Carbon Emission Characteristics and Spatiotemporal Patterns in a Typical Loess Plateau County: A Case Study of Qingcheng County (Postprint)

Authors: Long Zhi, Sun Yingqi, Lang Lixia, Chen Xingpeng, Zhang Zilong, Pang Jiaxing, Chen Xingpeng

Date: 2022-12-20T00:00:00+00:00

Abstract

County-level regions constitute a crucial component of China' s carbon emissions and the primary spatial carrier of carbon sink functions, serving as key administrative units for implementing dual-carbon goals and policies. Taking Qingcheng County as an example, this study examines the carbon emission characteristics and spatiotemporal patterns of a typical county in the Loess Plateau, providing insights and references for promoting ecological protection in the Yellow River Basin and achieving high-quality development and green low-carbon transition. The results indicate: (1) Carbon emission changes and structures in underdeveloped county-level regions exhibit distinct characteristics. Industrial enterprises below designated size represent the largest carbon emission source in Qingcheng County, with a low proportion of industrial carbon emissions and relatively high proportions from the tertiary industry and residential consumption. (2) The spatial distribution of carbon emissions in Qingcheng County conforms to the Pareto principle, where 80% of carbon emissions are concentrated in 20% of the area, demonstrating an overall spatial distribution pattern of "overall dispersion, local agglomeration." High-carbon zones are primarily concentrated in river valley areas, residual tableland areas, and the county seat; medium-carbon zones are mainly distributed in residual tableland areas and along transportation routes; low-carbon zones are extensively distributed across ridge-hill-gully areas. (3) Influenced by topography and landforms, carbon emissions in Loess Plateau counties exhibit significant spatiotemporal pattern differences. The largest patch index has increased in medium and high-carbon zones such as county seats, industrial concentration areas, and major townships, with improved integrity, reduced carbon source diversity, and a trend toward simplification of types. In transitional zones between medium and low-carbon areas such as transportation routes and urban-rural residential areas, carbon source diversity has increased while aggregation degree has decreased.

Full Text

Spatiotemporal Patterns and Characteristics of Carbon Emissions in the Loess Plateau: A Case Study of Qingcheng County

LONG Zhi[1,2,3], SUN Yingqi[1,4], LANG Lixia[1,2,3], CHEN Xingpeng[1,2,3], ZHANG Zilong[1,4], PANG Jiaxing[1,5,6]

[1]College of Earth and Environmental Sciences, Lanzhou University, Lanzhou, Gansu 730000, China
[2]Key Laboratory of Western China' s Environmental Systems (Ministry of Education), Lanzhou University, Lanzhou, Gansu 730000, China
[3]Research Institute for Circular Economy in Western China, Lanzhou University, Lanzhou, Gansu 730000, China
[4]Institute of Green Development for the Yellow River Drainage Basin, Lanzhou University, Lanzhou, Gansu 730000, China
[5]Institute of County Economic Development, Lanzhou University, Lanzhou, Gansu 730000, China
[6]Research and Evaluation Center for Ecological Civilization Construction, Lanzhou University, Lanzhou, Gansu 730000, China

Abstract

Counties constitute a crucial component of China' s carbon emissions, serve as the primary spatial carriers of carbon sink functions, and represent key administrative units for implementing national carbon peak and carbon neutrality goals. This study examines Qingcheng County as a typical case in the Loess Plateau to explore carbon emission characteristics and spatiotemporal patterns, providing insights for ecological protection, high-quality development, and green low-carbon transformation in the Yellow River Basin. The results reveal three key findings. (1) Carbon emission changes and structures in underdeveloped counties exhibit distinct features. Industrial enterprises below the designated size represent the largest emission source in Qingcheng County, with industrial carbon emissions accounting for a relatively low proportion while tertiary sector and residential emissions show comparatively higher shares. (2) The spatial distribution of carbon emissions in Qingcheng County follows the Pareto Principle: 80% of emissions concentrate in 20% of the area, demonstrating an "overall dispersion with local agglomeration" pattern. High-emission zones are primarily located in valley areas, broken plateau regions, and county seats; medium-emission zones mainly occur in broken plateau areas and along transportation routes; and low-emission zones are widely distributed across ridge-hill-gully landscapes. (3) Influenced by topography, county-level carbon emissions in the Loess Plateau display marked spatiotemporal heterogeneity. The largest patch index of medium and high-emission zones—including county seats, industrial concentration areas, and major towns—increases over time, indicating enhanced integrity, reduced carbon source diversity, and increasing homoge-

nization. Conversely, ecotones between medium and low-emission zones, such as transportation corridors and residential areas, show increased carbon source diversity and decreased aggregation.

Keywords: Loess Plateau; carbon emissions; spatiotemporal pattern; Qingcheng County

---

Introduction

Climate change, particularly global warming, poses a major challenge to building a global community of shared future and a community of life for humanity and nature [1]. Global warming demonstrates significant correlation with accumulated anthropogenic greenhouse gas emissions, particularly CO_2 [2]. As the world' s largest energy consumer, largest CO_2 emitter [3], and a responsible developing nation, China' s climate change response represents both an internal requirement for sustainable development and a responsibility toward building a global community of shared future. Since the First World Climate Conference in 1979, climate change and greenhouse gas emissions—especially carbon emissions—have attracted increasing attention from scholars worldwide, evolving into a critical scientific, political, economic, energy, and environmental issue. Researchers have conducted extensive studies on carbon emission accounting [4-7], carbon footprints [8-10], carbon rights [11], carbon finance [12-14], influencing factors [15-18], and relationships between carbon emissions and economic growth, industrial structure, and urbanization [19-22] across various scales, sectors, and scopes. Study scales span global, national, provincial, municipal, county, community, rural, and enterprise levels, encompassing both comprehensive and case studies [23-26]. Research sectors include manufacturing, power generation, construction, agriculture, forestry, commerce, tourism, and transportation [27-31]. Study scopes cover emissions from energy activities, industrial processes, product use, land use, and waste management, addressing both production and consumption perspectives.

Previous research has primarily focused on estimating carbon emissions at national and provincial levels [10, 33-37], with numerous studies concentrating on urban scales [22, 38-41]. Some studies have employed technical methods to disaggregate total emissions, producing county-level estimates for China [42], which have generated a series of county-scale carbon emission research outcomes [43-45]. Other studies have used top-down approaches based on population or GDP for disaggregation [46-48], but such estimation data overlook economic and industrial heterogeneity among counties, representing a primary source of deviation from reality. Most research has focused on meso- and macro-scales using county-level or higher administrative units, with few studies examining county-level carbon emissions through inventory accounting, particularly regarding long-term temporal sequences and spatialization. This study focuses on the county scale, achieving spatial representation of carbon emissions based on inventory accounting, and explores the changing trends, structural characteristics, and spatial distribution patterns of carbon emissions in a typical Loess Plateau county. This approach effectively supplements and expands existing research, laying a foundation for further spatial analysis studies and territorial spatial planning under the "dual carbon" goals.

1. Materials and Methods

1.1 Study Area and Data Sources Qingcheng County, located in eastern Gansu Province (Figure 1), sits at the intersection of Shaanxi, Gansu, and Ningxia provinces, exhibiting typicality and representativeness in topography, social development, and industrial structure. The county features fragmented plateau surfaces, narrow valleys and terraces, and undulating mountainous ridges and gullies—characteristic landforms of the Loess Plateau. As an impoverished county that exited poverty status in 2017 with a poverty incidence of 22.16% at the end of 2013, Qingcheng has a large agricultural population (76.75%), low urbanization levels, and lagging social development, representing a typical underdeveloped county. The county is a major crude oil production area with proven reserves of 4.3×10^{8} tons, natural gas reserves of 129.18×10^{8} m^3, and 2017 production of 455×10^{4} tons of crude oil and 3×10^{8} m^3 of natural gas, classifying it as a typical resource-based county. Industry focuses on oil and gas extraction support industries, with industrial enterprises concentrated in the Xichuan Industrial Zone in Maling and Pushu towns, and the Yima Industrial Zone in Yima town.

Data primarily derive from surveys of county Natural Resources Bureau, Industry and Information Technology Bureau, Housing and Urban-Rural Development Bureau, Agriculture and Rural Affairs Bureau, and Statistics Bureau, supplemented by the *Qingcheng County Statistical Yearbook* (2008-2017). Background data were obtained from the China Emission Accounts and Datasets (CEADs).

1.2 Carbon Emission Calculation Methods 1.2.1 Energy-related carbon emissions. According to the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, fossil energy carbon emissions are calculated based on the calorific value, carbon content per unit of heat value, and carbon oxidation rate for each energy type. The formula is:

$$CE = \Sigma(AC \times CF \times CC \times COF)$$

where CE represents carbon emissions from energy use; AC represents apparent consumption; CF represents net calorific value; CC represents carbon content; and COF represents carbon oxidation rate.

Regarding carbon oxidation rates, the default assumption of complete oxidation in combustion processes deviates from reality and yields overestimated results. The National Development and Reform Commission has adjusted relevant parameters through three batches of industry greenhouse gas emission accounting methods and reporting guidelines (trial) [49], with parameters referenced from these NDRC guidelines.

1.2.2 Livestock carbon emissions. Livestock carbon emissions primarily occur as methane from enteric fermentation and manure management in cattle, sheep, horses, pigs, donkeys, and mules. The calculation formula is:

$$CE = \Sigma(AAP \times \delta \times 12/16)$$

where CE represents annual carbon emissions from livestock; AAP represents the average annual breeding quantity of species i; δ represents the emission factor for species i; and 12/16 converts methane carbon content. For livestock with slaughter rates >1 (primarily pigs, rabbits, and poultry) with average lifecycles of 200 days, 105 days, and 55 days respectively, the average breeding quantity is adjusted based on slaughter volume:

$$AAP = \text{Days\_\{alive\}} \times (NAP /365)$$

where Days_{alive} represents the average lifecycle of species i and NAP represents annual production (slaughter volume). For livestock with slaughter rates <1, the average breeding quantity is adjusted based on year-end inventory:

$$AAP = (C + C_{1})/2$$

where C and C_{1} represent year-end inventories for species i in year t and t-1. Emission factors for livestock breeding are detailed in the *IPCC 2006 Guidelines* [50].

1.3 Landscape Pattern Indices **Largest Patch Index (LPI)** measures landscape dominance and integrity [51], reflecting the abundance of dominant patches in the landscape. In this study, the LPI of carbon sources measures the dominance of a particular carbon source type. A larger LPI value indicates that the largest patch comprises a greater proportion of landscape area.

Shannon' s Diversity Index (SHDI) reflects the number of landscape elements and changes in their proportional composition, serving as a common metric for diversity changes across landscapes or time periods [52]. In this context, SHDI measures carbon source diversity—higher values indicate greater spatial heterogeneity in carbon source distribution.

Aggregation Index (AI) is calculated based on the length of shared boundaries between like-type patch cells. When no shared boundaries exist among all cells of a type, aggregation is minimal; conversely, extensive shared boundaries indicate high aggregation. AI reflects patch clustering within landscapes [53]. In this study, carbon source AI describes the clustering or dispersion of a particular carbon source patch type, with higher values indicating more concentrated distribution of similar patches.

2. Results and Analysis

2.1 Carbon Emission Changes and Structural Characteristics From 2008 to 2017, Qingcheng County' s carbon emissions exhibited a "fluctuating decline" pattern (Figure 2). Total emissions decreased from 143.87×10^{4} t in 2008 to 117.73×10^{4} t in 2017, with the county's share of Gansu Province' s emissions dropping from 5.10% to 2.87%. After continuous decline from 2008-2015, emissions increased in 2016-2017 due to county economic recovery.

Carbon emission intensity showed distinct phased characteristics, with 2013 serving as the inflection point. During 2008-2013, intensity fluctuated downward from 2.09 t · $(10^4$ yuan$)^{-1}$ to 1.26 t · $(10^4$ yuan$)^{-1}$, then rebounded during 2014-2017, reaching 1.90 t · $(10^4$ yuan$)^{-1}$ in 2017.

Structurally, secondary industry represents the largest emission source in Qingcheng County, showing a 逐年下降特征. Secondary industry emissions decreased from 78.47×10^{4} t in 2008 to 55.67×10^{4} t in 2017, accounting for 54.54% and 47.28% of total emissions respectively. Industrial emissions below the designated size dominate, reaching 47.12×10^{4} t in 2017 (40.03% of total emissions), while above-designated-size industrial emissions represent only a small fraction. Residential energy use constitutes the second-largest source, with rural residential emissions exceeding urban residential emissions. Transportation emissions remained stable at approximately 11×10^{4} t, while livestock emissions accounted for <1% of the total.

Seasonally, emissions concentrated in the first and fourth quarters (34.65% and 35.19% respectively), reflecting industrial production cycles and heating demand impacts, with lower emissions in the second and third quarters (8.95% and 21.21% respectively).

At the township scale, Maling, Yima, Qingcheng, and Pushu towns exhibited the highest emissions (Figure 3). The Xichuan Industrial Zone in Maling and Pushu towns and the Yima Industrial Zone in Yima town represent the county' s primary industrial bases. Qingcheng town, as the county seat with relatively dense population and developed tertiary sector, also showed high emissions. Other townships had relatively low emissions.

The Lorenz curve of carbon emission spatial distribution (Figure 4) demonstrates compliance with the Pareto Principle: approximately 80% of emissions concentrate in 20% of the area.

2.2 Carbon Emission Distribution Characteristics Carbon emissions in Qingcheng County show significant spatiotemporal heterogeneity, displaying an "overall dispersion with local agglomeration" pattern (Figure 4). High-emission zones are primarily located in valley areas, broken plateau regions, and county seats; medium-emission zones occur mainly in broken plateau areas and along transportation routes; and low-emission zones are widely distributed across ridge-hill-gully landscapes.

Based on multi-source carbon emission data, spatial grid data, road networks, and land use data, we spatialized carbon emissions at 200 m$×$200 m resolution using ArcGIS overlay analysis tools (Figure 4). High-value carbon source areas are distributed in central-western and northern ridge-hill regions, while low-value areas occur mainly in valley areas and southern plateau regions. During the study period, the aggregation degree of high-emission zones in county seats, major towns, and industrial zones increased, enhancing integrity while reducing carbon source diversity and increasing homogenization. In ecotones between medium and low-emission zones, such as transportation corridors and residential areas, carbon source diversity increased while aggregation decreased.

2.3 Carbon Emission Spatiotemporal Patterns **Integrity perspective:** The LPI of carbon sources in Qingcheng County increased in medium and high-emission zones like county seats, industrial zones, and major towns, indicating enhanced integrity. Low-emission zones showed minimal change overall, though notable changes occurred around urban areas, major rural settlements, and road networks.

Diversity perspective: High SHDI values are distributed in the Huanjiang and Rouyuan River valleys, southern plateau regions, and major transportation corridors, while low values occur in central-western and northern ridge-hill areas. During the study period, diversity decreased in industrial zones, towns, and major settlements as carbon source types homogenized, while diversity increased in ecotones between medium and low-emission zones.

Aggregation perspective: Carbon source areas show high spatial aggregation, particularly for low-emission zones concentrated in central, western, and northern regions dominated by cropland. During the study period, aggregation increased in medium and high-emission zones like industrial zones and major settlements, while decreasing in ecotones between medium and low-emission zones.

3. Discussion

Qingcheng County, formerly home to a petrochemical plant, has industries dominated by oil and gas extraction, petroleum processing, and petroleum product manufacturing. Since 2008, some Changqing Petroleum Exploration Bureau units relocated from Qingcheng to Xi' an, significantly impacting local economic development [54]. In 2011, surrounding refineries implemented a "close four, upgrade one" strategy, shutting down refineries in Maling and other locations. Subsequent production reductions and preparations for relocation culminated in complete refinery shutdown by 2014, causing industrial economic depression and sharp declines in industrial energy consumption. This directly caused the continuous decline in Qingcheng' s carbon emissions from 2008-2015 and the rebound in emission intensity after 2013. Post-2014, persistent industrial contraction intensified the contradiction between resource abundance and economic poverty, creating a typical pattern of "high resource exploitation, low economic growth" [55]. Correspondingly, per capita GDP was only 24.07×10^{3} yuan, with emission intensity significantly higher than eastern county-level regions [56].

As a western underdeveloped region with lagging industrial development, Qingcheng' s industrial carbon emissions account for <50% of the total, dominated by below-designated-size enterprises. The number of above-designated-size industrial enterprises decreased from 11 in 2008 to 5 in 2017, making below-designated-size industrial emissions far exceed above-designated-size emissions. With low urbanization (agricultural population comprising 80.37% in 2008), large rural population base, and a 5-month frost period, rural residential emissions from self-heating exceed urban residential emissions from centralized heating.

The Loess Plateau' s fragmented topography, with thousands of gullies and ridges, constrains the distribution of towns, rural settlements, and cropland primarily to valleys, broken plateau areas, and gentler ridge slopes. This results in highly dispersed carbon source distribution. As a poor county in the Liupan Mountain contiguous destitute area, Qingcheng has low socioeconomic development, lagging industrialization and urbanization, and has not experienced dramatic land use changes. High-emission zones concentrate in the Xichuan Industrial Zone (Maling and Pushu towns), Yima Industrial Zone, and the county seat; medium-emission zones occur in broken plateau areas and along transportation routes; low-emission zones dominated by cropland are widely distributed in ridge-hill-gully areas. While medium and high-emission zones show substantial changes, they occupy small areas, whereas the extensive low-emission cropland areas show minimal change, resulting in generally unobvious spatiotemporal emission changes overall.

The Huanjiang and Rouyuan River valleys and southern Dongzhi Plateau area have dense settlements and intensive human activities, with interspersed high-, medium-, and low-emission zones, diverse carbon source types, and highly fragmented patches, resulting in low LPI and AI but high SHDI. In contrast, central-western and northern ridge-hill areas dominated by cropland have single carbon source types, poor diversity, and relatively concentrated distribution, showing high LPI and AI but low SHDI. During the study period, industrial zones, towns, and major settlements showed increased contiguous patch areas, enhanced integrity, reduced diversity, and homogenization, with increasing LPI and AI. Influenced by road networks and urban-rural development, cropland and other low-emission zones became increasingly fragmented, showing decreased LPI and AI but increased SHDI, particularly in ecotones between medium and low-emission zones around residential areas and road networks.

4. Conclusions

This study reveals three major conclusions. (1) Carbon emission changes and structures in underdeveloped counties have distinct characteristics. Influenced by industrial structure and economic development level, Qingcheng County' s carbon emissions show fluctuating declines while emission intensity shows fluctuating increases. Compared with eastern developed counties, industrial carbon emissions account for a relatively low proportion, with below-designated-size industrial emissions far exceeding above-designated-size emissions. Tertiary sector and residential emissions account for relatively high proportions, with rural residential emissions exceeding urban emissions. (2) The spatial distribution of carbon emissions in Qingcheng County follows the Pareto Principle: 80% of emissions concentrate in 20% of the area, showing an "overall dispersion with local agglomeration" pattern. High-emission zones concentrate in valleys, broken plateau areas, and county seats; medium-emission zones occur mainly in broken plateau areas and along transportation routes; and low-emission zones are widely distributed in ridge-hill-gully areas. (3) Influenced by topography, county-level carbon emissions in the Loess Plateau show clear spatiotemporal pattern differences. The largest patch index of medium and high-emission zones —including county seats, industrial zones, and major towns—increases, integrity improves, carbon source diversity decreases, and types tend to homogenize. In ecotones between medium and low-emission zones, such as transportation corridors and residential areas, carbon source diversity increases while aggregation decreases.

References

[1] Chen Yu. Analysis on the traditional frontier and modern frontier from the vision of Community of Shared Future[J]. World Regional Studies, 2021, 30(5): 893-902.

[2] Deutch John. Decoupling economic growth and carbon emissions[J]. Joule, 2017, 1(1): 3-5.

[3] Khan Uzma, Wang Huili, Ali Ishraq. A sustainable community of shared future for mankind: Origin, evolution and philosophical foundation[J]. Sustainability, 2021, 13(16): 9352.

[4] Nathan Andrew J, Zhang Boshu. A shared future for mankind: Rhetoric and reality in Chinese foreign policy under Xi Jinping[J]. Journal of Contemporary China, 2022, 31(133): 57-71.

[5] Zhang Hui. A community of shared future for mankind: The contemporary development of the social foundations theory of international law[J]. Social Sciences in China, 2019, 40(1): 186-202.

[6] Fan Zhixin, Fang Xiuqi, Su Yun. Changes in global grid pattern of carbon emissions[J]. Climate Change Research, 2018, 14(5): 505-512.

[7] Lashof Daniel A, Ahuja Dilip R. Relative contributions of greenhouse gas emissions to global warming[J]. Nature, 1990, 344: 529-531.

[8] Samset B H, Sand M, Smith C J, et al. Climate impacts from a removal of anthropogenic aerosol emissions[J]. Geophysical Research Letters, 2018, 45(2): 1020-1029.

[9] He Huachun, Guan Hongjun, Zhu Xiang, et al. Assessment on the energy flow and carbon emissions of integrated steelmaking plants[J]. Energy Reports, 2017, 3: 29-36.

[10] Yuan Jiahai, Xu Yan, Hu Zheng, et al. Peak energy consumption and CO_2 emissions in China[J]. Energy Policy, 2014, 68: 508-523.

[11] Long Zhi, Zhang Zilong, Liang Sai, et al. Spatially explicit carbon emissions at the county scale[J]. Resources, Conservation and Recycling, 2021, 173: 105706.

[12] Shan Yuli, Huang Qi, Guan Dabo, et al. China CO_2 emission accounts 2016-2017[J]. Scientific Data, 2020, 7(1): 54.

[13] Sarkodie Samuel Asumadu. Environmental performance, biocapacity, carbon & ecological footprint of nations: Drivers, trends and mitigation options[J]. Science of the Total Environment, 2021, 751: 141912.

[14] Zhang Wei, Li Jing, Li Guoxiang, et al. Emission reduction effect and carbon market efficiency of carbon emissions trading policy in China[J]. Energy, 2020, 196: 117117.

[15] Zhou Huijun, Ping Weiying, Wang Yong, et al. China' s initial allocation of interprovincial carbon emission rights considering historical carbon transfers: Program design and efficiency evaluation[J]. Ecological Indicators, 2021, 121: 106918.

[16] Guo Qianqian, Su Zhifang, Chiao Chaoshin. Carbon emissions trading policy, carbon finance, and carbon emissions reduction: Evidence from a quasi natural experiment in China[J]. Economic Change and Restructuring, 2022, 55(3): 1445-1480.

[17] Li Yanmei, Li Tingting, Lu Shuangshuang. Forecast of urban traffic carbon emission and analysis of influencing factors[J]. Energy Efficiency, 2021, 14(8): 84.

[18] Khan Khalid, Su Chiwei. Urbanization and carbon emissions: A panel threshold analysis[J]. Environmental Science and Pollution Research, 2021, 28(20): 26073-26081.

[19] Wang Keying, Wu Meng, Sun Yongping, et al. Resource abundance, industrial structure, and regional carbon emissions efficiency in China[J]. Resources Policy, 2019, 60: 203-214.

[20] Cai Bofeng, Wang Xiuquan, Huang Guohe, et al. Spatiotemporal changes of China' s carbon emissions[J]. Geophysical Research Letters, 2018, 45(16): 8536-8546.

[21] Chen Jiandong, Gao Ming, Cheng Shulei, et al. County level CO_2 emissions and sequestration in China during 1997-2017[J]. Scientific Data, 2020, 7(1): 391.

[22] Chen Qianli, Cai Bofeng, Dhakal Shobhakar, et al. CO_2 emission data for Chinese cities[J]. Resources, Conservation and Recycling, 2017, 126: 198-208.

[23] Chen Yi, Wang Xinyu, Sha Zhijie, et al. Uncertainty analysis for multi state weighted behaviours of rural area with carbon dioxide emission estimation[J]. Applied Soft Computing, 2012, 12(8): 2631-2639.

[24] Song Dan, Su Meirong, Yang Jin, et al. Greenhouse gas emission accounting and management of low carbon community[J]. Scientific World Journal, 2012,

2012: 613721.
[25] Zhang Zengkai, Guan Dabo, Wang Ran, et al. Embodied carbon emissions in the supply chains of multinational enterprises[J]. Nature Climate Change, 2020, 10(12): 1096-1101.
[26] Chandio Abbas Ali, Akram Waqar, Ahmad Fayyaz, et al. Dynamic relationship among agriculture, energy, forestry and carbon dioxide (CO_2) emissions: Empirical evidence from China[J]. Environmental Science and Pollution Research, 2020, 27(27): 34078-34089.
[27] Cheng YungHsiang, Chang YuHern, Lu I J. Urban transportation energy and carbon dioxide emission reduction strategies[J]. Applied Energy, 2015, 157: 953-973.
[28] Li Xuemei, Zhang Qing. Factors affecting carbon emission from energy consumption in Tianjin[J]. Arid Zone Research, 2019, 36(4): 997-1004.
[29] Huang Lizhen, Krigsvoll Guri, Johansen Fred, et al. Carbon emission of global construction sector[J]. Renewable & Sustainable Energy Reviews, 2018, 81: 1906-1916.
[30] Lenzen Manfred, Sun Yayen, Faturay Futu, et al. The carbon footprint of global tourism[J]. Nature Climate Change, 2018, 8(6): 522-528.
[31] Prastiyo Slamet Eko, Irham, Hardyastuti Suhatmini, et al. How agriculture, manufacture, and urbanization induced carbon emission? The case of Indonesia[J]. Environmental Science and Pollution Research, 2020, 27(33): 42092-42103.
[32] Yang Lisha, Lin Boqiang. Carbon dioxide emission in China power industry: Evidence and policy implications[J]. Renewable & Sustainable Energy Reviews, 2016, 60: 258-267.
[33] Chu Yingmin, Xie Luyue, Yuan Zaijian. Composition and spatio-temporal distribution of the agro-ecosystem carbon footprint: A case study in Hebei Province, North China[J]. Journal of Cleaner Production, 2018, 190: 838-846.
[34] Liu Zhu, Guan Dabo, Wei Yun, et al. The estimation and spatial distribution of the carbon emissions of county units in China[J]. Environmental Pollution and Control, 2020, 42(1): 113-119.
[35] Liu Chang, Su Wei. Carbon emission accounting in China[J]. Scientia Sinica Terrae, 2018, 48(7): 878-887.
[36] Pei Jie, Niu Zheng, Wang Li, et al. Spatial-temporal dynamics of carbon emissions and carbon sinks in economically developed areas of China: A case study of Guangdong Province[J]. Scientific Reports, 2018, 8(1): 13383.
[37] Shan Yuli, Guan Dabo, Zheng Heran, et al. Data descriptor: China CO_2 emission accounts 1997-2015[J]. Scientific Data, 2018, 5: 170201.
[38] Wei Wendong, Wang Xibo, Zhu He, et al. Carbon emissions of urban power grid in Jing-Ji region: Characteristics and influential factors[J]. Journal of Cleaner Production, 2017, 168: 428-440.
[39] Cai Bofeng, Guo Huanxiu, Ma Zipeng, et al. Benchmarking carbon emissions efficiency in Chinese cities: A comparative study based on high resolution gridded data[J]. Applied Energy, 2019, 242: 769-777.
[40] Mi Zhifu, Guan Dabo, Liu Zhu, et al. Cities: The core of climate change mitigation[J]. Journal of Cleaner Production, 2019, 207: 582-589.

[41] Mi Zhifu, Zheng Jiali, Meng Jing, et al. Carbon emissions of cities from a consumption-based perspective[J]. Applied Energy, 2019, 235: 509-518.
[42] Shao Ling, Guan Dabo, Zhang Ning, et al. Carbon emissions from fossil fuel consumption of Beijing in 2012[J]. Environmental Research Letters, 2016, 11(11): 114028.
[43] Wang Shaojian, Xie Zihan, Wang Zehong. The spatiotemporal pattern evolution and influencing factors of CO_2 emissions at the county level of China[J]. Acta Geographica Sinica, 2021, 76(12): 3103-3118.
[44] Hu Mengran. Spatial Pattern and Influencing Factors of Carbon Emissions at County Level in China[D]. Lanzhou: Lanzhou University, 2021.
[45] Wang Hao, Chen Caocao, Pan Tao, et al. County-scale characteristics of CO_2 emission' s spatial-temporal evolution in the Beijing-Tianjin-Hebei metropolitan region[J]. Environmental Science, 2014, 35(1): 385-393.
[46] Zhu Songli, Wang Hang, Wang Wentao, et al. Status of coordinated development between regional low-carbon economy and spatial land use pattern in the 12th Five-Year Plan[J]. China Population, Resources and Environment, 2017, 27(9): 135-142.
[47] Hu Xiangdong, Wang Jimin. Estimation of livestock greenhouse gases discharge in China[J]. Transactions of the CSAE, 2010, 26(10): 247-252.
[48] Liu Peifang, Chen Zhenlou, Xu Shiyuan, et al. Waste loading and treatment strategies on the excreta of domestic animals in the Yangtze Delta[J]. Resources and Environment in the Yangtze Basin, 2002, 11(5): 456-460.
[49] NDRC. Guidelines for greenhouse gas emissions accounting and reporting [EB/OL]. http://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=1776; https://www.ndrc.gov.cn/xxgk/zcfb/tz/201502/t20150209_{963759}.html; http://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=2313.
[50] IPCC. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [EB/OL]. https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_{Volume4}/19R_{V4
[51] Song Qi, Shi Zhou, Feng Chunhui, et al. Analysis of landscape pattern from 1990 to 2019 based on multi-temporal imagery in arid oasis[J]. Arid Zone Research, 2022, 39(2): 594-604.
[52] Guo Jie, Ding Guanqiao, Liu Xiaoman, et al. Effect of urban landscape pattern on regional carbon emissions and its differential regulation[J]. China Population, Resources and Environment, 2018, 28(10): 55-61.
[53] Zhu Dongguo, Xie Binggeng, Xiong Peng. Spatial-temporal evolution of land use pattern changes in Zhangjiajie city based on three-dimensional landscape pattern indices[J]. Economic Geography, 2017, 37(8): 168-175.
[54] Kou Xingliang. A Sociological Analysis on the Event of Changqing Oilfield Units Relocation[D]. Lanzhou: Lanzhou University, 2013.
[55] Zhang Zilong, Wang Bo, Long Zhi, et al. Fiscal decentralization, industrial upgrading, technological progress and "resource curse" : Empirical analysis of resource-based cities in the Yellow River Basin[J]. Economic Survey, 2021, 38(3): 133-141.
[56] Mo Huibin, Wang Shaojian. Spatio-temporal evolution and spatial effect mechanism of carbon emission at county level in the Yellow River Basin[J]. Scientia Geographica Sinica, 2021, 41(8): 1324-1335.