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The interactive relationship among construction land expansion, carbon emission, water resource and energy consumption in the suburb of Chongqing over the past 26 years

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ABSTRACT

Study on the interrelationship among construction land expansion, carbon emission, water resource and energy consumption will be the key point to protect water area and mitigate climate change. Through remote sensing, Geographic Information System technology and vector error correction mechanism, we analyzed the expansion of construction land and carbon emission characteristics. We evaluated land use, water area and energy consumption data over the past 26 years in Bishan, which is a typical city with highly expanded construction land in the suburb of Chongqing, and the relationship between carbon emission intensity and social economic indicators from the perspective of construction land expansion. Results showed that the construction land expansion in Bishan had an average annual growth rate of 17.8% from 1990 to 2015. The average annual increase rates of rural residential areas, town land, mining land, transportation land and water conservancy facility land were 13.7%, 34.2%, 4.3%, 32.4% and 13.8%, respectively. The correlation of construction land area and carbon emissions was extremely significant. The quantity of construction land and carbon emission intensity showed a 'U'-curve relationship. Moreover, the GDP and investment per capita significantly affected the per unit area of the construction land per capita in the level of 10%. Energy consumption remained as the main reason for carbon emission per unit area of the construction land.

Keywords: Construction land; Carbon emission; Water area; Environmental Kuznets curve; Vector error correction mechanism

1. Introduction

At present, the impact of social and economic construction on carbon emission and climate change is a research hot spot worldwide [1–5]. As a coupling system of social, economic and natural ecological environment, land use provides an important comprehensive perspective for study of global environmental changes, particularly man-made carbon emission [6]. On the one hand, as a natural carrier of carbon source or sink of land ecosystem, changes in land use type and management mode are an important factor that affects the rapid growth of global greenhouse gas emission [7]. On the other hand, land use is an important way to regulate the social and economic activities that impact the carbon emissions at the macro level [8]. In recent years, the number of research on carbon emission accounting and mechanism has increased from the perspective of construction land expansion [9,10].

Environmental Kuznets curve is a common method used to study the relationship between economic growth and environmental emissions [11–14]; that is, a reverse

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U-curve relationship exists between environmental emissions and per capita income. Carbon emission Kuznets curve (CKC) was established by Mahmud et al. [15] in 2009 and has become a new hot spot in the study of the relationship between social economic development and environmental carbon emissions [16–18]. Zhang et al. [19] studied the proportion of construction land in Wuxi, Jiangsu for 13 years using the CKC model; results indicated that the total amount of construction land CKC in Wuxi began to be an inverted U curve, the urban land CKC exhibited an N curve and other construction land CKC showed linear trend from 1996 to 2008. Haq et al. [18] studied foreign trade income, energy consumption and carbon emissions based on the data wherein a short period of time, energy consumption and carbon emissions were the main factors; in the long run, economic development and carbon emissions in Morocco did not show the existence of Kuznets curve hypothesis from 1971 to 2011. Thus far, the interactive relationship among construction land expansion, carbon emission, water resource and energy consumption in the suburb of big cities has not been reported yet. Factors influencing the carbon emissions of construction land have also not been investigated.

The economy of Bishan has performed well in the last three decades. This study utilised land use and energy consumption data in the suburb of Chongqing in Bishan from 2009 to 2015 to analyze the relationship between construction land expansion and the characteristics of carbon emissions, water conservancy facility land, construction land ratio and CKC model in Eviews software. This work also determined the relationship of construction land expansion in the suburban area of Chongqing to carbon emissions and energy consumption using the VEC model to assess and provide a reference for carbon emission reduction as well as study the changes in land usage in highly developed cities and low-carbon economy.

2. Methodology

2.1. Study area

Bishan district is located in the west of Chongqing (Fig. 1), closely adjacent to the downtown area (mainly nine districts) and about 30 km from the centre of the city. By the end of 2015, the area was 914.55 km^2, the cultivated land area was 26118 hectares and the per capita cultivated land area was 553.3 m^2. Soil in the area is dominated by paddy soil, followed by purple soil. The mountain area (E106.02°–106.20° and N29.17°–29.53°) is located in the humid subtropical monsoon climate zone and experiences humid climate and abundant rainfall. The area has four distinct seasons and an annual average temperature of 18.3°C. Bishan accounts for 17.6% of the total area and has few plains. This topography leads to minimal land resources for agriculture especially in recent years. With increasing population, the non-agricultural land area increases, the cultivated land area shrinks and industrialization and urbanization speed up. Bishan, the rim of Chongqing's downtown area and a typical suburb, has advantages in terms of geographical conditions and developing suburban economy. With the

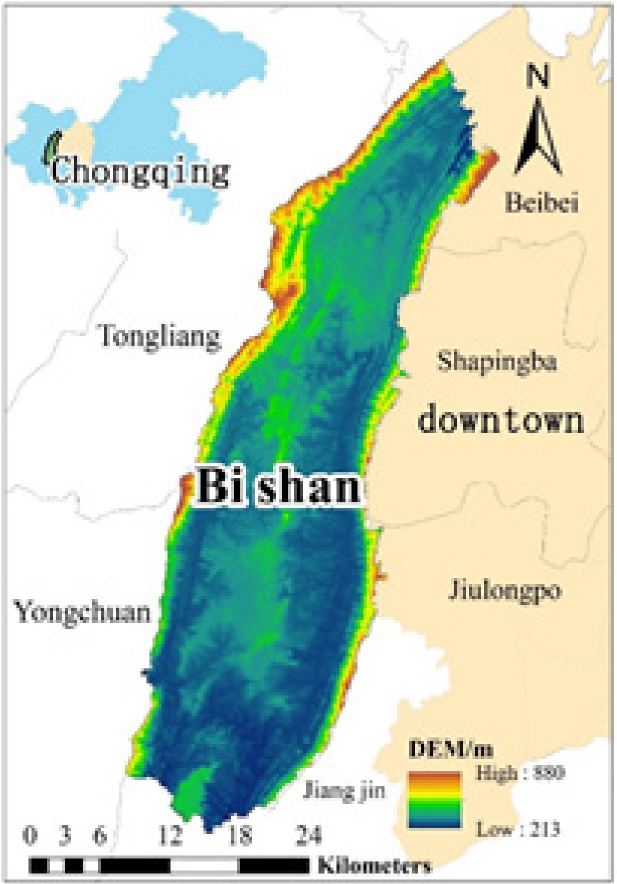

Fig. 1. Location of the study area.

rapid development of economy and the increasing cost of urban construction land, the expansion of construction land in Bishan district is very fierce. In June 2014, Bishan was included in the original batch of 'National Low Carbon Industrial Park'. In November 2016, building of light rails in Bishan station was started. Once the construction completed, travel from Bishan station to the University City of Chongqing in Shuangbei station would only take 6 min.

2.2. Data sources

We obtained the remote sensing images of Landsat TM/ETM in 1990, 1995, 2000, 2005, 2010 and 2015 and interpreted them in Erdas 9.2 software. The images were classified based on the LUCC classification standard of the Chinese Academy of Resources and Environment Science Data Centre [20–22]. Land use was categorised into six types: cultivated land, forest land, grassland, water area, construction land and unused land. Kappa test was performed on the classification results by random sampling method. The results had accuracies of 0.86 (1990), 0.85 (1995), 0.89 (2000), 0.78 (2005), 0.92 (2010) and 0.79 (2015), which are all higher than 0.7. In Bishan Land Consolidation Centre, 1:10000 of the original vector data of land use map were based on the supervised classification and visual changes to 1990, 1995, 2000, 2005, 2010 and 2015, 6 period TM/ETM remote sensing images. And we classified the land use of Bishan in ArcGIS 10.2.

The land use data in 1990, 1995, 2000, 2005, 2010 and 2015; the data of the total population in Bishan district; GDP; energy consumption; and fixed assets investment from 1990 to 2015 were obtained from *Chongqing statistical yearbook* and *Bishan statistical yearbook*.

2.3. Method for calculating the carbon emission intensity

Carbon emissions are categorised into two types based on their sources: natural emissions and anthropogenic emissions. This paper mainly studied carbon emissions caused by anthropogenic factors. Energy consumption and crop production were the major carbon sources, whereas forest land, garden land and grassland were the major carbon sinks. Carbon emissions from crop production and carbon uptake by woodland and grassland could be calculated using land carbon emission and absorption coefficients. Energy consumption of carbon emission could be determined through the carbon emission coefficient of energy consumption. The calculation formula for carbon emissions is presented as follows:

$$C = CE - CS = {}^{a}C + {}^{e}C - {}^{j}C - {}^{g}C = S_A \cdot \delta_A + \sum_{i=1}^{n} Q_i \theta_i - S_F \cdot \delta_F - S_G \cdot \delta_G \quad (1)$$

In the formula, C is the total carbon emission; CE is the carbon emission for carbon sources; CS is the carbon absorption for carbon sequestration; and ${}^{a}C$ and ${}^{e}C$ are the carbon emissions from crop production and energy consumption, respectively; ${}^{j}C$ and ${}^{g}C$ are the carbon absorptions in forest land and grassland, respectively; S_A, S_F and S_G are the areas of cultivated land, forest land and grassland, respectively; δ_A, δ_F and δ_G are the carbon emission (absorption) coefficients of cultivated land, forest land and grassland, respectively; Q_i is the consumption of energy i; θ_i is the carbon emission conversion factor for energy i; and n is the type of energy consumption (Table 1).

2.4. Empirical model

According to Kuznets curve theory and related research [19,12–14,23–25], the relationship between construction land expansion and CKC was established with a Kuznets curve model hypothesis.

$$I = \beta_0 + \beta_1 L + \beta_2 L^2 + \beta_3 L^3 + \varepsilon \quad (2)$$

In the formula, I is the carbon emission intensity; L is the total amount of construction land and the proportion of construction land to the total land area; β_0, β_1, β_2 and β_3 are undetermined parameters [19] (Table 2); and ε is the random error interference.

The intensity index of carbon emissions is the expansion of construction land changes from the perspective of carbon emissions. Carbon emission intensity index can be used to measure the area of the construction of the carbon emission contribution rate of land carbon emissions caused by the expansion of construction land units.

$$I = \frac{C}{L} \quad (3)$$

In the formula, I is the carbon emission intensity, C is the carbon emission in the study area and L is the total area of construction land in the study area.

Auto regressive distributed lag (ARDL) [12–15,18] is an empirical analysis used to determine factors influencing land use and CKC. The model calculation formula is as follows:

$$\ln CO_t = \beta + \beta_1 lnPC_t + \beta_2 lnEC_t + \beta_3 lnIC_t + \varepsilon_t \quad (4)$$

CO is the carbon emission of the construction land per hectare and represents the extent of the degradation of the unit land area and the environment [18]. Income is indicated by GDP per capita (*PC*). Per capita energy consumption (*EC*) and *PC* investment in fixed assets (*IC*) were searched from *Bishan statistical yearbook* and *Chongqing statistical yearbook* from 1990 to 2015. β, β_1 and β_2 are the constant parameters, ε is random error interference and t is the year.

This study applied augmented Dicky–Fuller (ADF) [26] and Phillips and Perron (PP) [27] tests to detect the relationship of per hectare of construction land to carbon emission and *EC*. The P values of the ADF test were 0.88 and 0.9, which are greater than 0.5, indicating that the sequence is non-stationary. The first-order difference sequences of the variables were tested by stationarity. The P values were 0.43 and 0.35, which

Table 2
The curves between construction land rate and carbon emission intensity

Type	β1	β2	β3	Curve
1	>0	0	0	Positive linear
	<0	0	0	Negative linear
2	>0	<0	0	Inverted U type
	<0	>0	0	U type
3	<0	>0	<0	Inverted N type
	>0	<0	>0	N type

Table 1
Coefficient of carbon emission (absorb-ability) and carbon source (sink) [19]

Carbon emission coefficient				Absorption coefficient of carbon sink		
Cultivated land	Coal	Petroleum	Natural gas	Crops	Forest land	Grassland
kg C·m^{-2}·a^{-1}	t C·t^{-1}	t C·t^{-1}	t C·t^{-1}	kg C·m^{-2}·a^{-1}	kg C·m^{-2}·a^{-1}	kg C·m^{-2}·a^{-1}
0.0425	0.7329	0.583	0.4226	0.000692	5.77	0.0021

are less than 0.5, indicating that the sequences are stationary. We then conducted Johansen [28] test, and at least two co-integration vectors were proved at the 5% level. Vector error correction mechanism (VECM) was performed [29] as follows:

$$\begin{cases} \Delta\ln CO_t = \lambda + \sum_{i=1}^{q1}\beta_1\Delta\ln CO_{t-i} + \sum_{i=0}^{q2}\beta_2\Delta\ln PC_{t-i} + \sum_{i=0}^{q3}\beta_3\Delta\ln EC_{t-i} \\ \qquad + \sum_{i=0}^{q4}\beta_4\Delta\ln IC_{t\text{-}i} + \phi_1 z_{t-1} + \varepsilon_t \\ \Delta\ln PC_t = \lambda + \sum_{i=0}^{q1}\beta_1\Delta\ln CO_{t-i} + \sum_{i=I}^{q2}\beta_2\Delta\ln PC_{t-i} + \sum_{i=0}^{q3}\beta_3\Delta\ln EC_{t-i} \\ \qquad + \sum_{i=0}^{q4}\beta_4\Delta\ln IC_{t\text{-}i} + \phi_2 z_{t-1} + \varepsilon_t \\ \Delta\ln EC_t = \lambda + \sum_{i=0}^{q1}\beta_1\Delta\ln CO_{t-i} + \sum_{i=0}^{q2}\beta_2\Delta\ln PC_{t-i} + \sum_{i=1}^{q3}\beta_3\Delta\ln EC_{t-i} \\ \qquad + \sum_{i=0}^{q4}\beta_4\Delta\ln IC_{t\text{-}i} + \phi_3 z_{t-1} + \varepsilon_t \\ \Delta\ln RC_t = \lambda + \sum_{i=0}^{q1}\beta_1\Delta\ln CO_{t-i} + \sum_{i=0}^{q2}\beta_2\Delta\ln PC_{t-i} + \sum_{i=0}^{q3}\beta_3\Delta\ln EC_{t-i} \\ \qquad + \sum_{i=1}^{q4}\beta_4\Delta\ln IC_{t\text{-}i} + \phi_4 z_{t-1} + \varepsilon_t \end{cases} \tag{5}$$

In the formula, Δ represents the difference operator, z_{t-1} is the error correction term, the magnitude of φ caught up the speed of adjustment from the disequilibrium in previous period and ε_t is the error term. The VECM distinguished between the long- and short-run causality. The F-statistics of the differentiated variables provided short-run causal effects [18]. The long-run causality was captured through the significance value of t-statistics of the lagged error correction term (ECT) as it was being derived from the long-run co-integration relationship [12,13]. Furthermore, the joint significance of the differenced variables and ECT through Wald test in each equation of VECM could also refer to strong granger causality [18].

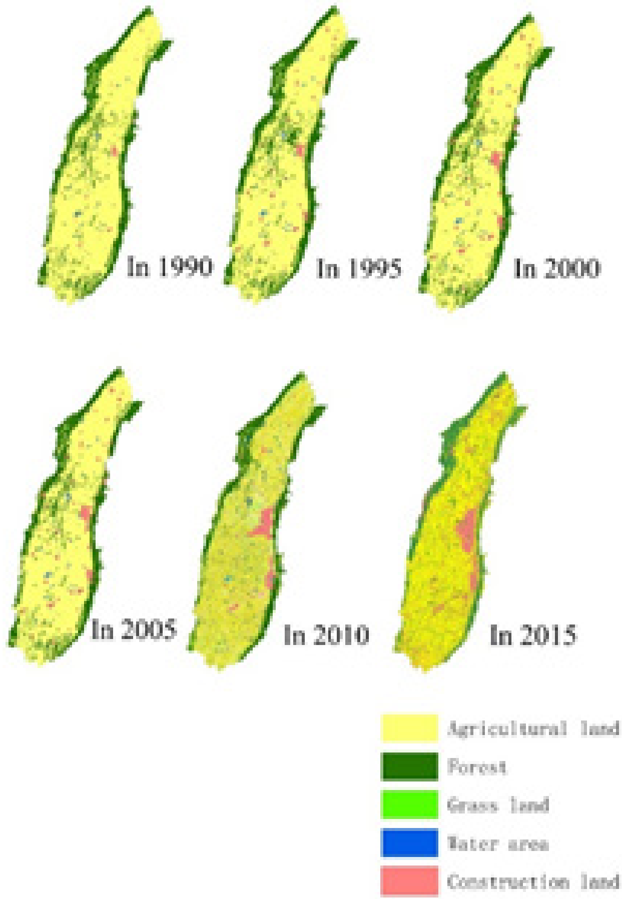

Fig. 2. Land use changes in Bishan from 1990 to 2015.

3. Results and discussion

3.1. Characteristics of construction land expansion in bishan district

In 2015, the total construction area was 15478.89 hm^2 (Fig. 2), which is 5.6 times the area of the building in 1990, with an average annual growth of 17.8%. In 1990–2005, the construction land area increased by 1.53 times and the increase in the construction land area could be mainly due to the increase in the rural residential land area. In 2005–2009, with the rapid development of construction land, the rural residential growth rate was the highest, showing 'South–North–West' expansion from the town centre, and the area of construction land increased nearly twice. In 2010–2015, with the slow construction growth rate of 6.5% and the characteristics of construction land expansion in the towns at the centre, to the south of the main new urban expansion, the rural residential land area decreased. Since 2011, the state has strictly controlled the approval of the quota of farmland occupied in the construction land, thereby decreasing the growth rate of the construction land 2010–2015 years lower than that before 2010.

From 1990 to 2015, rural settlements and towns were important parts for the construction of Bishan. Rural residents accounted for more than half of the total construction land in 1990–2009 and less than 50% of the total construction land in 2010 (Fig. 2). Rural settlements, towns, mining land, transportation land and water conservancy facility land had average annual growth rates of 13.7%, 34.2%, 4.3%, 32.4% and 13.8%, respectively. The town land and transportation land areas increased significantly over 26 y. This finding indicates the evident urbanization of Bishan and the rapid development of road infrastructure. In 1990–2010, the area of the five types of construction land increased yearly. Rural settlements and towns showed the fastest growth in 2005–2009, with average annual growth rates of 29.3% and 23.4%, respectively. The rapid growth may be due to the construction of new countryside by the government. In 2010–2015, the land area decreased yearly. A decrease of 0.34 percentage points was noted in rural residential areas. The rate of increase in town and transportation land areas decreased, with average annual growth rates of 5.96% and 8.91%. The mining land and land for water conservancy facilities for Bishan construction land were

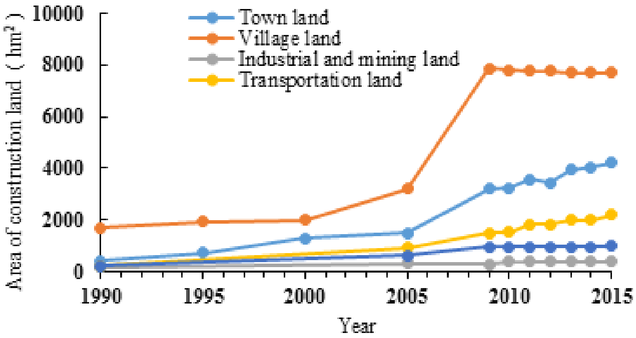

Fig. 3. Classification of construction land in the Bishan District from 1990 to 2015.

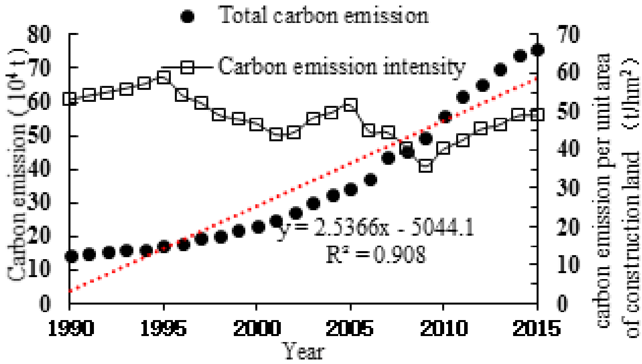

Fig. 4. Carbon emission situation in Bishan from 1990 to 2015.

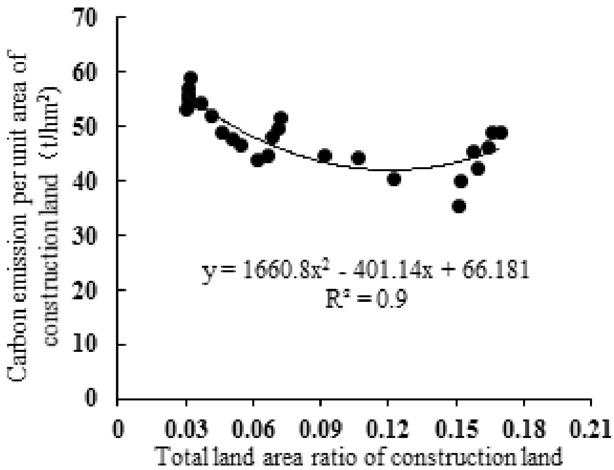

Fig. 5. The relationship between different types of construction land and carbon emission.

small, and the change was not obvious. The implementation of land ticket transactions and reclamation measures may cause the decrease in the rural residential area.

3.2. *Empirical study on Kuznets curve relationship between carbon emission and construction land*

Based on the EC and land use data in 1990–2015, we calculated the carbon emission of the constructed land and its intensity.

From 1990 to 2015, the carbon emissions in Bishan showed a rapid growth trend. The total carbon emissions were 14.6 × 10^4 t in 1990 and increased to 75.89 × 10^4 t (Fig. 4) in 2015. The carbon emissions per unit area of land and per unit area of construction land were 8.3 and 49.03 t/hm^2, respectively, in 2015. The analyses of carbon source and sequestration indicated that EC is the main reason for the increase in carbon emissions around Bishan. The energy demand of the city increased, resulting in increased carbon emissions annually. The unit construction land of carbon emissions contribution rate was divided into three stages: In 1990–1995, we observed a gradual growth of the mean construction land area, which increased by 10.8% from 53.1 t/hm^2 to 58.9 t/hm^2. The speed of the increase in the construction land area was slower than the increase in carbon emissions. The model of carbon emissions does not focus on intensive land use due to the increase in the construction land area, leading to increased carbon emission intensity. From 1995 to 2009, the carbon emission intensity decreased mainly because of the increase in the construction land area. The carbon emission intensity decreased from 1995 to 2000 and then increased from 2001 to 2005. This trend could be due to the slow increase in the construction land area and the higher EC of carbon emission intensity than energy contribution. In 2009–2015, the rapid increase in suburban areas and urban expansion led to the reduction in the areas of woodland, grassland, and other ecological lands. Carbon sequestration and absorption showed a downward trend yearly in Bishan.

We conducted correlation analysis in SPSS software. The correlation coefficients (r) in the total town land, rural residential land, mining land, transportation land, water conservation facility land and carbon emission were 0.983, 0.826, 0.964, 0.976, 0.990 and 0.981, which are significant at 1% level. According to the analysis of the description of various land use types, the increase in the construction land area positively affected carbon emissions. Regression analysis and inspection were performed to analyse the Kuznets curve relationship between carbon emission intensity and land use. The regression coefficient T value, adjustment coefficient R^2 value and F-measure were used to determine the presence of a linear, quadratic curve and cubic curve relationship. Next, we tested the relationship between town land, rural residential and industrial land, traffic land and land with water conservation facilities using CKC (Fig. 5).

Construction land change on is an important factor that leads to the increase in carbon emissions in the atmosphere [30]. The total construction land area showed a ‘U’-curve relationship with the increase in the total carbon emission intensity index (Fig. 5). The R^2 value was 0.932, which indicates that the model results are in good agreement with the statistical data. The curve inflection point in construction land accounted for 12.1% of the total land area at the critical point. The proportion decreased to less than 12.1% of the total construction land when the main factor of construction land expansion is not carbon emission. When the construction land occupied more than 12.1% of the total land, the carbon emission intensity gradually increased. At the start of 2009, the ratio of the construction land area to the total land area ratio reached 14.9% in Bishan. One of the main factors affecting carbon emission was land expansion during the Ming Dynasty (2009–2015) period of construction. The carbon emission intensity of construction land decreased in 1995–2001 and 2005–2009 but increased in the remaining years. All kinds of construction land area were significantly positively correlated with carbon emissions. Based on CKC analysis, the quantity of construction land and carbon emission intensity showed a 'U'-curve relationship. The relationship among town land, transportation land and carbon emission intensity showed an 'N' curve. Rural residential land use and carbon emission intensity showed an inverted 'N' relationship. No correlation was found between construction land and carbon emissions in the Kuznets curve. These results are consistent with those reported by Akbostancı et al. [16] and Haq et al. [18] but contradict those stated by Zhang et al. [19] and Zhao et al. [31], who stated no Kuznets curve trend on carbon emission of construction land. The construction land rapidly expanded in the suburban, which may lead to saturation of large cities with construction land. The government in Bishan district should carry out economic construction in the condition of low-carbon environmental protection. If the city and industrialization will not undergo intensive development mode, then the energy utilization efficiency of the increasing construction land area in Bishan will be low. With difficult protection and management, degradation of the extinction of forest and grassland carbon sequestration and disorderly development activities on local ecological function and environment will occur.

Table 3
Descriptive statistics of factors affecting carbon emission of construction land

	CO (t/(hm^{-2}·per))	PC (Yuan/per)	EC (t/per)	IC (Yuan/per)
Mean	0.81	16710.72	0.579	15969.49
Median	0.78	10096.83	0.62	3404.41
Maximum	1.11	54733.31	0.877	94406.59
Minimum	0.56	5358.8	0.18	875.04
Standard deviation	0.16	1.44	0.23	2.62
Skewness	0.58	1.57	−0.31	2.03
Kurtosis	−1.2	−0.91	1.38	−1.5
Observations	26	26	26	26

3.3. Analysis of influencing factors on carbon emission and construction land expansion

Analysis of the descriptive statistics of factors affecting the carbon emission of construction land from 1990 to 2015 (Table 3) showed that carbon emission intensity in all construction land was 0.81 t per hectare. The annual PC GDP was 16710.72 RMB. The average annual EC was 0.579 t PC. The average annual investment in fixed assets amounted to 15969.49 RMB per person.

The carbon emission effects of construction land expansion tested by Johansen (Table 4) showed that the goodness of fit on R^2 on ln (CO) of VECM was 0.98, indicating that the model results are in good agreement with the statistical data. From the economic index in 1990–2015, PC posed a negative impact on CO, whereas EC and IC showed a positive impact on CO. In the long run, the growth of GDP per capita was intensive, whereas that of per capita energy consumption and per capita investment in fixed assets remained extensive. The EC efficiency was expected to be very low, resulting in the increase in carbon emissions per unit area.

Stability tests were carried out through cumulative sum of recursive residual (CUSUM) and cumulative sum of squares of recursive residual (CUSUMQ) techniques. The plots of both CUSUM and CUSUMQ are within the critical bounds ($P < 0.05$). The straight lines in Figs. 6a and 6b indicate critical bounds at 5% significance level. These results confirm that all the coefficients of the ECM model are stable.

The first column of the table indicates causality (F-statistic) in the short run (Table 5). The second portion presents causality indicated through significance of R^2 (goodness of fit). The last portion presents the causality (F-statistic) of CO together with PC, EC and IC in the long run. Analysis of the short-run causal effects revealed that EC is the only variable that affects carbon emissions. The goodness of fit (R^2) values on Δln (CO), Δln(PC), Δln(EC) and Δln(IC) were 0.936, 0.917, 0.742 and 0.986, respectively, which indicate that the model results are in good agreement in the short run. A unidirectional causality was found among economic growth, EC and investment assets in the long run. Analysis of the long-run causality revealed that carbon emission was affected by economic growth, EC and investment assets. The impact of EC on the carbon emission of construction land was found to be significant at the 1% level. Energy consumption is still the main reason that affects the carbon emission of construction land. Liddle [32] also believed that the change in carbon emissions is mainly caused by energy intensity. However, in the present case, changes in carbon

Table 4
Results of each influencing factor via Johansen test

Dependent variable ln(CO)			Dependent variable Δln(CO)		
Regressors	Coefficient	t-Statistic	Variable	Coefficient	t-Statistic
ln(PC)	−0.15*	−2.06	Δln(PC(−1))	−3.18**	−0.09
ln(EC)	−0.51***	−4.7	Δln(EC(−1))	1.64*	0.339
ln(IC)	0.08**	−2.11	Δln(IC(−1))	1.05*	6.88
ε	1.24**	3.66	E	2.73**	−0.2

***was significant at 1% levels; **was significant at 5% levels; *was significantly at 10% levels

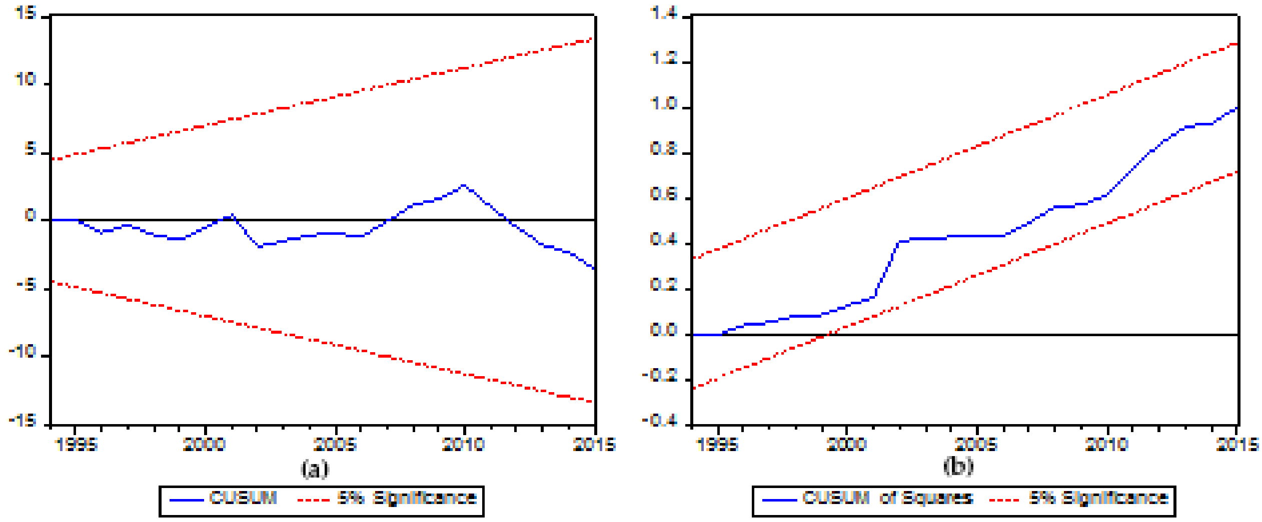

Fig. 6. Plots of cumulative sum of recursive residual (CUSUM) and cumulative sum of squares of recursive residual (CUSUMQ).

Table 5
Results of each influencing factor via vector error correction mechanism

Variable	Δln(CO)	Δln(PC)	Δln(EC)	Δln(IC)
Δln(CO)	–	1.64*	8.05***	–1.634*
Δln(PC)	–3.18	–	–0.09	–2.24
Δln(EC)	1.64	–2.35	–	–5.83
Δln(IC)	1.05	0.06	–0.04	–
R^2	0.936	0.917	0.742	0.986
F-statistic	18.2	23.85	6.16	156.46

emission did not pose a significant impact on PC, EC and IC in the short run.

4. Conclusions

This study investigated the interactive relationship among construction land, carbon emission and EC in the suburbs of Chongqing. The following conclusions can be drawn.

In 1990–2015, the average annual increase rate in the construction land area was 17.8%. The construction land expansion in the Bishan district was relatively fast and experienced a slow growth stage (1990–2004), accelerated growth phase (2005–2008) and deceleration growth phase (2009–2015), showing an expansion trend from centre to north and south. Rural residential areas, towns, mining land, transportation land and water conservation facility land had average annual growth rates of 13.7%, 34.2%, 4.3%, 32.4% and 13.8%, respectively. The areas of town land and transportation land increased significantly, resulting in increased urbanization level of the Bishan district and rapid road infrastructure development over the 26 years.

The average annual carbon emission of the studied areas increased by 16.1%. The average carbon emission intensity and the carbon emission intensity of the total land and construction land reached 8.3 and 49.03 t/hm^2, respectively, in 2015. All kinds of construction land area was significantly positively correlated with carbon emission. CKC and the quantity of construction land and carbon emission intensity showed a 'U'-curve relationship. Town land, transportation land and carbon emission intensity showed an 'N'-curve relationship.

Economic growth had a very significant impact on carbon emission intensity. The interaction among CO, PC, EC and IC based on the VECM model showed that the economic effects of PC, EC and IC on the carbon emission of construction land are significant at the 10% level. The impact of EC on the carbon emission of construction land is significant at the 1% level. Energy consumption is still the main reason that affects the carbon emission of construction land.

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