Estimation of tourism carbon footprint and carbon capacity

Tianyue Huang and Zi Tang*
School of Tourism and Cuisine, Harbin University of Commerce, Harbin, Heilongjiang 150028, China

Abstract

The calculation of tourism carbon footprint is of great significance to low-carbon tourism. This study estimates the tourism carbon footprint in Heilongjiang Province from 2009 to 2018 by using tourism carbon footprint and tourism carbon capacity models. The results show that the total tourism carbon footprint of Heilongjiang Province increased fast to 2.97 times from 5.926million tons in 2009 to 21.13million tons in 2018, while its per capita tourism carbon footprint increased from 53.9 kg to 116.0 kg. During the same period, tourism carbon capacity continued to grow steadily from 15.18billion tons to 21.96billion tons, and the growth rate was 50% of the growth rate of tourism carbon footprint. Tourism carbon emissions can be absorbed by environmental capacity, and the risk of carbon deficit is relatively small.

Keywords: tourism carbon footprint; tourism carbon capacity; low-carbon tourism; Heilongjiang Province

* Corresponding author: tz09@163.com

Received 18 January 2021; revised 25 February 2021; editorial decision 9 March 2021; accepted 9 March 2021

1 INTRODUCTION

The COVID-19 has spread to 200 countries, having an impact on global academic exchanges and the international flow of students, and it has also triggered people's reflection on ecological civilization. The impact of greenhouse gases, led by carbon dioxide, on the earth and the environment has already sounded the alarm for mankind. This is a fact that has been widely demonstrated internationally. Climate change problems have become a worldwide concern [1]. It has become a global consensus to reduce greenhouse gas emissions and actively respond to climate change. The tourism carbon footprint can be used to obtain the carbon dioxide content consumed by tourism in a certain area during a certain period. In 2018, scientists at the University of Sydney [2] estimated that the carbon footprint of global tourism may account for about 8% of all carbon emissions, and the total annual carbon emissions of tourism are nearly 4.3billion metric tons. Between 2009 and 2013, the global carbon footprint of the tourism industry increased from 3.9 to 4.5 $GtCO_2e$, four times the previous estimate, accounting for approximately 8% of global greenhouse gas emissions.

Rico *et al.* [3] analyzed the carbon footprint of tourism activities in Barcelona and believes that the main source of direct and indirect emissions due to energy use is transportation in and out of the port. Sharp *et al.* [4] used the life cycle assessment method to assess the consumption-based carbon footprint of ordinary tourists in Iceland, including direct and indirect emissions, and concluded that the carbon footprint of ordinary tourists depends on the distance taken by plane. Koiwanit *et al.* [5] used the method of screening Life Cycle Energy Analysis (LCEA), this study assessed the carbon footprint of a sample of home-stays in Thailand. Sun [6] proposed a framework to measure the total domestic carbon effect and the effect of foreign sources, and applied an analytical framework to Taiwan empirical research that shows that domestic tourism, international aviation and imports account for 47%, 28% and 25% of the carbon footprint of the tourism industry, respectively. Hans de Wit and Philip G. Altbach pointed out that people should choose low-carbon transportation, conduct online courses and web conferences, and carry out environmentally-friendly education international exchanges, so as to reduce the adverse effects of large-scale international flows on the climate and promote sustainable global development [7].

Many scholars have been paying close attention to China's carbon emissions. As cities and enterprises play an increasingly prominent role in climate change mitigation actions, they have paid more and more attention to the study of China's inter-provincial tourism carbon footprint [8]. Dou *et al.* [9] analyzed the carbon footprints of Hong Kong and Macao and their global

International Journal of Low-Carbon Technologies 2021, 16, 1040–1046

https://doi.org/10.1093/ijlct/ctab026 Advance Access publication 24 April 2021

footprints were approximately three times of their direct energy-related emissions. Yang *et al.* [10] drew a high-resolution hotspot map of the carbon footprints generated in China through international trade at the consumption level of various countries in the world. A large part of the carbon dioxide produced is driven by product exports. It is believed that it is necessary to link the final consumption of the product with the individual emission reduction actions that directly control carbon emissions [11]. Dong *et al.* [12] used tourism carbon footprint and tourism carbon capacity models to compare the tourism carbon footprint and tourism carbon capacity of Jiangsu Province over the past 15years. Wang *et al.* [13] adopted the "bottom-up" method to estimate the CO_2 emissions of China's tourism industry from 1995 to 2014. Zhang [14] calculated the tourism carbon footprint of the Liaoning Coastal Economic Zone from 2010 to 2014, and believes that the main measurement indicators of Dalian, Liaoning Province account for the largest proportion of the corresponding indicators of the economic belt tourism carbon footprint.

Considering the characteristics of China's inter-provincial tourism carbon footprint or lack of analysis of the relationship between carbon footprint and carbon capacity, there are certain obstacles to cooperative emission reduction actions between individual emission reduction actions in China and downstream consumers that drive emissions [15]. Xu *et al.* [16] calculated carbon footprints of rice production in Heilongjiang Province through the life cycle assessment method. Chen *et al.* [17] used structural decomposition analysis (SDA) to identify the main contributors of CO_2 emissions increase during 2002–2012 in Heilongjiang province. In Heilongjiang Province, few studies have focused on the carbon footprint of tourism. Based on the literature review of the nature and calculation methods of tourism carbon footprint, this paper uses tourism carbon footprint and tourism carbon capacity model to obtain tourism carbon footprint in Heilongjiang Province from 2009 to 2018, and has an in-depth understanding of Heilongjiang tourism carbon emissions and carbon fixation. The balance and dynamic changes of Heilongjiang Province provide theoretical support and data for the economic recovery of tourism and the development of low-carbon tourism in Heilongjiang Province.

2 MATERIALS AND METHODS

2.1 Tourism Carbon Footprint

Carbon footprint refers to all relevant sources, sinks, and storage within the spatial and temporal boundaries of a population, system or activity. It measures the total emissions of carbon dioxide and methane from a specific population, system or activity. Generally, all greenhouse gas emissions are in carbon dioxide equivalent (CO_2), and use 100-year global warming potential (GWP100) to calculate carbon dioxide equivalent. The more "carbon dioxide" that is the culprit of global warming is also produced, the larger the "carbon footprint". Conversely, the smaller the "carbon footprint". Carbon footprint is not only a simple quantification process of greenhouse gases, but also a way to reflect whether the behavior of the country, organization (enterprise), and individual conforms to the principles of environmental justice.

There are two types of carbon footprints. The first carbon footprint refers to the greenhouse gas emissions caused by the direct use of fossil fuels. Such as: energy consumption caused by family daily life and daily travel. The second carbon footprint refers to the amount of greenhouse gas emissions hidden in commodities that consumers use during the manufacturing, transportation, sales, and recycling processes of various commodities [18].

There are currently four methods for calculating carbon footprint: The first is the life cycle assessment method (LCA) [19]. The life cycle assessment method mainly adopts a "top-down" calculation model, which is a calculation method for the product and its "from beginning to end" process, to obtain the total carbon emissions by obtaining all input or output data during the life cycle of the product or service. The "carbon footprint" (CFP) of a product can indirectly reflect the environmental friendliness of a product. The second method is the calculation of carbon emissions from the energy and fossil fuel (IPCC). The IPCC carbon emission method is a greenhouse gas inventory guide prepared by the United Nations Climate Change Commission, which fully considers greenhouse gas emissions in the calculation process. For different sectors, the carbon footprint calculation method is different. The most commonly used formula is: carbon emissions=activity data × emission factor. The third is the input-output method (IO). The input-output method is a top-to-bottom calculation method that uses input and output for calculations. The calculation results are not accurate and are common used for macro-level calculations. The fourth method is the Kaya carbon emission identity. Kaya's carbon emission identity uses a simple mathematical formula to link economic, policy, and population factors with carbon dioxide produced by human activities.

Tourism Carbon Footprint (TCF) refers to the amount of greenhouse gas emissions generated by people during tourism. The greenhouse gas is mainly carbon dioxide. It is assumed that the carbon emissions of tourists during the entire consumption of tourism products are essentially the same. It can be calculated and compared in a unified way. In tourism activities, the carbon footprint of each link of food, lodging, travel, shopping and entertainment can be uniformly calculated with the relevant tourism income or tourist consumption. In summary, the main factors affecting carbon emissions in tourism activities are: tourist arrivals, tourism consumption levels, and energy consumption in tourism-related industries. The calculation method is as follows:

$$TCF = Y \bullet C \tag{1}$$

$$\overline{TCF} = \frac{TCF}{N} \tag{2}$$

where TCF is the tourism carbon footprint of the year, Y is the total revenue of the tourism industry for the year, and C is the carbon dioxide emission intensity of the tourism industry. In this paper, C uses the world average tourism carbon emission intensity of 623.13kg/10^3USD$ [10]. $\overline{TCF}$ is the tourism carbon footprint per capita, and N is the total number of tourists in the year.

2.2 Tourism Carbon Capacity Model

The tourism carbon capacity is the maximum capacity of a regional ecosystem to absorb CO_2 emissions from tourism under certain time and space conditions. The tourism carbon capacity model can indicate whether tourism carbon emissions in a certain area can be absorbed by the vegetation in the area and it is an effective way to judge whether a tourist destination can maintain carbon balance. The calculation of carbon capacity needs to consider the carbon absorption rate of green vegetation, mainly considering the carbon absorption rate of forests, grasslands and crops. Net Ecosystem Productivity (NEP) is the amount of carbon that 1hm^2 of vegetation can absorb in a year. NEP reflects the carbon sequestration capacity of vegetation and it can indicate the ability of green plants to use sunlight for photosynthesis in completing the process of fixing and converting inorganic carbon (CO_2) into organic carbon. The calculation method is as follows:

$$TCC = M \bullet NEP_i \bullet r \tag{3}$$

where TCC is the tourism carbon capacity, that is, the amount of carbon sequestered by vegetation; M is the vegetation area; NEP is the net ecosystem productivity of vegetation, the global forest and grassland carbon absorption capacity, i stands for the category of vegetation, and r is the correction coefficient. According to the Heilongjiang Statistical Yearbook, the carbon emissions of tourism are mainly related to Transport, Post and Telecommunication Services and Wholesale, Retail Trade & Catering Services in the tertiary industry. r is the proportion of tourism-related industries added value in *GDP*. The tourism carbon capacity can be obtained from the total carbon capacity by the correction coefficient r.

The formula for calculating per capita tourism carbon capacity is as follows:

$$\overline{TCC} = \frac{TCC}{N}. \tag{4}$$

Tourism Carbon Deficit (TCF) is the difference between the tourism carbon footprint and the tourism carbon capacity. It represents the extent of the impact of tourism activities on the ecological environment. By comparing the two, it is possible to measure whether the regional tourism industry in a certain period of time is green and sustainable:

$$TCD = TCC - TCF. \tag{5}$$

The formula for calculating per capita tourism carbon deficit is as follows:

$$\overline{TCD} = \frac{TCD}{N}. \tag{6}$$

2.3 Data source and data processing

The data on the number and income of domestic tourists, the number and income of overseas tourists, industry standard coal and vegetation area required by the research are all from Heilongjiang Statistical Yearbook-2010 to Heilongjiang Statistical Yearbook-2019. The number of domestic tourists and earnings in 2014 in accordance with the "accommodation +spots" caliber statistics, which cannot be compared with other years. The data of tourists and earnings of tourism industry of Heilongjiang from 2009 to 2018 are shown in Table 1. In this study, data from 2009 to 2012 used Forest Area and Public Green Land. Due to different statistical calibers, data Forest Area in 2012 continued to use the same area in 2011, and data from 2013 to 2018 used Public Green Land, Forests land and Area of Grassland. The proportion of tourism-related industries in *GDP* are derived from Heilongjiang Statistical Yearbook, which are shown in Table 2.

3 RESULTS

3.1 Tourism carbon footprint

According to formula (1)–(2) and the total number of domestic and international tourists in Heilongjiang Province from 2009 to 2018 and the total tourism revenue (in 100million USD$), the relevant values of Heilongjiang Province's tourism carbon footprint over the years are calculated. The calculation results are shown in Table 3. As Table 3 shown, the total tourism carbon footprint of Heilongjiang Province increased fast to 2.97 times from 5.93million tons in 2009 to 21.13million tons in 2018. Among them, carbon footprint from international tourism decreased by 100,000 tons. The proportion of domestic tourism carbon footprint to total tourism carbon footprint increased from 93.3% to 98.4%. The carbon footprint of international tourism reached the highest value of 572,000 tons in 2011, and slowly rebounded after falling to 246,000 tons in 2015. The total per capita tourism carbon footprint increased more than doubled from 53.9kg to 116.0kg. The per capita carbon emissions of international tourism increased from 279.3kg to 306.6kg, and the per capita carbon emissions of domestic tourism increased doubled from 51.0kg to 114.9kg. The basic characteristics of the dynamic changes in Heilongjiang's tourism carbon footprint from 2009 to 2018 are shown in Figure 1 and Figure 2.

(1) According to Figure 1, the total tourism carbon footprint is similar to the overall fluctuation trend of the domestic tourism carbon footprint, which is roughly an exponential curve fluctuating growth trend, changing from rapid growth to slow growth.
(2) The carbon footprint of international tourism accounts for a low proportion of the total tourism carbon footprint, but the per capita tourism carbon emissions of international tourism are much higher than the total per capita tourism carbon emissions and domestic per capita tourism carbon emissions. Before 2014, the per capita tourism carbon emissions of international tourism was 5 times of the other two categories. After

Table 1. *Tourists and earnings of tourism industry in Heilongjiang Province from 2009 to 2018.*

Year	International tourism		Domestic tourism	
	Tourists/10^4 person-times	Earnings/10^7 USD	Tourists/10^8 person-times	Earnings/10^7 USD
2009	142.5	63.9	2792607.7	887.1
2010	172.4	76.3	2755632.5	1229.0
2011	206.5	91.8	2768729.1	1597.8
2012	207.6	83.5	25174.0	1977.0
2013	152.9	60.4	29004.0	2176.6
2014	141.7	56.4	10531.0	1679.1
2015	83.5	39.5	12926.0	2146.6
2016	95.7	45.8	14380.3	2367.9
2017	103.9	48.0	16304.2	2779.4
2018	109.2	53.7	18100.0	3336.7

Table 2. *The proportion of tourism-related industries in GDP in Heilongjiang Province from 2009 to 2018.*

Year	Transport, post and telecommunication services/%	Wholesale, retail trade and catering services/%	Total(r)/%
2009	5.0	11.2	16.2
2010	4.7	11.4	16.1
2011	4.5	11.9	16.4
2012	4.3	12.4	16.7
2013	4.1	12.4	16.5
2014	4.5	13.4	17.9
2015	4.7	14.3	18.9
2016	4.9	15.1	20.0
2017	5.0	15.2	20.2
2018	5.1	15.6	20.7

2014, the per capita tourism carbon emissions of international tourism was twice of the other two categories (Figure 2).

(3) From Figure 1 and Figure 2, the total tourism carbon footprint is similar to the domestic tourism carbon footprint, and the total per capita tourism carbon footprint is similar to the domestic per capita tourism carbon footprint, indicating that the base number of tourists in Heilongjiang Province is small and the growth rate is slow, and the tourism industry still has a great foreground of development.

3.2 Tourism carbon capacity

Tourism carbon footprint can be used to judge whether the tourism development of a country or region is within the scope of ecological capacity, and to evaluate and analyze the pressure that humans exert on the ecosystem during tourism activities. If the carbon footprint is greater than the carbon capacity, it will lead to the unsustainable development of the tourism industry in the region. On the contrary, the ecological security foundation of the tourism industry will continue to be stable, basically ensuring the sustainable development of the tourism industry. The carbon capacity of forests accounts for more than half of all types of vegetation, followed by grassland, and farmland is the smallest, indicating that China's forest ecosystem has the largest ecological effect of carbon absorption [20]. From 1961 to 2010, the total NEP in Northeast accounted for 15%–37% of the total NEP in China fluctuated between 0.094PgC/a and 0.117PgC/a [21]. In this study, NEP takes the annual average value of 0.026PgC/a.

The tourism carbon capacity and tourism carbon deficit were calculated according to the formula (3) and formula (5). The per capita tourism carbon capacity and tourism carbon deficit were calculated according to the formula (4) and formula (6) in Section 2.1, and the results are shown in Table 4.

It can be seen from Table 4 that the tourism carbon capacity of Heilongjiang Province continued to grow steadily from 15.18billion tons in 2009 to 21.96billion tons in 2018, an approximately increase of 1.45 times, and the growth rate was 50% of the growth rate of tourism carbon footprint. From 2009 to 2013, the tourism carbon capacity per capita showed a slow decreasing trend, from 138.2tons to 60.9tons. From 2013 to 2018, the tourism carbon capacity per capita first increased and then declined, reaching the highest value of near 179.5tons in 2014, and then slowly decreasing by 2018, 120.5tons. As Heilongjiang Province has a relatively large area of vegetation, tourism carbon emissions can be absorbed by the environmental capacity, and the risk of carbon deficits in tourism is relatively small.

4 DISCUSSION

The tourism carbon footprint can be used to obtain the carbon dioxide content consumed by tourism in a certain area during a certain period. As the rapid development of tourism in Heilongjiang Province and the gradual increase in popularity, the number of tourists and tourism income has increased, along with the increase in tourism carbon emissions, it is reasonable for the tourism carbon footprint to show an upward trend.

The carbon footprint is greater than the tourism carbon capacity, and the amount of vegetation can carry the carbon emissions of tourism activities, indicating that the tourism industry is green and sustainable. As the ratio of vegetation area to tourist base is too large, Heilongjiang Province should also pay attention to tourism carbon capacity while reducing the risk of tourism

Table 3. *Tourism carbon footprint in Heilongjiang Province from 2009 to 2018.*

Year	International tourism		Domestic tourism		$TCF/10^4$ t	$\overline{TCF}$/kg
	$TCF/10^4$ t	$\overline{TCF}$/kg	$TCF/10^4$ t	$\overline{TCF}$/kg		
2009	39.8	279.3	552.8	51.0	592.6	53.9
2010	47.5	275.6	765.9	48.8	813.4	51.2
2011	57.2	276.9	995.6	49.2	1052.8	51.5
2012	52.1	250.8	1231.9	48.9	1284.0	50.6
2013	37.7	246.4	1356.3	46.8	1394.0	47.8
2014	35.1	247.8	1046.3	99.4	1081.4	101.3
2015	24.6	295.1	1337.6	103.5	1362.3	104.7
2016	28.5	298.2	1475.5	102.6	1504.1	103.9
2017	29.9	287.7	1732.0	106.2	1761.8	107.4
2018	33.5	306.6	2079.2	114.9	2112.6	116.0

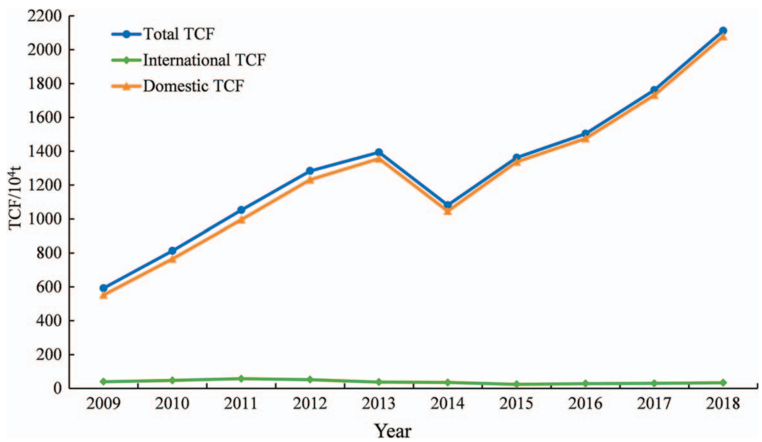

Figure 1. *The dynamic changes of tourism carbon footprint in Heilongjiang Province from 2009 to 2018.*

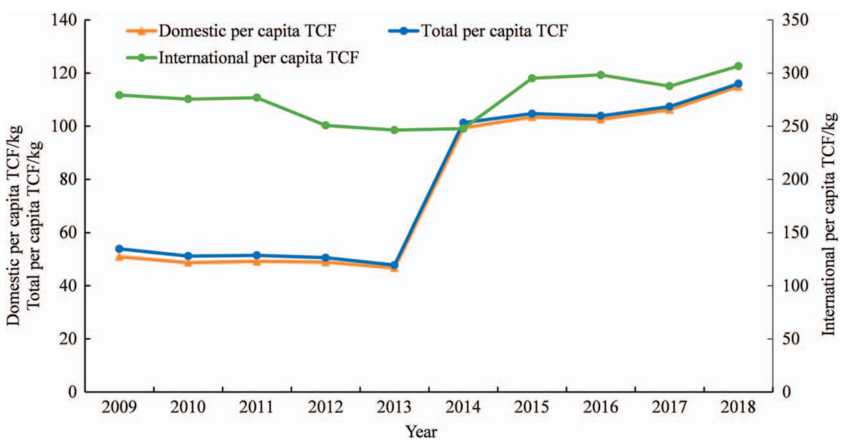

Figure 2. *The dynamic changes of per capita tourism carbon footprint in Heilongjiang Province from 2009 to 2018.*

carbon deficit while developing tourism economy. The increase in tourism carbon emissions will have a negative impact on climate change. Relevant departments should improve the carbon emission efficiency of Heilongjiang's tourism industry, vigorously develop low-carbon, eco-tourism and increase plant carbon sinks.

This study preliminarily estimates the comparison of tourism carbon footprint and tourism carbon capacity, which can be used to evaluate tourism ecological safety and sustainable development in a larger area. At present, there is no relevant research on the calculation of tourism carbon footprint in Heilongjiang Province, and there is only bottom-up method for the calculation of tourism carbon emissions [22]. Due to the different research methods and data sources, the conclusions are different, but the difference has not reached the order of magnitude, so the results are

Table 4. *Tourism carbon capacity and deficit in Heilongjiang Province from 2009 to 2018.*

Year	$TCC/10^8$ t	$\overline{TCC}$/t	$TCD/10^8$ t	$\overline{TCD}$/t
2009	151.8	138.2	151.8	138.1
2010	150.5	94.8	150.4	94.7
2011	158.0	77.3	157.9	77.2
2012	161.1	63.5	161.0	63.4
2013	177.5	60.9	177.3	60.8
2014	191.5	179.5	191.4	179.4
2015	203.0	156.0	202.8	155.9
2016	214.1	147.9	214.0	147.8
2017	216.2	131.7	216.0	131.6
2018	219.6	120.5	219.4	120.5

relatively reasonable. This study focuses on the comparative study of tourism carbon footprint and tourism carbon capacity in Heilongjiang Province, which provides a clear reference for the relevant departments to formulate emission reduction measures. In subsequent studies, the carbon footprint of Heilongjiang's tourism industry can also be quantified in specific aspects, such as hotels, activities and transportation infrastructure.

5 CONCLUSIONS

This study estimates the tourism carbon footprint in Heilongjiang Province from 2009 to 2018 by using tourism carbon footprint and tourism carbon capacity models. The research results can be summarized as the following conclusions:

(1) The total tourism carbon footprint in Heilongjiang Province increased from 2009 to 2018.
(2) The tourism carbon footprint mainly comes from the contribution of the domestic tourism carbon footprint.
(3) The tourism carbon capacity of Heilongjiang Province continued to grow steadily from 2009 to 2018.
(4) The value of the tourism carbon deficit is all positive which means the overall tourism carbon deficit risk is relatively small.

According to the above, the tourism carbon emissions show a continuous growth trend, and there is no trend to stabilize or decline. The slow growth of tourism carbon capacity indicates that tourism ecological problems still exist objectively.

In accordance with the results of this study, the following suggestions can be put forward:

(1) It is necessary to increase the promotion of low-carbon tourism and establish a multi-sectoral cooperation mechanism. Government and related enterprises in Heilongjiang Province should actively participate in publicizing low-carbon tourism to the public.
(2) Heilongjiang provincial government should appropriately learn from the successful experience of other regions, such as formulating and improving appropriate standards, encouraging public participation and promoting the development of low-carbon tourism.
(3) The relationship between investment and consumption expenditure should be effectively managed. The establishment of a systematic and standard tourism consumer price in the market requires not only to strengthen tax support but also to play the role of market supervision.

FUNDING

This study was supported by National Natural Science Foundation of China (41801137, 415011597), China Postdoctoral Science Foundation (2016M600257, 2014M560731), postdoctoral program of Heilongjiang Province (LBH-Z16093), projects of philosophy and social sciences of Heilongjiang Province (20JYE275, 20JYH068, 19JYE271), doctoral research projects of Harbin University of Commerce (2016BS05), young innovative talents project of Harbin University of Commerce (2019CX19), and graduate innovative research project of Harbin University of Commerce (YJSCX2020-655HSD).

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