

Article

Regional CO₂ Budget and Abatement Countermeasures for Forest Scenic Spots: A Case Study of the Shenyang National Forest Park

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Abstract: We used the carbon carrying capacity as an indicator of environmental productivity, clarified the emission reduction thresholds and measures for achieving a carbon neutral tourism destination, and proposed a simple, objective, and universal method for estimating the carbon budget of forest tourism scenic spots with function of both carbon sinks and carbon emissions. According to the Intergovernmental Panel on Climate Change Guidelines for Greenhouse Gas Inventories and the Climate Friendly Parks tool, a carbon emissions list with a clear border and relatively complete content was established to characterize the negative impact of tourism activities on the environment. Forest resource inventory data and the CO₂Fix method could be used to accurately calculate the carbon sinks of forest tourism scenic spots. In 2019, the total CO₂ emissions in Shenyang National Forest Park were 1841.445 t. The amount of CO₂ sequestered by the forest was 1336.787 t, accounting for 72.59% of the total CO₂ emissions. Thus, tourism had a net CO₂ deficit of 504.658 t. Electricity consumption, garbage disposal, raw coal consumption, infrastructure construction, and land-use changes of forestland were the top five sources of CO₂ emissions. The augmentation of the carbon pool could be improved by 65.358% of the total budget through forest management. The reduction aims of 133.41%–150.32% could be easily reached through emissions-cutting measures. Based on these results, we suggest several measures for low-carbon sustainable tourism.

Keywords: forest tourism; carbon capacity; carbon emissions list; CO₂Fix method; reduction countermeasures



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1. Introduction

National forest parks not only bear the important responsibility of protecting key eco-environments and landscapes, but must also meet the needs of public sightseeing and recreation [1]. The number of visitors to the China Forest Park has increased rapidly. In 2019, the number reached 1.8 billion, accounting for 20% of the total number of domestic tourists. China's forest tourism has been conducted following the traditional tourism model. Energy use in tourism activities, especially fossil fuel energy, has produced a large amount of greenhouse gas emissions [2]. This contrasted starkly with global efforts to curb CO₂ emissions in all sectors. To reduce the pressure on the environment, the United Nations World Tourism Organization has endorsed carbon-free destinations as an avenue to deal with the problem of increasing emissions due to tourism, which is likely to become an important new concept and tool within the sustainable tourism paradigm. Potential tourism destinations may profit from following a three-step procedure to achieve carbon neutrality: measurement, decarbonizing, and offsetting [3]. Countries such as Norway and New Zealand developed carbon balance strategies for tourism development and have adopted effective measures to reduce greenhouse gas emissions. The CO₂ emissions in forest scenic areas can usually be compensated for by projects such as afforestation or forest

management. Controlling CO₂ emissions is an inevitable step for China to achieve its carbon reduction targets, and it will profoundly affect all sectors, including forest tourism. Determining the carbon carrying capacity threshold is the first step in forest tourism carbon management. Management of carbon emissions and carbon offsets are important ways of promoting the sustainable development of forest tourism.

The carrying capacity is the maximum that environmental resource levels can support before unacceptable changes occur in the system [4,5], and is an indicator of environmental productivity. Carbon carrying capacity is the ability of the regional carbon sinks to offset CO₂ emissions during a certain period, and is contingent on the interactions between travel activities and the forest environment. It would be impossible to determine the carbon carrying capacity of an area over the long run because the consequences of both tourism activity and the biological evolution of forests are inherently difficult to quantify and may fluctuate. However, for a certain period, using environmental carrying capacity indicators to judge whether the scale or intensity of tourism activities is too great is still of positive significance. A forest tourism scenic spot has the dual attributes of being a carbon source and a carbon sink. Transportation, accommodations, and tourism services in forest scenic spots generate CO₂ emissions. A series of problems that are related to CO₂ emissions, such as climate disturbances and a decrease in biodiversity, pose a challenge to the ecological environment of the forest. CO₂ emissions can characterize the negative impacts of tourism activities on the ecological environment well [6]. However, forest ecosystems serve as carbon sinks, and the forest, water areas, and plantation in forest scenic area have a CO₂ sequestration capacity. The measures we can take to curb climate change include reducing greenhouse gas emissions and increasing CO₂ absorption. Within forest tourism scenic spots, we need to comprehensively consider the CO₂ emissions and sinks, calculate the threshold of the carbon carrying capacity, and use this threshold as the goal for low-carbon emission reduction measures. Regional CO₂ sequestration analysis and the subsequent integration of possible CO₂ sinks into a portfolio of measures may be vital to establishing effective regional CO₂ policies [7].

In order to monitor CO₂ emissions and determine appropriate emission reduction measures for specific areas, it is necessary to comprehensively consider CO₂ emissions and absorption [8]. Many studies have focused on the carbon carrying capacity of natural tourism scenic spots. However, these studies did not devote enough attention to the boundaries of the CO₂ emissions in the scenic spot and the specific items on the emission inventory.

One of the difficulties in estimating the tourism carbon carrying capacity is to define the boundaries of the CO₂ emissions in the forest scenic spot. In 2004 the Environmental Protection Agency, working under the auspices of the Climate Friendly Parks initiative, developed the Climate Leadership in Parks (CLIP) tool to estimate the greenhouse gas (GHG) emissions in national parks. The resulting inventory included three scopes. Scope 1 included direct emissions inside the boundary from transportation, fuel use, and waste water treatment. Scope 2 included the emissions outside the boundary from electricity production. Scope 3 included emissions due to visitors using personal vehicles within the park. The World Resources Institute (WRI) has adopted a classification to delimit the scope of GHG inventories. Scopes 1 and 2 are like those of the CLIP, but scope 3 emissions are defined as upstream emissions due to electricity and fossil fuel use and upstream and downstream emissions associated with key urban materials such as food and cement [9].

Villalba used a life cycle-based approach, which was consistent with the WRI's scope 3 extended GHG emissions inventory, to estimate the total emissions of Yosemite National Park. Scope 3 included the upstream and downstream emissions, which accounted for 29.98% of the total emissions in 2011 [10]. Ding studied the carbon budget of Hongcun, a rural tourist destination, using different measurement calibers (whether it measured CO₂ emissions from external traffic out of scenic spots). Without considering external traffic, the net CO₂ emissions were 13.47 t. When external traffic was considered, the CO₂ emissions increased to 89,090 t. Thus, the statistical boundary of the CO₂ emissions

had a great influence on the estimation results [11]. Chan estimated the amount of CO₂ emitted from tourism activities related to the Oak Valley Resort in Wonju, Korea, in 2006. The total annual carbon emissions were estimated to be 8453 t yr⁻¹, and the boundary of the transportation carbon emissions extended from the visitors' homes to the scenic area [12]. Zhang established a list of CO₂ emissions, including tourists and residents around the scenic spot, to estimate the carbon emissions of the tourism in the Wutai Mountain scenic spot [13].

Scholars have proposed different metrics. The total GHG emissions attributed to a certain area may be developed based on the definition of the spatial boundary or on a life cycle perspective [9,14]. However, the life cycle metric is suitable for estimating tourism industry GHG emissions. For areas with clear geographical boundaries, such as the Oak Valley Resort and Yosemite National Park, the spatial boundary should be used for the estimate, not a life cycle perspective; otherwise, the scenic area's CO₂ emissions would be overestimated.

Another difficulty in tourist destination carbon emissions inventory calculations is carbon source identification. Approaches focused on direct emissions, such as energy use and waste disposal within the geographic boundaries, are frequently used [11,15]. However, only emissions due to the use of fossil fuel energy and waste disposal ignore several important carbon emission sources. Scholars have broadened the scope of research on carbon sources and have proposed a detailed carbon budget for tourism areas. Walz et al. presented a detailed regional CO₂ budget for the Alpine tourist region. The total CO₂ emissions were 109,300 t in 2005. About 79.3% of these emissions originated from heating activities, 17.9% from mobility, 2.8% from machines, and 0.1% from other activities [7]. Tang et al. proposed a factor decomposition model for analyzing destination carbon emissions. The total energy consumption was measured through both direct and indirect energy consumption. The direct energy consumption included transportation, accommodations, catering, sight-seeing, shopping, and entertainment carbon emissions. The indirect GHG emissions were the carbon emissions produced during the construction of the buildings and roads [16]. The accounting of the CO₂ emission inventory includes the CO₂ emissions generated during the development and construction stage, which provided ideas for the improvements to the quality of the carbon emission inventory made in this study.

The accuracy of existing studies with regard to estimating forest carbon sinks needs to be improved. Chan used light detection and ranging remote sensing data to estimate carbon sequestration in forests. This is an advanced method, but it is very difficult to perform in social science research [12]. Most studies are based on preliminary estimates of the annual net changes in the global or national carbon pools based on existing studies, and they estimate the amount of carbon sequestration using a comparison between the destination land area and the existing literature research area [11,13]. These research methods can produce inaccurate results. Some documents only estimate the carbon sink of vegetation, without considering the contribution of soil carbon sequestration [12,17]. Therefore, a great deal of work needs to be done to improve the estimation of carbon sinks in forest tourist attractions.

Forest tourism scenic spots have the dual attributes of being carbon sources and carbon sinks. A single level analysis can easily lead to one-sided research conclusions. Therefore, it is necessary to combine the two in research. In this study, the following improvements were made: (1) a clear boundary and comprehensive CO₂ emission inventory was established that is suitable for research on carbon emissions in forest tourism scenic spots; (2) A new theoretical approach was used to measure the reasonable environmental impact threshold of tourism activities and to assess the carbon carrying capacity of the area. This will impact forest tourism scenic spots and improve the response to national environmental regulations.

2. Study Area and Data Collection

Shenyang is located in the central part of Liaoning Province and is the capital city of Liaoning Province (41°11'45''–43°3'13'' N, 122°25'9''–123°48'24'' E). Shenyang National

Forest Park is in the peri-urban area of the city of Shenyang. The 933.3 ha forest park consists of hotels, restaurants, picking farms, and an international ski resort. It is covered by 577 ha of natural secondary forest, and tourists can enter the scenic area by car and bus. In 2019, almost 190,000 tourists visited the park, 72% of which came from Shenyang and surrounding cities (see Figure 1).

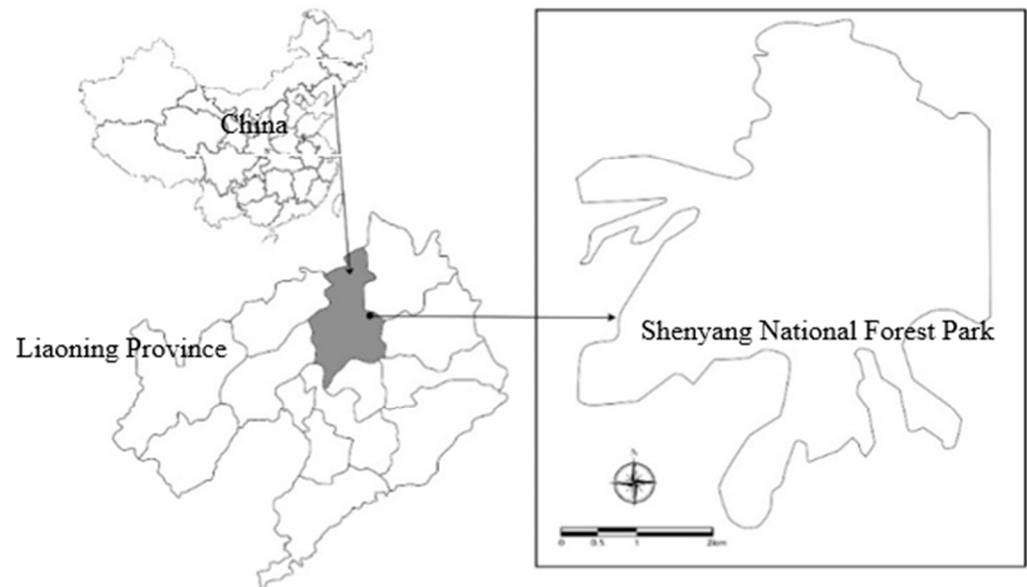


Figure 1. The location of Shenyang National Forest Park.

The data used in this study were primarily obtained through field investigations. The survey objects and data were as follows. First, the forest resources inventory data, the total area and construction type of the infrastructure such as hotels and roads, the annual energy consumption and waste disposal, and the annual public transportation energy consumption within the boundary of the park were obtained from the Park Administrative Committee. Second, the tourism enterprises inside the scenic area, such as catering, accommodations, shopping, and entertainment, provided the annual energy consumption data. Third, the tourist energy consumption data for the traffic inside the park were obtained using the random sampling method. A total of 372 respondents completed the survey questionnaires. The other tourist energy consumption data, such as consumption through restaurants and entertainment, were obtained during the second stage of the research.

3. Methods

3.1. Research System

The CO₂ budget of forest tourism scenic spots includes two aspects: carbon emissions and carbon sinks. In order to establish a budget that reflects the typical regional structures, we used a bottom-up approach and used data collected within the region. In this study, the geographical boundary of the forest tourism scenic area was used as the CO₂ emission estimation boundary and the direct CO₂ emissions and embodied emissions in the scenic area were used as the accounting content of the carbon emission inventory. First, the direct CO₂ emissions included emissions that occurred in the scenic spots due to infrastructure construction, daily operations of the park's administrative committee and enterprises, and tourist activities. Second, the embodied CO₂ emissions refer to the important indirect CO₂ emissions in scenic spots. Due to the breadth, depth, and complexity of the indirect carbon emissions, it was unrealistic to adopt a full life cycle method to calculate the CO₂ emissions. There is currently a lack of research on indirect CO₂ emissions in scenic spots; however, similar research on city CO₂ emissions and the CFP tool provide a clear research methodology. Considering the data acquisition situation, only the main indirect CO₂ emissions need to be studied. The CO₂ emissions related to electricity and heating were

not within the boundary of the scenic spot, but their upstream production consumed a large amount of fossil fuels, so they were recognized as the main source of CO₂ emissions. Moreover, they have generally been classified as the embodied emissions of the study area [18]. The calculation of the indirect carbon emissions related to the water supply, wastewater, and waste also followed this idea and these sources were classified as embodied emissions. This does not include the indirect CO₂ emissions produced in the materialization stage, such as in the supply of various tourism commodities, raw materials for catering, and construction materials.

The other aspect of research on the carbon carrying capacity of forest tourism scenic spots is measuring the regional carbon removal capacity, that is, the carbon sinks. The ecosystems with carbon sink functions in scenic spots include forest ecosystems, grassland ecosystems, agricultural ecosystems, and water ecosystems. Among them, forest ecosystems were the main factors. The calculation of these carbon sinks requires the comprehensive estimation of the above-ground biomass carbon pools, the underground biomass, and the annual changes in the soil carbon pools. Consequently, a research system for calculating the carbon carrying capacity of forest tourism scenic spots was constructed (Figure 2).

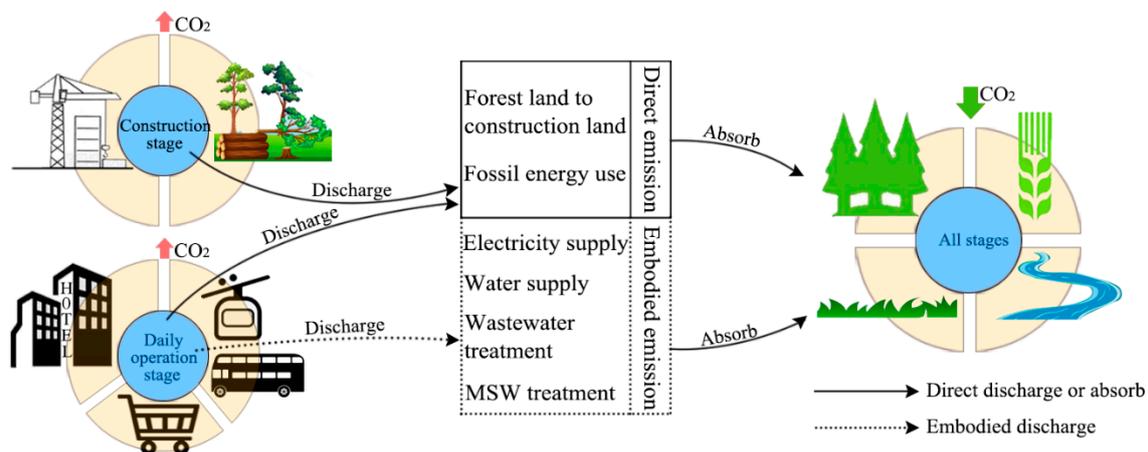


Figure 2. Framework of the carbon carrying capacity in forest scenic spots.

3.2. Method of Determining the Annual CO₂ Emissions Inventory of Forest Scenic Spots

According to the city CO₂ emissions method and the CFP tool, the annual CO₂ emissions of forest tourism scenic spots can be expressed as Equation (1):

$$C_{\text{annual-emissions}} = C_C + C_E + C_D \quad (1)$$

where $C_{\text{annual-emissions}}$ is the annual emissions of the scenic spot; C_C is the average annual CO₂ emissions of the infrastructure construction stage; and C_E is the annual CO₂ emissions from energy consumption, which occurred in both the infrastructure construction stage and the daily operation stage. C_D is the annual embodied emissions, including indirect emissions due to electricity, water, wastewater, and municipal solid waste (MSW) treatment.

3.2.1. C_C Annual Average CO₂ Emissions in the Infrastructure Construction Stage

C_C is the annual average CO₂ emissions in the construction stage, which includes two parts: the emissions due to land use conversion from forest land to settled land, and direct energy consumption during the construction of buildings and roads inside the park. This is expressed by Equation (2):

$$C_C = C_H + C_R + C_F \quad (2)$$

Then, it can be expressed in more detail as Equation (3):

$$C_c = \sum_{h=1}^3 S_h \times c_h + \sum_{r=1}^3 S_r \times c_r + S_f \times c_f \div N \div T_C \quad (3)$$

where C_H and C_R are the average annual CO_2 emissions related to houses and roads during the construction stage, respectively (kg CO_2), and C_F is the average annual CO_2 emissions due to land use conversion from forest land to settled land (kg CO_2). S_h is the area covered by different types of buildings (m^2); C_h is the average annual CO_2 emissions per unit area ($\text{kg CO}_2 \text{ m}^{-2} \text{ yr}^{-1}$) of the different types of housing during the construction stage; S_r is the area of the different types of roads (m^2); C_r is the average annual CO_2 emissions per unit area ($\text{kg CO}_2 \text{ m}^{-2} \text{ yr}^{-1}$) during the construction of different types of roads; S_f is the area converted from forest land to settled land (m^2); and C_f is the average annual loss of biomass due to the conversion of forest land to settled land per unit area (kg C m^{-2}). N is 20 years. T_C is 12/44 for the conversion of C from CO_2 based on the ratio of their molecular weights.

C_F is the annual average CO_2 emissions due to the conversion of forest land to settled land, and it is described in detail below. First, according to the Intergovernmental Panel on Climate Change (IPCC) Guidelines for national greenhouse gas inventories, 20 years is the default length of carbon stock changes caused by land use conversion from forest land to settled land. Second, the net loss of the total forest ecosystem carbon stocks was used to estimate the CO_2 emissions into the atmosphere. These consisted of the above-ground biomass and the below-ground biomass and the changes in the soil carbon pools. As was suggested by Wu et al. [19], the conversion of forest land to farmland and grassland (picking farm and lawns inside the forest tourism scenic spot) can cause the overall loss of above-ground and under-ground biomass, reducing the soil carbon storage by 60 and 36%, respectively, compared to natural secondary forests. The average total loss of carbon emissions caused by biomass loss was $23.691 \text{ t C ha yr}^{-1}$, and the average carbon emissions from the soils were calculated to be $51.124 \text{ t C ha yr}^{-1}$ according to the CO_2Fix model. Table 5 shows the data sources input during the calculation process.

$C_H + C_R$ are the annual average CO_2 emissions during the infrastructure construction stage, which were calculated based on data compiled from the literature. In this study, the average annual CO_2 emissions during the construction period were calculated based on the model for building life cycle carbon emissions [20–22]. Shenyang National Forest Park is in northeastern China, where the service life of houses is 50 years. The average annual CO_2 emissions during the construction phase of wooden structures, light steel structures, and steel–concrete structures were 0.069, 0.111, and $0.135 \text{ kg CO}_2 \text{ m}^{-2} \text{ yr}^{-1}$, respectively. The service life of roads and viewing platforms are 20 years. The average annual CO_2 emissions during the construction of asphalt roads, concrete roads and platforms, and cement based composite roads were 1.318, 2.033, and $0.210 \text{ kg CO}_2 \text{ m}^{-2} \text{ yr}^{-1}$, respectively.

3.2.2. C_E Energy Consumption CO_2 Emissions

The C_E includes two parts: direct CO_2 emissions from fossil fuel energy consumption and indirect energy consumption through electricity in the scenic area. All the energy consumed by the park management, tourism enterprises, and tourists generate carbon emissions. First, through a survey of the park's administrative committee and tourism enterprises, the annual consumption data for raw coal, gasoline, diesel, liquefied petroleum gas (LPG), and electricity were obtained and the CO_2 emissions were estimated. Second, through a random sampling survey of tourists, the average travel distance of individual tourists traveling in scenic spots was obtained, and the carbon emissions due to the tourists' transportation energy consumption was calculated. The energy consumption of the public transportation used by tourists in the scenic area, such as buses and cruise ships, was

counted in the energy consumption data of the enterprises in the scenic area. C_E can be expressed as Equation (4):

$$C_E = \sum_{j=1}^3 \sum_{i=1}^5 B_{ij} \times EF_i \quad (4)$$

where C_E is the annual energy consumption CO₂ emissions (kg CO₂); B is the annual energy consumption (kg or kW·h); EF is the carbon emissions coefficient (kg CO₂ kg⁻¹ or kW·h); j represents the administrative committee, tourism enterprises, and tourists in the scenic spot, and i represents the five energy sources: raw coal, gasoline, diesel, LPG, and electricity.

3.2.3. C_D Water and MSW Embodied CO₂ Emissions

C_D is the annual water and MSW embodied emissions including three parts: indirect CO₂ emissions related to the water supply, wastewater treatment, and MSW treatment. Through a survey of the park's administrative committee and tourism enterprises, the annual water consumption data and garbage removal data were obtained. This paper summarizes the energy consumption embodied CO₂ emissions related to water extraction, water production, and water transport based on the existing literature [23]. During the water treatment process in the sewage treatment plant, the biological treatment process generates CO₂ emissions. CO₂ emissions are also generated due to the electricity consumption during the treatment process. Based on the existing literature, the CO₂ emissions from wastewater treatment are 0.837 kg CO₂ m⁻³. Since 2017, the treatment of garbage in Shenyang has transitioned to centralized cleaning, incineration, and power generation. According to the literature, the calculated CO₂ emissions coefficient per unit of garbage is 0.561 kg CO₂ kg⁻¹ [24].

Equation (5) for calculating the embodied CO₂ emissions related to the water supply, garbage treatment, and sewage treatment is:

$$C_D = \sum_{k=1}^3 S_k \times EF_k \quad (5)$$

where C_D is the embodied CO₂ emissions (kg CO₂) related to the water supply, garbage treatment, and sewage treatment in the scenic area; S is the water, sewage discharge, and garbage removal (m³ or kg) used in the scenic area each year; and EF is the CO₂ emissions coefficient (kg CO₂ m⁻³ or kg⁻¹) for the water supply, sewage treatment, and garbage treatment.

3.3. Method of Measuring the Annual CO₂ Sinks of Forest Tourism Scenic Spots

The area accounted for by grassland, arable land, and water in Shenyang National Forest Park is very small, so the influences of carbon sinks can be almost ignored. The carbon removal function of the tourist area depends on the forest ecosystem. Therefore, in this study, only the carbon sinks in the forest ecosystem were measured, and the carbon storage was calculated using the CO2Fix3.2 model. The CO2Fix model is a model that quantifies the C stocks and fluxes in forests, plantations, and multistate agroforestry [25]. It calculates the changes in the C pools in the biomass, soil (litter and humus), and wood products with a time-step of one year using the carbon accounting approach, in which the accumulated biomass is converted into C sequestration and storage [26]. The forest resources in the scenic spot are public welfare forests, in which logging is prohibited. Therefore, the wood products carbon pool was not considered, and only the biological carbon pool and the soil carbon pool were measured. The model requires data for the stem volume growth, the associated fraction allocation of the biomass compartments (foliage, branches, and roots), and the climate. The input data used for the model were obtained from the following. First, the tree species and age were obtained from the forest inventory data provided by the Shenyang National Forest Park's administrative committee. Second, the tree biomass and litter parameters were obtained according to comparison data collected

in a similar climatic zone in northern China. The current annual increment (CAI) of the trees was based on previous research data collected by our research team members [27–30]. According to the logistic growth equations for calculating the relationship between the biomass density and forest age of various forest types [31], we obtained the initial carbon density. The data for the growth rate of the branches, leaves, and roots relative to the trunk used in the CO2Fix model were obtained from Ben’s research [32]. The C stocks in the living biomass were estimated using a cohort module approach. Third, the average monthly temperature, annual precipitation, and evapotranspiration for the soil module input data was obtained from the World Bank web and the details are provided in Table 5. The output data was the biomass carbon storage, soil carbon storage, and forest ecosystem carbon storage per hectare. It could be obtained by Equation (6):

$$C_{\text{annual-sinks}} = (C_{t+1} - C_t) \div T_C \quad (6)$$

where C_t is the carbon storage of the forest ecosystem for one year; $C_{t+1} - C_t$ is the annual change in the forest ecosystem’s carbon storage; and T_C is 12/44.

3.4. Evaluation of the Status of the Carbon Budget

The CO₂ budget focuses on CO₂ emissions and sinks within the forest park and can be obtained by Equation (7). Based on the discussions in Sections 3.2 and 3.3, we can calculate the carbon balance situation of the forest scenic spot:

$$C_{\text{ED}} \text{ OR } C_{\text{ES}} = C_{\text{annual-emissions}} - C_{\text{annual-sinks}} \quad (7)$$

The difference between $C_{\text{annual-emissions}}$ and $C_{\text{annual-sinks}}$ is the conclusion of the budget. If $C_{\text{annual-emissions}}$ is less than $C_{\text{annual-sinks}}$, there is a carbon surplus (C_{ES}). If $C_{\text{annual-emissions}}$ is greater than $C_{\text{annual-sinks}}$, there is a carbon deficit (C_{ED}). In order to achieve the goal of carbon-free destinations, C_{ED} was the quantitative target for reducing the CO₂ emissions of forest scenic spots.

4. Results

In 2019, the annual CO₂ emissions from Shenyang National Forest Park were 1841.445 t CO₂. The calculation process was as follows.

4.1. Results of the CO₂ emissions inventory of C_C

In 2019, the CO₂ emissions during the infrastructure construction stage were 303.77 t CO₂, accounting for 16.496% of the total emissions inventory (Table 1).

Table 1. Annual average CO₂ emissions of the infrastructure construction stage of the scenic spot.

Building Types	Emissions Standard ² (kg CO ₂ m ⁻² yr ⁻¹)	Building Construction				Land Use Change from Forestland to Settled Land				
		Facility Name ¹	Construction Year ¹	Area ¹ (m ²)	Lifetime ¹ (year)	CO ₂ Emissions (t CO ₂ yr ⁻¹)	Default Assumptions of Carbon Stock Changes (20 years)	Biomass Carbon Density Lost ³ (t C ha ⁻¹)	Soil Carbon Density Lost ³ (t C ha ⁻¹)	CO ₂ Emissions (t CO ₂ yr ⁻¹)
Reinforced concrete building c	0.135	New hotels and villas (2 story)	2000	4050	50	0.547	2000–2019	23.691	51.124	2.778
		Performance venue	2002	1339		0.181	2002–2021			1.837
		Office building (2 story)	2002	1015		0.137	2002–2021			0.697
		Landscape architecture	2003	6094		0.823	2003–2022			8.359
		Reserve room	2007	1038		0.140	2007–2026			1.424

Table 1. Cont.

Building Construction						Land Use Change from Forestland to Settled Land				
Building Types	Emissions Standard ² (kg CO ₂ m ⁻² yr ⁻¹)	Facility Name ¹	Construction Year ¹	Area ¹ (m ²)	Lifetime ¹ (year)	CO ₂ Emissions (t CO ₂ yr ⁻¹)	Default Assumptions of Carbon Stock Changes (20 years)	Biomass Carbon Density Lost ³ (t C ha ⁻¹)	Soil Carbon Density Lost ³ (t C ha ⁻¹)	CO ₂ Emissions (t CO ₂ yr ⁻¹)
Asphalt pavement	1.318	Primary road	2000	33,950	20	44.746	2000–2019			46.569
		Secondary road	2002	13,650		17.991	2002–2021			18.724
		Parking lots	2003	21,800		28.732	2003–2022			29.903
		Secondary road	2008	5950		7.842	2008–2027			8.162
		Parking lots for ski facility	2010	8500		11.203	2010–2029			11.659
Concrete pavement	2.033	Sales square	2001	2500	20	5.083	2001–2020			3.429
		Observation decks trails	2003	10,300		20.940	2003–2022			14.129
Farmland	0	Picking farm	2003	8500	-	0	2002–2021		30.674	8.473
Grassland	0	Lawn	2002	12,000	-	0	2003–2022		18.405	9.262
In 2019	-	-	-	-	-	138.365		-	-	165.405

¹ Infrastructure data for Shenyang National Forest Park, including completion date and building area. ² Data from literature, as shown in Section 3.2.1. ³ CO2Fix model output data. The area of forest land occupied by the two-story building is half of the building's area.

4.2. Results of the CO₂ Emissions Inventory of C_E

4.2.1. CO₂ Emissions from Tourists Driving Personal Vehicles in the Scenic Area

In 2019, 190,000 people visited the Shenyang National Forest Park. According to the tourist questionnaire, the average distance the tourists traveled in the scenic area and the number of vehicles entering the park were calculated. The CO₂ emissions from tourists' personal vehicles within the scenic area were 16.472 t CO₂ (Table 2), accounting for 0.895% of the total emissions inventory.

Table 2. CO₂ emissions list for transportation within the scenic spot.

	Percent of Tourists ¹ (%)	Percent of Vehicles into Park ¹ (%)	Avg. Number of Occupants Inside Vehicle ¹ (persons)	Vehicles into Park ¹ (10 ⁴ cars)	Avg. Travel Distance in the Park ¹ (km)	Carbon Emissions Factor ² (kg CO ₂ km ⁻¹)	CO ₂ Emissions (t CO ₂ yr ⁻¹)
Personal vehicles	61	78	3.740	2.417	3.180	0.208	15.987
Group tours buses	36	42	33.160	0.087	2.360	0.236	0.485
Total	-	-	-	-	-	-	16.472

¹ Calculated from tourist questionnaire data; ² Available online: <http://www.tanpaifang.com/>.

4.2.2. CO₂ Emissions Related to the Energy Consumption of the Park Operations

According to the annual energy consumption of the administrative committee and enterprises in the scenic spot, it was estimated that the CO₂ emissions generated by the energy consumption related to park operations were 1107.175 t CO₂, accounting for 60.125% of the total emissions inventory (See Table 3).

Table 3. CO₂ emissions list for the administrative committee and enterprises in the scenic spot.

	Raw Coal ¹ (kg)	Gasoline ¹ (kg)	Diesel Oil ¹ (kg)	LPG ¹ (kg)	Electricity ¹ (kW·h)	Total
Administrative committee	206,720	15,764	20,042	2166	435,887	-
Catering, accommodations, shopping, and entertainment enterprises	7000	3987	-	2560	66,000	-
Carbon emissions factor ² (kg CO ₂ kg ⁻¹ or kW·h)	1.900	2.925	3.096	3.101	1.129	-
CO ₂ emissions (t CO ₂ yr ⁻¹)	406.068	57.772	62.050	14.655	566.630	1107.175

¹ According to a survey of energy consumption conducted by the administrative committee and enterprises in the park. ² Available online: <http://www.tanpaifang.com/>. (Electricity carbon emissions factor according to Northeast Power.).

4.3. Results of the CO₂ Emissions Inventory of C_D

Based on the annual tap water consumption and garbage removal reported by the scenic spot administrative committee, the embodied CO₂ emissions of CD were 414.117 t CO₂, accounting for 22.489% of the total emissions inventory (See Table 4).

Table 4. Embodied CO₂ emissions list for water supply, wastewater, and MSW treatment.

	Water Consumption ¹ (m ³)	Wastewater/Water ² (%)	Wastewater Treatment ¹ (m ³)	MSW Treatment ¹ (kg)	Total
Administrative committee and enterprises	2737.5	0.8	2190	730,000	-
Carbon emissions factor ² (kg CO ₂ m ⁻³ or kg ⁻¹)	1.007	-	0.837	0.561	-
CO ₂ emissions (t CO ₂ yr ⁻¹)	2.757	-	1.83	409.53	414.117

¹According to a survey of the wastewater and MSW of Shenyang National Forest Park data. ²Data from the literature, as shown in Section 3.2.3.

4.4. Results of the Annual Carbon Sinks in the Forest Scenic Spot

The CO2Fix model version 3.2 was parameterized using the biomass and soil input data. The details are presented in Table 5. From this, we calculated the status of the carbon sinks in the forest ecosystem of the forest scenic spot in 2019.

Table 5. CO₂ sinks in the forest ecosystem in 2019.

	Starting Age (Year)	Area (ha)	Stems, Foliage, Branches, Roots Initial Carbon (t C ha ⁻¹)	Wood Density (dry mass) (t m ⁻³)	Foliage, Branches, Roots Turnover Rate (1 yr ⁻¹)	Foliage, Branches, Roots, Stems, Litter Fall (t ha ⁻¹ yr ⁻¹)	ΔC (t C ha ⁻¹)	CO ₂ Sinks (t CO ₂)
Data Sources	Forest Inventory Data		[31,33]	[34];	[34,35]	[36]	Output Data	-
Oak	28	28.00	16.6/0.8/3.9/5.9	0.68	1.0/0.05/0.08	2.78/0.57/0.04/0.10	0.97	99.583
	38	52.99	22.1/1.1/5.3/7.9				1.26	244.814
	43	67.60	25.1/1.2/6.0/7.9				0.95	235.473
Larch	43	3.90	36.5/1.6/4.0/15.3	0.49	0.05/1.0/0.1	1.02/0.87/0.17/0.03	4.18	59.774
Acacia	35	3.09	22.9/1.0/4.2/8.5	0.47	1.0/0.05/0.1	3.32/0.48/0.15/0.05	-1.33	-15.069
	38	1.10	24.9/1.0/4.5/9.2				-1.34	-5.400
	48	0.80	31.5/1.3/5.7/11.7				-1.43	-4.165
Northeast China ash	38	99.80	15.5/0.8/3.2/5.4	0.68	0.33/0.05/0.1	2.78/0.57/0.04/0.20	0.37	135.395
	43	9.80	17.0/0.9/3.4/5.9				1.03	37.011
Pinus tabulaeformis	18	44.80	10.9/0.5/1.2/4.6	0.36	0.33/0.05/0.1	1.43/0.57/0.04/1.03	-1.29	-211.900
	38	38.50	24.1/1.1/2.7/10.1				-0.02	-2.823
	43	126.20	25.7/1.1/2.8/10.8				0.51	235.994
	48	59.70	26.6/1.2/2.9/11.2				1.13	247.357
	53	40.30	27.2/1.2/2.9/11.4				1.90	280.743
Total	-	576.570	-	-	-	-	-	1336.787

4.5. Regional CO₂ Budget and Abatement Countermeasures for Forest Tourism Scenic Spots

4.5.1. Regional CO₂ Budget of the Forest Scenic Spot

The CO₂ budget indicates that the emissions were greater than the sinks; the deficit was about C_{ED} = 504.658 t CO₂. Although the CO₂ sinks in the forest ecosystems accounted for 1336.787 t, the total emissions were 1841.445 t CO₂ in 2019.

Based on the composition of the carbon emissions, about 303.77 t CO₂ were from the infrastructure construction stage (16.496%), 1123.558 t CO₂ were from energy consumption (61.015%), and 414.117 t CO₂ were from embodied CO₂ emissions (22.489%). Furthermore, among them, electricity consumption, MSW removal, raw coal consumption, conversion of forest land into construction land, and direct CO₂ emissions during the construction phase were among the top five on the carbon emission list, and thus, these factors should be the focus of the abatement countermeasures (Figure 3).

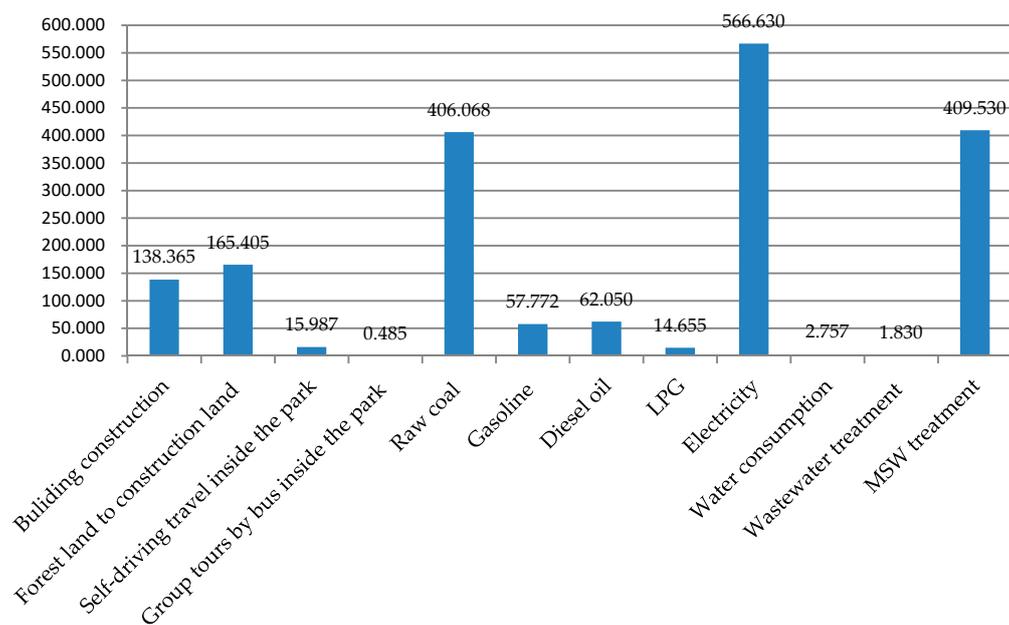


Figure 3. Total CO₂ emissions list.

4.5.2. Countermeasures and Their Impacts

Overall, the catalogue of measures encompasses about ten measures, of which the selection of five measures is discussed in this paper (Figure 3).

The management of secondary forests will improve the carbon balance of forest tourism scenic spots. The measures taken to improve forest management will increase the annual growth rate of the forest. If the growth rate increases by 5%, while the other input conditions remain unchanged [37], the results of the CO₂Fix3.2 model indicate that the carbon sink will increase by 329.833 t CO₂ and the carbon balance budget will increase by 65.358%.

Many emission reductions measures could improve the carbon balance of forest tourism scenic spots. In accordance with the findings on the CO₂ budget, measures related to electricity consumption will be the most efficient. Shenyang National Forest Park has a total indoor building area of 13,540 m² and an outdoor road and landscape area of 96,650 m². According to the lighting power density value (LPD limit, Wm⁻²) specified in the City Night Lighting Technical Specifications, the general commercial business lighting power density is 12 W m⁻² and the road lighting density is 0.6 W m⁻². Thus, for a daily lighting time of 4 hours, it is estimated that the electricity consumption is 321,816.120 kW·h. If LED lighting is used, it is estimated that the electricity consumption by lighting will be decreased by 50% [38]. After these renovations, it is expected that CO₂ emissions will be reduced by 181.665 t CO₂ and will improve the carbon balance by 35.997%.

The contribution of garbage disposal to the list is 22.240%. Shenyang National Forest Park has an average daily waste production of 2 t, of which perishable organic waste accounts for 33.7–40.6%. If it is composted for fermentation and used as fertilizer for the picking farm and trees, it is estimated that the CO₂ emissions will be reduced by 138.012–166.269 t CO₂, and the carbon balance budget will be improved by 27.347–32.947%.

The raw coal consumption of Shenyang National Forest Park is about 213.72 t per year. If the calorific value remains unchanged and raw coal is replaced with natural gas, the annual natural gas consumption will be 114,870 m³ and the CO₂ emissions will be 248.175 t, which will improve the carbon balance budget by 49.177%.

In addition, the CO₂ emissions due to land use changes from forest land to settled land were 303.77 t CO₂, contributing 16.496% to the inventory in 2019. For the conversion of forest land to construction land, the 20-year interval is taken as the default length of the carbon pool change transition period after the land use changes. Since the construction

period was concentrated from 2000 to 2010, the impact of the carbon emissions of the forest land use change will decrease after 2020, and the decline from 2020 to 2022 will be 105.434–162.508 t CO₂. If there is no additional infrastructure construction, the carbon budget balance will be improved by 20.892–32.202% (See Figure 4).

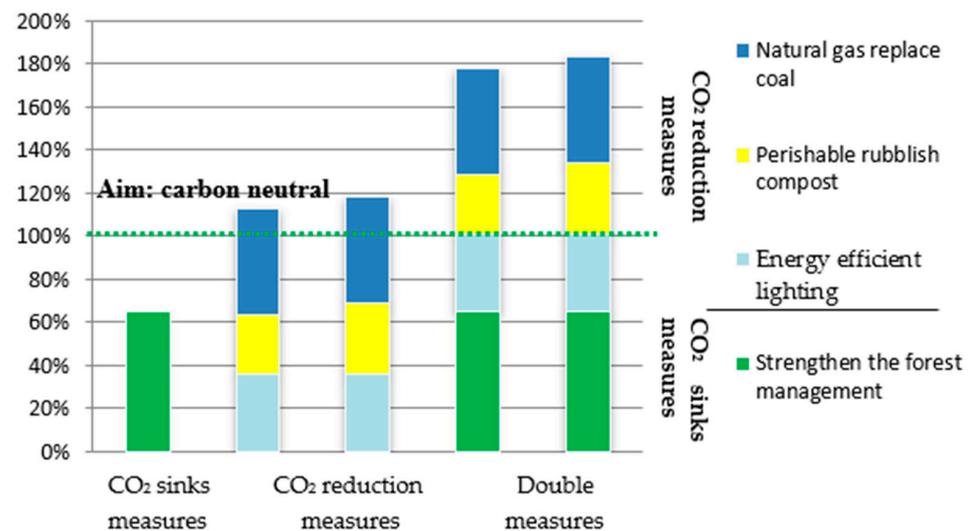


Figure 4. Different counter measures for improving the total budget.

5. Discussion

The regional CO₂ budget is an important basis for identifying the most efficient measures and policies for improving the CO₂ budget on a regional level and for quantifying their impacts in the future. The methodological framework of this study is laid out according to the IPCC guidelines for greenhouse gas inventories and the CFP tool. In order to increase the accuracy of the information and to establish a better basis for the comparison of future budgets for the same scenic spot, a bottom-up approach was used in this study. The emissions and sinks were drawn from various local information sources, which may reduce the comparability of the results to those of other studies. However, the results are accurate enough for a small-scale CO₂ budget study and will provide assistance for scenic spots managers to take specific emission reduction measures.

First, the system boundary defined in this study does not include the relevant CO₂ emissions related to commodities transported outside the scenic area, that is, the CO₂ emissions of commodity production and transportation were not considered. There are significant uncertainties in the commodities outside the scenic area, and its proportion of the total emissions was not large. This does not affect the accuracy of the emission inventory. Second, the emissions only considered the traffic within the study area. As a forest park, it is a popular holiday destination. Large numbers of tourists travel long distances to visit the park, but only a small proportion of the total travelling emissions occur within the region, and the larger proportion that occur outside the park were not accounted for in this study. Third, the contribution rate of the carbon emissions from the construction stage of the scenic spot and the changes in the use of forest land to the emissions was 16.496%, so they are important emissions, but they have often been overlooked in previous studies of the carbon emissions of scenic spots.

6. Conclusions

The bottom-up CO₂ budget for the Shenyang National Forest Park is a relatively complete CO₂ budget of a forest scenic spot in northern China.

The carbon deficit of Shenyang National Forest Park in 2019 was 504.658 t CO₂. The number of tourists and the tourism intensity of Shenyang National Forest Park reached a medium level in the forest scenic spots in northern China. The conclusions of this

study indicate that there was indeed a high carbon emission phenomenon in this forest scenic spot.

The analysis of the carbon emission inventory found that electricity consumption, garbage removal, and raw coal consumption caused the most CO₂ emissions. Measures such as the use of energy saving lighting, the composting of perishable garbage, and the use of natural gas instead of raw coal will improve the carbon balance budget by 112.521–118.121%. This would achieve the carbon balance goal and generate a carbon reduction surplus.

Increasing the carbon sinks through forest management measures will improve the carbon budget by 65.358%. The double measures to increase forest carbon sink and reduce emissions will improve the carbon balance budget the most and will enable forest tourism scenic spots to achieve a carbon reduction surplus of 393.023–421.283 t CO₂.

Through measures such as protective development, recycling, and cleaner production, the carbon emissions of scenic spots can be minimized and green tourism and low carbon scenic spots can be achieved.

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