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Research on Planning and Design of Rural Carbon-Negative Courtyards Based on Carbon Emission Accounting and Assessment

Zhijun Chen [1] and Hongguang Liu [2,*]

[1] College of Horticulture, Nanjing Agriculture University, Nanjing 210095, China; 2023804338@stu.njau.edu.cn
[2] College of Public Administration, Nanjing Agriculture University, Nanjing 210095, China
* Correspondence: liuhg@njau.edu.cn

Abstract

Carbon emissions in rural areas have increased significantly, resulting in huge emission reduction potential, but research on carbon accounting at the courtyard scale is insufficient. To fill the gap in micro-level carbon management and support the green transformation of rural areas, this study focuses on the planning and design of rural carbon-negative courtyards, aiming to achieve negative emissions in courtyards through carbon accounting and strategic design. This conceptual design was developed for rural areas in Nanjing, Jiangsu Province, China, located in the Yangtze River Delta region with a subtropical monsoon climate. The favorable climatic and ecological conditions provide a suitable context for integrating renewable energy systems and ecological resource management within courtyard spaces. We establish a carbon accounting list and model at the courtyard scale; divide this into five functional zones, planting, residential, breeding, pond, and woodland areas; propose targeted carbon-reduction strategies applicable to courtyards such as photovoltaic and ground-source heat pump technologies; and systematically calculate courtyard carbon sources and sinks. The comprehensive carbon sink of the courtyard in this study removes 2173.27 kg CO_2 per year; the residential area is the main carbon source, accounting for 81.8% of total emissions, while woodland is the core carbon sink, accounting for 11.2% of the total carbon reduction; the emission reduction contributions of PV and ground-source heat pump technologies account for 65.2% and 22.9% respectively. We clarify the spatial types of carbon sources and sinks and propose implementation paths to achieve carbon-negative emissions, such as green buildings and energy optimization. By situating the design in Nanjing, Jiangsu Province, this study provides region-specific support for achieving China's "dual carbon" goals and promotes the transformation of rural courtyards from carbon emission sources into carbon sink carriers.

Keywords: rural carbon-negative courtyard; carbon accounting; carbon sources and sinks; rural planning; renewable energy

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1. Introduction

In recent years, carbon emissions in rural areas have risen significantly, emerging as a non-negligible source of carbon emissions, while their enormous emission reduction potential has also attracted increasing attention [1]. China has explicitly set the goals of achieving "carbon peaking" by 2030 and "carbon neutrality" by 2060. As a fundamental task for advancing the "dual carbon" goals, the scientific construction and continuous improvement of carbon emission accounting systems are of particular importance [2,3]. In April 2022, China issued an implementation plan for accelerating the establishment of a

unified and standardized carbon emission statistical accounting system [4], laying a solid accounting foundation for the implementation of the "dual carbon" goals. As the basic unit bearing rural production and livelihoods, rural courtyards serve as both micro-carriers of carbon emissions and core hubs to be tapped for their carbon sink potential. This study focuses on rural areas in Nanjing, Jiangsu Province, China, a typical region in the Yangtze River Delta characterized by a subtropical monsoon climate and mixed agricultural and woodland landscapes. Existing studies have mostly focused on rural carbon systems at the regional or village scale [5], and the construction of carbon accounting systems and carbon-negative design at the courtyard scale are insufficient to support precise carbon management needs at the micro level. Specifically, current rural carbon accounting studies generally suffer from single methods and poor scenario adaptability: most directly apply accounting methods designed for regional scales without considering the unique carbon dynamic characteristics of courtyard systems, leading to vague calculation scopes and incomplete scenario coverage, resulting in incomplete carbon accounting inventories for rural courtyards. Meanwhile, most existing studies adopt unified parameters for estimation without accounting for differences in courtyard land-use structures and production modes, leading to deviations between accounting results and actual conditions, which hinders the formulation of targeted emission reduction strategies for rural courtyards [6]. To address these issues, this study accomplishes two aspects: Theoretically, it incorporates the carbon cycles of agricultural activities such as courtyard planting and livestock farming, as well as hidden carbon sinks, including the soil and vegetation, into the carbon accounting inventory of rural courtyards, and constructs a complete courtyard-scale carbon cycle mechanism that realizes the synergy of the carbon cycle, water cycle and material cycle. Methodologically, it builds a two-dimensional accounting framework integrating land-use classification and carbon source/sink processes, integrates the source-based accounting method and land-use-based accounting method, and establishes a differentiated parameter system by combining multi-source data from field monitoring, remote sensing interpretation, and farmer surveys [7,8].

Meanwhile, existing research on rural carbon negativity still faces the dilemmas of technology transplantation and cultural disconnection. Current carbon-negative technologies are mostly directly transplanted from urban scenarios without considering the resource endowments and architectural characteristics of rural areas, resulting in high implementation costs and low emission reduction efficiency. Furthermore, most existing designs focus on single-technology applications, failing to explore the carbon sink value of traditional rural ecological practices, leading to a lack of local adaptability and sustainability in the proposed schemes. Against this backdrop, this study proposes a collaborative design path integrating traditional ecological wisdom and modern carbon-negative technologies. By systematically evaluating traditional ecological practices of courtyards in different regions and quantifying their carbon sink effects, this approach unites technical feasibility and cultural adaptability. Specifically, it reduces carbon emissions in the construction and operation stages of rural courtyards through carbon-negative planning and design and strengthens carbon sink functions via measures such as vegetation configuration and soil improvement, ultimately realizing the goal of carbon negativity.

In summary, this study focuses on courtyard-scale carbon accounting and the carbon-negative design of rural courtyards. It not only improves the micro-system of rural carbon management from a methodological perspective but also provides a replicable carbon-negative courtyard model from a practical standpoint. This research offers precise technical support for rural green transformation and presents an innovative micro-perspective path for the implementation of the "dual carbon" strategy in rural areas, thus bearing significant theoretical and practical implications. Its innovative value is mainly reflected in two aspects:

First, by constructing a rural courtyard carbon accounting framework from the perspective of land use, it provides a scientific basis for clarifying the carbon-negative function of rural courtyards in regional carbon cycles and formulating differentiated development paths for courtyard carbon emission reduction. Second, by expanding a rural courtyard carbon accounting database and exploring carbon sink potential from the perspective of carbon sources and sinks, it investigates the collaborative linking mechanism of different land-use types and provides innovative directions and implementation paths for the construction of rural carbon-negative courtyards, considering data improvement and emission reduction with sink enhancement.

2. Materials and Methods

2.1. Accounting Area

We set up the conceptual model of rural carbon-negative courtyards (Figure 1):

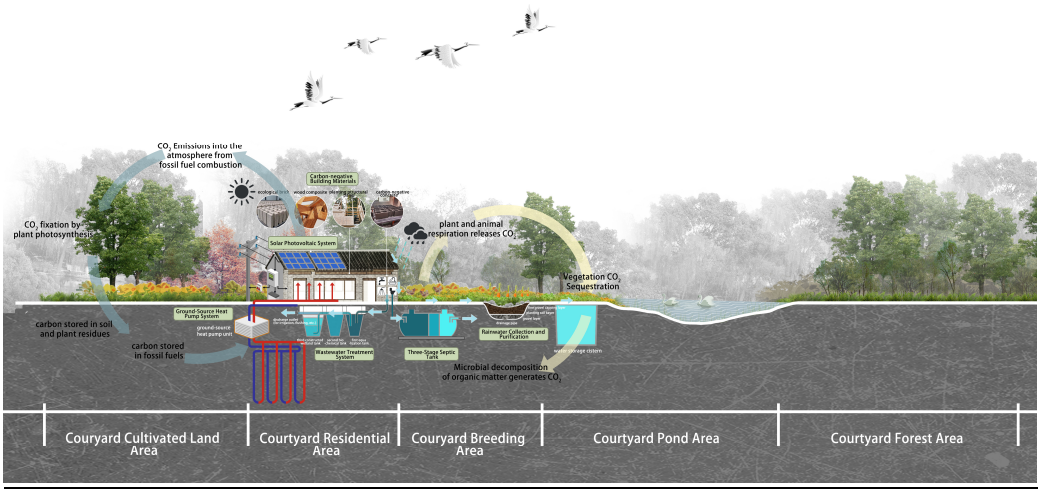

Figure 1. Rural courtyard conceptual model.

Centered on a carbon-negative orientation and ecology-first principle, the conceptual model of rural carbon-negative courtyards developed for rural Nanjing, Jiangsu Province, China, includes an integrated ecosystem with a synergistic carbon cycle, water cycle, and material cycle through the layout of five functional zones. By integrating technologies such as plant-based carbon sequestration, application of carbon-negative building materials, renewable energy substitutes, and waste resource utilization, each zone of the courtyard forms a flow cycle of carbon involving the atmosphere, vegetation, soil, and water bodies. On this basis, technologies like vertical planting, organic agriculture, and forest–poultry integration are integrated to realize a systematic cycle of resource input, production utilization, and waste regeneration within the courtyard. Under the subtropical monsoon climatic conditions of the study area, this approach improves energy efficiency, reduces environmental loads, and facilitates the transformation of a carbon emission source to a carbon sink carrier. Meanwhile, it satisfies daily functions such as residential needs, planting, and breeding, achieving the sustainable goal of maximizing ecological value within a limited space (Figure 2).

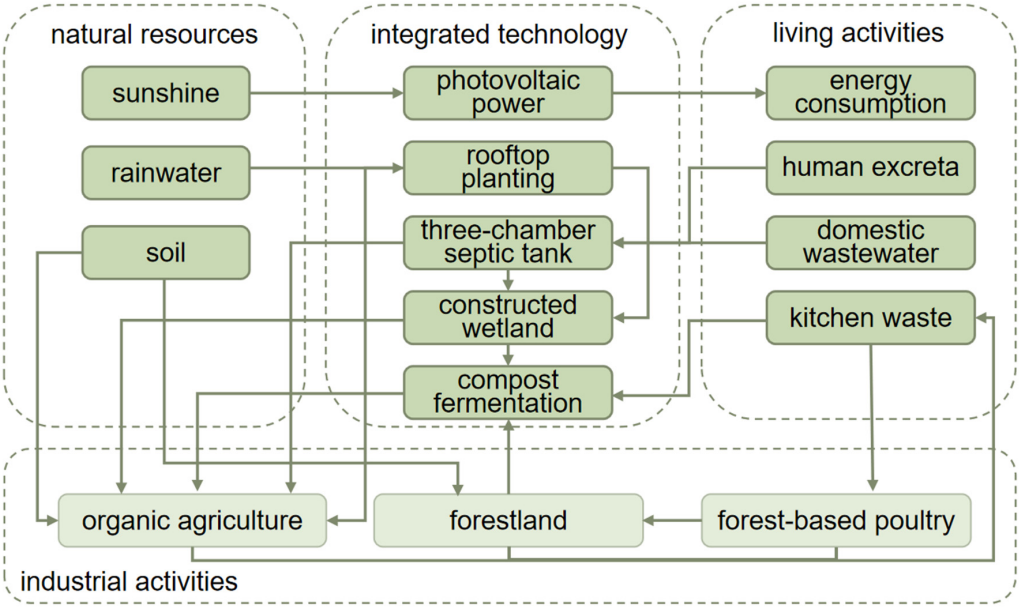

Figure 2. Schematic diagram of courtyard integrated ecosystem.

Core zone division and functions of rural courtyards: (1) Courtyard planting zone: Focuses on vegetation carbon sequestration and soil carbon pool construction. Plants absorb CO_2 through photosynthesis; plant litter returns to the soil after microbial decomposition, continuously replenishing the soil carbon pool for long-term carbon sequestration. It also provides pastoral landscapes and potential spaces for cash crops in the courtyard. (2) Courtyard residential zone: Emphasizes energy self-sufficiency and application of carbon-negative building materials. The main building uses new plates, ecological bricks, carbon-negative concrete, and other carbon-negative materials to reduce carbon emissions from building materials at the source. Solar photovoltaic panels are installed on the roof to replace fossil fuel energy with clean energy power generation; a ground-source heat pump system is equipped underground to efficiently meet heating and cooling needs, achieving the dual goals of energy self-sufficiency and carbon emission reduction, and constructing a carbon-negative living space. (3) Courtyard livestock zone: Undertakes animal and plant respiration and waste treatment functions. Breeding animals release CO_2 through respiration; their manure is decomposed by microorganisms via a three-stage septic tank and converted into organic fertilizer, which is directionally returned to the planting zone for absorption and utilization in crops, realizing waste reduction and resource utilization. (4) The courtyard pond zone: serves as an ecological buffer zone for rainwater collection, purification, and utilization. The water circulation system achieves cascaded recycling and efficient utilization of water resources through a combination of rainwater harvesting, constructed wetland treatment, and three-stage purification pond filtration. Meanwhile, aquatic vegetation facilitates photosynthesis-assisted carbon sequestration; creates a stable aquatic environment to provide habitats for fish, insects, and other organisms; and enhances the biodiversity of the courtyard ecosystem. (5) Courtyard forest zone: Targets large-scale vegetation carbon sequestration and biodiversity conservation. Multi-layered vegetation communities, including arbors and shrubs, realize long-term carbon sequestration through photosynthesis, forming a stable vegetation carbon pool. The understory space provides diverse habitats for birds, insects, and other organisms. Meanwhile, canopy shading and transpiration regulate the courtyard's temperature and humidity, optimize the microclimate, and enhance the stability and service functions of the courtyard ecosystem.

2.2. Accounting List

The study refers to the 2006 IPCC guidelines for national greenhouse gas inventories and the supplementary content of the 2019 guidelines, selects appropriate emission factors based on actual conditions, and constructs a carbon accounting inventory for rural courtyards (Table 1) [5]. The geographical scope is defined as independent rural courtyards, which are divided into cultivated land, woodland, ponds, breeding areas, and residential areas according to land-use types, to account for direct or indirect carbon emissions generated by residents' productive activities and daily life. The selection of emission factors follows the principles of being systematic and scientific, fully considering the complexity and unity of the rural courtyard system, and combining the characteristics of multiple production and living sectors to refine the carbon source/sink composition of each land-type subsystem; the accounting inventory covers the main production and living activities of the courtyard, showing the basic characteristics of carbon emissions from rural courtyards. Based on this, a carbon accounting method and system for rural courtyards is constructed (Figure 3). The definition of calculation boundaries and the criteria for data selection are detailed in the Appendix A.

Table 1. Carbon accounting inventory at rural courtyard.

Land-Use Type	Secondary Classification	Tertiary Classification	Activity Level Data
cropland	crop carbon sequestration	carbon absorption during photosynthesis in crops	agricultural land area
	investment in agricultural supplies	carbon emissions from the use of pesticides and fertilizers	fertilizer application rate
	planting activity	carbon emissions from agricultural plowing and irrigation	agricultural land area
forest land	biomass carbon sink	carbon sequestration in tree forests	area of forest land
		carbon sequestration in shrubland	shrub coverage
		carbon sequestration capacity of understory herbs	grassland coverage
	soil carbon sink	carbon storage in soil organic matter	area of forest land
water bodies	water body surface	water body carbon sink	water body area
livestock area	treatment of livestock and poultry waste	carbon emissions from livestock and poultry manure	amount of livestock and poultry raised
	intestinal fermentation in livestock and poultry	carbon emissions from the intestines of livestock and poultry	amount of livestock and poultry raised
residential area	house construction	carbon emissions from construction	area of structure
	energy and fuel consumption	carbon emissions from the consumption of energy and fuel	gas and coal consumption
	thermal consumption	carbon emissions from the consumption of heat for daily life	heat consumption
	electricity consumption	carbon emissions from the consumption of electricity for daily life	electricity consumption
	waste disposal	carbon emissions from landfilling and incinerating domestic waste	the amount of straw and firewood used

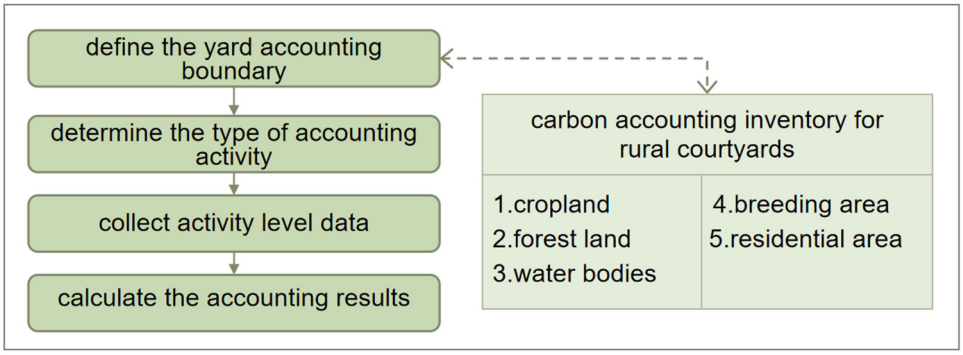

Figure 3. Carbon accounting inventory for rural courtyard.

2.3. Accounting Method

For carbon accounting of courtyard cultivated land areas, two critical processes are integrated: on one hand, crops sequester carbon through photosynthesis throughout their life cycles, while on the other hand, the input of agricultural production materials and the implementation of farming activities constitute the primary sources of carbon emissions. Therefore, the net carbon sink method is adopted to calculate the carbon sink activity of courtyard cultivated land areas, and the specific calculation of the cultivated land's carbon sink activity is as follows:

$$N_t = C_t - T_t \tag{1}$$

$$C_t = \sum_{i=1}^{n} CF_i \times Y_i / H_i \tag{2}$$

$$T_t = \sum_{i=1}^{\eta} E_i \times \delta_i \tag{3}$$

N_t: carbon sink activity of cultivated land; C_t: carbon sequestration capacity of farmland; T_t: carbon emissions from farmland; CF_i: carbon uptake rate of crop i; Y_i: economic yield of crop i; H_i: economic coefficient of crop i; E_i: usage amount of the i-th agricultural production material; and δi: emission factor of the i-th agricultural production material.

Relevant emission factors, including the economic coefficients of various crops, carbon sequestration rates [5], emission factors of pesticides and chemical fertilizers [9,10], and emission factors of farmland tillage and irrigation [11,12], are derived from relevant references.

The carbon accounting of forest areas is divided into biomass carbon sinks and soil carbon sinks. The forest volume expansion method [13] is used to account for the carbon sink capacity of trees, understory vegetation, and forest land [14], with reference to guidelines for carbon storage measurement of forest ecosystems and guidelines for carbon sink measurement and monitoring of afforestation projects [15].

$$N_f = N_v + N_b + N_s \tag{4}$$

$$N_f = \sum(S_i \times N_i) + \alpha\sum(S_i \times N_i) + \beta\sum(S_i \times N_i) \tag{5}$$

$$N_i = V_i \times \sigma \times \rho \times (1 + R_i) \times \gamma \tag{6}$$

α: carbon conversion coefficient of understory plants, with a value of 0.195; β: the forest carbon conversion coefficient, with a value of 1.244; σ: coefficient for converting forest volume to biomass volume, i.e., the biomass expansion factor, which is generally 1.90 [15]; ρ: coefficient for converting wood biomass volume to dry biomass mass, i.e., the volume density, which is generally 0.5 [16]; R_i: root-to-shoot ratio of trees in the i-th type of forest land; and γ: coefficient for converting dry biomass mass to carbon sequestration,

i.e., the carbon content rate, which is generally 0.5 [17]. A calculation model composed of σ (biomass expansion factor), ρ (volume density), R (root-to-shoot ratio), and γ (carbon content rate) was established [18] (Table 2).

Table 2. The carbon storage measurement model for major tree species.

Dominant Tree Species	σ	ρ	R	γ
wetland peat	2.556	0.359	0.299	0.531
China fir	2.083	0.307	0.242	0.513
camphorwood	2.298	0.465	0.217	0.492
other hard-bodied	1.656	0.606	0.220	0.485
poplar	1.989	0.364	0.210	0.450
other soft-bodied	2.214	0.422	0.212	0.450
broadleaf mix	2.015	0.522	0.235	0.451
mixed coniferous and broadleaf	2.079	0.476	0.221	0.457

Water carbon accounting in the courtyard pond area was performed as follows:

$$N_w = \sum_{i=1}^{n} area_i \times \delta_i \quad (7)$$

N_w: carbon sink of courtyard water bodies; *areai*: the area of the *i*-th type of water bodies; δ_i: the annual carbon sequestration coefficient of the *i*-th type of water bodies; the specific values refer to the carbon absorption or emission coefficients of water bodies [19,20].

Carbon accounting in breeding areas. The carbon emission accounting of courtyard breeding areas includes CH_4 and N_2O emissions from enteric fermentation and manure management of different types of livestock and poultry, and the calculation formula is as follows [21]:

$$C_l = \sum_{i=1}^{n} N_i \times \theta_i \times 28 + m_i \times \mu_i \times 265 \quad (8)$$

C_l: carbon emissions from aquaculture areas; N_i: the average annual number of livestock and poultry in the *i*-th type; θi: CH_4 emission coefficient of the *i*-th type of livestock and poultry; μi: N_2O emission coefficient of the *i*-th type of livestock and poultry.

The formula for calculating the average annual livestock and poultry rearing quantity is as follows [21]:

$$T_i = D_i \times M_i / 365 \quad (9)$$

T_i: average number of livestock and poultry of the *i*-th type; D_i: average life cycle of the *i*-th type of livestock and poultry; and M_i: annual production of the *i*-th type of livestock and poultry. The carbon emission coefficients for livestock and poultry breeding were referenced from guidelines for provincial greenhouse gas emission inventories [22] (Table 3).

The carbon accounting of courtyard residential areas is divided into two parts: the carbon accounting of courtyard buildings and carbon accounting of household life. Both are calculated using the emission coefficient method [23,24], and the calculation formula is as follows:

C_r denotes the carbon emissions of the residential area; C_a denotes the carbon emissions of courtyard buildings; and C_d denotes the carbon emissions of household life.

$$C_r = C_a + C_d \quad (10)$$

Table 3. Livestock and poultry farming emission sources and emission factors.

Carbon Source	CH_4 Coefficient		N_2O Emission Coefficient from Feces
	Intestinal Fermentation	Fecal Excretion	
beef	51.40	1.50	0.85
cow	68.00	8.33	1.00
sheep	5.00	0.15	0.28
pig	1.00	3.50	0.18
poultry	0.00	0.02	0.007

The carbon accounting of courtyard buildings can be divided into four stages: building material production and transportation, construction, operation, and disposal. Carbon emissions from the operation stage are included in household life carbon emissions, and the specific calculation formula is shown in (Table 4).

$$C_a = C_{SC} + C_{YS} + C_{JZ} + C_{CZ} \quad (11)$$

Table 4. Carbon accounting of rural courtyard architecture.

Accounting Category	Formula	Symbol Meaning
carbon emissions during the production and transportation of building materials	$C_{SC} = \sum_{i=1}^{n} M_i \times F_i$ $C_{YS} = \sum_{i=1}^{n} M_i D_i T_i$	C_{SC}: carbon emissions during the production phase of building materials; M_i: consumption of building materials; Fi: emission coefficient of building materials C_{YS}: carbon emissions during the transportation of building materials; M_i: consumption of building materials; D_i: average distance of transportation of building materials; T_i: emission coefficient per unit weight transport distance of building materials
carbon emissions during the construction phase	$C_{JZ} = C_{jx} + C_{ls}$ $C_{jx} = \sum_{i=1}^{n} B_i K_i N F_i$ $C_{ls} = Q_{rg} f_{ls}$	C_{JZ}: carbon emissions during the construction phase; C_{jx}: carbon emissions from the energy consumption of machinery in the construction area; C_{ls}: energy consumption and carbon emissions from temporary construction facilities; B_i: consumption of construction machinery per shift during the construction phase; K_i: energy consumption per unit of construction machinery per shift; NF_i: emission coefficient of energy for construction machinery; Q_{rg}: total man-days for the construction phase; f_{ls}: emission coefficient for temporary facilities per unit of working day
carbon emissions during the disposal phase	$C_{CZ} = C_{hs} - C_{td}$ $C_{hs} = \sum_{i=1,j=1}^{n} K_{ij} M_i R_j$ $C_{td} = \sum_{i=1,j=1}^{n} K_{ij} M_i F_j$	C_{CZ}: total carbon emissions during the waste recycling phase; C_{hs}: carbon emissions from waste recycling and disposal processes; C_{td}: carbon reduction from replacing traditional building materials with recycled ones; R_j: emission factor for recycling unit mass of waste and producing recycled building materials; M_i: weight of recyclable waste; K_{ij}: percentage of recycled waste that can be used to produce recycled building materials; F_j: emission coefficient of traditional building materials replaced by recycled building materials

Household life carbon accounting, which refers to the carbon accounting of the building operation stage, includes carbon emissions from direct and indirect energy consumption as well as carbon reductions from renewable energy systems such as solar photovoltaic power generation. The formula is as follows:

$$C_d = \sum_{i=1}^{n} E_i F_i \tag{12}$$

$$E_i = \sum_{i=1}^{n} E_{i,j} - ER_{i,j} \tag{13}$$

C_d: carbon emissions of the building operation stage; E_i: consumption of the i-th type of energy in the building operation stage; F_i: carbon emission factor of the i-th type of energy; and $E_{i,j}$: the amount of the i-th type of energy consumed by the j-th type of system and provided by renewable energy systems.

Carbon accounting of solar photovoltaic power generation:

$$E_{PV} = IK_E K_S A_\rho \tag{14}$$

$$N_{PV} = E_{PV} EFe \tag{15}$$

E_{PV}: annual power generation of the photovoltaic (PV) system; I: annual solar irradiance on the surface of the PV module; K_E: conversion efficiency of the PV module; K_S: conversion efficiency of the PV system; A_ρ: the net area of PV panels in the PV system; N_{PV}: annual carbon reduction in the PV system; and EF_e: carbon emission factor of electric energy.

The conversion efficiency of PV modules is determined by their material; the efficiency of crystalline silicon modules will be greater than 19%, and that of thin-film modules will be greater than 12%. The conversion efficiency of the PV system is taken as 75–80% [23].

Carbon accounting for energy saved by ground-source heat pumps:

$$E_G = \text{area} \times F_i \tag{16}$$

E_G: annual carbon emission reduction in the ground-source heat pump (GSHP) system; and area: building area of the courtyard. The average annual CO_2 emission reduction per unit building area of the GSHP system is 9.95 kg [25].

The carbon emission factors of major fossil fuel energy consumption and carbon emission factors of common building materials are shown below (Tables 5 and 6).

Table 5. Carbon emission factors of major fossil fuel energy consumption.

Fuel	Carbon Content Per Unit of Calorific Value (kgC/GJ)	Carbon Oxidation Rate (%)	Average Low-Temperature Heat Value (KJ/kg or KJ/m^3)	Carbon Emission Factor (kgCO_{2e}/kg or kgCO_{2e}/m^3)
coke	29.5	0.93	28,435	2.86
gasoline	18.9	0.98	43,124	2.93
diesel	20.2	0.98	42,705	3.10
natural gas	15.3	0.99	32,238	1.79

Table 6. Carbon emission factors of common building materials.

Building Materials	Cement	Steel	Glass	Wood	Aluminum
carbon emission factor ($kgCO_{2e}/kg$)	0.815	1.789	0.996	−842.8	2.6

Summary of carbon accounting for rural courtyards:

$$T_{rc} = N_t + N_f + N_w - C_l - C_r \quad (17)$$

N_t: carbon sink capacity of the courtyard cropland area; N_f: carbon sink capacity of the courtyard forest area; N_w: carbon sink capacity of the courtyard pond area; C_l: carbon emission of the courtyard breeding area; and C_r: carbon emission of the courtyard residential area. A positive calculation result indicates that an area is a carbon sink, while a negative result indicates that it produces carbon emissions.

3. Results

3.1. Subsection

3.1.1. Design Plan for a Rural Carbon-Negative Courtyard

The design scheme of rural carbon-negative courtyard adopts a systematic integration strategy to realize the organic integration of composite functional modules including areas for residence, production, leisure and landscape (Figure 4). For plant configuration, it follows the principle of synergy between ecological adaptability and landscape aesthetics, using the rational gradient configuration of native tree species and horticultural plants to construct a rural living spatial pattern that is naturally harmonious and ecologically vibrant. The color system takes natural wood colors, as well as gray and green, as the keynote to ensure visual consistency in the design style. Finally, it achieves the goal of providing an ideal human home environment with a "green view at the window, scenic view in the courtyard", realizing the seamless connection between architectural space and natural ecology.

The residential building, as the core component of the entire rural carbon-negative courtyard, adopts a wood–glass integrated design with a partial glass-roofed sunshade canopy; this not only ensures sufficient indoor daylighting and good ventilation but also fosters visual interaction with the external landscape; its interior features clear functional zoning including bedrooms, living rooms, kitchens, and bathrooms, providing residents with a comfortable and convenient resting environment. Adjacent to the south side of the residential building and connected to the main structure is a spacious activity area consisting of a four-season garden and a sunny lawn: the four-season garden follows a circular flower border design, planted with perennial flowers and seasonal plants to ensure year-round scenery and rich colors, while the sunny lawn serves as an open space for outdoor activities like picnics and games, with its edges dotted with landscape stones and tree specimens to enhance spatial rhythm and layering. To the north of the residential building lies the courtyard woodland, where natural trees are planted as a green backdrop; through a multi-layered configuration of arbors, shrubs, and groundcovers, it constructs a rustic ecological space that plays a regulatory role in air purification and summer shading, adds dense greenery and natural ambiance to the courtyard, and acts as an important carbon sink. To the east of the woodland, a courtyard breeding area and a planting area are closely linked to form an integrated planting–breeding rural production model: the planting area occupies most of the northeastern region with a neat row–ridge design for easy cultivation and management, meeting family self-sufficiency needs for vegetables and crops while adding pleasure to farming. A courtyard pond is located in the southeast of

the residential building, with natural gentle slopes at its edges planted with aquatic plants to improve the water quality and add dynamic water features; a viewing platform beside the pond serves as an ideal spot for rest, scenery appreciation, and waterfront leisure.

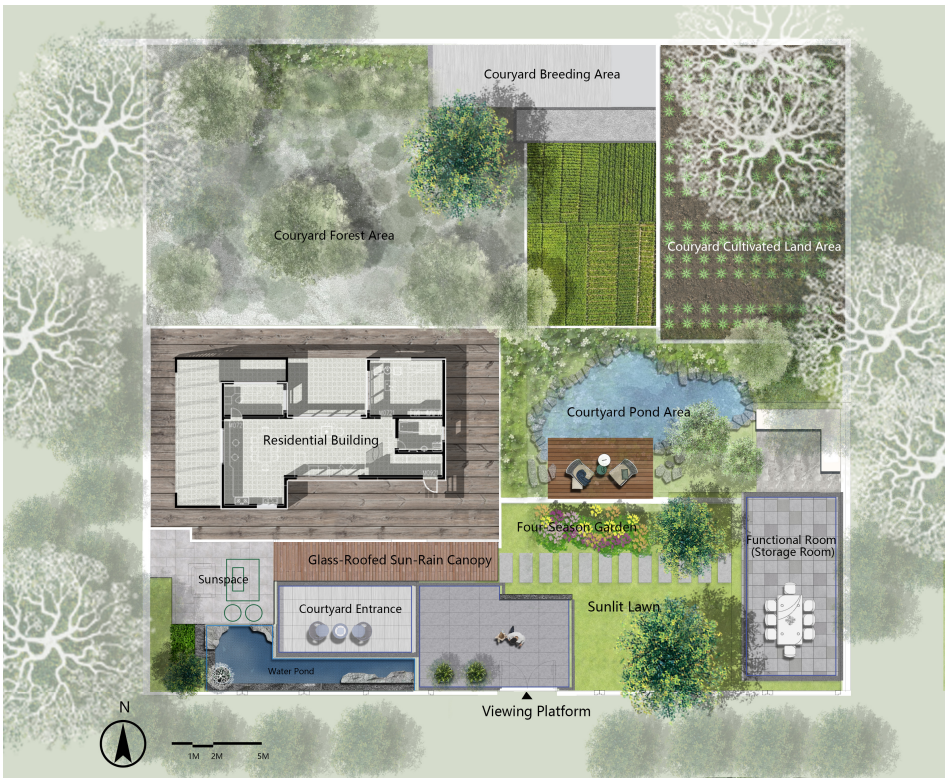

Figure 4. Rural courtyard floor plan.

3.1.2. Carbon Emission Accounting and Analysis of Rural Carbon-Negative Courtyard

Carbon accounting of the courtyard cultivated land area: The carbon emissions of the courtyard cultivated land (200 m^2) amount to 75.73 kg CO_2/year.

Carbon accounting of the courtyard forest area: The carbon sink capacity of the courtyard woodland (400 m^2) is 485.0 kg CO_2/year.

Carbon accounting of the courtyard pond area: The carbon sink capacity of the courtyard pond area (100 m^2) is 28.4 kg CO_2/year.

Carbon accounting of the courtyard breeding area: The carbon emissions of the courtyard breeding area (80 m^2) reach 318.2 kg CO_2/year.

Carbon accounting of courtyard residential area: For the residential building (100 m^2), its embodied carbon is 7.8 kg CO_2/m^2; with a service life of 25 years, the annual amortized embodied carbon is 31.2 kg CO_2/year. Household living carbon emissions are 1740 kg CO_2/year. The solar photovoltaic roof generates 6289 kWh/year, equivalent to an emission reduction of 2830 kg CO_2/year; the ground-source heat pump system achieves an emission reduction of 995 kg CO_2/year.

The accounting results indicate that the cultivated land, breeding area, and residential area are carbon-emitting land types, while the woodland and water areas are carbon-absorbing land types. The comprehensive carbon sink capacity of the courtyard is 2173.27 kg CO_2/year. Notably, the residential area acts as both the dominant carbon source and a key emission reducer: its annual emissions account for 81.8% of the total emissions from all land types, whereas the carbon emissions from the cultivated land and livestock farm account for 3.5% and 14.7% respectively. Woodland is the primary natural carbon sink, contributing 11.2% of the total carbon reduction; the solar photo-

voltaic roof and ground-source heat pump system account for 65.2% and 22.9% of the total carbon reductions, respectively (Figure 5).

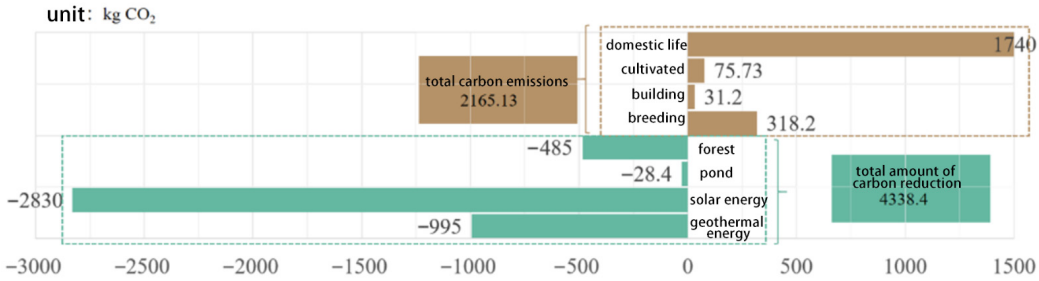

Figure 5. Rural courtyard carbon accounting calculation summary.

3.2. Design Strategies for Carbon-Negative Courtyards in Rural Areas

By constructing a carbon accounting methodology system for rural courtyards and analyzing the carbon emission structure of courtyards, targeted planning and design strategies for rural carbon-negative courtyards are proposed (Figure 6). (1) Rational functional layout combined with the natural environment: Conduct functional zoning of courtyard planting areas, breeding areas, living areas, and ecological areas by integrating form and function. (2) Promote green buildings to reduce operational energy consumption: Reduce building energy consumption through energy-saving retrofitting, passive design, and solar photovoltaic roofs. (3) Construct courtyard circulation systems to promote resource recycling: develop solar landscape lights, courtyard water circulation systems, and emphasize the utilization of local materials. (4) Ecological greening upgrading and reconstruction to strengthen courtyard carbon sink capacity: Carry out forest land transformation and increase vegetation coverage to enhance the carbon sink capacity of courtyards. On the basis of implementing carbon-negative strategies, quantify the benefits of carbon reduction and sink enhancement of various measures, and finally realize the "negative carbon emission" development model of rural courtyards [26]. (5) Apply new technologies to unleash carbon-negative innovation: Adopt ground-source heat pumps for cross-seasonal heat storage to realize summer storage and winter use of thermal energy [27].

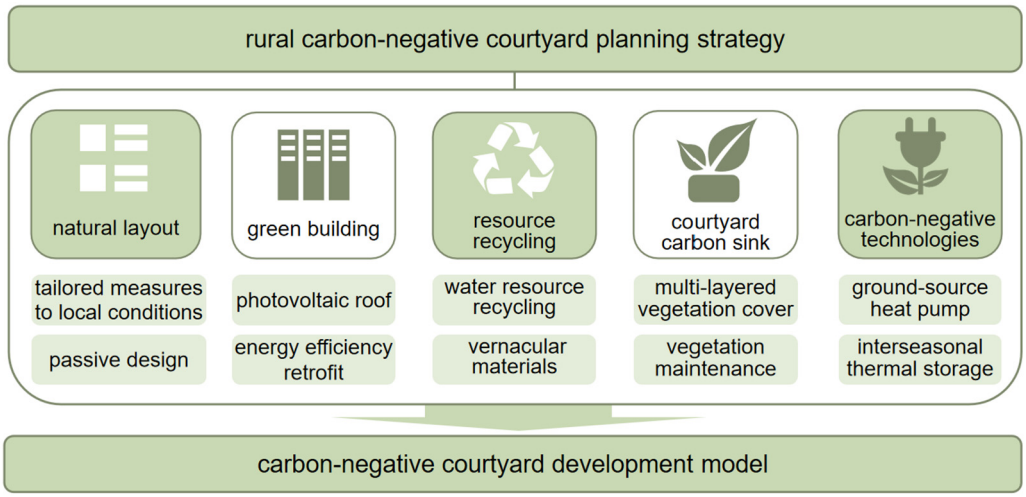

Figure 6. Rural carbon-negative courtyard planning strategies.

3.2.1. Layout Design of Carbon-Negative Courtyards

The rational functional layout is based on the natural environment. The steps are as follows: First, conduct a pre-investigation to identify natural conditions such as the terrain and sunlight, avoid large-scale earthworks, and minimize environmental disturbance and

destruction. Meanwhile, integrate regional natural and cultural characteristics to enhance courtyard recognition and achieve organic integration with the surrounding environment. Second, evaluate residents' needs and clarify the priority of living, production, leisure, and ecological functions. Optimize spatial connections through circulation organization and sightline design, emphasize layout compactness, and construct a courtyard spatial system integrating ecology and functions.

3.2.2. Carbon-Negative Courtyard Architectural Design

Promote green building concepts and reduce building operational energy consumption. Through the rational arrangement of building orientation and functional zones, optimization of external building materials and envelope structures, enhancement of the greening environment around buildings, and integration of renewable energy utilization, rural carbon-negative buildings can be effectively constructed.

Spatial structure and functional layout: The geometric characteristics of building form, spatial layout, envelope structure, and interface design directly determine indoor daylighting, ventilation, and heat exchange conditions, thus affecting building energy consumption. In architectural design, the north–south orientation should be prioritized, the window-to-wall ratio should be increased to expand the area of natural daylighting and ventilation, and building ventilation paths should be rationally designed to achieve passive regulation, thereby reducing active energy consumption demand and building carbon emissions.

External materials and envelope structures: Courtyard buildings exhibit significant differences in carbon emissions during construction and use due to variations in materials and structures. Reducing embodied carbon in building materials is key to carbon-negative buildings; therefore, local eco-friendly materials with thermal insulation, heat insulation, and humidity-regulation properties should be selected for application in envelope structures, facade decoration, and wall design, balancing low-energy consumption comfort and rural cultural expression.

Greening and microclimate around buildings: The climatic environment significantly influences building planning. Green vegetation plays a role in carbon sequestration, oxygen release, temperature reduction, and humidity increase through respiration and transpiration. In addition to ground greening, designing vertical greening and roof greening in combination with building characteristics can form a natural barrier, blocking solar radiation in summer and reducing heat loss in winter. Through natural regulation, it reduces carbon emissions from air conditioning electricity. Meanwhile, building greening softens hard interfaces, creates rich landscape layers, and enhances the aesthetic value of the courtyard.

Renewable energy utilization: Rural carbon-negative courtyard buildings integrate renewable energy sources such as solar energy and biomass to construct a high-efficiency carbon-negative energy system with multi-energy complementarity, improving energy self-sufficiency and carbon-negative benefits. Solar energy utilization becomes the core path due to its high technical maturity and strong adaptability, and its utilization methods are divided into active conversion and passive design. Active conversion: It uses solar energy to provide power to the building through photothermal and photovoltaic technologies. Photothermal technology meets thermal energy demands, such as domestic hot water and winter heating; photovoltaic technology utilizes courtyard space for the installation of photovoltaic panels for electricity supply, thereby reducing external energy consumption. Passive design: Represented by sunrooms, it enhances daylighting and solar radiation heat absorption through large-area transparent envelope structures, works alongside thermal insulation design and heat storage materials to reduce heat loss, cuts thermal energy consump-

tion and carbon emissions, and maximizes the use of natural conditions to optimize the indoor environment.

3.2.3. Carbon-Negative Infrastructure Design

It is important to construct a courtyard circulation system to promote resource recycling and adopt circulatory systems and energy-efficient technologies in lighting, greening, water use, and other links to achieve resource recycling and energy consumption reduction, contributing to the courtyard's carbon-negative goals.

Courtyard landscape power supply design: Solar lighting technology can be applied to roads and green space landscape lights inside the courtyard, and landscape lighting design should be combined with rural styles to endow different lighting effects to each node; for example, warm yellow can create a warm and safe atmosphere. Lamp materials can use anti-corrosion wood to extend service life and reduce carbon emissions from maintenance, replacement, and electricity supply.

Courtyard rain garden design: The courtyard collects and treats rainwater through facilities such as rain gardens, permeable pavements, and grassed swales. After being purified to meet standards, the rainwater flows into the water storage tank and is used for vegetable garden irrigation, toilet flushing, landscape and courtyard facility cleaning, etc., to reduce water resource consumption. Devices like rain gardens, sunken green spaces, and dry creeks can slow down the flow rate of rainwater and prevent soil compaction. Among them, rain gardens use the permeation, filtration, and purification effects of plants, pebbles, and soil to remove large-particle impurities such as fallen leaves and sediment, and simulate natural hydrological processes through the synergistic effect of the three; excess rainwater not absorbed by the soil flows into the edge water storage module through grassed swales for storage, thereby realizing efficient collection, purification, and utilization of water resources.

Courtyard ecological wall design: In the construction of rural courtyards, walls are important components of yards. Over time, rural walls are often seriously damaged and overly enclosed, hindering environmental interaction between the inside and outside of courtyards. Therefore, a relatively transparent wall design should be adopted. For materials, waste bricks, tiles, etc., from the demolition of local buildings should be selected to realize resource recycling and reduce carbon emissions. At the same time, local culture and technology should be integrated into the courtyard landscape to highlight the rural carbon-negative concept.

3.2.4. Carbon-Negative Green Space Landscape Design

Ecological greening enhancement and renovation are implemented to strengthen the carbon sequestration capacity of courtyards. Plant carbon sequestration is a critical pathway to achieve a carbon-negative goal in rural courtyards, while plant landscape design serves as the core focus. By increasing vegetation coverage through vegetable gardens, flower gardens, and house-side green spaces, we not only reinforce the central role of vegetation in carbon sequestration but also leverage its ecological functions—including air purification, climate regulation, water conservation, carbon sequestration, and oxygen release—to enhance the courtyard's carbon sequestration capacity, ecosystem stability, living environment quality, and comprehensive carbon sequestration benefits [28,29]. Priority should be given to plant selection, configuration, and planting structure [30].

Plant selection: Scientific plant selection and planting design enable rural courtyards to achieve organic integration of production, ecological, and landscape functions while maintaining natural ecological stability. Rural courtyards rooted in natural ecosystems possess robust native ecological foundations. In plant selection, ecological diversity should

be the guiding premise, with native plants prioritized. On one hand, native plants exhibit stronger environmental adaptability and growth stability; their localized and naturalized traits also significantly reduce planting and maintenance costs, minimize resource consumption, and eliminate additional carbon emissions at the source. On the other hand, native plants highlight regional characteristics, shaping the unique local charm of rural courtyard landscapes. Based on this, agricultural planting zones should be planned to create pastoral landscapes that combine production and aesthetic value, supporting rural economic development. For example, diverse planting spaces (orchards, farm gardens, fruit-picking groves) should be established according to local environmental conditions. Adaptable, low-maintenance fruit and vegetable varieties should be prioritized to promote natural, healthy, and green planting concepts, forming a naturally evolving rural landscape. Corridors, landscape, and other elements should be integrated to create functional, aesthetic rural plant landscapes that improve residents' quality of life.

Plant configuration. Reasonable plant configuration strategies for rural courtyards not only meet practical and aesthetic landscape needs but also maximize the carbon sequestration potential of plants. Rural landscapes emphasize practicality and aesthetics, and plant configuration, as the key to landscape construction, must balance function and beauty through the interspersion of deciduous and evergreen plants, combination of colorful-leafed and green-leafed plants, and matching of fast-growing and slow-growing tree species. We highlight seasonal phenological changes, enhance courtyard ornamental value, and create a four-season landscape effect: flower viewing in spring, shade provision in summer, fruit harvesting in autumn, and leaf appreciation in winter. In terms of carbon sequestration capacity, arbors outperform shrubs, and deciduous plants exceed evergreen ones [31,32] (Table 7). Thus, plant configuration should prioritize: increasing the number of arbors, raising the proportion of deciduous species, and rationally planning planting density and vegetation coverage to lay a foundation for long-term carbon sequestration in plant landscapes [33]. Additionally, slow-growing tree species have longer life cycles, higher total carbon sequestration, and lower planting-phase emissions. Using slow-growing species as keystone tree species in configurations improves long-term carbon sequestration effects and provides ecological support for the "carbon-negative emission" model of rural courtyards.

Table 7. Carbon sequestration capacity of different vegetation types.

Vegetation Form	Carbon Sequestration Per Unit Area	Unit	Average Carbon Sequestration Per Plant	Unit
tree	19.3	($kg/m^2 \cdot a$)	156.7	(kg·a)
shrub	10.9	($kg/m^2 \cdot a$)	60.0	(kg·a)
herbaceous ground cover	0.4	($kg/m^2 \cdot a$)	/	/
evergreen plant	4.2	($kg/m^2 \cdot a$)	109.1	(kg·a)
deciduous plant	5.0	($kg/m^2 \cdot a$)	147.3	(kg·a)

Vegetation planting structure: The design strategy for vegetation planting structures in rural courtyards should first focus on constructing multi-layered complex plant communities through three-dimensional matching of trees, shrubs, and herbs. It should prioritize the preservation of native vegetation and adopt naturalistic planting methods not only to achieve a balance between carbon sequestration effects and landscape aesthetics, but also to maintain the natural ecological attributes of rural courtyards. Studies have shown (Table 8) that plant communities with complex structures exhibit higher carbon sequestration efficiency per unit area and have more advantages in landscape presentation. Through a three-dimensional configuration of trees, shrubs, and herbs, not only can the long-term carbon sequestration effects of plant communities be enhanced, but also the landscape

ornamental value can be improved by leveraging rich vertical layers. In addition, the carbon sequestration potential of native vegetation is significantly higher than that of single-type artificial forests. Therefore, in the construction of courtyard green space landscapes, preserving native vegetation, adopting naturalistic planting methods, and reducing human intervention are effective pathways to enhance carbon sequestration functions and ecological value [34].

Table 8. Carbon sequestration capacity of different vegetation structures.

Vegetation Structure	Carbon Sequestration Per Unit Area	Unit
arbor–bush–herbaceous	29.60	($kg/m^2 \cdot a$)
bush–herbaceous	4.30	($kg/m^2 \cdot a$)
arbor–herbaceous	7.10	($kg/m^2 \cdot a$)
herbaceous	0.75	($kg/m^2 \cdot a$)

3.2.5. Carbon-Negative Technology Utilization Design

Ground-source heat pump system: Applying emerging technologies and leveraging carbon-negative innovations serve as the core technical support and driving force for constructing rural carbon-negative courtyards. For winter heating: Low-temperature liquid refrigerant first circulates in underground pipelines, absorbs heat from the constant-temperature layer, and evaporates to capture heat. The refrigerant then enters an indoor compressor and is pressurized into high-temperature, high-pressure gas. This gas condenses and releases heat in an indoor heat exchanger, transferring heat to circulating water to power floor heating or fan coil systems for space heating, while the refrigerant itself condenses into a high-pressure liquid. Finally, the high-pressure liquid is depressurized via a throttling device to revert it to a low-temperature, low-pressure liquid, which returns to underground pipelines to complete the cycle. For summer heat storage, the system operates in reverse: Refrigerant evaporates and absorbs heat indoors, then condenses and releases heat underground, extracting indoor heat and dissipating it into the soil. At this stage, the earth acts as an efficient heat sink for cooling, forming a closed-loop energy utilization mode of "heat extraction in winter and heat storage in summer."

4. Discussion

4.1. Research Status of Carbon-Negative Design

A growing number of scholars have shown increasing interest in research in the field of carbon-negative design. Mari Ariluoma conducted a study on the carbon sequestration and storage potential of urban green spaces in residential courtyards of urban areas. She aimed to identify effective methods to enhance the carbon sink and storage potential of courtyards, explore their significance at the urban level, and provide recommendations and support for the sustainable planning of urban green spaces from the perspective of climate change mitigation [35]. Mairéad Connolly's article argues that understanding household carbon emissions is a critical component of developing climate mitigation strategies to achieve the goals of the Paris Agreement. Yet there is a paucity of analytical research on consumption patterns and associated carbon emissions among urban and rural residents in developing countries [36]. Zhao points out that cities, as concentrated areas of human energy activities and carbon emissions, have profound impacts on the global carbon cycle and climate change. Conducting research on urban carbon cycles and the carbon balance helps researchers deeply understand the status and role of cities in the process of regional carbon cycles [37]. Zhang shifted the focus of carbon emission reduction research from cities to rural areas, arguing that rural emission reduction and sink enhancement are some of the key measures to achieve the dual carbon goals [38]. This

study focuses on implementation strategies for carbon-negative landscape construction from the initial design stage, aiming to mitigate the ecological impacts associated with high carbon emissions from rural areas in Nanjing, Jiangsu Province, China. It seeks to reduce rural carbon emissions and support regional ecological restoration and sustainable development under the "dual carbon" framework.

4.2. Analysis of Uncertainties and Limitations

Although the carbon accounting system and design scheme for rural carbon-negative courtyards constructed in this study are feasible in both theory and practice, there are still the following uncertainties and limitations:

Insufficient data representativeness: The carbon accounting data are mainly derived from statistical yearbooks and surveys/estimates of individual courtyards in Nanjing, Jiangsu Province, China. In some rural areas, statistical data are missing or insufficient in accuracy, and the lack of support from large-sample, cross-regional long-term monitoring data may lead to deviations in data representativeness. The average coefficients from IPCC guidelines and official documents are adopted for emission factors, which makes it difficult to accurately reflect the differentiated impacts of regional climate, planting structure, and soil type on the carbon sequestration rate of farmland/soil and the carbon fixation coefficient of ponds [20,39].

Limitations in regional adaptability: The research cases are developed based on the courtyard characteristics in the Nanjing region, where land-use structures, climatic conditions, and production modes are region-specific, limiting the broader applicability of the proposed carbon-negative strategies [30]. The calculation of emission reductions from photovoltaic systems and ground-source heat pumps in residential areas is based on efficiency parameters under ideal working conditions, without considering actual operating losses such as equipment aging and extreme weather [25]; the quantification of carbon sequestration effects of traditional ecological wisdom is only based on a review of the existing literature, lacking support from long-term fixed-point monitoring data, and the estimation of carbon sequestration potential has a certain subjectivity.

4.3. Policy Recommendations and Future Prospects

Based on the findings of this study, the following policy recommendations and future research directions are proposed to advance the implementation of rural carbon-negative courtyards:

Establish a regionally differentiated carbon-negative technology system. Conduct comparative studies on carbon accounting and carbon-negative design of rural courtyards across different climate zones and economic development levels. Targeting the high carbon emission share of residential areas, introduce renewable energy subsidy policies to lower the cost threshold for rural households to install renewable energy systems. Meanwhile, formulate technology lists aligned with regional resource endowments: prioritize photovoltaic technology promotion in sun-abundant northern regions, and give precedence to ground-source heat pumps and pond carbon sink systems in water-rich southern regions [5].

Build a collaborative incentive mechanism integrating technology, ecology, and society. Investigate rural residents' acceptance of and willingness to pay for carbon-negative technologies, analyze the impact mechanism of socio-cultural factors on the implementation of carbon-negative courtyards, and comprehensively consider technical feasibility, ecological benefits, and social equity [34]. Encourage the use of local eco-friendly materials and carbon-negative building materials in courtyard construction, and provide tax reductions or building material subsidies for courtyards adopting low-emission materials. For

agricultural production, promote integrated planting and breeding circular models, and offer ecological compensation for courtyard breeding projects that achieve waste resource utilization [6].

Develop a full-chain rural carbon management system. Establish long-term fixed monitoring sites for rural courtyard carbon cycles to obtain continuous carbon emission and carbon sink data, and optimize the accuracy of accounting parameters. Develop a dynamic simulation model of courtyard carbon budget, considering the impacts of climate change, technology upgrading, and residents' behavioral changes to predict courtyard carbon balance trends under different scenarios [40]. Launch rural carbon-negative courtyard demonstration projects, award the title of "green courtyard" to those meeting carbon-negative standards, and strengthen rural residents' carbon literacy education through technical training and case demonstrations to enhance their awareness and acceptance of carbon-negative technologies.

Optimize precise carbon-negative design methods. Compare the application effects of different carbon accounting models (e.g., life cycle assessment, input-output analysis) at the rural courtyard scale, and analyze their advantages, disadvantages, and applicable scenarios. Meanwhile, conduct scenario simulations of multiple carbon-negative technology combinations, evaluate the relative emission reduction benefits of different measures, and provide more targeted solutions for courtyard carbon-negative design [41].

This study provides technical support from a micro perspective for the achievement of rural carbon peaking and carbon neutrality goals by constructing a courtyard-scale carbon accounting framework and carbon-negative design pathways. In the future, it is necessary to further break through regional limitations, strengthen data foundations, integrate social dimensions, promote the transformation of rural carbon-negative courtyards from theoretical research to widespread practice, and contribute to rural green transformation and sustainable development.

5. Conclusions

To explore the planning practice of carbon-negative rural courtyards, this paper constructs a carbon emission accounting system for rural courtyards, evaluates the accounting results, analyzes the courtyard emission characteristics, explores the implementation paths of carbon-negative rural courtyards under the "dual carbon" goals, and ultimately achieves negative emissions in a courtyard. Thus, the following conclusions are drawn:

(1) In terms of carbon emission accounting: The courtyard land space is classified by use into carbon sink spaces (e.g., woodlands and water areas) and carbon source spaces (e.g., cultivated land, breeding areas, and residential areas).

(2) In terms of carbon-negative implementation paths: Combining the main sources of carbon emissions, measures such as building green buildings, optimizing energy structures, promoting resource recycling, and enhancing green space carbon sinks are proposed.

(3) In terms of carbon-negative transformation and development: Guided by green, ecological, and smart principles, the relationship between economic development and ecological civilization construction is coordinated to build ecologically friendly carbon-negative rural courtyards.

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Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found in the China Energy Statistical Yearbook and the IPCC Guidelines for National Greenhouse Gas Inventories.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1. Accounting Scope

The Greenhouse Effect is primarily caused by greenhouse gases (GHGs) such as CO_2, CH_4, N_2O, and CFCS, among which CO_2 accounts for approximately 77%. Therefore, carbon accounting centers on the emission and absorption of CO_2. To standardize accounting results, CH_4 and N_2O are calculated using the conversion factors specified in the IPCC Fourth Assessment Report: the conversion factor of CH_4 to CO_2 is $\varphi = 25$, and that of N_2O to CO_2 is $\varphi = 298$ [42,43]. The scope of emission accounting was proposed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) in the Greenhouse Gas Protocol, aiming to clarify emission boundaries, avoid double counting, and enhance the scientific rigor and consistency of accounting (Table A1) [40,41]. The accounting scope defined in this paper is Scope 1, i.e., direct emissions from carbon sources and demand-driven activities within the boundary, including production processes, stationary combustion, mobile combustion, and fugitive emissions.

Table A1. Summary of Scope 1, Scope 2, and Scope 3.

Emission Range	Definition	Composition
Scope 1	refers to direct emissions from carbon sources and demand-driven activities within the boundary data	production processes, stationary combustion, mobile combustion, fugitive emissions, and others
Scope 2	indirect emissions from purchased energy to meet activities within the boundary	purchased energy
Scope 3	other indirect emissions occurring in the value chain, including upstream emissions and downstream emissions	raw material extraction and production, transportation, purchased product use, sold product use, and others

Carbon accounting for rural courtyards adopts two classification frameworks: the source-based accounting method and the land-type accounting method.

The source-based accounting method divides accounting units according to the direct sources of carbon emissions and the absorption pathways of carbon sinks, tracing carbon processes to specific production and living activities. Combining the characteristics of rural courtyards, carbon accounting is conducted from three dimensions—carbon sources from production activities, carbon sources from living activities, and carbon sink sources—covering agricultural material input, planting activities, livestock and poultry breeding, residential energy consumption, crop photosynthesis, and carbon sequestration by forest and grassland vegetation in the courtyard. This method directly identifies high-emission links corresponding to human activities, thereby formulating targeted emission reduction measures.

The land-type accounting method classifies accounting based on land-use types related to carbon emissions/carbon sinks, focusing on differences in spatial carriers. In this paper, in accordance with the current land-use classification (GB/T 21010-2017) and combined with rural realities [44], the spaces of carbon emission/carbon absorption in the courtyard are categorized by use into carbon sink spaces such as woodlands and water areas, as

well as carbon source spaces such as cultivated land, breeding areas, and residential areas. Carbon accounting is carried out for specific land types, and the carbon source intensity and carbon sink potential of different land types are analyzed.

Appendix A.2. Accounting Method

Data acquisition for rural courtyard carbon accounting: Considering the practical context of rural development, this study adopts a bottom-up data collection approach for activity-level data related to greenhouse gas (GHG) emissions. The specific data sources include two components: existing statistical data extracted from statistical yearbooks and primary data obtained through field surveys. In cases where both types of data are unavailable, data are determined through expert judgment by functional departments or relevant industry specialists, which are then integrated to form the foundational data set for rural courtyard carbon accounting. The selection of emission factors strictly adheres to the technical framework outlined in the IPCC guidelines. The primary references include official documents and peer-reviewed studies such as the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [10], 2019 refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [45], China Energy Statistical Yearbook 2022 [46], and guidelines for compilation of provincial greenhouse gas inventories (Trial) [47]. Notably, some factors, which are influenced by multiple parameters, need to be calculated based on region-specific actual values to ensure accuracy.

This study integrates the source accounting method and land-use type accounting method, using specific carbon sinks/sources as the accounting categories to conduct comprehensive rural courtyard carbon accounting. It reflects the emission characteristics of rural courtyards through land-use types and presents a detailed classification of courtyard carbon sources and sinks.

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