Applied Energy Symposium 2020: Low carbon cities and urban energy systems
October 10-17, 2020
Paper ID: CUE2020-D-071

Land Use Based Method Evaluating and Restraining Carbon Emissions for Urban Planning

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ABSTRACT

Urban carbon emissions are greatly influenced by land use patterns in urban areas, which are largely decided by the urban planning program. The procedure for planning program adjustment aim for low carbon is urgently needed in the actual planning process. This paper establishes a land use-based method (LU-BM) using land-based emission factor (LB-EF) approach to evaluate and restrain carbon emissions for urban planning. Through the three-step processes of "Establishment of quantitative approach", "Analysis of the pre-planning program", and "Adjustment of the pre-planning program", the total carbon emissions of 2035 planning of the central urban district in Changxing county, China was evaluated, and the land-use composition and carbon emission intensity in different functional zones were adjusted using land-use planning map and control indexes as the adjustment tools. By calculation, the comprehensive adjustments proposed by LU-BM in total cut 39.67 percent CO_2 emission equivalents compared with the original planning, the effects were significant. The results indicate that land use planning and management can be a valuable tool to restrain carbon emissions in planning stage.

Keywords: carbon emission control, urban areas, urban planning, land use pattern, quantitative approach

1. INTRODUCTION

Urban area, the primary place to carry out carbon emission activities, generates about 70 percent of Global Greenhouse Gas (GHG) emissions [1]; urban planning, which exerts a decisive impact on Carbon dioxide (CO_2) emissions in urban areas, has a longer-term effect on constraining CO_2 emissions from human activities than policies. Therefore, methods for formulating a more low-carbon urban planning program in planning stage are urgently needed.

Quantitative evaluation of carbon emission effect of planning program is the core work to achieve low carbon urban development. Currently, the mainstream quantitative evaluation methods can be categorized as follows:

1) **Evaluation model method.** Liu et al. [2] built a "population-economy-land-carbon emission" model for new towns based on system dynamics to provide a quantitative assessment for understanding the impact of urban planning scenarios on carbon emissions. However, this model is only suitable for entirely new towns, but not applicable to new towns built up from complex existing states. Yeo and Lee [3] derived a methodology for estimating urban energy demand characteristics in post-development stages based on the environmental planning information. Nevertheless, the method proposed by Yeo did not allow for the impact of human activities on carbon emissions. In general, evaluation model method could obtain accurate prediction results, but due to the limited input parameters, the simulation process cannot consider the complex current situation and the impact of multi-layer influencing factors on carbon emissions. Moreover, evaluation model methods cannot be used to adjust a planning program with constraints on carbon emissions.

2) **Greenhouse Gas (GHG) inventory method.** Gu [4] built the greenhouse gas inventory for urban areas that gives a more complete picture of the overall greenhouse gas status. However, traditional inventory methods centralize emission data with sectors such as industry,

Selection and peer-review under responsibility of the scientific committee of CUE2020

transportation, household life, and agriculture, which show weak corresponding relationship with the control elements of urban planning. To solve this problem, suitable planning elements must be found as an intermediary to establish the quantitative relationship between CO_2 emissions and urban planning.

Land use pattern is one of the most important drivers of carbon emissions and is also a key target for planning management and regulation. Jiang et al. [5] constructed an urban GHG inventory from the spatial planning perspective using land-based emission factor (LB-EF) approach, which decomposes CO_2 emissions into the product of land areas and CO_2 emissions per unit land area. Although this method only stays in the theoretical stage at present, exploring the CO_2 emission effect of planning program based on land use makes it possible to identify and locate the primary sources related to the amounts and composition of the land patches. Chuai et al. [6] calculated the total carbon emissions in coastal Jiangsu, China. The detailed carbon emission items were assigned to different land use types, and the land use structure aiming at low carbon emissions was optimized by using a Linear Programming Model. Nevertheless, the optimization method proposed by Chuai does not involve the control of the carbon emission intensity of land patches and is not applicable to urban scale.

In this paper, a land use-based method (LU-BM) is proposed using LB-EF approach to evaluate and restrain carbon emissions for urban planning. LU-BM can reflect the comprehensive influence of human behavior, built environment, and technology factors on the carbon emission of planning program. We evaluated and improved the 2035 planning program of the central urban district in Changxing county, Zhejiang province, China (abbreviated as 2035 Changxing Planning) using LU-BM. By calculation, the adjustments of pre-planning program could effectively control and reduce the future carbon emissions.

2. DESCRIPTION OF LU-BM

The LU-BM proposed in this paper is comprised by three parts (Fig 1). The procedures of LU-BM are explained in details as follow.

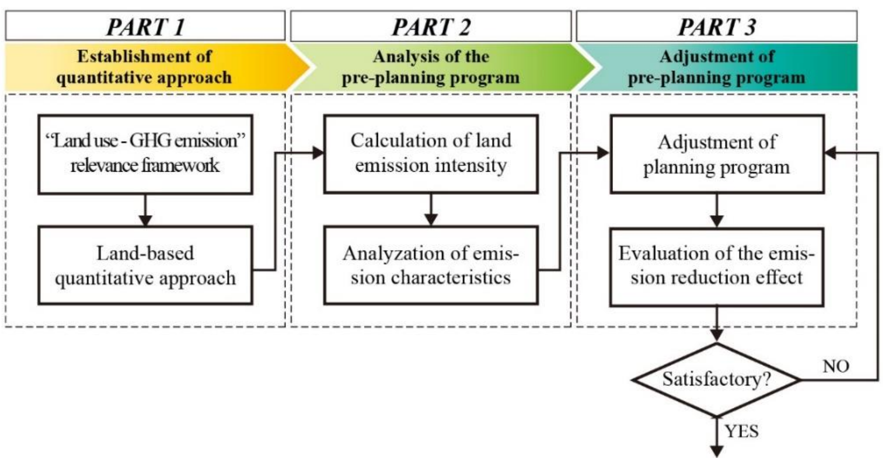


Fig 1 The flowchart of LU-BM.

2.1 LU-BM part 1: Establishment of quantitative approach

2.1.1 Step 1 Establishing a "Land use - GHG emission" relevance framework

According to the classification of development lands, the "Land use - GHG emission" relevance framework can be constructed by analyzing the carbon emission or absorption activities of different types of development lands.

2.1.2 Step 2 Establishing the quantitative approach of carbon emission intensity of development lands

Land areas and carbon emissions per unit of land area (abbreviated as intensity of land) are the important driving factors of CO_2 emissions. The intensity of land (***CI***) can be calculated by Eq. (1):

$$\boldsymbol{CI_i} = \frac{\boldsymbol{C_i}}{\boldsymbol{S_i}} = \frac{\boldsymbol{A_i}}{\boldsymbol{S_i}} \times \frac{\boldsymbol{C_i}}{\boldsymbol{A_i}}, \quad (\boldsymbol{i = 1, 2, 3 \dots n}) \;; \qquad (\mathbf{1.1})$$

$$= \frac{\boldsymbol{A_i}}{\boldsymbol{S_i}} \times \frac{\boldsymbol{E_{Fi}}}{\boldsymbol{A_i}} \times \frac{\boldsymbol{C_i}}{\boldsymbol{E_{Fi}}}, \quad (\boldsymbol{i = 1, 2, 3 \dots n}) \qquad (\mathbf{1.2})$$

$$= \frac{\boldsymbol{A_i}}{\boldsymbol{S_i}} \times \frac{\boldsymbol{E_{Ti}} \;\; (\mathbf{1} - \boldsymbol{R_i})}{\boldsymbol{A_i}} \times \frac{\boldsymbol{C_i}}{\boldsymbol{E_{Fi}}} \;; \qquad (\mathbf{1.3}) \;\; (\mathbf{1})$$

where CI_i is the intensity of development land in category i; C_i stands for total CO_2 emissions of development land in category i; S_i stands for total areas of development lands in category i; A_i is the activity level; E_{Fi} refers to fossil energy consumption; E_{Ti} is the total energy consumption; R_i represents the percentage of energy generated by renewable energy; n is the total amount of categories of development land.

Each type of development land is a single sub-system of the quantitative approach. The appropriate formula should be chosen from Eq. (1) to calculate the intensity values of each types of development land. Basically, if the carbon emissions are directly produced in the activity process, such as production process of many kinds of industry, Eq. (1.1) should be chosen; if the emissions derive from energy consumption, Eq. (1.2) should be chosen; and if the energy consumption involves the use of renewable energy, Eq. (1.3) can be adopted.

2.2 LU-BM part 2: Analysis of pre-planning program

In part 2, a pre-planning program with no consideration of carbon emission control can be used as the baseline scenario to provide the basic carbon emission amount in the future.

2.2.1 Step 1. Calculation of intensity of lands in the pre-planning program

The intensity of planning lands can be calculated based on the information from the pre-planning and regional status statistical data. According to Eq. (1), the values of A_i/S_i, E_i/A_i could reference the development goals given by the planning. The value of C_i/E_i is relatively stable, which could directly reference its status value.

2.2.2 Step 2. Analyzation of emission characteristics of pre-planning program

Analyzing the emission characteristics of pre-planning program at functional-zone level. Then recognizing the crucial kind of lands and the major functional-zones which have much higher carbon emission intensity or contribute the most to the total carbon emissions than other lands or zones.

2.3 LU-BM part 3: Adjustment of pre-planning program

2.3.1 Step 1. Adjustment of planning program

According to the analyses, synthetical strategies including the adjustment of land emission intensity and land-use composition are recommend to adjust the land use pattern and form a new planning program.

To adjust the land emission intensity, planning strategies for mitigating carbon emission intensities of the crucial kind of lands in each zone need to be proposed firstly. Then, the control indexes corresponding to planning strategies should be put forward according to the land-based quantitative approach for each zone. Planning strategies generally include technological innovation, industrial category replacement, renewable energy utilization, and public services increase. The control indexes usually refer to A_i/S_i, C_i/A_i, and R_i, which are from Eq. (1).

Next, the composition of different kinds of land can be varied by adjusting land-use planning map. The principle is to reduce the areas of the lands with high emission intensity, and increase the areas of green lands or the lands with less emission intensity. The adjustment of land areas is constraint by the following conditions (2):

$$\begin{cases} \sum_{i=1}^{n} \boldsymbol{S}_i' = \boldsymbol{S_T}, \quad (i = 1,2,3 \ldots n) \\ \boldsymbol{S}_i' \geq \boldsymbol{S}_{i\_Min} = \boldsymbol{SPA}_i \cdot \boldsymbol{CAP}_P, \quad (i = 1,2,3 \ldots n) \end{cases} \tag{2}$$

where S_i' represents the adjusted area of land in category i; S_T is the total area of development land; S_{i_Min} stands for the minimal total area of land in category i; SPA_i is the minimal per capita area of land in category i; CAP_P is the planned population size.

After adjustment, intensity of development land with carbon emission constraint need to be calculated according to Eq. (1), and the adjusted land areas need to be recounted.

2.3.2 Step 2. Evaluation of the emission reduction effect

In this step, the rate of emission reduction in the low-carbon scenario should be calculated to indicate the evaluation of the emission reduction effect. The evaluation method could reference the quantitative approach established in Part 1. By evaluation, if the effect of carbon emission reduction of the improved planning meets the target value, and the improved planning still conforms to the planned urban functions, the optimized planning can be adopted. If not, the planning program should be re-adjusted according to Step 1.

3. A CASE OF LU-BM APPLICATION

3.1 Study Area

Changxing, a water-county in the southern Yangtze River area with typical geographical features, representing 138 county administrative units in the southeast coast of China. Changxing is in the late stage of industrialization, it is characterized by excessive built-up area per capita, extensive land use pattern, and the pretty-high energy consumptions. As a result, land-use adjustment in Changxing is urgently needed. Because the central urban district of Changxing will become the focal area for future urbanization, we took it as the study area to apply the LU-BM.

3.2 Results for part 1: Establishment of quantitative approach

3.2.1 Establishing a "Land use - GHG emission" relevance framework

The land use in the central urban district of Changxing can be classified into eight main types [14]. The "Land use - GHG emission" relevance framework was drawn as Table 1.

Table 1. "Land use-GHG emission" relevance framework.

Classification of development land use	GHG emissions/absorption project
Industrial land (M)	CO_2 from mining, manufacturing, construction and other industrial energy activities
	Direct emissions from industrial processes
Municipal utilities land (U)	CO_2 generated by energy consumption in electric power production
	CO_2 from energy consumption in water supply and wastewater treatment facilities
	CH_4 directly produced by wastewater treatment
	Energy consumption emissions from waste transit transport facilities
	Direct emissions from waste disposal
Administration and public services land (A)	CO_2 of energy activities in service industries such as administrative office, education and health care
Commercial and business facilities land (B)	CO_2 generated by energy activities such as commercial leisure and cultural entertainment
Residential land (R)	CO_2 of life consumption generated by urban residents
Street and transportation land (S)	CO_2 of energy consumption from external transportation and urban road transport
Logistics and warehouse land (W)	CO_2 of energy consumption from material reserve, transit and distribution
Green land and Square land (G)	CO_2 of green vegetation photosynthetic absorption and fixation

3.2.2 Establishing the quantitative approach of carbon emission intensity of development lands

Using the quantitative approach described in the Step 2 of Part 2, a calculation table [8] was built to choose characterizations of different variables in formula (1).

3.3 Results for part 2: Input and analysis of pre-planning program

3.3.1 Calculation of intensity of lands in the pre-planning program

Data collection was performed according to the calculation table, and the carbon emission intensity of various types of lands were calculated [9]. Results show that the carbon emission intensities of various types of development lands from high to low are Land-M, Land-W, Land-U, Land-B, Land-S, Land-A, and Land-R, respectively [10].

3.3.2 Analyzation of emission characteristics of pre-planning program

The analysis results show that the net CO_2 emissions of the central urban district in 2035 are expected to reach 10.726 million tons. The largest contribution to total CO_2 emissions is Land-M (71%). Land-S, Land-R, and Land-B account for 12 percent, 6 percent, and 4 percent of total emissions, respectively (Fig 2).

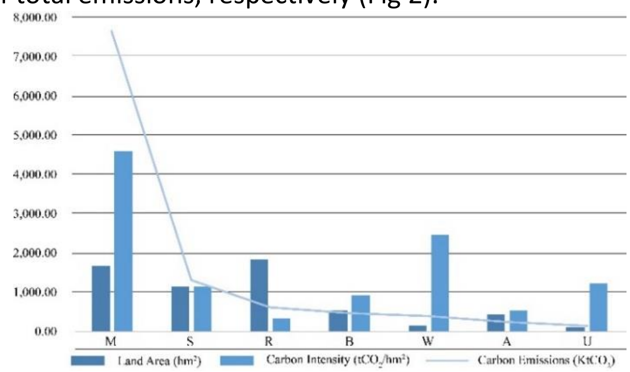


Fig 2 Current carbon emissions, intensity and the areas of various types of land.

At functional-zone level, the master plan divides the central urban district into four functional zones, i.e. Taihu Zone in the east, High-end Industrial Zone in the middle, Integrated Services Zone in the west, and Industrial Cluster Zone in the south (Fig 3). Among the four areas, High-end Industrial Zone shows the highest total carbon emission, followed by the Industrial Cluster Zone. Taihu Zone and Integrated Services Zone are areas with relatively low total carbon emissions.

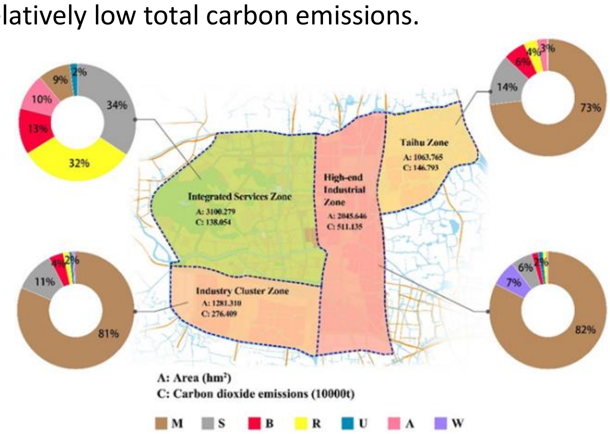
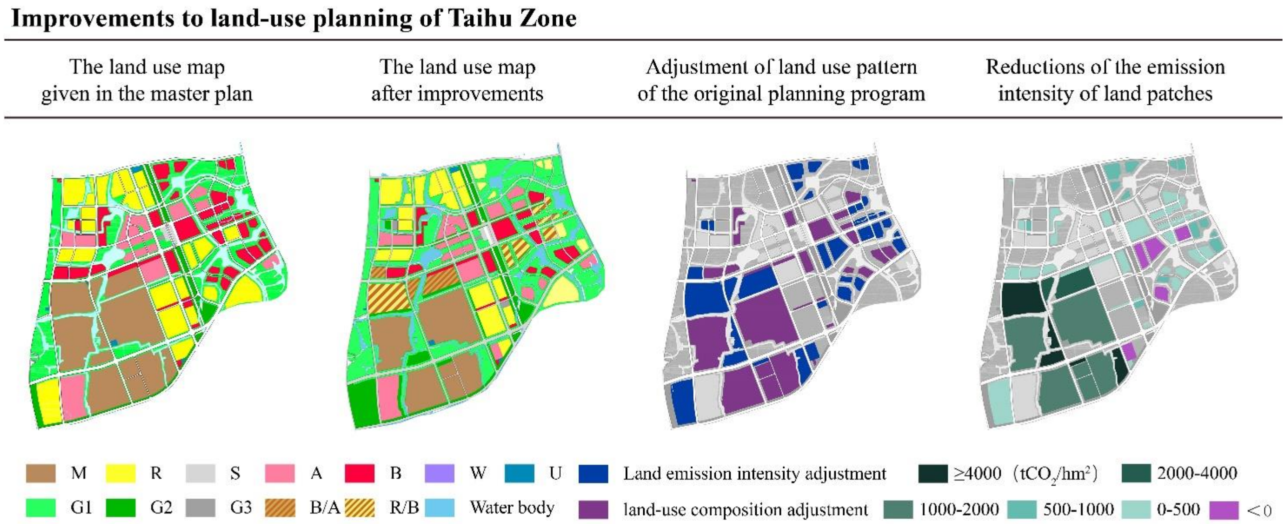


Fig 3 Current carbon emission characteristics of four functional-zones.

3.4 Results for part 3: Adjustment of pre-planning program

3.4.1 Adjustment of planning program

The planning strategies and control indexes of different zones were decided [11], and the land use adjustment aim for low carbon were performed specific to four functional zones, respectively. Taking Taihu Zone as an example (Fig 4), its carbon emissions mainly come from industry, transportation, commercial and household activities. In terms of land-use composition adjustment, the areas of Lands-M and Lands-B were reduced; some of Lands-R were converted into Lands-R/B and Lands-G; and Lands-B/A were newly developed. As for the adjustment of land-use carbon emission intensity, industries were reselected to reduce the carbon emission intensity of Lands-M; Public green buildings and renewable energy utilization rate were taken into consideration to reduce the carbon emission intensity of Lands-B; Public services facilities and mixed-lands were increased to reduce the carbon emissions intensity of Lands-S.



		A	B	M	R	S	U	W	G1	G2	G3	B/A (50%/50%)	R/B (60%/40%)
Land Area (hm^2)	Before	83.59	99.03	233.63	163.76	182.31	2.65	-	261.98	36.81	-	-	-
	After	75.68	69.87	168.64	153.22	182.31	4.25	-	294.95	36.81	3.24	24.72	50.07
Carbon Intensity (tCO_2/hm^2)	Before	512.82	911.42	4,591.41	326.34	1,128.86	1,204.31	-	-1.09	-1.09	-	712.12	560.37
	After	512.82	731.67	3,203.01	326.34	1,124.87	1,204.31		-1.09	-1.09	0.00	622.24	488.47

Fig 4 The Land-use Adjustment of Taihu Zone.

3.4.2 Evaluation of the emission reduction effect

We compared the carbon emission amounts before and after the adjustment. Fig 5 shows that the CO_2 emission equivalent of the pre-adjustment planning program is 10.724 million tons, and the adjusted value reduces to 6.469 million tons, about 60.33 percent of the pre-adjustment one. By calculation, the adjustments of composition and layout of development land-use reduce about 21.67 percent CO_2 emission equivalents, and the carbon emission intensity constraint of different planning-lands by applying control indexes reduces 18.01 percent CO_2 emission equivalents. In conclusion, the comprehensive adjustments proposed by LU-BM in total cut 39.67 percent CO_2 emission equivalents compared with the original planning. The carbon emission reduction primarily comes from Lands-M and Lands-S, followed by Lands-B and Lands-R.

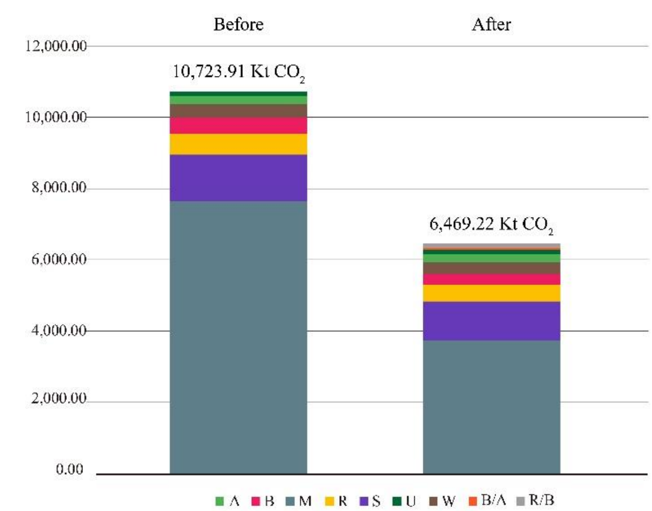


Fig 5 The contrast of carbon emissions of planning program before and after adjustment.

3.5 *Uncertainty analysis of carbon emission reduction effect of the adjusted planning program*

The Monte Carlo Simulation Method was used to simulate the interval distribution of the net CO_2 emissions of the adjusted planning program in this study. We determined the area and intensity distribution functions of different types of land, then used Crystal Ball software to simulate the net carbon emissions of the optimized planning program for 10,000 times. We found that the carbon effect of land use varies greatly under different land use patterns. With 95% confidence, the distribution interval of net CO_2 emission equivalents of the optimized planning program was 4.600-9.673 million tons, the average was 6.914 million tons, the average emission reduction rate of the optimized planning program was 35.53% and the maximum was 57.10%. In our case, the CO_2 emission equivalents of the improved planning program is 6.469 million tons, with a reduction rate of 39.67%. These two results are within the simulation interval and lower than the median results of Monte Carlo Simulation, indicating that the improved planning program achieved a reliable and substantial carbon emission reduction effect.

According to Chuai et al. [6], the adjustment of land use composition can reduce energy-related carbon emissions by 31.66 percent on macro scale. We believe that the increase in urbanization rate may reduce the possibility of land use composition adjustment and limit the emission reduction effect of composition adjustment. Therefore, the adjustment of land use composition has important emission control effects in the early stage of urban construction; but in the middle and late stages of urban construction, city managers and urban planners should pay more attention to control the carbon intensity of land use, which reaches a carbon emission reduction rate of 18.01% in our case study.

4. CONCLUSIONS

In this paper, a land use-based method was built as a working procedure to evaluate the carbon emission effects of a region in the future based on its planning program, and propose reasonable low-carbon improvement strategies to the land-use intensity and composition. The central urban district of Changxing County in China was used as a study case to confirm the operability and effectiveness of this method. The case study results reveal that, land use adjustment has significant carbon emission reduction effect at urban scale. For Changxing, the land-use adjustment process reduced about 39.67 percent CO_2 emission equivalent compared with the original planning program.

The main contributions of LU-BM were summarized as follows: 1) A land-based quantitative evaluation approach for urban areas is proposed by LU-BM. 2) LU-BM can reflect the comprehensive influence of human behavior, built environment, and technology factors on the emission of planning program. 3) Land-use planning map and control indexes are used as the important policy instruments to restrain carbon emission based on LU-BM. 4) Our case study confirms that land use planning and management can be a valuable tool to restrain carbon emissions in planning stage.

ACKNOWLEDGEMENT

This work was supported by the National Key R&D Program of China (No. 2018YFC0704700), and the National Natural Science Foundation of China (51878441).

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