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Approach for Village Carbon Emissions Index and Planning Strategies Generation Based on Two-Stage Optimization Models

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Abstract: With the implementation of China's rural revitalization strategy, the social economy of villages is expected to fully develop; however, their carbon emissions must be controlled within a reasonable range. Realization of this goal is part of the guidance and control of village planning. Clarifying the coupling relationship between village land uses and rural carbon emissions is fundamental for low-carbon village planning. In this study, by exploring the relationships between carbon emissions factors, land-use types, and human activities, the reference range of carbon emissions coefficients for various land-use types in rural areas is obtained. Then, based on the interval values of carbon emissions coefficients, a two-stage optimization model for village carbon emissions analysis is established, which is used to generate the minimal value of village carbon emissions and planning schemes to achieve different carbon emissions target values. First, the smallest carbon emissions value for a certain village is obtained based on a linear programming model. Then, to analyze the planning scheme possibilities under different carbon emissions targets, an objective planning model (including various parameters) is constructed. Through this two-stage optimization model, the optimal planning scheme is set and corresponding planning indicators under different scenarios are obtained through a sensitivity analysis. Combined with a case study in Dongzhuang Village, Shanghai, the results indicate that, with continuous improvement of the basic national carbon emissions database, the range of carbon emissions coefficients for typical local land uses can be determined, and the carbon emissions and land-use types of villages can be co-planned using the two-stage optimization model. With the proposed model, the range of carbon emissions for villages and scenario analysis results considering carbon emissions values associated with various land-use planning schemes can be obtained, contributing greatly to low-carbon village planning.

Keywords: village planning; carbon neutrality; optimization model; carbon emission coefficient of typical land

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1. Introduction

In order to achieve the goals of "carbon peaking" and "carbon neutrality", China has successively issued carbon peak implementation plans and a series of related policies for key areas and industries [1]. The carbon emissions standard accounting system and the basic database for carbon emissions accounting in major industrial and agricultural sectors have also gradually improved in China. Urban and rural land-use planning is closely related to carbon neutrality strategies: organisms, earth, water, and air are the four repositories that mainly store carbon and have a significant impact on the carbon cycle, all of which directly or indirectly intervene in land-use planning. Therefore, territorial spatial planning is widely considered to be an effective and necessary means to control greenhouse gas emissions [2,3] and is also an important systematic policy tool to coordinate carbon sources and sinks in order to achieve carbon neutrality [4].

In addition to providing production and living space for their residents, rural areas also serve the function of "offsetting" the ecological damages caused by urban areas [5,6]. With the advancement of the rural revitalization strategy in China, the level of social and economic development in village areas has been continuously improved. While rural living standards and the quality of the living environment have improved, increases in carbon emissions have put pressure on national carbon emission controls. Thus, significant attention was paid to how village planning responds to increases in carbon emissions in rural areas [7,8]. Clarifying the relationships between village planning and carbon emissions is expected to provide a foundation for carbon emissions reduction through village planning.

To reveal the coupling relationship between village planning and carbon emissions, it is first necessary to calculate the carbon emission intensities of various land-use types. The amount of carbon emissions and the carbon sink capacity associated with certain land uses are usually derived from the differences in carbon storage over a certain period of time [9]. Existing carbon storage assessment models have mainly been obtained through remote sensing information, biomass conversion accounting, and other methods that require a large amount of ground survey data and calculations to obtain ecosystem carbon storage estimates [10]. With the introduction of bottom-up accounting method guidelines, represented by the Intergovernmental Panel on Climate Change Guidelines (IPCC TFI) for national greenhouse gas (GHG) emissions inventories [11] and the Guidelines for Compiling Provincial Greenhouse Gas Inventories (GCPG), more authoritative methods and guidelines were developed for the establishment of carbon emissions accounting systems in various industries and departments [12]. On the basis of GHG emissions accounting for each production sector, considering the differences in the types and levels of activities on various types of land, the relationships between land-use types and carbon emissions coefficients can be semi-quantitatively established. Yang Ke conducted a comparative analysis of the soil carbon emissions coefficient and its influencing factors for cultivated land [13]. Dong [14] and Cao et al. [15] provided the carbon emissions coefficient range and influencing factors for rice fields in Shanghai, combined with research on the Shanghai area. Tang et al. analyzed the carbon sink coefficient of grassland and its influencing factors [16]. Wu et al. calculated and compared the carbon emissions coefficients of bamboo forests and arbor forests in the area south of the Yangtze River [17]. Zhao [18] and Lin [19] calculated the carbon emissions associated with the daily consumption of the residents of Shanghai. Huang et al. calculated and compared the weights of carbon emissions from various activities in rural areas [20]. Luo determined the carbon emissions coefficients associated with various activities and land uses in rural areas through on-site investigations and the "Guide", calculated the carbon sources and carbon sinks for four villages in Zhejiang, and evaluated the rural ecological index based on carbon emissions [21].

It can be concluded, from the above, that much research has been conducted to determine the carbon emissions coefficients for different land-use types. Considering the influence of many factors on carbon emissions, the carbon emissions coefficients of various land uses exhibit certain differences under different circumstances. As the methods for determining the carbon emissions coefficients associated with various land uses are easy to implement, the approximate range for the carbon emissions coefficient of each land-use type can be calculated. However, how to use the range of carbon emissions coefficients of various land uses to promote the formulation of low-carbon village planning needs more discussion.

In terms of reducing carbon emissions through land-use planning, many scholars have actively explored ways to connect the greenhouse gas inventory system and land-use planning. Harris [22], Köhler [23], and Du [24] combined energy planning models with urban spatial planning in order to guide the improvement of urban planning based on energy consumption and carbon emissions data from the building, transportation, and industry sectors. From the perspective of urban consumption, Zheng Degao proposed that the sub-sectors of the four major production sectors of the IPCC guidelines correspond to the six aspects of "construction, transportation, industry, other energy activities, agriculture/forestry and other land use, and waste" should be identified. Based on the six dimensions of consumption-side carbon emissions accounting, the structural characteristics of carbon emissions at different scales can be described. Then, Degao proposed building urban carbon reduction units at the regional scale and provided key technologies and core indicators for the planning of carbon reduction [25]. Pedro conducted a superimposed analysis of the spatial distribution of urban carbon emissions and urban land using a GIS platform to support the generation of urban planning policies [26]. Some scholars have also combined land-use planning models with carbon emissions accounting models in order to quickly account for the changes in carbon emissions under different planning schemes and guide the optimization of low-carbon territorial spatial planning schemes at different scales [27].

It can be seen from the existing studies that there is a consensus on considering carbon emissions in land-use planning. Many studies have discussed the impact of land-use planning on the carbon emissions intensity associated with energy consumption, transportation-based carbon emissions intensity, and green space carbon sinks. However, carbon accounting based on the planning scheme is typically a post-assessment method that can measure the carbon emissions associated with the current planning scheme, making it difficult to provide a low-carbon planning strategy with clear goals of carbon emissions reduction.

For the integration of low-carbon planning and village planning, there are two important points for planning preparation. The first is establishing a feasible carbon emissions baseline for the village. In the case of satisfying upper-level planning and rigid local constraints, clarifying the maximum and minimum carbon emissions quantities that can be achieved in a specific planning area creates a baseline with which the lowest carbon levels under different planning schemes can be judged. The second point is generating a planning scheme that achieves the carbon emissions targets, as well as other targets that have been set.

In response to the above problems, in this study, we propose a model and a method for the coordination of village land-use planning and carbon emissions control that clarifies the carbon emissions limits of the village in the early stage of planning, as well as generating the carbon emissions limits after the village carbon emissions target is determined. Feasible land-use planning options under the emissions targets are proposed. Combined with village planning in Shanghai, the proposed model and method are illustrated and verified.

2. Relationship between Village Planning and Carbon Emissions

After the promulgation of China's "Regulations on the Management of Village and Market Town Planning and Construction" [28], many provinces and cities have formulated local village planning guidelines or guidelines based on their actual conditions, in order to standardize village planning. Due to regional differences in the expression of village planning content, we adopted the "Guidelines for the Compilation of Shanghai Village Planning (Trial)" revised and issued in 2014 [29] as an example, combined with the carbon source and carbon sink accounting method system given in the GCPG, in order to identify the relationship between the village planning content and the carbon sources and sinks of the village.

The scope of Shanghai village planning includes administrative villages, based on the overall planning and land-use planning of towns. The overall planning of villages clarifies the overall contents of the location, nature, scale, development direction, and infrastructure configuration of each village within the township-level administrative area and the planning period is 15 years. Under the guidance of the overall village planning, the construction plan specifically arranges various constructs in the village over a period of 5 years. This plan mainly includes four aspects: village positioning and scale, village area planning, settlement planning, and recent construction planning. In the technical requirements, the land-use indicators, infrastructure configuration standards, and construction intensity requirements of various land uses in the village are specified in detail.

These guidelines are mainly used to guide the compilation of provincial GHG inventories. This study refers to the accounting scope and rules of the guidelines, in order to determine the relationship between village planning and carbon emissions. The GCPG clarifies the inventory compilation rules in five areas—energy activities, industrial production processes, agriculture, land-use change and forestry, and waste disposal—and proposes a calculation method for the estimation of emissions. Six types of greenhouse gases are included in the guidelines: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. For the convenience of comparison, different greenhouse gases are generally converted into equivalent CO_2 emissions, according to the corresponding coefficients [12]. The carbon emissions described in this study are all equivalent CO_2 emissions after conversion. For the convenience of calculation and modeling, the carbon emissions intensity of carbon sources and carbon sinks in this paper are represented using carbon emissions coefficients. The carbon emissions coefficient of a carbon source is positive, while the carbon emissions coefficient of a carbon sink is negative. Due to the different geographical boundaries, village carbon emissions accounting refers to the accounting scope and method system specified in the guidelines but does not completely copy it.

The relationships between village planning and village carbon emissions are shown in Figure 1. Village land-use planning potentially affects human activities which, in turn, affects the carbon emissions associated with various land uses. According to the guidelines [12] and the main contents of village planning, carbon sinks in rural areas are mainly affected by the following factors:

(1) Soil improvement of agricultural land increases organic matter content, leading to carbon sink benefits, where the carbon sink capacity depends on the influence of agricultural land type and agricultural land area, and is closely related to the local agricultural layout and agricultural development planning;
(2) The utilization of renewable energy, such as solar and wind energy, and carbon trading to offset the carbon emissions generated by energy consumption, results in a carbon sink effect. This is included in the content of the village infrastructure planning;
(3) The carbon sink benefits of ecological land, such as forests, grasslands, gardens, and river systems, within the planning scope, are mainly affected by the area and type of land used, as well as the associated vegetation types.

In this study, we focus on the relationship between direct carbon emissions from local activities and planning. Therefore, we did not consider the carbon emissions embodied in externally imported products that residents consume daily. However, the carbon emissions implied by the consumption of energy, fertilizers, and pesticides required for industrial and agricultural production were included. Direct carbon emissions in rural areas are mainly affected by the following factors:

(1) The decrease in soil quality in agricultural land leads to soil carbon emissions due to the reduction of organic matter content. The amount of carbon emissions depends on the influence of the type and area of the agricultural land, and is closely related to the local agricultural layout and economic development plan;
(2) Carbon emissions caused by fuels, fertilizers, and pesticides consumed in industrial and agricultural production;
(3) Carbon emissions from energy consumption in buildings, industries, and transportation. Energy consumption carbon emissions are the most important source of carbon emissions in China. In villages, it is mainly affected by the building area and its energy consumption intensity, the industrial output value and its energy consumption intensity, and traffic volume and transportation energy consumption intensity. This consumption is affected by the land-use layout, various architectural plans and designs, and road traffic planning.

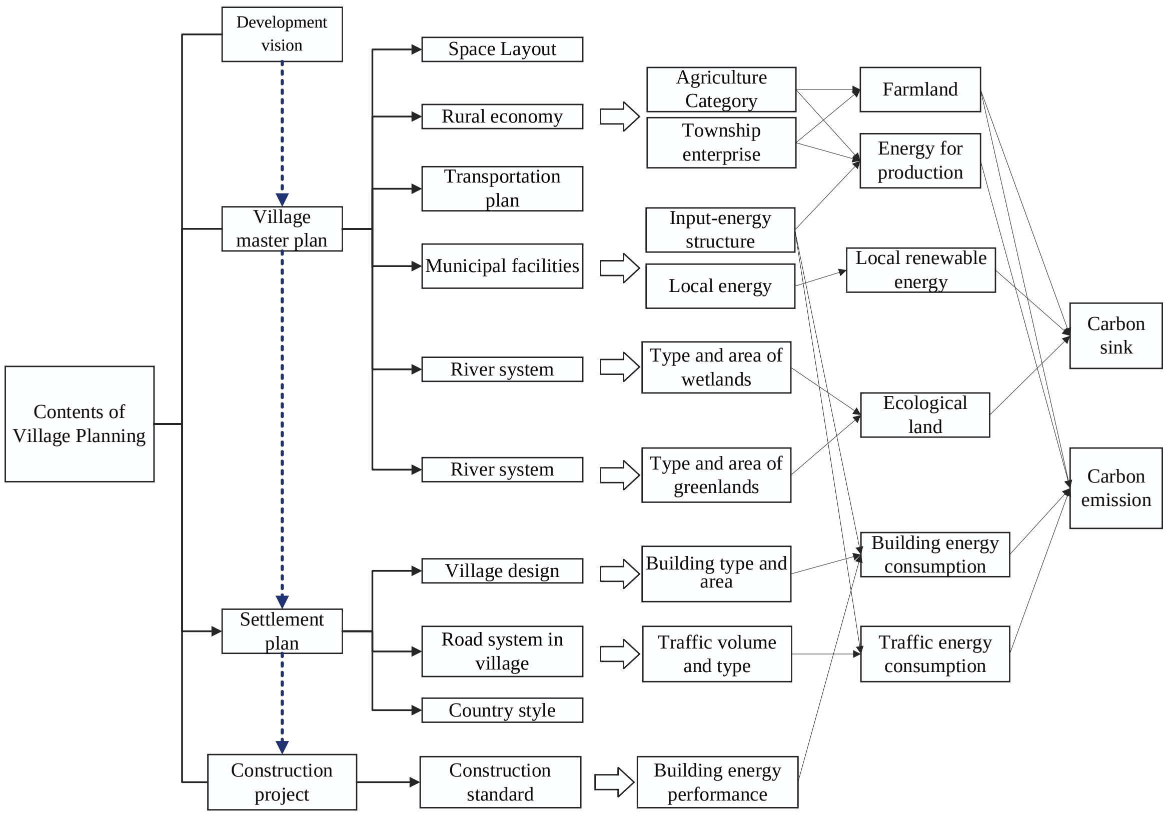

Figure 1. Relationships between village planning content and carbon emissions.

For a village that needs to carry out low-carbon planning, the quantitative values of carbon sources and sinks are affected by the land area and the corresponding activity intensity (converted to the carbon emissions coefficient per unit of land area). As shown in Table 1, the planning scheme has an impact on the carbon sources and sinks, in terms of intensity and scale. The total area of a certain village is fixed, but the land-use structure may differ under various planning schemes. Another important factor is the carbon emissions coefficient of each land type. For example, the carbon sink ability of forest and grassland depends on the choice of forest and grassland coverage, as well as plant species.

Table 1. Relationship between carbon emissions and village planning variables.

	Intensity	Scale	Related Plan Content
Carbon sink	Agriculture category	Farmland area	Rural economy
	Local renewable energy technology	Installation capacity/area	Municipal facilities
	Type of wetland	Wetland area	River system
	Type of greenland	Greenland area	River system planning
Carbon emission	Type of farmland	Farmland area	Rural economy
	Industrial type and energy intensity	Value of township enterprise	Township enterprise development plan
	Energy intensity of buildings	Building area	Village and building design
	Energy intensity of transportations	Volume of traffic	Transportation plan

In addition, the village development vision and schedule are the general starting points of village planning, which have a decisive impact on the resulting carbon emissions intensity. However, as the village development vision and schedule are mostly constrained by upper-level planning and realistic conditions, they are taken as the default premise in subsequent research; that is, the village development vision and schedule are constants, not variables, in the model analysis. Based on this, in this study, the land-use structure and the choice of specific land-use schemes are taken as variables, in order to explore the relationship between the village planning scheme and the coefficients and the total amount of carbon emissions.

3. Quantified Carbon Emissions Coefficients of Typical Land-Use Types

Carbon emissions occur dynamically and continuously in the process of daily production and life. Therefore, the daily production and life patterns of villagers have an important impact on the carbon emissions associated with buildings, transportation, and industrial processes. With reference to the carbon accounting guidelines, the carbon emissions and carbon sink accounting boundaries are determined according to the following principles:

(1) Carbon emissions and carbon sinks that occur directly within geographic boundaries are considered;
(2) Carbon emissions corresponding to energy consumption, such as electricity and fuel consumed by residents in their daily production and living activities, within the geographic boundary are included, but the carbon emissions corresponding to the daily consumption of clothing, home appliances, and daily necessities are not included. Waste and carbon emissions from non-water treatment are also not included;
(3) The electricity generated by the residents within the geographical boundary through the utilization of renewable energy is preferentially used to offset the purchased electricity and, when it exceeds the electricity purchased by the local residents, it will be converted into a carbon sink, according to the local conversion factor.

In this section, based on an investigation of the daily production and living patterns of rural residents in Shanghai, combined with the characteristics of various land-use types, the energy consumption intensities of typical land uses are calculated, and the carbon emissions coefficients of typical rural land-use types can be calculated as Table 2 ilustrated. The carbon emissions indicators of large land-use types are calculated by weighting the carbon indicators of small land-use types, with respect to the area proportion.

Industrial energy consumption in rural areas mainly includes agricultural production, daily energy consumption, and industrial and commercial activities. In addition to carbon emissions or fixation caused by changes in soil organic matter content, rural carbon emissions mainly include those from energy and material consumption in agriculture, industry, construction, and transportation.

This part of energy consumption is based on statistical data, which are generally determined with respect to the energy consumption per unit of output value, and the production scale can be related to the land area. Thus, the general relationships between industrial planning and energy consumption can be obtained, as shown in Table 3. By investigating the specific type and scale of the industry to be developed, combined with existing carbon emissions indicators for this type of industry, the average energy carbon emissions coefficient per unit area of industrial land can be obtained through a weighted average, according to the land area and output value, as shown in Equation (1):

$$c_{\mathrm{Vm}} = \frac{\sum A_{\mathrm{Vmi}} \times c_{\mathrm{Vmi}}}{\sum A_{\mathrm{Vmi}}} \tag{1}$$

where c_{Vm} is the average carbon emissions coefficient per unit land area for this type of land (in $tCO_2/hm^2.a$), and A_{vmi} and c_{vmi} are the land area of specific industrial industries or enterprises and the annual carbon emissions per unit land area, respectively (in hm^2 and $tCO_2/hm^2.a$). The carbon emissions coefficients of various industrial products in China can be obtained by consulting relevant databases. When calculating c_{vmi}, it must be converted according to the annual output and land area indicators.

Table 2. Carbon emissions indicators associated with land-use classifications.

Level 1 Categories of Land-Use	Level 2 Categories of Land-Use	Level 3 Categories of Land-Use	Land Area ($hm^{4.5}$)	Carbon Emissions Coefficient (tCO_2/hm^2) Related to Level 3	Related to Level 2	Related to Level 1
Farmland (N)	Cultivated land (N1)	Cereal (N11)	A_{N11}	c_{N11}	c_{N1}	c_N
		Vegetable (N12)	A_{N12}	c_{N12}		
	Plantation (N2)	Orchard (N21)	A_{N21}	c_{N21}	c_{N2}	
		Others (N22)	A_{N22}	c_{N22}		
	Forestland (N3)	Nursery garden (N31)	A_{N31}	c_{N31}	c_{N3}	
		Others (N32)	A_{31}	c_{31}		
	Grassland (N4)		A_{N4}	c_{N4}	c_{N4}	
	Farmland affiliated (N5)	Field road (N51)	A_{N51}	c_{N51}	c_{N5}	
		Pond (N52)	A_{N52}	c_{N52}		
		Facility for agricultural (N53)	A_{N53}	c_{N53}		
		Livestock breeding (N54)	A_{N54}	c_{N54}		
		Fishpond (N55)	A_{55}	c_{55}		
		Irrigation and water conservancy (N56)	A_{N56}	c_{N56}		
		Others (N57)	A_{N57}	c_{N57}		
Construction land (V)	Residential land (Vr)	Housing land (Vr1)	A_{Vr1}	c_{Vr1}	c_{Vr}	c_V
		Collective building land (Vr2)	A_{Vr1}	c_{Vr1}		
	Industrial land (Vm)		A_{Vm}	c_{Vm}	c_{Vm}	
	Warehouse land (Vw)		A_{Vw}	c_{Vw}	c_{Vw}	
	Land for public facilities (Vc)	Public service facilities land (Vc1)	A_{Vc1}	c_{Vc1}	c_{Vc}	
		Commercial land (Vc2)	A_{Vc2}	c_{Vc2}		
	Land for municipal facilities (Vu)		A_{Vu}	c_{Vu}	c_{Vu}	
	Transportation land (Vs)	Land for roads (Vs1)	A_{Vs1}	c_{Vc1}	c_{Vs}	
		Parking lot (Vs2)	A_{Vs2}	c_{Vc2}		
		Transportation facilities (Vs3)	A_{Vs3}	c_{Vc3}		
	Green land (Vg)		A_{Vg}	c_{Vg}	c_{Vg}	
	Others (Vb)		A_{Vb}	c_{Vb}	c_{Vb}	
Wetland and unutilized (E)	Unutilized		A_{mo}	c_{mo}	c_{mo}	c_E
	Water area (E1)		A_{E1}	c_{E1}	c_{E1}	
	Others (E9)		A_{E9}	c_{E9}	c_{E9}	

Table 3. Example of industrial land planning and associated carbon emissions coefficients.

Industry Type	Factory Area (hm^2)	Carbon Emissions Coefficient (tCO_2/hm^2)
Industry 1	A_{Vm1}	c_{Vm1}
Industry 2	A_{Vm2}	c_{Vm2}
……	……	……
Industry i	A_{Vmi}	c_{Vmi}

We can also calculate the average energy consumption intensity per unit area of agricultural land with a similar method, using the type and scale of agriculture to be developed. The energy consumption of various types of buildings can be calculated using physical models of the local buildings, the energy consumption behavior of villagers, and the local post-climate conditions, in order to obtain the energy consumption per unit of building area. The density equal-weighted conversion obtains the average energy consumption intensity per unit area of residential land, from which the carbon emissions caused by building energy consumption can be obtained. In addition, according to the accounting rules in the guide, the carbon emissions generated by transportation energy consumption are not counted in land-use units, and the carbon emissions from transportation land use are not represented by transportation land use.

4. Two-Stage Optimization Model for Carbon-Oriented Village Planning

An important result for the village planning scheme is the four land-use categories and sub-categories of village agricultural land, village construction land, water area and unused land, and urban construction land. Village planning guides all kinds of production and living activities to be carried out in an orderly manner on all kinds of land, and carbon emissions are generated in this process. Therefore, the village's production and lifestyle are affected by the planning scheme, and the implementation of the village planning scheme is reflected in the village land balance sheet. Different land-use balance sheets correspond to different carbon emissions. In this section, we establish a land-use optimization model. Then, we calculate the land-use balance sheet with the lowest total carbon emissions in the village through the optimization model, which provides a reference for the assessment of the carbon level in the planning, allowing for further adjustments to the plan.

4.1. Model Method Considering Uncertainty

The planning proposal determines the essential characteristics of planning uncertainty, which are reflected in planning objects and planning subjects, among which the uncertainty of objects is the main source of uncertainty. It can be seen from the above carbon emissions accounting methods, that carbon emissions accounting requires that the activities that will occur on the land in the future are predetermined, following which, the carbon emissions associated with human activities can be obtained, according to their type and intensity. Human activities are random and unpredictable on an individual basis, but a large number of similar activities also show commonalities; as such, the focus of this study is the use of mathematical models to objectively process and analyze data in the planning process without considering the subjective uncertainty of the planning subject [30]. On the basis of seeking the determining rule of objects through the analysis of uncertainty, from the perspective of the whole and development, a more effective planning scheme can be obtained [31]. Courtney has stated that even the most uncertain objects contain information that can be analyzed, and the uncertainties that remain after various scenarios are called residual uncertainties, which can be divided into four levels [32].

Energy and material consumption account for more than 90% of China's carbon emissions [33]. Based on Courtney's uncertainty classification theory, when the object changes continuously within a certain range, it can be regarded as being in the third level of uncertainty. Village planning weakens the impact of uncertainty through scenario analysis, and we can draw regular conclusions. Against the background of the current accelerated realization of informatization, continuous expansion of the basic database of human activities and carbon emissions coefficients has greatly improved the completeness of basic data. Combined with scientific data analysis models, the internal regularity of the data, as well as the characteristics of planning objects, can be analyzed. This makes the results more accurate and understandable, while further reducing the uncertainty of the prediction.

Based on the uncertain characteristics of low-carbon village planning and the concept of uncertain planning, in this study, we take scenario planning as the dominant model for low-carbon village planning, the main feature of which is the synergy between scenarios. On the basis of fully considering possible future development scenarios, the maximum and minimum ranges of carbon emissions are obtained, based on the optimization model, through which a global overall understanding can be obtained. All of the quantitative results are presented, and complete information about the relationships between planning schemes and carbon emissions scenarios can be obtained, thus more effectively supporting planning decisions.

4.2. Optimization Model for a Village's Minimum Carbon Emission

The impact of village planning on carbon and carbon sinks is ultimately reflected in the land-use balance sheet, which defines a row vector A, where the element A_i is the land area of the *i*th type of land. We define a column vector C, in which the element c_i is the average carbon emissions per unit area of the *i*th type of land; that is, the carbon emissions coefficient of this type of land. The value of c_i is based on the fineness of the classification of land-use types, which can be either the average value of multiple types of a specific land use or the specific carbon emissions of specific construction projects converted to unit land area. Therefore, both A_i and c_i are variables affected by the planning scheme, which satisfy the constraints shown in Equation (2) in the actual planning project:

$$\begin{cases} 0 \le A_i \le A_i^0 \\ c_i^- \le c_i \le c_i^+ \end{cases} \tag{2}$$

where $A_i{}^0$ is the maximum land area of the *i*th type of land, and c_i^- and c_i^+ are the minimum and maximum values of the carbon emissions intensity of the *i*th type of land, respectively. When the type of land is a carbon sink, c_i^- and c_i^+ are negative.

For a given village, its total land area is limited, and the sum of the areas of all land-use types should be equal to the total land area within the planning scope. This constraint relationship can be expressed by Equation (3):

$$\sum A_i = A_0 \tag{3}$$

where A_0 is the total land area within the planning scope.

The change in the village planning scheme means a change in the land-use balance sheet, which means that the variables A_i and c_i have changed. The village carbon emissions C_{Total} can be expressed by Equation (4):

$$C_{\text{Total}} = \sum A_i c_i \tag{4}$$

A_i and c_i constitute a feasible region under the condition of satisfying their respective constraints, and the minimum value of C_{Total} can be calculated using a non-linear optimization algorithm. When the minimum value C_0 of C_{Total} is obtained, the solutions A_i' and c_i' corresponding to A_i and c_i are obtained simultaneously, and the carbon emissions $A_i' \times c_i'$ of various land uses can be calculated when the total net carbon emissions of the village are minimized.

The optimization model for the village land-use combination is shown in Figure 2. By implementing the land-use indicators into the planning scheme, an optimization model is constructed to explore the maximum and minimum carbon emissions of the planning under the most primitive constraints. Among them, the carbon emissions coefficients of various land-use types are affected by the uncertainty of human activities. However, in the statistical sense, the values have certain ranges. According to low- and high-emissions scenarios, the uncertain range can be determined. Values are converted into unique upper and lower limits for ease of modeling. In addition, by setting scenarios, the original non-linear optimal model for comprehensive optimization of the various land-use carbon emissions coefficients c_i and land areas A_i can be transformed into a linear programming model, which is easier to understand in the optimization process and for which mature and complete algorithms exist. At the same time, it provides the possibility of conducting a sensitivity analysis of the planning variables.

4.3. Goal Programming Model for Land-Use Planning Scheme Generation

An obvious disadvantage in the application of optimization models is that, when any planning conditions have changed, the optimized planning scheme may need to change. This is because the constraints in the optimization model are all "hard" constraints, which lack flexibility. When a certain constraint cannot be satisfied or the constraint value changes, a new model needs to be built; however, in the actual planning, the planning conditions are constantly changing. For problems with many changing scenarios, not only is repeated construction of the optimization model time-consuming, but it is also difficult to establish a connection between the planning constraints and the optimal solutions. Due to the lack of a clear logical relationship between planning variables and carbon emissions results, it is difficult to support carbon emissions-oriented village planning by only using an inelastic land-use combination optimization model. Therefore, after we determine the minimum carbon emissions of the village, a new quantitative model is necessary for further analysis.

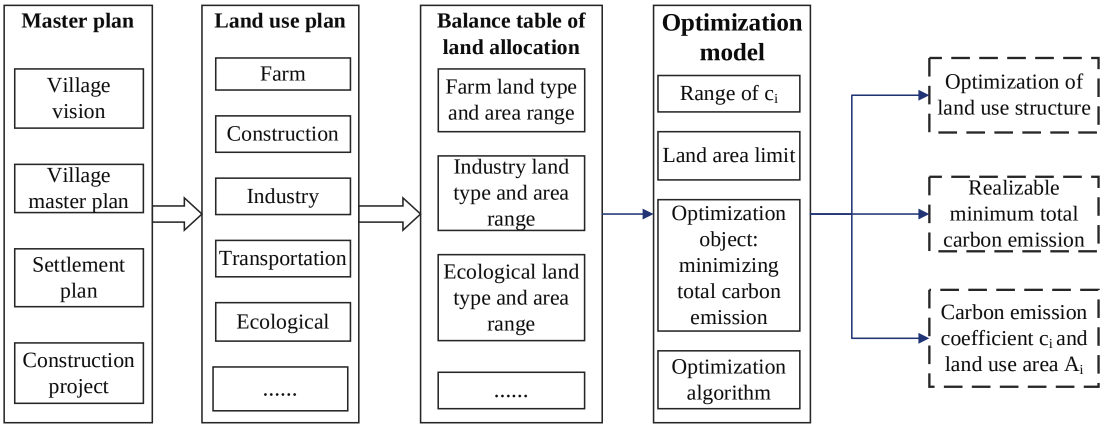

Figure 2. First optimization of land-use structure.

As shown in Figure 3, in order to present the relationships between the planning variables and village carbon emissions more efficiently and completely, on the basis of the village land combination optimization model, the carbon emissions coefficients of various land uses are considered in a step-by-step manner. The range of value changes and the land-use area adjustment simplifies the optimization process, and we can build a linear objective programming model that is convenient for sensitivity and theoretical analyses. By adjusting the village carbon emissions target, a feasible planning scenario set is generated, showing the relationship between carbon emissions and the adjustment of the planning scheme, thus supporting the adjustment and selection of the planning scheme. The steps in constructing the objective programming model include objective function construction and constraint matrix construction.

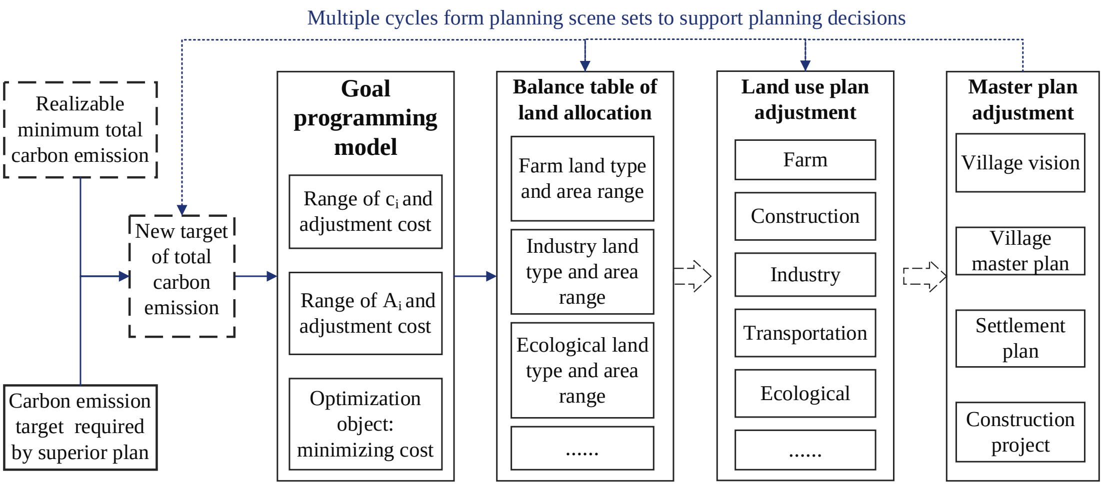

Figure 3. Goal programming-based optimization of land-use structure.

First, we construct the optimization objective function. On the basis of the optimal calculation results for the village land combination, we define the additional cost functions $f_1(A_i' + \alpha_i)$ and $f_2(c_i' + \beta_i)$ that need to be paid when each planning variable is adjusted, on the basis of the values of A_i' and c_i', where α_i and β_i are the adjustment quantities of the corresponding parameters (also known as slack variables). The costs $w_i \times f_1(A_i' + \alpha_i)$ and $v_i \times f_2(c_i' + \beta_i)$ reflect the area of the *i*th land-use type and the cost of the project planning adjustment, respectively, where w_i and v_i are weight factors characterizing the *i*th land type size and the relative ease of adjustment in project planning, respectively. The sum of the costs of various land-use adjustments, g, is the total cost of adjusting the village planning scheme. The cost may involve the construction costs or those related to other qualitative evaluations of the difficulty of planning adjustment. The qualitative evaluation needs to be transformed through expert voting or other evaluation methods, and it is given as a scale value. It was shown that even when w varies between 0 and ∞, the number of optimal solutions is still less than the number of row vectors of the constraint matrix [34]. The objective function is constructed based on the minimum adjustment cost, as the objective or in combination with other objectives, as shown in Equation (5):

$$\min g = \sum w_i \times f_1(A_i' + \alpha_i) + \sum v_i \times f_2(c_i' + \beta_i) \tag{5}$$

Next, we construct the constraint matrix of the objective programming model. The slack variables α_i and β_i are added on the basis of the optimization calculation, and the planning variables are allowed to change on the basis of the optimal values $A_i{}'$ and $c_i{}'$. The fluctuation ranges of α_i and β_i can be determined according to the actual situation of the project. In addition, we add a slack variable δ to the optimization result C_0; that is, when considering other planning objectives, the village's carbon emissions need to be increased on the basis of the minimum value to meet other planning objectives. The adjustment of the carbon emissions target can be either a fixed value adjustment (e.g., increasing or reducing a certain amount of carbon emissions) or an elastic adjustment (i.e., allowing C_{Total} to freely change within a certain range). The constraint matrix is shown in Equation (6):

$$\begin{cases} 0 \le C_{Total} - \delta \le C_0 \\ 0 \le A_i + \alpha_i \le A_i^0 \\ c_i^- \le c_i + \beta_i \le c_i^+ \\ C_T = \sum A_i c_i \\ \sum A_i = A_0 \\ \delta \ge 0 \end{cases} \tag{6}$$

By adding the slack factor δ to the village carbon emissions target and including it in the constraint term of the optimization model, a new optimization model is constructed. Taking the planning scheme when the village carbon emissions are the lowest as the baseline scenario, the specific value of an increase in the village carbon emissions or A comprises a feasible planning strategy for a specific scope. In this optimization model, adjustment of the weight factor in the objective function can be carried out to calculate the adjustment strategy set of the planning scheme under different demands, which can be used for planning decision analysis and selection.

5. Model Utilization and Verification

This section presents a village planning case in Shanghai, in order to discuss the feasibility of promoting the formation of planning schemes based on carbon emissions constraints through the proposed two-stage optimization model.

5.1. Case Introduction

The case study area was located in Liantang Town, Qingpu District, Shanghai. The administrative village includes four natural villages with a total area of 316 hm^2. There are 508 farm households and a resident population of 1600. According to the regulations of the superior plan, "Qingpu District Liantang Town Overall Planning and Land Utilization Overall Planning (2017–2035)" and "Shanghai Rural Village Housing Construction Management Measures" [35], the sources for the indicators of the main local land uses are given in Table 4. The village planning is shown in Figure 4. The whole area is 3.16 km^2. There are four natural villages where there is a large amount of construction land. Other areas are farmland, woodland, water, and grassland.

Table 4. Method used to acquire basic data.

Data Type	Data Source
Land-use limit	High-level planning, current village land
Planting area of various crops	Questionnaire
Type of aquaculture	Questionnaire
Plant type	Questionnaire and on-site inspection
Resident energy consumption	Questionnaire
Public building energy consumption	Questionnaire
Commercial building energy consumption	Questionnaire

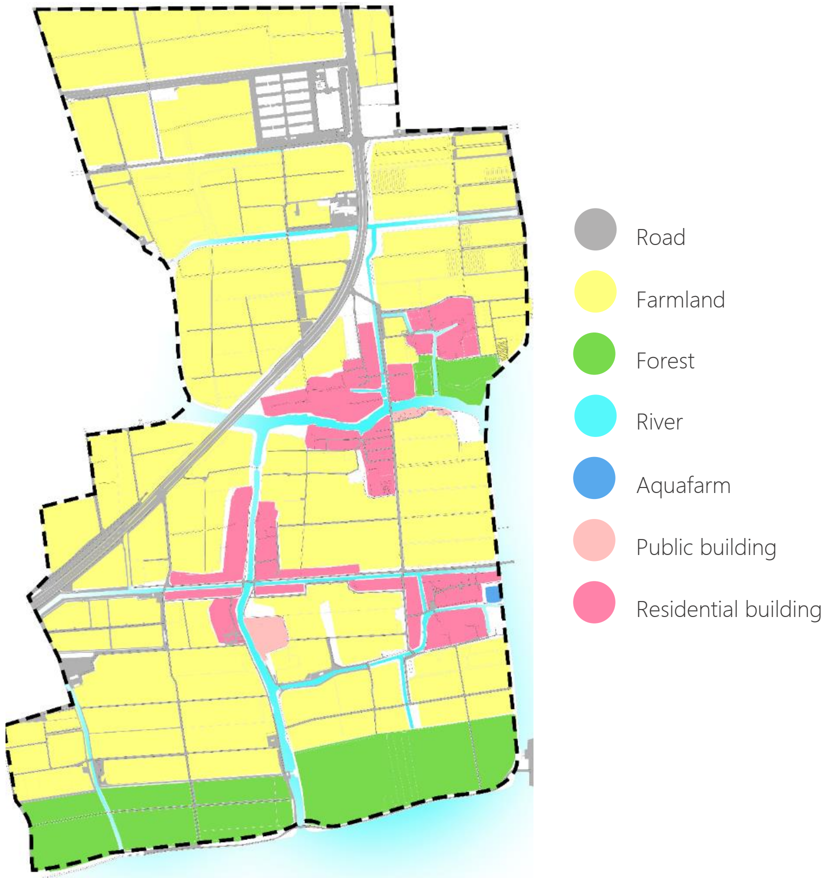

Figure 4. Base map of Dongzhuang Village.

Considering that the activities envisaged in the planning will occur in the future, they are difficult to measure directly. Therefore, the emissions factor method was adopted when calculating the carbon emissions coefficients, and the CO_2 emissions data were obtained through the calculation of the typical activity level in the various land-use types, with respect to their area and related parameters. The carbon-related land-use categories in Chinese rural areas cover seven categories: construction land, cultivated land, garden land, forestland, grassland, water area, and unused land. The carbon emissions coefficient of each land-use type was mainly obtained from the default emissions factors recommended in the IPCC guidelines and related research papers. The power consumed was calculated using the carbon emissions factor of 0.7880 kg CO_2/kWh for the East China regional power grid, the carbon emissions factor of liquefied gas was 2.98 kg CO_2/kg, and the coal emissions factor was 2.62 kg CO_2/kg. In the existing carbon emissions accounting reports and guidelines, the subject is generally an independent legal person engaged in production and business activities. In this study, the carbon emissions subject was converted from an independent legal person to a unit of land area (tCO_2/hm^2). Thus, the carbon emissions coefficients of various land-use types were determined from the investigation methods listed in Table 4. According to the basic data of planning objects combined with the carbon emissions factors of various activities recommended by the existing literature, the carbon emissions coefficients for various land-use types were calculated.

As an example, the carbon emissions coefficient of cultivated land was calculated based on the carbon emissions per unit of agricultural products combined with the yield per unit of area to obtain the carbon emissions coefficient per unit of cultivated land area. The carbon emissions coefficients per unit of land area for forest and grassland were obtained from a previous study [36]. Considering roadside greening, the carbon emissions coefficient per unit of the roadside land area was calculated using the road greening rate multiplied by the carbon emissions coefficient of green space.

The carbon emissions coefficients of residential, public, and commercial buildings only comprised the carbon emissions due to energy consumption during their use. First, the annual electricity and fuel consumption of various buildings were obtained through investigation, which were converted into annual electricity and fuel consumption indicators, according to the building area. Then, from the energy consumption data and the carbon emissions factors for fuel and power, the carbon emissions coefficient of construction areas was obtained. After sorting out these basic data, the land-use constraints and the range of carbon emissions coefficients relating to Dongzhuang Village were determined, which are listed in Table 5.

Table 5. Land-use constraints and carbon emissions coefficient ranges.

Level 2 Categories of Land Use	Level 3 Categories of Land Use	Land Area Variable	Land Area Variable Constraint (hm^2)	Carbon Emissions Coefficient c_i ($tCO_2/hm^2.a$)	
				Lower Limit	Upper Limit
Cultivated land (N1)	Cereal (N11)	A1	≥165.06	9.46	13.9
	Vegetable (N12)	A2	≥4.05	4.31	5.23
Plantation (N2)	Orchard (N21)	A3	3.69	0.37	2.13
Forestland (N3)	Nursery garden (N31)	A4	≥1.97	−3.21	−2.84
	Others (N32)	A5	≥39.13	−4.28	−1.83
Farmland affiliated (N5)	Field road (N51)	A6	≥1.66	−0.07	−0.02
	Pond (N52)	A7	≥36.81	4.23	6.18
	Facility for agricultural (N53)	A8	≥5.82	9.87	15.12
	Irrigation and water conservancy (N56)	A9	≥0.01	−0.57	0
Residential land (Vr)	Housing land (Vr1)	A10	≥9.73, ≤14.23	28.63	50.23
Industrial land (Vm)		A11	≤3.17	67.38	101.74
Land for public facilities (Vc)	Public service facilities land (Vc1)	A12	≥0.42	55.16	97.19
	Commercial land (Vc2)	A13	≥0.77	51.22	82.74
Land for municipal facilities (Vu)		A14	≥3.47	4.73	11.03
Transportation land (Vs)	Land for road (Vs1)	A15	≥7.45	−0.07	−0.02
	Parking lot (Vs2)	A16	≥0.12	0	0
	Transportation facilities (Vs3)	A17	≥0.01	0	0
Water area (E1)		A18	≥6.81	−0.62	−0.06

5.2. Minimum Carbon Emissions Based on Optimization Model

According to the carbon emissions coefficient values for various land uses and the variable range of the land area, given the total land area of the village, an optimization model was established to calculate the area of each land-use type when the annual carbon emissions of the village were minimized. The optimization model is given in Equation (7).

$$\min C_{\text{Total}} = \sum A_i c_i \tag{7}$$

subject to

$$\begin{gathered} \mathbf{B} * \mathbf{A} \leq \mathbf{b} \\ \sum_{i=1}^{18} A_i = 316 \\ A_i \geq 0 \end{gathered} \tag{8}$$

$$\text{where } \boldsymbol{B} = \begin{bmatrix} -1 & 0 & 0 & 0 \ldots & 0 \\ 0 & -1 & 0 & \ldots & 0 \\ 0 & 0 & -1 & \ldots & 0 \\ & & \vdots & & \\ 0 \quad 0 & \cdots & 0 \quad 1 & \ldots & 0 \\ & & \vdots & & \\ 0 \quad 0 & 0 \quad 0 & 0 & \ldots & -1 \end{bmatrix}, \boldsymbol{A} = \begin{bmatrix} A_1 \\ A_2 \\ \ldots \\ A_{18} \end{bmatrix}, \boldsymbol{b} = \begin{bmatrix} -165.06 \\ -4.05 \\ \vdots \\ -6.81 \end{bmatrix}$$

Through the optimization calculation, we determined when the carbon emissions intensities of various land-use types varied between their lowest and highest values. The annual CO_2 emissions of the village varied between 1836.31 and 3091.09 t. It can be seen, from the optimization calculation results in Table 6, that the optimal solution was obtained at the limit of the constraint values for all land-use types, which is in line with the actual logic: the land used for carbon emissions was minimized and the land used for carbon sinks was maximized.

Table 6. Optimization results.

Level 2 Categories of Land Use	Level 3 Categories of Land Use	Land-Area Variable	Optimized Land Area (hm^2)	Carbon Emissions (tCO_2/a)	Shadow Price ($tCO_2/a/hm^2$)
Cultivated land (N1)	Cereal (N11)	A1	165.06	1561.47	13.74
	Vegetable (N12)	A2	4.05	17.46	8.59
Plantation (N2)	Orchard (N21)	A3	3.69	1.37	4.65
Forestland (N3)	Nursery garden (N31)	A4	1.97	−6.32	1.07
	Others (N32)	A5	68.51	−293.22	0
Farmland affiliated (N5)	Field road (N51)	A6	1.66	−0.12	4.21
	Pond (N52)	A7	36.81	155.71	8.51
	Facility for agricultural (N53)	A8	5.82	57.44	14.15
	Irrigation and water conservancy (N56)	A9	0.01	−0.01	3.71
Residential land (Vr)	Housing land (Vr1)	A10	9.37	268.26	32.91
Industrial land (Vm)		A11	0	0	0
Land for public facilities (Vc)	Public service facilities land (Vc1)	A12	0.42	23.17	59.44
	Commercial land (Vc2)	A13	0.77	39.44	55.5
Land for municipal facilities (Vu)		A14	3.47	16.41	9.01
Transportation land (Vs)	Land for road (Vs1)	A15	7.45	−0.52	4.21
	Parking lot (Vs2)	A16	0.12	0	4.28
	Transportation facilities (Vs3)	A17	0.01	0	4.28
Water area (E1)		A18	6.81	−4.22	3.66
Total carbon emission(tCO_2/a)		-	-	1836.31	-

In the optimization model, changing some of the constraints had no effect on the optimization results, while a slight change in some constraints caused the optimization results to change, resulting in a new optimal solution. The shadow price is often used to reflect the importance of a constraint, and the shadow price of each variable is also listed in Table 6. From the shadow price of the planning model, it can be seen that the shadow prices of the homestead, public service facility, and commercial service land areas were relatively large. When the constraints were relaxed (i.e., the allowable land area increased), a rapid increase in total carbon emissions resulted; therefore, the land area should be strictly controlled. In addition, due to the high energy consumption of agricultural facilities, its carbon emissions were also large, and an increase in its lower limit led to an increase in the total carbon emissions of the village. Due to the constraint of the given minimum value, the forest area in the actual result was much larger than the constraint value, indicating that the planning scheme did not play a substantial role in constraining the forest area. The area of industrial land was 0 in the optimal land-use plan, and it was not meaningful to change its planning constraint value, so the shadow price was 0.

5.3. Land-Use Scheme Generation Based on Goal Programming Model

The actual planning involves the influence of various constraints, and the planning scheme needs to be adjusted according to the associated requirements. Such adjustment and analysis should be carried out under the condition of meeting the new goals. Through the target planning model, the land can be fully adjusted and the optimal trade-off adjustment plan can be given for some of the lands, in combination with the results of the optimization calculation or other planning objectives. The following is presented with the aim of minimizing the planning investment, exploring the relationships between the carbon price and the reduction of residential and industrial land, and obtaining the optimal planning strategy under different scenarios.

According to local policies, investment in the reduction and withdrawal of industrial enterprises within the village was 2.90 million dollars/hm^2, while the comprehensive investment in farmhouse reduction was 9.63 million dollars/hm^2. Assuming that carbon emissions credits must be purchased and that the carbon price will change, on the basis of the optimal carbon emissions of 1836.31 tCO_2/a, when the annual carbon emissions increase by d_0, it is necessary to pay the cost of $w \times d_0$ to purchase carbon emissions credits to offset the carbon emissions. There is also a need to pay for the reduction of industrial and residential land inputs. When w continues to increase from 0, the expenditure for purchasing carbon emissions credits also increases. A model can be constructed to observe the impact of the price change of carbon emissions credits on the land-use planning scheme and to clarify the range of carbon emissions credit prices that can affect the adjustment of the land-use planning scheme. The target programming model is given in Equations (9) and (10):

$$\min f^- = w * d_0 - 5968.75 * d_1 - 1800 * d_2 \tag{9}$$

subject to

$$\begin{cases} \sum\limits_{i=1}^{18} A_i \times c_i - d_0 = 1836.31 \\ 9.37 \leq A_{10} + d_1 \leq 13.87 \\ 0 \leq A_{11} - d_2 \leq 3.17 \\ 0 \leq d_0 \leq 1254.5;\ d_1 \geq 0; d_2 \geq 0 \end{cases} \tag{10}$$

By solving the parametric programming model, when w increases from 0 to infinity, the planning scheme changes at three nodes; that is, the price of carbon emissions allowances drives the change in land-use planning. It can be seen, from Table 7, that the solution of the optimal model is discontinuous, and the optimal solution may remain unchanged when a certain parameter in the model changes; that is, the number of optimal solutions is limited in number. When the carbon price is lower than 8.59 USD/t, it is uneconomical to reduce industrial and residential land from the perspective of investment; when the carbon price reaches 785.00 USD/t, it becomes cost-effective to reduce industrial land; and, when the carbon price reaches 5667.81 USD/t, it is economically optimal to reduce the residential area to zero. It is worth noting that the optimal solution gives discontinuous discrete solutions. In actual planning, the optimal solution at the key nodes obtained by optimization can be used as the basis for any choice. On the basis of completely vacating the industrial land, it is possible to continue to partially reduce the residential land (which can be reduced by 0.14 hm^2).

Table 7. Optimized house and industrial land replacement schemes under different carbon prices.

Carbon Price (USD/tCO_2)	Total Carbon Emissions (tCO_2/a)	Area of Residential Land (hm^2)	Area of Industrial Land (hm^2)	Cost for Land Replacement (million dollars)	50-Year Incremental Carbon Cost (million dollars)
$w \leq 8.59$	2211.57	13.87	3.17	3.36	0.16
$8.59 < w \leq 785.00$	1984.40	13.87	0.00	12.27	5.81
$w \geq 5667.81$	1836.31	9.37	0.00	54.24	0.00

6. Results Discussion

In the low-carbon village planning, formulating scientific carbon emission targets is the first priority. When determining the carbon emission target of the village, it is necessary to consider the comprehensive compromise between the ideal minimum carbon emission value and other targets, and then determine the achievable carbon emission target. This section discusses the application of the two-stage optimization model proposed in this paper in this regard.

6.1. Quantified Village's Minimum Carbon Emissions Value

It can be seen from the case study, that after determining the carbon emissions coefficients for various land uses, combined with the local overall planning requirements and other rigid requirements, the minimum carbon emissions of the village can be obtained in the early stage of the village planning. When calculating the minimum value of village carbon emissions, the demands of all stakeholders were incorporated into the model by implementing constraints, as such the obtained minimum value of village carbon emissions was achievable and the corresponding land-use planning scheme was also clearly drawn. Thus, in subsequent planning, there is a clear carbon emissions target that may be achieved, which may serve as a benchmark for reference when evaluating the emissions levels under other planning schemes.

The minimum value of village carbon emissions obtained by the method of the optimization model is the minimum value of carbon emissions that can be achieved through land-use planning according to local conditions and upper planning constraints. There are many factors that affect the minimum value of village carbon emissions, some of which are not related to village planning. The minimum carbon emission value corresponds to the maximum contribution of village land planning to reduce village carbon emissions. Different from the currently widely used method of calculating the carbon emission value of the planning scheme after obtaining the village planning scheme, and then adjusting the scheme, the method of obtaining the village carbon emissions based on the optimization model is the leading method. At the beginning of the preparation, the planning scheme with the lowest carbon emission was found through the optimization algorithm, which made the subsequent low-carbon village planning preparation more purposeful.

6.2. Single Objective Optimization: Obtaining the Minimum Achievable Carbon Emission Value

Of course, in most cases, the final planning scheme will not be based on a minimum carbon scenario. When generating a new planning scheme, in order to ensure that the carbon emissions target is still considered, the minimum carbon emissions value of the village can be used as a constraint. During the process of gradually increasing the total carbon emissions of the village—that is, when the carbon emissions constraint of the village was gradually relaxed—we observed changes in planning options and other planning objectives. The carbon emissions target can be included as a constraint item of the model by treating it as a variable, and the carbon emissions, economy, and acceptance of the planning scheme can be included into the optimization target; thus, a goal programming model including parameter variables can be constructed for optimization in this scenario.

Through a trade-off analysis of the economics and carbon emissions of the optimal planning scheme given in Figure 5, it can be seen that the interactions among the various elements were discrete and discontinuous. Due to the complexity of planning, many variables had complex coupling relationships, and it was difficult to observe intuitive relationships between different planning variables. Through the objective programming model, with its parameters and sensitivity analysis, the mutual coupling relationships between different programming variables could be observed more completely; that is, considering the possible changes to the optimal planning scheme under a specific objective when some parameters changed in any interval. From the limited solution of the optimal linear programming model including parameters, the minimum and maximum possible scenarios could be completely listed, which is of great significance for obtaining a complete understanding of the relationships between the planning scheme and carbon emissions.

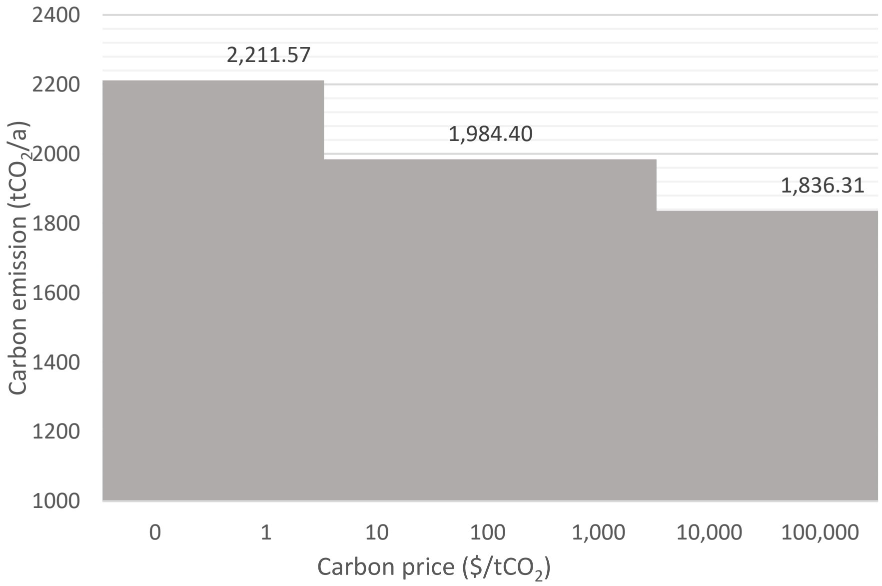

Figure 5. Carbon emissions of optimal planning schemes under different carbon prices.

The carbon emissions indicators of large land-use types were calculated by weighting the carbon indicators of small land-use types with respect to their area proportion. The finer the division of land-use types when the village planning was conducted, the smaller the range for the carbon emissions coefficients of the land-use types, as determined through investigation and research. However, in order to maintain flexibility of planning, it was impossible to set very fine-grained specific land-use types in village planning. In this case, the carbon emissions coefficients of various types of land had large fluctuation ranges, and the minimum carbon emissions obtained by the optimization model may be more difficult to achieve. In this case, we needed to be very careful when setting the real carbon emissions target of the village, in order to avoid the difficulty of actually achieving the carbon emissions target. Therefore, when using the minimum value calculation model for village carbon emissions proposed in this paper, it is necessary to conduct more adequate research on the carbon emissions coefficients of various types of local land uses in order to determine more reasonable carbon emissions coefficients for various land-use types. When generating a village planning scheme based on a given carbon emissions value, only some feasible schemes were given, such that the planners can adjust the scheme generated by the model when they require a different outcome.

6.3. Availability and Limitations of Methods

The above case analysis shows that after obtaining the carbon emission coefficient data of various land uses, the minimum value of the village carbon emission that satisfies each constraint can be accurately obtained by modeling and solving the optimization model. By constructing a goal planning model with the change of the carbon emission of the village, a comprehensive and optimal village land-use planning scheme with multi-objectives under different carbon emission values can be obtained. The comprehensive application of the two-stage optimization model integrates village land use planning and carbon emission control, so as to ensure that the low-carbon target is achieved. Since the above two models are mathematically linear optimization models, the models are simple and the solution is fast and stable, which is very suitable for programming applications. Combining the optimization model with the goal programming model is the most important contribution of this study.

Therefore, the accuracy of the model proposed in this paper and the effectiveness of its application depend on the reliability of the carbon emissions coefficients obtained for various land uses. With the completion of a basic carbon emissions database for urban and rural industries, this problem will be well-resolved.

7. Conclusions

Full consideration of carbon emissions constraints in village planning is of great significance for low-carbon planning. Aimed at the problem of determining the target value of village carbon emissions and generating the village planning scheme under the derived carbon constraints, in this paper, we established a two-stage optimization model by determining the carbon emissions coefficients of various land uses and explored a method for the generation of village planning schemes under carbon constraints. Combined with case studies, the constructed model was demonstrated and verified. The main conclusions of this study are as follows:

The case study demonstrated that, under the condition of the existing basic data related to carbon emissions, combined with an investigation of the individualized material and energy consumption data of the planning objects, and considering the differences in land-use activities, the carbon emissions coefficients of various land uses can be determined, according to the land-use type. With the gradual improvement of a carbon emissions factor database for major industrial products, energy, and daily necessities of residents, it will be possible to establish a broader and more refined basic database of land-use types and their associated carbon emissions factors.

By building a linear programming model, we optimized the land-use structure and obtained the minimum carbon emissions value through the derived solution. We considered the complexity and multi-objective nature of village planning, which typically does not provide a so-called optimal solution using a black-box algorithm. For problems with numerous changing scenarios, not only is the repeated construction of the optimization model time- and labor-intensive, but it also makes it difficult to establish a connection between the planning constraints and the optimal solutions. Therefore, we introduced a target planning model with variable parameters for low-carbon village planning. Through the timely exchange of constraints and target items, it was possible to determine which changes in planning conditions would lead to the optimal solution. Combined with a case study in Shanghai, the utilization process and the applicability of this two-stage optimization model for a carbon-oriented village planning method were proposed.

In this study, we presented a preliminary demonstration of a low-carbon planning method supported by the proposed two-stage optimization model. The case study indicated that the combination of the optimization model and the target planning model allows for great flexibility, as the model structure can be adjusted according to the actual needs. The village planning method based on the optimization model provided an exploration of quantifying the relationship between carbon emissions and land planning, and its application should be tested under more scenarios.

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References

1. The Office of the Central Committee of the Central Committee of China. Opinions on Promoting the Green Development of Urban and Rural Development. Available online: http://www.gov.cn/zhengce/2021-10/21/content_5644083.htm (accessed on 12 December 2021).
2. Privitera, R.; Palermo, V.; Martinico, F.; Fichera, A.; La Rosa, D. Towards lower carbon cities: Urban morphology contribution in climate change adaptation strategies. *Eur. Plan. Stud.* **2018**, *26*, 812–837. [CrossRef]
3. Wang, S.H.; Huang, S.L.; Huang, P.J. Can spatial planning really mitigate carbon dioxide emissions in urban areas? A case study in Taipei, Taiwan. *Landsc. Urban Plan.* **2018**, *169*, 22–36. [CrossRef]
4. Hurlimann, A.; Moosavi, S.; Browne, G.R. Urban planning policy must do more to integrate climate change adaptation and mitigation actions. *Land Use Policy* **2021**, *101*, 105188. [CrossRef]
5. Gu, C.L. *Rural Planning in the New Era*; Science Press: Beijing, China, 2019.
6. Li, J. *Principles of Rural Planning*; China Construction Industry Press: Beijing, China, 2019.
7. Markantoni, M.; Woolvin, M. The role of rural communities in the transition to a low-carbon Scotland: A review. *Local Environ.* **2015**, *20*, 202–219. [CrossRef]
8. Zhu, X.; Zhang, T.; Gao, W.; Mei, D. Analysis on spatial pattern and driving factors of carbon emission in urban–rural fringe mixed-use communities: Cases study in East Asia. *Sustainability* **2020**, *12*, 3101. [CrossRef]
9. Huang, S.; Xi, F.; Chen, Y.; Gao, M.; Pan, X.; Ren, C. Land Use Optimization and Simulation of Low-Carbon-Oriented—A Case Study of Jinhua, China. *Land* **2021**, *10*, 1020. [CrossRef]
10. Mousavi Sarvine Baghi, E.S.; Ranjbar, E. Seeking low carbon urban design through modelling of carbon emission from different sources in urban neighbourhoods, case study: Semnan. *Int. J. Urban Sustain. Dev.* **2021**, *13*, 546–568. [CrossRef]
11. IPCC Updates Methodology for Greenhouse Gas Inventories. Available online: https://bit.ly/2PYwytS (accessed on 23 March 2022).
12. National Center for Climate Change Strategy and International Cooperation (NCSC). Guidelines for Compiling Provincial Greenhouse Gas Inventories. Available online: http://www.ncsc.org.cn/SY/tjkhybg/202003/t20200319_769763.shtml# (accessed on 23 March 2022).
13. Yang, K. *Study on Soil Carbon Sequestration Potential in Typical Farming Areas in My Country*; China University of Geosciences (Beijing): Beijing, China, 2016.
14. Dong, L.; Li, X.; Jiang, X.; Liu, X. Life cycle assessment of rice production energy consumption and carbon footprint in Shanghai Chongming Island. *J. Agric. Environ. Sci.* **2014**, *33*, 1254–1260.
15. Cao, L.; Li, M.; Wang, X.; Zhao, Z.; Pan, X. Carbon footprint of rice production in Shanghai based on life cycle assessment. *Acta Ecol.* **2014**, *34*, 491–499.
16. Tang, X.; Zhao, X.; Bai, Y.; Tang, Z.; Wang, W.; Zhao, Y.; Wan, H.; Xie, Z.; Shi, X.; Wu, B.; et al. Carbon pools in China's terrestrial ecosystems: New estimates based on an intensive field survey. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 4021–4026. [CrossRef]
17. Xu, X.; Xu, P.; Zhu, J.; Li, H.; Xiong, Z. Bamboo construction materials: Carbon storage and potential to reduce associated CO_2 emissions. *Sci. Total Environ.* **2022**, *814*, 152697. [CrossRef] [PubMed]
18. Zhao, Q. *Research on Shanghai Greenhouse Gas Emission Inventory*; Fudan University: Shanghai, China, 2011.
19. Lin, B.; Xu, B. Growth of industrial CO_2 emissions in Shanghai city: Evidence from a dynamic vector autoregression analysis. *Energy* **2018**, *151*, 167–177. [CrossRef]
20. Huang, Y.; Shen, L.; Liu, H. Grey relational analysis, principal component analysis and forecasting of carbon emissions based on long short-term memory in China. *J. Clean. Prod.* **2019**, *209*, 415–423. [CrossRef]
21. Luo, X. *Research on Rural Low-Carbon Ecological Evaluation System Based on Carbon Emission Accounting*; Zhejiang University: Hangzhou, China, 2017.
22. Harris, S.; Weinzettel, J.; Bigano, A.; Källmén, A. Low carbon cities in 2050? GHG emissions of European cities using production-based and consumption-based emission accounting methods. *J. Clean. Prod.* **2020**, *248*, 119206. [CrossRef]
23. Köhler, J.; Turnheim, B.; Hodson, M. Low carbon transitions pathways in mobility: Applying the MLP in a combined case study and simulation bridging analysis of passenger transport in the Netherlands. *Technol. Forecast. Soc. Change* **2020**, *151*, 119314. [CrossRef]
24. Du, L.; Li, X.; Zhao, H.; Ma, W.; Jiang, P. System dynamic modeling of urban carbon emissions based on the regional National Economy and Social Development Plan: A case study of Shanghai city. *J. Clean. Prod.* **2018**, *172*, 1501–1513. [CrossRef]
25. Zheng, D.; Wu, H.; Lin, C.; Weng, T. Research on the integration of urban carbon reduction unit construction and planning technology based on carbon accounting. *Urban Plan. J.* **2021**, *264*, 43–50.

26. Pedro, J.; Silva, C.; Pinheiro, M.D. Integrating GIS spatial dimension into BREEAM communities sustainability assessment to support urban planning policies, Lisbon case study. *Land Use Policy* **2019**, *83*, 424–434. [CrossRef]
27. Feng, Z. *Simulation and Analysis of Low-Carbon Planning for Rural Land in Mountainous Areas in Zhejiang*; Zhejiang University: Hangzhou, China, 2015.
28. Order of the State Council of the People's Republic of China. Regulations on the Management of Village and Market Town Planning and Construction. Available online: http://www.gov.cn/zhengce/2021-10/21/content_5644083.htm (accessed on 23 March 2022).
29. Shanghai Municipal Administration of Planning and Land and Resources. Guidelines for Compilation and Management of Village Planning in Shanghai. 2014. Available online: https://ghzyj.sh.gov.cn/gzdt/20191101/0032-410578.html (accessed on 23 March 2022).
30. Yeung, D.W.K.; Petrosyan, L.A. Generalized dynamic games with durable strategies under uncertain planning horizon. *J. Comput. Appl. Math.* **2021**, *395*, 113595. [CrossRef]
31. Courtney, H.; Kirkland, J.; Viguerie, P. Strategy under uncertainty. *Harv. Bus. Rev.* **1997**, *75*, 67–79.
32. Courtney, H. Decision-driven scenarios for assessing four levels of uncertainty. *Strategy Leadersh.* **2003**. [CrossRef]
33. Wei, Y. *China Energy Report (2008): Carbon Emission Research*; Chinese Science Press: Beijing, China, 2008.
34. Gaspars-Wieloch, H. A new application for the Goal Programming—The Target Decision Rule for uncertain problems. *J. Risk Financ. Manag.* **2020**, *13*, 280. [CrossRef]
35. Shanghai Municipal People's Government. Shanghai Rural Village Housing Construction Management Measures. Available online: https://www.shanghai.gov.cn/nw45024/20200824/0001-45024_59422.html (accessed on 23 March 2022).
36. Qiu, L.; Zeng, W.; Kant, S.; Wang, S. The Role of Social Capital in Rural Households' Perceptions toward the Benefits of Forest Carbon Sequestration Projects: Evidence from a Rural Household Survey in Sichuan and Yunnan Provinces, China. *Land* **2021**, *10*, 91. [CrossRef]