2012	2013	2014	2015	2016	2017	2018	2019	2020
Xiaojin county	64.60	63.42	62.39	60.80	53.35	53.41	48.00	48.08	44.58
Wenchuan county	83.57	81.95	80.53	78.37	68.68	68.68	61.63	61.64	57.07
Songpan county	61.24	60.71	60.33	59.39	52.66	53.31	48.44	49.08	46.04
Ruoergai county	64.51	64.61	64.88	64.54	57.84	59.17	54.33	55.64	52.77
Rangtang county	34.62	35.06	35.58	35.76	32.38	33.46	31.04	32.1	30.73
Maoxian county	88.49	87.58	86.88	85.38	75.58	76.36	69.26	70.05	65.60
Ma’erkang county	50.23	50.17	50.23	49.83	44.53	45.42	41.59	42.47	40.17
Lixian county	38.37	37.50	36.72	35.61	31.09	30.96	27.67	27.56	25.40
Jiuzhaigou county	67.33	65.94	64.71	62.89	55.03	54.95	49.23	49.16	45.44
Jinchuan county	55.36	54.62	54.01	52.91	46.68	47.00	42.48	42.81	39.94

County	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hongyuan county	38.15	38.35	38.65	38.58	34.70	35.61	32.82	33.72	32.09
Heishui county	49.41	47.97	46.64	44.90	38.89	38.42	34.04	33.59	30.65
Aba county	63.62	64.24	65.02	65.20	58.88	60.69	56.16	57.94	55.35
Total	759.48	752.11	746.55	734.16	650.27	657.43	596.67	603.83	565.84

In terms of the total carbon emissions in Aba prefecture during 2012–2020, all the county-level cities showed a downward trend to varying degrees. In terms of the absolute value of carbon emissions in 2012, the top five county-level cities with the highest carbon emissions in Aba prefecture were Maoxian county, Wenchuan county, Jiuzhaigou county, Xiaojin county, and Ruoergai county; the top five county-level cities with the lowest carbon emissions were Ma’erkang county, Heishui county, Lixian county, Hongyuan county, and Rangtang county. In 2020, this situation changed significantly; the top five county-level cities with the highest carbon emissions were Maoxian county, Wenchuan county, Aba county, Ruoergai county, and Songpan county; the top five county-level cities with the lowest carbon emissions were Jinchuan county, Hongyuan county, Rangtang county, Heishui county, and Lixian county. In terms of carbon emission reduction, the top five county-level cities with the highest reduction rate in Aba prefecture were Wenchuan county, Maoxian county, Jiuzhaigou county, Xiaojin county, and Heishui county; the top five county-level cities with the lowest reduction rate were Ruoergai county, Ma’erkang county, Aba county, Hongyuan county, and Rangtang county.

According to the spatiotemporal evolution of carbon emissions in Aba prefecture, there was a shift from the southeast to the southeast and northwest areas during 2012–2020 regarding its high-value areas. In 2012, the high-value areas included Maoxian county and Wenchuan county, which were in the southeast of Aba prefecture; in addition to Maoxian county and Wenchuan county, in 2020, the high-value areas also included Aba county and Ruoergai county, which were located in the northwest of Aba prefecture. Regarding its low-value areas, Aba prefecture shows a trend from dispersion to concentration during 2012–2020, and in 2020, Lixian county became the only low-value area in Aba prefecture.

Table 5 Carbon uptake of Aba prefecture during 2012–2020 (unit: thousand tons)

County	2012	2013	2014	2015	2016	2017	2018	2019	2020
Xiaojin county	1968.50	1973.70	1979.93	1981.14	1980.93	1983.68	1983.04	1983.5	1984.38
Wenchuan county	1957.91	1947.16	1956.86	1957.04	1957.64	1959.2	1959.92	1962.8	1979.18
Songpan county	1960.64	1959.88	1956.56	1958.43	1960.32	1960.27	1957.12	1958.37	1958.76
Ruoergai county	2220.26	2221.67	2221.50	2222.08	2223.81	2224.09	2224.10	2225.19	2225.60
Rangtang county	1917.33	1921.12	1911.89	1909.87	1909.99	1909.94	1909.35	1910.15	1910.19

County	2012	2013	2014	2015	2016	2017	2018	2019	2020
Maoxian county	1742.29	1736.24	1752.00	1757.84	1757.65	1757.26	1757.49	1755.76	1760.25
Ma’erkang county	987.83	987.59	988.48	988.08	989.04	989.29	988.68	988.85	989.16
Lixian county	1146.44	1147.15	1146.11	1146.96	1147.26	1147.49	1146.08	1146.38	1146.55
Jiuzhaigou county	5014.59	5014.61	5014.53	5014.92	5014.87	5015.15	5014.97	5015.29	5015.23
Jinchuan county	2178.31	2182.51	2182.84	2183.86	2183.6	2184.29	2183.89	2184.67	2185.12
Hongyuan county	975.52	1003.69	993.47	992.4	990.57	991.41	982.14	981.56	981.53
Heishui county	1655.19	1654.47	1654.56	1656.48	1654.74	1655.31	1656.03	1656.65	1657.11
Aba county	307.38	308.18	308.98	310.08	312.14	312.81	312.96	314.16	316.81
Total	24032.20	24057.98	24067.73	24079.17	24082.57	24090.19	24075.77	24083.33	24109.88

According to the total amount of carbon uptake in Aba prefecture, due to the sustained greening and agricultural development efforts, the vast majority of Aba prefecture showed an increasing trend in carbon uptake to varying degrees during the study period. Regarding the absolute value of carbon uptake in 2012, the top five county-level cities with the highest carbon uptake in Aba prefecture were Jiuzhaigou county, Ruoergai county, Jinchuan county, Xiaojin county, and Songpan county. Xiaojin county and Songpan county; the top five county-level cities with the lowest carbon uptake in Aba prefecture were Heishui county, Lixian county, Ma’erkang county, Hongyuan county, and Aba county. In 2020, the top five county-level cities with the highest carbon uptake in Aba prefecture were Jiuzhaigou county, Ruoergai county, Jinchuan county, Xiaojin county, and Wenchuan county; the top five county-level cities with the lowest carbon uptake in Aba prefecture were Heishui county, Lixian county, Ma’erkang county, Hongyuan county, and Aba county. In terms of the increase in carbon uptake, the top five county-level cities with the largest increase in Aba prefecture were Wenchuan county, Maoxian county, Xiaojin county, Aba county, and Jinchuan county; the top five county-level cities with the smallest increase were Ruoergai county, Heishui county, Ma’erkang county, Jiuzhaigou county, and Lixian county. It is worth noting that Songpan county and Rangtang county witnessed a decrease in their carbon uptake.

According to the spatiotemporal evolution of carbon uptake in Aba prefecture, during 2012–2020, it showed a generally consistent pattern of carbon uptake distribution, high in the southwest and northeast parts and low in the central part. Additionally, the high-value areas were mainly distributed in Jiuzhaigou county in the northeast part, mostly because its primeval forests covered more than half of its area, with the characteristics of a vast forest area and strong carbon sink capacity. The low-value areas were mainly distributed in Aba county in the northwest part, mostly because its primeval forests covered only 10.30 percent, with the characteristics of large non-forestry land and weak carbon sink capacity.

Table 6 CBI of Aba prefecture during 2012–2020

County	2012	2013	2014	2015	2016	2017	2018	2019	2020
Xiaojin county	0.033	0.032	0.032	0.031	0.027	0.027	0.024	0.024	0.022
Wenchuan county	0.043	0.042	0.041	0.040	0.035	0.035	0.031	0.031	0.029
Songpan county	0.031	0.031	0.031	0.030	0.027	0.027	0.025	0.025	0.024
Ruoergai county	0.029	0.029	0.029	0.029	0.026	0.027	0.024	0.025	0.024
Rangtang county	0.018	0.018	0.019	0.019	0.017	0.018	0.016	0.017	0.016
Maoxian county	0.051	0.050	0.050	0.049	0.043	0.043	0.039	0.040	0.037
Ma’erkang county	0.051	0.051	0.051	0.050	0.045	0.046	0.042	0.043	0.041
Lixian county	0.033	0.033	0.032	0.031	0.027	0.027	0.024	0.024	0.022
Jiuzhaigou county	0.013	0.013	0.013	0.013	0.011	0.011	0.010	0.010	0.009
Jinchuan county	0.025	0.025	0.025	0.024	0.021	0.022	0.019	0.020	0.018
Hongyuan county	0.039	0.038	0.039	0.039	0.035	0.036	0.033	0.034	0.033
Heishui county	0.030	0.029	0.028	0.027	0.024	0.023	0.021	0.020	0.018
Aba county	0.207	0.208	0.210	0.210	0.189	0.194	0.179	0.184	0.175
Total	0.032	0.031	0.031	0.030	0.027	0.027	0.025	0.025	0.023

The CBI of Aba prefecture is consistent with the trend of continuous decrease of carbon emissions and continuous increase of carbon uptake in the previous section. During 2012–2020, the vast majority of areas in Aba prefecture showed a downward trend to varying degrees. The CBI in Aba prefecture was 0.032 in 2012 and decreased to 0.023 in 2020, a decrease of 0.009. In terms of the absolute value of CBI in 2012, the top five county-level cities with the highest CBI were Aba county, Maoxian county, Ma’erkang county, Wenchuan county, and Hongyuan county in Aba prefecture; the top five county-level cities with the lowest CBI were Heishui county, Ruoergai county, Jinchuan county, Rangtang county, and Jiuzhaigou county. In 2020, the top five county-level cities with the highest CBI were Aba county, Ma’erkang county, Maoxian county, Hongyuan county, and Wenchuan county; the top five county-level cities with the lowest CBI were Lixian county, Heishui county, Jinchuan county, Rangtang county, and Jiuzhaigou county. In terms of the decrease in CBI, the top five county-level cities with the largest decrease in Aba prefecture were Aba county, Maoxian county, Wenchuan county, Heishui county, and Xiaojin county; the top five county-level cities with the smallest decrease were Songpan county, Hongyuan county, Ruoergai county, Jiuzhaigou county, and Rangtang county.

According to the spatiotemporal evolution of CBI in Aba prefecture, its spatial distribution of CBI showed a trend of gradual strengthening along the northwest-southeast direction during 2012–2020. Additionally, the high-value areas were mainly distributed in Aba county in the northwest part, mostly because Aba county demonstrated a weaker carbon sink capacity and more carbon emissions.

Optimized paths for Alleviating the Carbon Balance Situation in Northwestern Sichuan under the Carbon Peaking and Carbon Neutrality Goals

To cope with the five dilemmas faced by Northwestern Sichuan in alleviating the carbon pressure situation as mentioned in the previous section, including inadequate publicity and education about the carbon peaking and carbon neutrality goals, the incomplete monitoring and statistical system, insufficient support in ecological conservation and construction and the imperfect ecological compensation system, we proposed the following optimized paths for alleviating the carbon pressure situation in Northwestern Sichuan:

First, we should intensify the education and publicity of the carbon peaking and carbon neutrality goals. This is necessary to strengthen the awareness, recognition, and understanding of the concept of “carbon peaking and carbon neutrality” goals among government officials in Northwestern Sichuan, in that the goals involve technology, economy, society, and other interdisciplinary research fields, such as the impact of climate change on natural and socioeconomic systems, as well as technical pathways, economic impacts and policy measures for mitigating and adapting to climate changes. We should actively organize special training on the carbon peaking and carbon neutrality goals, and implement the decision of The Central Committee of the Communist Party of China (CPC) and the State Council on the goals, and clarify the policies and regulations, work content, and work requirements regarding the goals. Furthermore, we need to enhance the professionalism and business abilities to lead cadres at all levels in Northwestern Sichuan to promote green and low-carbon development, grasp the major situation and key tasks of the unit, the department, and the region for the realization of the goals and comprehensively strengthen the publicity and education of the goals to lay a good foundation for the carbon peaking and carbon neutrality work in Northwestern Sichuan. In addition, we should carry out various forms of publicity by making full use of news media and other means, continuously raise awareness of the ecological environment and low-carbon development among farmers and herders, and seek the support and participation of the majority of farmers and herders.

Second, we should do a good job in the statistics and accounting of carbon emissions and carbon uptake. To promote all walks of life to achieve carbon peaking and carbon neutrality goals, we must accurately grasp the carbon emissions and carbon uptake in our respective fields. The same is true for carbon emissions and carbon uptake in the ecological field. Although China has initially established the carbon emission and carbon uptake accounting methods, there are obvious problems in the current accounting work, such as limited selection of carbon sources, unclear accounting boundaries, large deviations from the results of different institutions, and low continuity of accounting results which not only affect the scientific nature and authority of carbon emission and carbon uptake accounting data at different levels, and also pose challenges for the future carbon emission reduction and carbon trading activities. In China, the existing carbon accounting methods make it increasingly difficult to respond to the carbon peaking and carbon neutrality situation, so it is urgent to comprehensively improve the quality of carbon accounting work. Therefore, by the basic data and technical advantages of land survey and remote sensing monitoring, based on the distribution characteristics and biological growth status of ecosystems in Northwestern Sichuan, and under the requirements of the *Sichuan Forestry and Grasslands Carbon Sink Action Plan*, we should explore the zoning classifications and monitoring techniques of carbon emission and carbon uptake monitoring objects in Northwestern Sichuan, choose the appropriate data acquisition method, and model the relationship between biological reserves and carbon neutrality according to local conditions. Moreover, we should speed up the establishment of a forestry and grassland carbon sink monitoring and statistical system that conforms to the relevant national standards, satisfies the work needs and displays the characteristics of ethnic regions, and further carry out the survey on the carbon sink background of ecosystems, the calculation of the carbon reserves of natural ecosystems, and the accounting of carbon sink capacity of natural ecosystems to provide technical support and data support for Northwestern Sichuan to clarify the ecological resource background, identify shortcomings and enhance the carbon sink capacity.

Third, we should continue to reinforce ecological management and conservation. Unlike other regions, Northwestern Sichuan has fragile ecosystems characterized by instability, sensitivity, and variability. As a result, the grassland and wetland ecosystems with simple structures are unstable and prone to degradation and desertification. Once they are destroyed, restoring these fragile ecosystems. Accordingly, we should provide more investments and project supports for ecological management and conservation in Northwestern Sichuan and give preference to ecological conservation factors, pollution prevention factors, and supervisory capacity factors when allocating special funds at the provincial level a, so that more ecological projects are implemented and a long-term investment mechanism for the management and conservation of forests and grasslands can be established. Besides, attempts should be made to build a normal cross-border supervision and management mechanism of grassland and wetlands between Sichuan and Qinghai, Gansu, and other regions to alleviate degradation and desertification and desertification and preventing rodents, pests, and insects. Furthermore, we need to create closer ties between Northwestern Sichuan and research institutes inside and outside, actively conduct the experimental work of grassland and wetland conservation in alpine areas, explore and summarize new technologies and methods for the conservation of grasslands and wetlands in alpine regions, and achieve better conservation outcomes.

Fourth, we should gradually improve the ecological compensation system. The current ecological compensation system of Northwestern Sichuan needs to be improved because there are still problems, such as low participation of enterprises and the public and an insufficient supply of high-quality ecological products and services. It is, therefore, urgent to establish a government-led, market-oriented, and sustainable ecological conservation compensation system with wide participation of enterprises and society to stimulate the wide participation in ecological conservation. Besides, both the government and the market should play their part so that we can further play the leading role of financial funding, reinforce the integration of various ecological conservation compensation needs and policies, and improve the compensation system for the paid use of resources and conservation. At the same time, we should guide ecological beneficiaries to compensate ecological conservation personnel and facilitate the establishing a long-term market-oriented and diversified ecological compensation system. Dangling modifier, it is essential to increase the subsidy standards for ecological restoration, such as control of rodents, pests and insects, grassland improvement, and desertification control based on the current standards, and gradually raise the grassland-livestock balance, and the grassland grazing ban awards and subsidy standards so that a win-win situation of ecological conservation and income increases can be achieved. Farmers and herders can be motivated to participate in local ecological conservation. Moreover, we should improve the financial compensation mechanism and try to explore diversified ecological compensation systems such as project compensation, policy support, financial investments, and talent support.

Fifth, we should do a good job in the non-agricultural employment of farmers and herders. To speed up implementing the rural revitalization strategy, solve the three rural issues, and relieve the pressures of production activities on the local environment, we should comprehensively and thoroughly promote the non-agricultural employment of the surplus labor force of farmers and herdsmen in Northwestern Sichuan, and constantly scale up and enhance the quality of non-agricultural employment. It is, therefore, necessary to do a good job in non-agricultural employment of the surplus labor force of farmers and herders. For instance, we should provide preferential treatment for the development of competitive industries in Northwestern Sichuan regarding policies, funds, and talents and accelerate the transformation and upgrading of traditional industries. Many efforts should also be devoted to the vigorous growth of modern animal husbandries, such as developing livestock reduction planning and incentive policies, setting reasonable grazing capacity limits for grasslands, and promoting the building of modern quality-based animal husbandry while reinforcing the infrastructure of animal husbandry and supporting the establishment of high-yield and quality artificial grasslands, forage reserve bases and forage seed bases. Furthermore, we should strive to foster new industries and facilitate the development of the grass products processing industry and the traditional Chinese and Tibetan medicine planting and processing industry. Based on the unique local cultural deposits and rich tourism resources, we may promote the integration of primary, secondary, and tertiary industries, build an innovative development model for “agriculture + culture + tourism,” expand non-agricultural employment for farmers and herdsmen, increase income channels, and gradually reduce overgrazing. In addition, we should do a good job in compulsory education and vocational training for farmers and herdsmen, do our utmost to make sure that farmers and herders acquire labor skills through training, and build sound mechanisms for training, export, management, and services so that the farmers and herders may develop more job opportunities and increase their incomes in developed areas in secondary and tertiary industries.

Conclusion and Recommendations

Based on the IPCC approach, we measured and analyzed the carbon emissions, carbon uptake a, and CBI of county-level cities in Northwestern Sichuan during 2012–2020. Combining the research results, came up with the corresponding optimized paths. The main conclusions are as follows:

First, there was a continuous trend of declining carbon emissions, increased carbon uptake, and decreased CBI in Northwestern Sichuan during the sample period, but there was also a large variability among county-level cities.

Second, Northwestern Sichuan differs in the spatiotemporal layout of carbon emissions, carbon uptake, and CBI. There was a shift from the southeast area to both the southeast and northwest areas during 2012–2020 regarding its high-value areas of carbon emissions. During 2012–2020, it showed a generally consistent pattern of carbon uptake distribution, being high in the southwest and northeast parts and low in the central part. The high-value areas were mainly distributed in the northeast part. Besides, the low-value areas of CBI were mainly distributed in the northwest part.

Third, in alleviating the carbon pressure situation, Northwestern Sichuan is now facing a series of problems, such as reduced publicity and education regarding the carbon peaking and carbon neutrality goals, the lack of a carbon sink monitoring and statistical system, insufficient support of projects, funds, and talents in ecological conservation and construction, main contradictions between conservation and development, and an imperfect ecological compensation system.

Fourth, the optimized paths for alleviating the carbon pressure situation in Northwestern Sichuan include intensifying the education and publicity of the carbon peaking and carbon neutrality goals, doing a good job in the statistics and accounting of carbon emissions and carbon uptaking, reinforcing ecological management and conservation, improving the ecological compensation system, and doing a good job in the non-agricultural employment of farmers and herders.

Based on the above findings on the carbon pressure situation in Northwestern Sichuan, some policy recommendations are offered, as follows:

First, we should continue to reinforce ecological management and conservation. Northwestern Sichuan shows a decreasing trend in its carbon pressure situation, so it is necessary to consolidate the carbon sink capacity of areas with fragile ecosystems, reduce the destruction of herders to carbon sequestration organisms such as forests and grasslands, and establish a long-term investment mechanism for the management and conservation of forests and grasslands. As an upstream area of the Yangtze River and Yellow River, Northwestern Sichuan plays a particularly significant role in stabilizing the water ecosystem.

Second, we should intensify the education and publicity of the carbon peaking and carbon neutrality goals. It is thus necessary to strengthen the awareness of the concept of “carbon peaking and carbon neutrality” goals among government officials in Northwestern Sichuan, improve the professionalism of leading cadres at all levels to promote green and low-carbon development, strengthen publicity and education for the masses, and continuously raise the awareness of the ecological environment and low-carbon development among farmers and herders.

Third, we should do a good job in the statistics and accounting of carbon emissions and carbon uptake. Based on the characteristics of ecosystems in Northwestern Sichuan, we need to explore the zoning classifications and monitoring techniques of carbon emission and carbon uptake monitoring objects in Northwestern Sichuan and model the relationships between biological reserves and carbon neutrality according to local conditions. Moreover, we should speed up establishing a forestry and grassland carbon sink monitoring and statistical system that conforms to the relevant national standards and displays the characteristics of ecological demonstration zones.

Fourth, we should gradually improve the ecological compensation system in Northwestern Sichuan. It is urgent to establish a government-led, market-oriented, and sustainable ecological conservation compensation system with wide participation of enterprises and society, improve the financial compensation mechanism and try to explore diversified ecological compensation systems such as project compensation, financial investments, and talent support.

Fifth, we should do a good job in the non-agricultural employment of farmers and herders. We should devote efforts to the vigorous growth of modern animal husbandry, make every effort to foster new industries, and facilitate the development of the grass products processing industry and the traditional Chinese and Tibetan medicine planting and processing industry. In addition, we should do a good job in compulsory education and vocational training for farmers and herders, so that they may have more job opportunities and increase their income in developed areas in secondary and tertiary industries.

REFERENCES

Chen, P. (2022). The impact of low-carbon city pilots on carbon emission: New evidence from high-resolution carbon emission data, *Kybernetes*, Vol. ahead-of-print No. ahead-of-print.

Chen, Y. (2016). Research on the problems and optimized paths of low-carbon economy development in Handan city. *Economic & Trade*, (02):337.

Coondoo, D., & Dinda, S. (2002). Causality between income and emission: A country group-specific econometric analysis. *Ecological Economics*. (3)

Feng Han, F. Xie, R. Lu, Y., Fang, J. Y., & Liu, Y. (2018). The effects of urban agglomeration economies on carbon emissions: Evidence from Chinese cities. *Journal of Cleaner Production*.

Gu, Z. F., Xu, L. H., Ma, Q. W., Shi, Y. J., Lu, Z. W., & Wu, Y. Q. (2022). Temporal and spatial evolution of carbon emission in Zhejiang metropolitan area and its influencing factors. *Journal of Natural Resources, 37*(06):1524–1539.

Huang, Z. H., & Zhou, S. C. (2018). Carbon security assessment and its influencing factors in Zhejiang province. *Bulletin of Soil and Water Conservation, 38*(04):234–240+246.

Li, J. B., Zhang, Z. Q., Qu, J. S., Xiong, & Y. L. (2014). Spatiotemporal pattern analysis of CO_2 emission at the provincial level in China. *Economic Geography, 34*(09):158–165.

Liang Z., & Xu, B. (2017). Spatial distribution of carbon balance and its gravity center migration in China. *Economic Geography, 37*(02):179-186.

Liu, B. L., Chen, X. Y., Chen, M., Wang, F., & Zhou, Y. Z. (2017). Dynamic change of carbon footprint and carbon carrying capacity of coal resource-based cities. *Coal Engineering, 49*(02):124–127.

Ma, X., Xue, T. T., WAQAS, A., & Wang, J. D. (2019). Research on the effect of regional innovation on carbon balance under environmental regulation. *Chinese Journal of Management, 16*(01):85–95.

Jian, X. Y. (2022). Study on carbon emission pressure, emission reduction potential and green utilization of land use in Guizhou province [Electronic version]. *Journal of Guizhou University of Finance and Economics*.

Qian, P., & Ma, C. H. (2019). Temporal and spatial dynamics of carbon emissions from energy consumption in China. *Journal of Southwest University (Natural Science Edition), 41*(10):93–100.

Song, M., Chang, L. Y., & Hao, X. G. (2021). Spatial and temporal evolution of carbon balance and its driving factors in the middle reaches of Yangtze River. *Journal of Environmental Economics, 6*(02):23–40.

Tang, H. S., Ma, H. L., Su, Y., Xin, C. C., & Wang, J. J. (2016). Carbon emissions and carbon uptake of different land use types in Xinjiang. *Arid Zone Research, 33*(03):486–492.

Tu, W., & Liu, Q. P. (2021). Study on the relationship between tourism carbon emission and carbon carrying capacity in East China. *Ecological Economy, 37*(11):144–149+155.

Wang, H. T., & Wang, M. P. (2011). Grey correlation analysis of spatiotemporal patterns of carbon emissions in 30 provinces and regions of China. *China Population, Resources and Environment, 21*(07):140–145.

Wang, P., & Yin, F. C. (2022). Regional energy consumption carbon emissions and optimized path: A case study of Weifang City, Shandong Province. *Henan Sciences, 40*(03):449–456.

Wang, X. X., & Nan, L. (2014). Decoupling analysis of energy consumption CBI in Shaanxi province based on LMDI model. *Journal of Ecology and Rural Environment, 30*(03):311–316.

Wang, Z., & Fan, J. (2022). The influencing factors and research prospects of carbon emissions from energy consumption. *Geographical Research, 41*(10):2587–2599.

Wei, Y. T., Li, S. J., & Zhang, H. (2022). Temporal and spatial characteristics of carbon emission and its influencing factors in Chengdu-Chongqing urban agglomeration. *China Environmental Science, 42*(10):4807–4816.

Wu, J. Y., Yuan, T., Li, J., & Xu, D. M. (2022). A study on characteristics and optimization strategies of main functional areas in Guangdong province from the perspective of carbon neutrality. *Journal of South China Normal University (Natural Science Edition), 54*(03):111–127.

York, R., Rosa, E. A. & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, 46:351–365.

Zheng, Q. Y., & Wen, Z. M. (2022). Optimization of county-level township system based on carbon emissions and carbon sinks: A case study of Quanzhou County, Guangxi. *Development of Small Cities & Towns, 40*(11):88–94.

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