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Carbon Effects of Different Land Use Patterns in China During 2004-2013

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Abstract: Since the 1980s, global warming has become a major problem facing the human all over the world. The main reason of climate becoming warm is due to the excessive emissions of greenhouse gas, especially CO2. Land use is one of the important factors that cause carbon emissions. Different patterns of land use have different carbon emission characteristics, and the results are also different. In this paper, the land was divided into cultivated land, garden land, forest land, grassland, residential and mining land, traffic land, water body, land use change and main ways of carbon emissions and carbon sequestration from different type of land were analyzed. The paper also analyzed the variation tendency of several carbon emission indexes including the amount of carbon emissions and carbon sequestration, the ratio of carbon source and carbon sink, per capita and per hectare carbon emissions from 2004 to 2013. And relevant regulation measurements on land use in China were proposed on the base of low-carbon goals.

Keywords: Different Land Use Patterns, Carbon Effect, Carbon Emission, Carbon Sequestration, China.

1. Introduction

Since the 1980s, the global warming has been the common concern of human beings. The main reason of climate becoming warm is due to the excessive emissions of greenhouse gas, especially CO_2. Land use is one of the important factors that cause carbon emission [1]. Land use changes directly affect the distribution and structure of terrestrial ecosystem, and change the process of carbon storage and carbon flux [2]. According to estimates from the famous carbon cycle research expert Houghton Richard: During 1850-1998, the amount of carbon dioxide emissions caused by the change of land use accounted for 1/3 of the total ones from human activities, and the amount of carbon emissions caused by the change of land use reached 10.6 billion tons, accounted for 30% caused by human activities [3, 4].

Researches about carbon emissions of land use have become hotspots in recent years, which mainly focused on the carbon cycle of land use on the ecosystem [1], regional land carbon emission and carbon flux measurement, low carbon optimization for regional land, while less from the perspective of nationwide, so nationwide land in China was chosen as the research object in this paper, and the time series of land use carbon emission was as the key study point. The paper analyzed the changes of land use and the variation tendency of several carbon emission indexes including the amount of carbon emissions and carbon sequestration, the ratio of carbon source and carbon sink, per capita and per hectare carbon emissions from 2004 to 2013. And relevant regulation measurements on land use in China were proposed on the base of low-carbon goals.

2. Data Sources and Research Methods

2.1. Data sources

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The acreage of each kind of land comes from “Bulletin of China Land and Resources”. The acreage of urban green space comes from “China City Statistical Yearbook”. The amount of coal, oil, and natural gas caused by industry, traffic, business activities and living, and the acreage of farmland irrigation, total power of agricultural machinery, area of the crops, production of major agricultural products comes from “China Statistical Yearbook”. The usage amount of chemical fertilizer, pesticide and agricultural films comes from “Environmental Statistic”. The data of population comes from “The Statistics Bulletins of the National Economic and Social Development”. The territory of China is 9.6 million km^2.

2.2. Research methods

2.2.1 The main ways of carbon emissions and carbon sequestration for different types of land use

According to the original classification system of land use in China, the land is divided into 8 types: cultivated land, garden land, forest land, grassland, residential and mining land, traffic land, water body and unused land. The main sources of land use carbon emissions include agricultural land (mainly cultivated land), construction land (mainly for residential land and industrial and mining land, transportation land). The main sources of land use carbon sequestration include cultivated land, garden land, forest land, grassland, urban green space and water body. The main ways of carbon emissions and carbon sequestration for various types of land is shown in Table 1.

Table 1: The main ways of carbon emissions and carbon sequestration for different types of land use

Land types		The way of carbon emissions	The way of carbon sequestration
Agricultural land	Cultivated land	The use of agricultural machinery, agricultural irrigation, chemical fertilizer, pesticide and agricultural films	Photosynthesis of crops
	Garden land	—	Photosynthesis of fruit trees
	Forest land	—	Photosynthesis of trees
	Grassland	—	Photosynthesis of grassland
Construction land	Residential and mining land	Energy consumption, human respiration	Photosynthesis of urban green space
	Traffic land	Energy consumption	—
Unused land	Water body	—	Waters carbon sequestration and settlement
	Unused land	—	—

Because it is difficult to obtain the data about the acreage of water body, the carbon sequestration of water body is not calculated.

2.2.2 Measurement of carbon emissions

2.2.2.1 Agricultural land

Most of the carbon emissions from agricultural land are produced by agricultural inputs, and less one is caused by the decomposition of crop residues and the release of soil organic carbon [5]. Carbon emissions of agricultural land mainly come from the use of agricultural machinery, agricultural irrigation, fertilizers, pesticides and agricultural films.

The calculation formula for carbon emissions from agricultural machinery and agricultural irrigation is as follows [6]： $CE_{mach} = S_{mach} \times P + P_{mach} \times Q$ $\quad$ $CE_{irri} = S_{irri} \times R$

CE_{mach} and CE_{irri} represent the amount of carbon emissions from the use of agricultural machinery and irrigation process. S_{mach} represents the area of crops. P_{mach} represents the total power of agricultural machinery, S_{irri} represents irrigated area. P, Q, R represent carbon emission factors, which are separately 16.47 kg(C)/hm^2、0.18 kg(C)/KW、266.48 kg(C)/hm^2 [7].

The calculation formula for carbon emissions from the use of chemical fertilizers, pesticides and agricultural films is as follows [6]: $E_t = \sum T_i \times \delta_i$

E_t represents the amount of carbon emissions from the use of cultivated land. T_i represents the emissions of various carbon emission sources. δ_i represents the emission factors of various carbon emission sources.

The factors of chemical fertilizers, pesticides and agricultural films are shown in Table 2

Table 2: The carbon emission factors of chemical fertilizers, pesticides and agricultural films

Terms	Carbon emission factors	Unit	Data sources
Chemical fertilizers	857.54	g/kg	Oak Ridge National Laboratory
Pesticides	4.9341	kg/kg	Oak Ridge National Laboratory
Agricultural films	5.18	kg/kg	IREEA

2.2.2.2 Construction land

By referring to the carbon emission factors of IPCC, carbon emission calculation formula of construction land is as follows: $E_c = \sum_j Q_j C_{fj} + Y\lambda$

E_c, Q_j, C_{fj}, Y and λ represent construction land carbon emissions, energy consumption of J, energy carbon emission factor of J, amount of population, per capita emission factor.

Carbon emission factors of various types of energy consumption and per capita carbon emission factor are shown in Table 3.

Table 3: Carbon emission factors of various types of energy consumption

Terms	Average value	Unit
Coal	0.7329	t(c)/t
Petroleum	0.5574	t(c)/t
Natural gas	0.4226	t(c)/t
Per capita carbon emission factor	328.5	kg/capita/a

Note: the data come from the average of IEE, climate change project finished by The State Science and Technology Commission in China, DOE/EIA and Xianjin Huang [8], Guoquan xu [9].

2.2.2.3 Measurement of carbon sequestration

2.2.2.3.1. Cultivated land

The amount of carbon sequestration comes from the sum of every crop's carbon sequestration, and each kind of crop's carbon sequestration can be calculated through economic yield, economic factor and the carbon sequestration rate [6]. Its carbon sequestration formula is as follows:

$$Ct = \sum_i C_{di} = \sum_i C_{fi} D_{wi} = \sum_i C_{fi} Y_{wi} / H_i$$

Ct represents the carbon sequestration of cultivated land. C_{di} represents the sequestration amount of carbon in the whole growth period. C_{fi} represents the rate of carbon sequestration. Y_{wi} represents the economic yield. D_{wi} represents biomass production. H_i represents the economic factor.

The economic factor and carbon sequestration rate of main crops in China are shown in Table 4.

Table 4: The economic factor and carbon sequestration rate of main crops in China

Terms	Rice	Wheat	Corn	Soy bean	Tubers	Cotto n	Pean ut	Rape-seed	Hem p	Sugar cane	Beet	Tobac co
Economic factor	0.45	0.40	0.40	0.35	0.70	0.10	0.43	0.25	0.39	0.50	0.7	0.55
Carbon sequestration rate	0.4144	0.4853	0.4709	0.45	0.4226	0.45	0.45	0.45	0.45	0.45	0.4072	0.45

Note: the data come from Kerang Li [10], Jingyun Fang, Xiulan Wang [11]

2.2.2.3.2. Garden land, forest land, grassland, urban green space

The carbon sequestration calculation formula of garden land， forest land, grassland, urban green space is as follows: $C_i = S_i \times V_i$

C_i represents the amount of carbon sequestration including garden land， forest land, grassland and urban green space, S_i represents the acreage of garden land， forest land, grassland and urban green space, V_i represents rate of carbon sequestration. The carbon sequestration of urban green space is the average of forest land and grassland, taking into account that the urban green space contain both trees, shrubs, and grassland [6]. The carbon sequestration factor of garden land, forest land, grassland and urban green space is shown in Table 5.

Table 5: The carbon sequestration factor of garden land, forest land, grassland and urban green space

Terms	Value	Unit	Data source	Terms	Value	Unit	Data source
Garden land	0.0730	kg(c)/(m^2 a)	Rongqin Zhao [12]	Grassland	0.0021	kg(c)/(m^2 a)	Jingyun Fang [13]
Forest land	0.0577	kg(c)/(m^2 a)	Jingyun Fang [13]	Urban green space	2.8861	kg(c)/(m^2 a)	The average of forest land and grassland

3. Results

3.1. Analysis of land use in China from 2004 to 2013

The acreage of different types of land is shown in Table 6, and changes of land use shown in Fig. 1.

Table 6: The acreage of different types of land during 2004-2013 unit: 10^4 hectares

Year	Cultivated land	Garden land	Forest land	Grassland	Other agricultural land	Residential and mining land	Traffic land	Water body
2004	12244.43	1128.78	23504.70	26270.68	2553.27	2572.84	223.32	358.95
2005	12208.27	1154.90	23574.11	26214.38	2553.09	2601.51	230.85	359.87
2006	12177.59	1181.82	23612.13	26193.20	2554.10	2635.45	239.52	361.52
2007	12173.52	1181.31	23611.74	26186.46	2549.11	2664.72	244.43	362.86
2008	12171.60	1180.00	23606.67	26180.00	2546.67	2693.33	246.67	366.67
2009	13538.46	1125.21	23746.32	24687.76	2434.64	2714.07	255.41	369.10
2010	13526.83	1206.59	24319.19	23710.25	2391.13	2844.65	264.65	372.34
2011	13523.86	1382.21	24691.43	22747.18	2378.18	2974.38	274.36	375.22
2012	13515.85	1417.75	25339.69	21956.53	2362.91	3024.53	283.55	378.07
2013	13516.34	1417.80	25325.39	21951.39	2363.00	3026.04	284.34	379.12

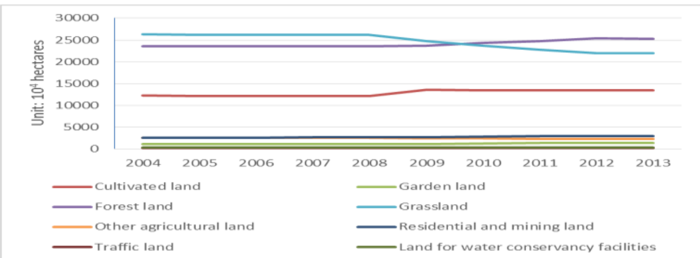

Fig. 1: Changes of land use during 2004-2013

(1) General situation of land use. The area of construction land was obviously less than that of agricultural land, and the main types of agricultural land were grassland, forest land and cultivated land.

(2) The situation of land use change. The overall change of land use is agricultural land. Although the area of construction is increasing because of urbanization, advance of all kinds of infrastructure construction and improvement of the level of industrialization, it increases marginally. The change of construction land is less than agricultural land. The amount of grassland begun to reduce significantly from 2009, while forest

land and cultivated land increased gradually, the reason for this was that Chinese government implemented the policy of "conservation intensive land use and stick to the red line of 1.8 billion mu cultivated land".

3.2. Analysis of land use carbon emissions in China from 2004 to 2013

3.2.1. Analysis of total carbon emissions and carbon sequestration

The carbon emissions, carbon sequestration and net carbon emissions of land use are shown in Table 7

Table 7 The carbon emissions, carbon sequestration and net carbon emissions of land use in China from 2004 to 2013

Year	Carbon emissions /10^4t		Carbon sequestration /10^4t					Net carbon emissions /10^4t
	Cultivated land	Construction land	Cultivated land	Garden land	Forest land	Grassland	Urban green space	
2004	7422.80	110500.37	63470.76	8240.09	13562.21	551.68	3100.26	28998.16
2005	7636.68	117373.25	64752.17	8430.77	13602.26	550.50	3436.57	34237.66
2006	7884.93	123133.43	68139.34	8627.29	13624.20	550.06	3496.52	36580.96
2007	8151.55	129981.25	69890.64	8623.56	13623.97	549.92	4268.96	41175.75
2008	8387.08	133890.23	74381.68	8614.00	13621.05	549.78	4618.83	40491.98
2009	8616.88	140106.82	73510.22	8214.03	13701.63	518.44	4831.38	47948.00
2010	8863.65	145135.58	74654.89	8808.11	14032.17	497.92	4889.66	51116.49
2011	9107.57	150671.30	78157.14	10090.13	14246.96	477.69	5143.48	51663.48
2012	9307.65	150604.99	81326.20	10349.58	14621.00	461.09	5406.12	47748.65
2013	9456.47	152113.24	82918.21	10349.94	14612.75	460.98	5696.90	47530.93

In general, the total amount of carbon emissions and carbon sequestration in China showed an increasing trend and the amount of carbon emissions are always higher than carbon sequestration from 2004 to 2013. Since 2010, the growth rate of carbon emission is lower than that of carbon sequestration (as shown in Fig. 2). The increase of carbon emissions is closely related to the rapid development of urbanization, industrialization and land conversion [14].

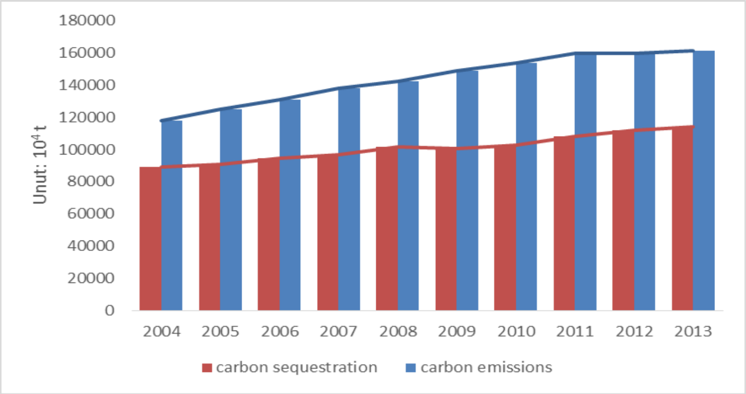

Fig. 2: The change of carbon emissions and carbon sequestration on land use in China from 2004 to 2013

3.2.2. Analysis of carbon emissions and carbon sequestration structure

Table 8: The carbon emissions from agricultural land in China from 2004 to 2013

Year	Agricultural machinery /10^4t	Agricultural irrigation /10^4t	Fertilizers /10^4t	Agricultural films /10^4t	Pesticides /10^4t	Total/10^4t
2004	264.43	1451.74	4152.52	870.23	683.88	7422.80
2005	268.40	1466.42	4268.63	912.88	720.35	7636.68
2006	271.67	1485.64	4413.24	955.96	758.42	7884.93
2007	266.54	1506.10	4574.57	1003.61	800.72	8151.55
2008	272.16	1558.15	4692.07	1039.59	825.11	8387.08
2009	276.99	1579.20	4840.18	1077.28	843.24	8616.88
2010	281.33	1608.15	4981.04	1125.61	867.52	8863.65
2011	284.87	1643.69	5108.71	1188.57	881.72	9107.57
2012	287.61	1665.25	5229.27	1234.40	891.13	9307.65
2013	289.84	1691.44	5294.67	1291.47	889.06	9456.47

Analysis of carbon emissions structure. The carbon emission sources for land mainly include agricultural land and construction land, and the carbon emissions from construction land take a large part. The carbon emissions of agricultural land mainly come from the use of fertilizers, agricultural irrigation, the use of agricultural films, pesticides and agricultural machinery. And the amount of carbon emissions from fertilizers take the large part, accounted for 56%. the second large one is agricultural irrigation, accounted for 19%. The amount of carbon emissions from agricultural land is shown in Table 8.

Construction land is the main source of land carbon emissions, including carbon emissions from industrial land, transportation land, commercial land, residential land and carbon emissions from human respiration. Carbon emissions from industrial land and human respiration accounted for the main part of construction land carbon emissions. The amount of carbon emissions from construction land are shown in Table 9.

Table 9: The amount of carbon emissions from construction land in China

Year	Industry/10^4t	Traffic/10^4t	Commercial/10^4t	Living/10^4t	Human respiration /10^4t	Total/10^4t
2004	51011.09	6206.38	1988.17	8593.67	42701.06	110500.37
2005	56673.30	6707.69	2167.20	8871.71	42953.35	117373.25
2006	61239.44	7284.13	2308.06	9121.13	43180.67	123133.43
2007	67130.18	7734.65	2462.10	9249.94	43404.38	129981.25
2008	70712.93	8181.64	2524.30	8845.91	43625.46	133890.23
2009	76374.36	8238.33	2658.03	8989.90	43846.21	140106.82
2010	79992.74	9025.92	2690.15	9374.92	44051.85	145135.58
2011	83858.92	9779.86	2998.38	9773.69	44260.45	150671.30
2012	82206.62	10700.76	3169.47	10047.92	44480.21	150604.99
2013	82278.05	11357.85	3341.13	10436.55	44699.65	152113.24

Analysis of carbon sequestration structure. The source of carbon sequestration mainly includes cultivated land, forest land, garden land, grassland and urban green space. Carbon sequestration in China increased year by year, and forest land, crop is an important carbon sink.

The carbon sequestration of land use in China from 2004 to 2013 is shown in Table 10, and the change of that is shown in Fig. 3.

Table 10: The carbon sequestration of land use in China from 2004 to 2013

Year	Cultivated land /10^4t	Forest land /10^4t	Garden land /10^4t	Grassland /10^4t	Urban green space /10^4t	Total/10^4t
2004	63470.76	13562.21	8240.09	551.68	3100.26	88925.02
2005	64752.17	13602.26	8430.77	550.50	3436.57	90772.27
2006	68139.34	13624.20	8627.29	550.06	3496.52	94437.40
2007	69890.64	13623.97	8623.56	549.92	4268.96	96957.06
2008	74381.68	13621.05	8614.00	549.78	4618.83	101785.34
2009	73510.22	13701.63	8214.03	518.44	4831.38	100775.71
2010	74654.89	14032.17	8808.11	497.92	4889.66	102882.74
2011	78157.14	14246.96	10090.13	477.69	5143.48	108115.39
2012	81326.20	14621.00	10349.58	461.09	5406.12	112163.99
2013	82918.21	14612.75	10349.94	460.98	5696.90	114038.77

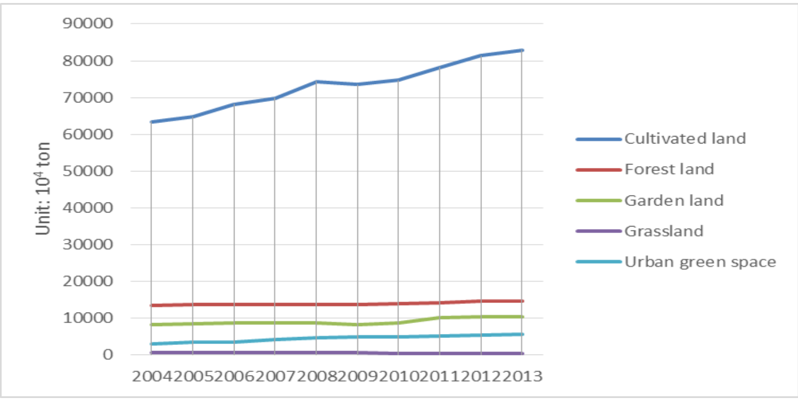

Fig. 3: The change of carbon sequestration of land use in China from 2004 to 2013

3.2.3. Analysis of carbon emission intensity

Ratio between carbon source and carbon sinks. The ratio between carbon source and carbon sinks of land use can intuitively reflect carbon emissions and carbon sequestration of land and has an important value on land use for low-carbon. The ratio between carbon source and carbon sinks is increasing during the year of 2004 to 2010 and it begun to reduce after 2010 (shown in Table 11), it indicates that the relevant measures to protect the ecological environment of land have been effective.

Per capita and per hectare carbon emissions. The carbon emission intensity of per capita and per hectare is increasing gradually during the year of 2004 to 2013, and the reason is mainly because urbanization and industrialization is accelerating, and the carbon emission intensity of construction land has increased.

Table 11: Analysis of carbon emission intensity in China from 2004 to 2013

Year	Ratio between carbon source and carbon sinks	Per capita carbon emissions （t/capita）	Per hectare construction land carbon emissions.（t/hm^2）	Per hectare carbon emissions.（t/hm^2）
2004	1.33	0.91	37.38	1.23
2005	1.38	0.96	39.16	1.30
2006	1.39	1.00	40.48	1.36
2007	1.43	1.05	42.22	1.44
2008	1.40	1.07	43.03	1.48
2009	1.48	1.12	44.55	1.55
2010	1.50	1.15	44.23	1.60
2011	1.48	1.19	44.09	1.66
2012	1.43	1.18	43.38	1.67
2013	1.42	1.19	43.79	1.68

3.3. Effects of land use change on carbon emissions

3.3.1. Analysis on mechanism of the impact of land use changing on carbon emissions

The role of different land use patterns is different in the effects of production, living and ecology, so the process of carbon emissions is different significantly [15], land use change has a significant impact on carbon emissions. The impacts of land use change on carbon emissions include direct and indirect ones. The direct impact is that carbon emissions and carbon sequestration are different in different patterns of land use, and the mutual conversion between different types of land will directly affect the carbon emission of land, also affect soil respiration rate. The indirect impact is that the ways of production, living and energy consumption are different between different land use patterns, so the carbon emissions caused by human are different significantly. Land use change will increase or decrease the demand for some kind of energy consumption and change the combination mode of energy consumption in different type of land, then change the carbon emissions intensity and structure of land use [16].

3.3.2. Analysis of carbon emission effects of land use change

Great changes have taken place in patterns of land use in China because of the accelerating urbanization and industrialization process during the year of 2004 to 2013. Construction land is the main carbon source and owns the largest proportion of carbon emissions, cultivated land is the second largest carbon source. Crops on the cultivated land is the most important carbon sink, followed by forest land, garden land and urban green space. The carbon sequestration capacity of grassland is very small. Cultivated land and forest land increased a large area, so that the amount of carbon sequestration also increased. Because of a substantial increase in energy consumption from construction land , the increase of carbon source far greater than that of carbon sinks, which makes carbon emissions are still higher than the amount of carbon absorbed. From the point of land use type, the increase of 1 hectares of cultivated land, 1.6 tons of carbon emissions increase, while 1 hectares increasing of construction land, carbon emissions increased by 77.9 tons, which indicates that construction land owns the strongest capacity for carbon emissions. The amount of carbon sequestration increased by 15.9 tons for each increase of 1 hectares of cultivated land and forest land, only 20.41% of carbon emissions increasing from construction land. The amount of carbon emissions increasing from construction land is the main reason for the increasing of carbon emissions in China.

4. Conclusion and Suggestion

4.1. Conclusion

Construction land is the main carbon source, cultivated and forest land are the main carbon sink. The trend on change of the carbon emissions in China was increasing from 2004 to 2013. The reason construction became the main carbon source was the increasing of energy consumption, and cultivated land became the second largest carbon source because the use of fertilizers, agricultural irrigation, agricultural films, pesticides and agricultural machinery. Carbon fixation through crops and forest land are the main patterns for carbon sequestration in China, which plays a leading role in reducing carbon in the atmosphere.

Carbon emission reduction efforts still need to be strengthened. Although the ratio between carbon source and carbon sinks begun to reduce after 2010, the lowering range was small， while per capita and per hectare carbon emissions were in the situation of increasing, which indicated that relevant policies formulated by the Chinese government had a certain role in promoting reducing carbon emissions but not obvious, carbon emission reduction efforts still need to be strengthened.

Providing guidance for low carbon optimization of land use structure. According to the research of this paper, different land use patterns have different carbon effects, and the research on carbon emission effects of different land use patterns is of great significance to the optimization of land use structure.

4.2. Suggestion

Explore low carbon utilization mode of land. The amount of land use carbon emissions is significantly greater than that of carbon sequestration, therefore, it is needed to explore low carbon utilization mode of land. It should be efforts to control construction land and cultivated land carbon emissions, improve energy efficiency, reduce the use of fertilizer, expand the area of forest land.

Develop low carbon utilization technology of land. Developing new technologies to reduce energy consumption in the process of cultivated and construction land use, and control carbon emissions.

Carry out the evaluation of low carbon utilization of land. Construction land is the main carbon source of land use carbon emission. If we need to control the construction of carbon emissions, we need to improve the threshold of construction land approval, add more carbon emission index assesses of construction land supply and carry out the evaluation of low carbon use of land.

Implement the regulation policy on low carbon land use. There are two methods to implement the regulation policy on low carbon land use: administrative and economic regulation. To be more specific, the government can levy a certain carbon tax to construction land developer through administrative means, and then these funds can be used to reward the users who have increased carbon sink. The government also can give a certain carbon emission quota for all kinds of construction land. The right of carbon emissions for land use can be traded through market mechanism. The government should also guide the low carbon land use through offering preferential policies, credit policies to developers for low carbon development.

5. Acknowledgements

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