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A Coupled Study on Carbon Emission Assessment and Emission Reduction Coupling of Tourism Activities in Beautiful Countryside Taking Zhahan Village, Qiongzhong County, Hainan as an Example

Liping Zhu*, Yadong Zhou† and Qing Li*****
*Hainan College of Vocation and Technique, Haikou 570216, China
**Hainan Vocational College of Political Science and Law, Haikou 571900, China
***Hainan Academy of Agricultural Reclamation Group Co. Ltd., Haikou 570311, China
†Corresponding author: Yadong Zhou; hcvtzyd@163.com

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ABSTRACT

Taking Zhahan village in Qiongzhong County, Hainan, as an example, and based on its 160,000 tourist arrivals in 2019 and taking into account the real circumstances of Hainan, this research composes the emission models of carbon emissions from tourism transportation, tourism accommodation, tourism catering, other tourism activities and pollutants in this village. The outcomes indicate that Zhahan village's tourism catering consumes the most energy and emits the most carbon, accounting for 53.95% of all carbon emissions. Furthermore, the emission of tourism accommodation is the second, occupying 24.13%. Then, its tourism waste emission is the third, constituting 13.61%. In addition, its annual sewage discharge from tourism activities amounts to 15,144 t. This article promoted 1MW photovoltaic and 10 square solar hot water in the entire village, scientifically developing the evaluation system of rural tourism carbon emission, and making a low carbon brand of emission reduction coupling. The research and operation can be replicated and extended to enable the harmonious development of tourism development and organic unity of energy resource utilization.

INTRODUCTION

Zhahan Village in Hongmao Town, Qiongzhong Li and Miao Autonomous County, Hainan Province, is located in the high mountain basin between Limu Mountain and Yinggeling. Its altitude is 800 meters above sea level, making it one of the villages with the most elevated terrain in Hainan. The village is surrounded by natural forest reserves to the east, west, and north, totaling 104,000 mu. The climate in the reserve area is mild, with plentiful rainfall and streams winding. The village is hidden in the clouds, with the advantages of the original scenery incomparable to modern cities. Meanwhile, its average year-round temperature is 22, which is lower than Hainan's 26°C; therefore, it has the reputation of being the "heavenly Zhahan" (Zeng & Wu 2018), which is a holiday, tourism, leisure, and summer resort desired by urbanites. Among the 108 families in the village, 65% are Hmong villagers, and 35% are Li villagers (Hainan Lakeview Life 2018). Due to the high altitude of the entire village, the inconvenient access roads, and the treacherous terrain, the development of Zhahan village is disconnected from the socio-economic growth of China. The per capita annual income of the village residents in 2009 was 946 RMB, a typical poor village in Qiongzhong County.

ORCID details of the authors:

Yadong Zhou
https://orcid.org/0000-0003-1532-641X

Since the extraordinary natural environment and the continuous promotion of the national poverty alleviation policy, the Miao and Li compatriots started to see hope for the future. In 2013, Zhahan village was honored as the "most beautiful Chinese countryside" in constructing beautiful countryside, so it became well-known inside and outside the province within one night. Since 2013, tourists from all over the world have been visiting Zhahan village for tourism, holiday, and adventure, thus making the per capita annual income of Zhahan village residents approach more than 18,000 yuan in 2020 and achieving the progress of the village out of poverty (China Youth Daily 2021). On the contrary, while all tourism activities bring villagers a wealthy life, carbon emissions are also growing, and environmental problems are becoming more prominent. Since 2018, Hainan has introduced the construction of the free trade port around the Regulations of Hainan Province on the Prevention and Control of Atmospheric Pollution, Emission Standards for Pollutants in Betel Nut Processing Industry in Hainan Province (DB46/455-2018), Compensation Implementation Plan for Horizontal Ecological Protection in Upstream and Downstream Watersheds in Hainan Province (Trial) and other regulations, but there is a shortage of environmental protection laws and regulations concerning the construction of new rural areas. Based on incomplete statistics, the village has seen an immediate increase in the daily domestic waste produced since 2018, forcing environmental issues to become increasingly obvious. The continuous promotion of rural revitalization guarantees the harmonious unification and sustainable development of rural tourism, and the environment turns into an important topic. Accordingly, this study takes the dimension of tourism as the entry point, investigates the overall structure of Zhahan village in terms of energy consumption via data collection and research in the village for one year, further launches each emission model, and puts forward recommendations for the harmonious development of energy resource utilization and tourism opening positioning.

CARBON EMISSION MODEL CONSTRUCTION OF RURAL REVITALIZATION TOURISM

Carbon Emission Model Construction of Transportation

The carbon emission of the transportation of the village tour is currently mostly accounted for by the total consumption of petroleum, gas, and electricity of the annual tourism transportation and the coefficient of each energy unit emission. Normally, the tourists to the village come to this province from a radius of 5 km, while tourists from other provinces only account for less than 5%. Because of the village's high altitude, there is only one access road into the village, and the roads in the village are simple; hence, most local tourist transportation is largely self-driving. In the meantime, vehicles usually do not need to drive again after entering the village and stopping at the accommodation, so the transportation means and driving range are comparatively single. The literature utilizes the IPCC carbon emission estimation method and the top-down and bottom-up calculation methods of transport energy consumption (Peihua & Pu 2011, Chunlin 2018). The exact parameters through actual parameters to build its evaluation formula are as below:

$$C_{ct} = \sum_{i=1}^{n} P_t \times N_i \times D_i \times 2 \quad \dots(1)$$

In the formula, C_{ct} is the carbon emission of passenger transportation, kg; P_t is the carbon emission factor (kg.km^{-1}) of the village road type of transportation to Zhahan village, and the empirical value is 0.133 kg.km^{-1}. Ni is the number of passengers who pick to travel by car; D_i is the distance traveled by car.

Carbon Emission Model Construction of Tourist Accommodation

The structure of the guesthouse in Zhahan village is identical. The carbon emissions of tourist accommodations are concentrated in the lighting, ventilation, air conditioning, and hot water supply of basic accommodation facilities, mainly indirect carbon emissions based on electricity consumption. Integrate the advantages and disadvantages of the top-down method and bottom-up method for carbon emission accounting of the accommodation industry by Hongxia et al. (2017) and the literature of Yanyan et al. (2020) to compose the formula.

$$C_{ht} = B \times T \times P \times 0.936 \times H \quad \dots(2)$$

In the formula is the carbon emission from the accommodation, kg. B is the total number of guesthouses; T is the occupancy rate of guesthouses; P is the weighted electricity consumption per guesthouse, kWh; 0.936 is the amount of CO_2 emitted by standard coal to make 1kWh of electricity, kg; H is the proportion of coal-fired power generation in Hainan. Based on the Hainan Provincial Bureau of Statistics announced in March 2021, the province's clean energy generation occupied 41.8% of all industrial power generation above the scale in 2020, (Ecological Civilization Construction 2021), hence 58.2% is chosen here.

Carbon Emission Model Construction of Tourism Catering

The carbon emission of tourism catering is primarily the carbon emission generated by the consumption of energy resources such as natural gas, gas, and firewood applied in meals, non-staple food, and services offered by the village for tourists. It is estimated that the tourism catering will be moderately more complicated, and the real condition of 7 restaurants of a certain scale in Zhahan village will be calculated, combined with the energy consumption of ingredients consumed by individual tourists dining, as well as the cooking and environmental consumption of natural gas and electricity, as presented by Huang Heping. Most of the tourists visit Zhahan village to taste the local food. Zhahan village's meat consumption is largely based on the village's chickens, ducks, geese, pork, and lamb. Its aquatic products are dominated by local fish and shrimp from streams and lakes and special wild vegetables. According to the General Office of the State Council issued in 2014, the Notice of the General Office of the State Council on Issuing the Outline of the Program for Food and Nutrition Development in China (2014-2020) sets food consumption targets, integrated with the IPCC (Intergovernmental Panel on Climate Change) Guidelines for GHG inventories generated by different foods (Jianhong et al. 2011). The evaluation models are built by:

$$C_{ft} = N \times D \times \sum(\alpha_i \times \delta_i) + \sum(\beta_i \times 0.936 \times H) + \sum \; (\varepsilon_i \times 2.117) \quad \ldots(3)$$

In the formula, is the catering carbon emission kg; *N* is the total number of tourists; *D* is the average number of tourist days. Under the statistics of Zhahan village, the average annual tourist stay is 1.17 days; is the average daily consumption of *i* food consumption per tourist, kg; is the emission of *i* food per kg, kg; is the average daily electricity consumption of a restaurant, kWh; is the average daily gas consumption of a restaurant, kg. 2.117 is the CO_2 emission from 1kg of natural gas combustion, kg.

Carbon Emission Model Construction of Other Tourism Activities

Carbon emissions from other rural tourism activities largely comprise rural entertainment, leisure, shopping for agricultural products, and Zhahan village making full use of the village's superior air and environmental resources. In order to attract tourists and widen the tourism industry, they dig out the rural characteristics of tourism, execute a children's recreation ground, designated route adventure, rock climbing, fishing, and other recreational activities. In addition, it endeavors walking picking and high-end ornamental planting under traditional agriculture. The carbon emissions of other rural tourism activities are counted in terms of the total number of people in each activity with the related activities involved in electricity, water, and environmental carbon emission systems. On the basis of the carbon emission study by Wang Kai et al. on scenic spots, the following formula is adopted to calculate the carbon emission based on the actual situation in Hainan.

$$C_{lt} = \sum_{l=1}^{n} N_l \times \delta_l \quad \ldots(4)$$

In the formula, is the total amount of carbon emissions when tourists engage in other activities, kg; is the number of tourists participating in l other activities; is the CO_2 emission coefficient of joining in l activities; n is the number of types of tourist attractions or tourist activities.

Emission Model Construction of Tourism Waste

Emission construction of tourism solid waste: Tourism waste contains solid waste, sewage, manure, soot, SO_2, NOx, etc. Integrate with the fact that solids comprise organic household waste such as food waste and paper generated by food and shelter and inorganic waste such as plastic and metal packaging discarded during recreation, (Yingmiaol et al. 2012). As well as, after a study to determine the daily per capita waste generation data of 3.5 kg/person-day, which is 2.5 kg for food waste and 1 kg for park waste (Peng et al. 2008) for reference. Solid waste in rural tourism contains the product of the total amount of a certain waste generated per day and the emissions generated per unit mass of that waste. The evaluation models are built by:

$$C_{gt} = N \times D \times \sum_{i=1}^{n}(G_i \times \delta_i) \quad \ldots(5)$$

In the formula, is the amount of CO_2 emitted from tourism solid waste, is the daily per capita production of *i* kinds of waste, kg/day; is the amount of CO_2 made by 1kg of *i* kinds of waste stored, kg.

Emission construction of tourism liquid waste: The discharge of liquid waste in rural tourism is largely the sewage discharge generated by tourists' accommodation and dining, and the total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) required to treat the sewage.

$$S_{yt} = (N_z + N_c + N_q) \times \delta_i \quad \ldots(6)$$

In the formula, is the weighted total number of accommodations, person; is the per capita water discharge of accommodation travelers, dining travelers, and other tourists, t/person; is the weighted total number of dining tourists, person; is the weighted total number of other travelers, person; is the total water consumption, t. Integrate with the literature tourism accommodation activities per capita NOX, total phosphorus, chemical oxygen demand, and biochemical oxygen demand are taken as 0.004kg/d, 0.00066kg/d, 0.03759kg/d, 0.00872kg/d, respectively (Meifeng & Jianchao 2012).

ANALYSIS OF THE PERCENTAGE OF EACH TOURISM SEGMENT

Fundamental Data

Rural tourism in Zhahan village was initiated in 2012, using the original ecological circumstances and the features of minority resources located in the "ecological environment + folk culture" of rural leisure tourism. Therefore, the first step is to accomplish full ecological tourism to alleviate poverty. Since 2012, Zhahan village has increased from 5 thatched guesthouses built by the village community to several individual guesthouses in 2020, with an average of 1 to 2 spare rooms per family. As a result, under normal conditions, the total number of guesthouses on holidays has around 50 to 60 rooms, with other forms of accommodation through combining cycling, camping, boat-shaped tent houses, and village buses, which have turned into a tourist fashion in the village.

Based on field survey statistics, the tourism receiving capacity of Zhahan village before the pandemic in 2019 was approximately 130,000 people/times, the total tourism income was more than 10 million, and the annual average occupancy rate of the guesthouse was 58%. As the living standard of people enhances and the connotation construction of rural revitalization deepens, the leisure methods, tourism methods, and tourism activities of rural tourism have been diversified and refined in the past few years, and carbon emissions, energy resource utilization, and consumption have also been diversified and exponentially expanded (Ruiying et al. 2018) influenced by the pandemic, tourism in the village was favored by the province's residents in the first half of 2021, welcoming more than 80,000 visitors of all types. In accordance with the village statistics, merely sightseeing tours and buying agricultural products accounted for 32.2%, cycling, camping, etc., accounted for 28%, accommodation, and leisure tourism accounted for 32%, and others accounted for 7.8%.

Data Outcome

The annual carbon emission calculations of rural tourism transportation are given in Table 1. The tourist number to the village, except for those who are biking and camping, tourist number by car accounts for 72% of the total tourists. With an average of 4 people per car, there are 28,800 household cars and 115,200 tourists, the annual traffic emissions. Based on the current national six standards for NOx emissions in China, 60 mg/Km for domestic cars, and a 9.5 km length village road, Qiongzhong G224 National Road, from the village entrance to the village cottage.

Table 2 shows the annual carbon emission calculation for rural tourism guesthouses. Combined with Hainan's exceptional climate conditions for weighted estimates, and calculated by utilizing a one horsepower air conditioner 18 h a day in the guesthouse, 60-80L electric water heater 2kW 3 h a day, 70W TV 10 h a day, 100W light 12 h a day, and 100 to 113 guesthouse rooms.

The calculations in Table 3 show that there are 160,000 tourists throughout the year, of which 32.2% are tourists who only sightsee and buy agricultural products, and this group of tourists considers consuming one meal. Biking and camping tourists accounted for 28%, and this part of travelers considered consuming two meals. Tourists for accommodation and leisure tourism accounted for 32%; this part of travelers consider having three meals. Other accounted for 7.8%, considering this part of travelers does

Table 1: Annual carbon emission calculation of rural tourism transportation.

Transportation	P_t /kg/km	Number of vehicles/unit	N_t/person-times	D_t/km	C_{ct}/kg	C_{tn}/kg
Car	0.133	28800	115200	9.5	72777	32.8

Table 2: Annual carbon emission calculation for rural tourism guesthouses.

B/room	T/%	P/kWh*room	H/%	γ/ kg	C_{ht}/kg
113	58	24	58.2	0.936	312758

Table 3: Annual carbon emissions calculation for rural tourism's food consumption (Heping et al. 2019, Enter Renaissance Forum 2014, Mengrong et al. 2021).

Food Category	Per capita Kg/m3	Emission factor for primary processing/kg	Emission factor for reprocessing/kg	$\Sigma\delta_i$/Kg	$N \times D \times \Sigma(a \times \delta)$/Kg	C_{fc}/Kg
Rice, pasta	0.037	0.82	0.89	0.06	646213	699308.88
Soybeans	0.036	0.26	0.06	0.01		
Pork	0.08	4.25	1.11	0.38		
Beef and lamb	0.11	26.14	1.11	3.00		
Chicken, duck and goose	0.13	4.25	1.11	0.70		
Shrimp	0.10	1.88	0.28	0.22		
Fish	0.11	1.88	0.28	0.24		
Eggs	0.25	1.14	0.70	0.46		
Vegetables	0.44	0.26	0.06	0.14		
Vegetable oil	0.08	0.26		0.02		
Fruits	0.16	0.89		0.20		
Firewood	0.65	1.87		1.22		
Natural gas	0.20	2.117		0.42	*6701.62*	
Electricity	0.5	0.936		0.468	*40655.16*	

not have meals in the village. Weighted calculation of 83,306 people, an average of 33 people per day per family dining, divided into 17 people each for lunch and dinner (the proportion of rural tourism consumption of breakfast is not high, here, do not do the calculation). With a daily dining time of 3 hours per meal, if 2 to 3 horsepower for air conditioners, rice cookers, cooking, etc., are adopted during meals, the daily electricity consumption for every meal is 14-17 kWh. The villagers of Zhahan village keep cooking with firewood, and more than 80% of the travelers also like to have wood-fired meals. However, firewood's volatile organic compound emission is also quite significant, approaching 115 Kg apart from the carbon emission.

According to Table 4, rural tourism activities comprise sightseeing tours (32.2% of the total annual number of people), adventure activities (28% of the total annual number of people), and other activities (number of people in accommodation + number of people in other activities, 39.8% of the total annual number of people).

Table 5 reveals that among the footprint of tourism activities in Zhahan Village, tourism catering is the most prominent activity in the village in terms of CO_2 emissions, accounting for 53.95% of total emissions. Emissions from ingredients account for most of these emissions, largely through electricity, gas, or firewood. Tourist accommodation contributes 24.13%, direct or indirect emissions of waste account for 13.61% of total emissions, and carbon emissions from transportation account for only 5.61%.

According to Table 6, the wastewater discharge of rural tourism accommodation activities is 88.68 $L.d^{-1}$. Due to the overall hotness of the Hainan region, the water consumption of accommodation visitors is higher than the national level, and the average water consumption is 120 $L.d^{-1}$. The per capita sewage discharge in catering activities is 40.95 $L.d^{-1}$ (Hong et al. 2015), estimated here as two meals; the sewage discharge from tourist toilets is 7.54 $L.d^{-1}$ (Ling-yu et al. 2009), which is taken twice. The waste COD is the amount of oxygen used for five days.

Table 4: Annual carbon emissions calculation of other rural tourism activities.

Number of sightseeing people to total number of tourists (%)	Number of adventure people to total number of tourists (%)	Number of people in accommodation + other as a percentage of the total number of tourists (%)	CO_2 emission factor for sightseeing (%)	CO_2 emission factor for adventure (%)	CO_2 emission factor for accommodation + others (%)	C_{lc} (kg)
32.2	28	39.8	0.417	0.057	0.172	34990.4

Table 5: Annual carbon emissions calculation of rural tourism's solid waste.

Total number of garbage generators	Total mass of annual garbage [kg]	Emission factor of transported garbage [$kg.t^{-1}$]	Mass of food waste [kg]	Emission factor of food waste/[kg]	The total amount of park waste [kg]	The emission factor of park waste / [kg=]	C_{lc} [kg]
111840	391440	5.11t	279600	0.44	111840	0.46	176470

Table 6: Wastewater waste discharge of rural tourism.

N_z	O_z(t)	N_c	O_c(t)	N_q	O_q(t)	C_{yt}(t)	TN(t)	TP(t)	COD_5(t)	BOD(t)
63680	0.120	83306	0.041	44800	0.015	15144	56.3	9.3	2650	122.7

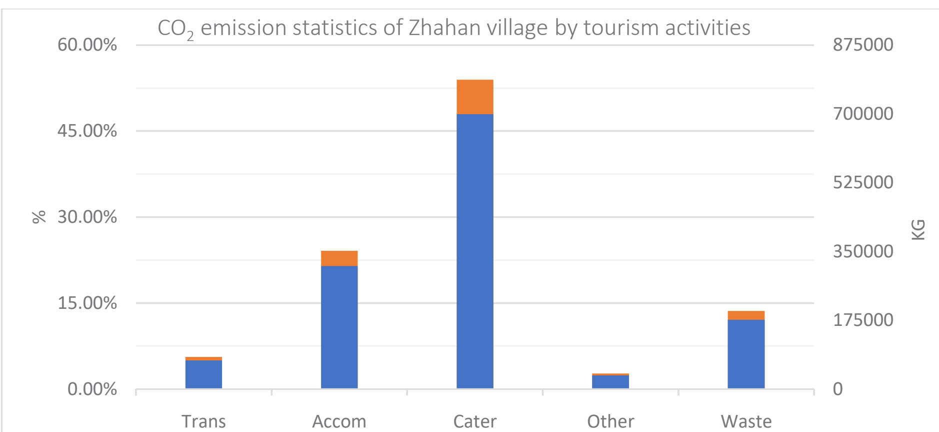

Fig. 1: Comparison of CO_2 emissions from tourism activities in Zhahan Village.

RESULT ANALYSIS OF TOURISM EMISSIONS

Comparison of CO_2 Emissions from Tourism Activities

Through the above precise assessment of tourism activity footprint emissions, Zhahan village emits 1296.3 t of CO_2 from tourism waste for transportation, accommodation, catering, and other activities in a year. The comparison of specific tourism activities is depicted in Fig. 1.

Fig. 1 reveals that among the footprint of tourism activities in Zhahan Village, tourism catering is the most prominent activity in the village regarding CO_2 emissions, accounting for 53.95% of total emissions. Emissions from ingredients account for most of these emissions, mainly through electricity, gas, or firewood. Tourist accommodation contributes 24.13%, direct or indirect emissions of waste account for 13.61% of total emissions, and carbon emissions from transportation account for only 5.61%.

Emissions of Nitrogen Oxides and Sewage

Zhahan village welcomes more than 160,000 visitors a year, and the amount of sewage discharged by it amounts to 15,144t. Since a considerable amount of water is discharged, the chemical and biochemical oxygen demand for treating these water resources amount to 2650t and 122.7t. The amount of nitrogen oxides emitted by tourist vehicles is not high, only 32.8kg per year, but nitrogen oxide emitted directly or indirectly by waste is as high as 75.3t.

Emission Reduction Coupling

With the accelerated development of tourism resources in Zhahan Village, carbon emission is also growing proportionally to overall carbon emission. To determine the issue of high carbon emission of rural tourism in Zhahan village, to preserve the reputation of "heavenly Zhahan" to the maximum extent, and to accomplish the simultaneous development of clear water, lush mountains, tourism, and wealth, it is required to present the planning of energy resource utilization and harmonious development via comprehensive energy analysis of tourism. For this reason, Zhahan village must have a sense of advance in rural revitalization and do well in advance to arrange for neutralization and zero-carbon emission.

They are encouraging the whole village and setting up a 1MW photovoltaic power station and solar water heater. The villagers of each household take out 40 square meters of the roof, and the village collective vacates 2,000 square meters of the public part to plan and construct 1MW solar photovoltaic power station. In this way, the annual power generation capacity is 286,150,000 KWH (Yadong et al. 2020), and CO_2 emission reduction is 1434 t, which benefits the villagers on average by about 10,000 yuan, further enhances the quality of rural revitalization and decreases the quality of the entire CO_2 emission of tourism activities for a year.

Supervise residents and guesthouses to install solar water heaters. According to the analysis of actual solar water heater energy-saving measurements made by Li Chenyu et al. (2009), the average installation of 10 square solar water heaters per household can generate a 60°C hot water output of approximately 700 L.(Chenyu et al. 2018). In this case, the annual power saving is about 5230 kWh, the annual CO_2 emission reduction is 4865 kg, and the annual CO_2 emission reduction is 150 t for 30 guesthouses on average.

Scientific planning of rural tourism activities. Launch a parking plant for fuel tour buses and private cars at the village entrance, and organize electric buses to pick up and drop off people to guarantee that the exhaust fumes do not enter the village. Install several electric vehicles charging piles utilizing the village's self-generated electricity to fulfill the village's electric vehicle charging needs. Arrange the gradual transformation of village infrastructure to energy-saving and emission-reducing standards, adapting national characteristics and contemporary atmosphere to low-carbon, energy-saving, and environmental protection. Motivate and direct the restaurant industry to change the concept of applying coal and firewood, and choose more natural gas and electricity to lower the direct impact on the air quality of tourist sites.

Unify action and create a low-carbon brand. Zhahan village is small in area and late in development, and expects to develop tourism development and economy harmoniously through making “carbon neutral” tourism, education theme brand, and demonstration education base. Propose low-carbon evaluation to estimate the village team, villagers, and tourists in an all-around way and encourage rural tourism’s institutionalized and low-carbon development.

CONCLUSION

Zhahan village is a pearl in the high mountain basin of central Hainan and a direct beneficiary of the construction of China's beautiful countryside and the implementation of comprehensive rural revitalization. Its use of natural resources to raise rural tourism and special agricultural products has enabled the villagers to move from poverty to prosperity. Still, tourism carbon emission is an essential issue that village tourism must encounter.

According to 160,000 tourists in Zhahan village in a year, the carbon emission model created for each link of tourism, the carbon emission of tourism vehicles, tourism accommodation, tourism catering, and other activities in the village is estimated to be 1296.3 t, and the carbon emission of tourism solid waste is 176 t. The huge sewage discharge in tourism liquid waste is 15144t; tourism catering carbon emission contributes the most significant proportion, which must attract the attention of associated departments.

To accomplish zero carbon emission, every resident of Zhahan village must work together to "create zero carbon emission, and clear water and lush mountains, which are sustainable wealth," and propose to construct "carbon neutral" and create tourism and education theme brands. Subsequently, the entire village will stimulate the solar photovoltaic 1MW power station and the installation of 10 square meters of solar water heaters in guesthouses, which can directly achieve 1,584 tons of emission reduction, thus directly carbon neutralizing the enormous CO_2 emissions brought on by the electricity used for accommodation and catering in the village.

A three-dimensional parity system for village cadres, villagers, and tourism is proposed to encourage the institutionalization of rural tourism. It can be replicated and radiated in the province and even in the whole Chinese rural revitalization.

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