Research on estimation of carbon emissions in the process of highway construction using quota method

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Abstract. Nowadays, global warming has caused phenomena such as glacier melting, reduction of the Arctic layer, sea level rise, and changes in rainfall patterns, which have a profound impact on human survival systems. From a global perspective, transportation has become one of the most important and fastest-growing areas for GHG emissions. However, research and exploration on greenhouse gas emission assessment techniques and related policies in this field are relatively limited and still in the initial stage. Most research on carbon emission measurement during the construction period is focused on a certain road, requiring a large number of parameters to be input in order to output carbon emission values. It cannot replace the calculation of carbon emissions from other highway construction. This article proposes the unit quota method for the first time and elaborates on the detailed calculation process. It can estimate a single road, multiple roads, and also estimate the total carbon emissions through the total construction kilometers at the city, provincial, and national levels.

Keywords: Highway construction, Carbon Emission Calculation, Energy Consumption Calculation, quota method.

1 Introduction

Nowadays, global warming has caused phenomena such as glacier melting, reduction of the Arctic layer, sea level rise, and changes in rainfall patterns, which have a profound impact on human survival systems. From a global perspective, transportation has become one of the most important and fastest-growing areas for GHG emissions. The total mileage of Chinese highways has increased from 4.2375 million kilometers[1] in 2012 to over 5.3548 million kilometers[2]in 2022,with an average annual growth rate of 11.1%. Highway construction has caused varying degrees of impact on the natural and social environment. However, research and exploration on greenhouse gas emission assessment techniques and related policies in this field are relatively limited and still in the initial stage.

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Some research reports have proposed energy consumption calculation methods for construction, maintenance, and operation stages throughout the entire life cycle of highways. Han Zhang et al. (2010) [3] used a composite life cycle analysis method to evaluate the energy consumption and greenhouse gas emissions of 200mm cement concrete overlay and 190mm hot mix asphalt mixture overlay during the material production and maintenance stages. Darrell Cass et al. (2011) [4] used a composite lifecycle analysis method to quantitatively analyze the energy consumption and environmental impact of a major repair project on an interstate highway in southwestern Michigan, United States. South Pan Meiping[5]Research on LCA based calculation method Sha Aimin [6] uses the life cycle assessment method to divide the construction process of asphalt pavement into five stages: raw material production, transportation, mixing, paving, and rolling. Zhang Yi[7] analysis of energy consumption of pavement construction with LCA.The model considered the loss of materials and energy during the process, and applied a calculation software with EXCEL as the backend processing to collect more than 70 categories of related emissions and energy consumption lists for quantitative calculation. A greenhouse gas calculation software (CHANGER) developed by the International Road Federation (IRF). The UK Transport Research Laboratory has developed the Carbon Emissions Calculation Tool (asPECT), which focuses on the calculation of carbon sequestration throughout the entire life cycle of road engineering. The research team led by Professor Arpad Horvath of the University of California, Berkeley, developed the pavement environment and economic benefits life cycle analysis and evaluation system PaLATE in 2003.

However, most research on carbon emission measurement during the construction period is focused on a certain road, requiring a large number of parameters to be input in order to output carbon emission values. It cannot replace the calculation of carbon emissions from other highway construction. Therefore, this study can be applied to the unit quota method for various highway construction periods, and is generally applicable to estimating carbon emissions during highway construction periods. This article proposes the unit quota method for the first time and elaborates on the detailed calculation process. It can estimate a single road, multiple roads, and also estimate the total carbon emissions through the total construction kilometers at the city, provincial, and national levels.

2 Unit quota method calculation formula

The carbon emissions during the construction period consist of four parts: material production stage, material transportation stage, mechanical construction stage, and mixing station disassembly and assembly stage, which are calculated using the following formula:

$$M = \sum_{i=1}^{n} \sum_{j=1}^{n} M_{ij} \quad (1)$$

In the formula: M - Total carbon emissions per kilometer during construction period, kg;M_{ij}—carbon emissions per kilometer for the i-th and jth impact categories, kg;

The overall energy consumption of each energy source is translated into standard coal with reference to the highway engineering budget quota[8], the number of machine teams, and general calculation principles as per GB/T 2589-2008[9].

See in table 1.

Table 1. Energy sources and conversion factor for coal equivalent[9]

Energy type	Average low calorific value	Equivalent conversion coefficient
raw coal	20908 kJ/kg	0.7143kgce/kg
cleaned coal	26344 kJ/kg	0.9000 kgce/kg
fuel oil	41816 kJ/kg	1.4286kgce/kg
Gasoline/ kerosene	43070 kJ/kg	1.4714kgce/kg
Diesel	42652 kJ/kg	1.4571kgce/kg
Residual oil	41816 kJ/kg	1.4286kgce/kg
liquefied petroleum gas	50179 kJ/kg	1.7143 kgce/kg
Oilfield natural gas	38931 kJ/kg	1.3300 kgce/m^3
Gas field natural gas	35554 kJ/kg	1.2143kgce/m^3
Electricity	3600 kJ/kW·h	0.1229kgce/kWh

A carbon atom produces a carbon dioxide molecule once it has completely burned. The relative atomic mass of a carbon atom is 12, while the mass of a carbon dioxide molecule is 44. One kg of SCE (Standard Coal Equivalent) burns with full combustion energy generated that is about equivalent to 0.7 kg of pure carbon. From there, one can compute that a full combustion of one kilogram.

3 Road base and cushion construction Carbon Emission calculations.

Tables 2 and Tables 3 display the carbon emission calculation results for the highway base and cushion construction.

Table 2. carbon emission calculation results for the highway base and cushion construction ($1000m^2$)

machine	machine shift	Equivalent Carbon Emission (kg)		
Smooth road surface		15cm thick	20cm thick	50cm thick
Motor grader	0.33	28.26	28.26	28.26
6-8t smooth wheel roller	0.25	76.38	76.38	76.38
12-15t smooth wheel roller	0.66	325.44	325.44	325.44
Sprinkler	0.38	11.1	11.1	11.1
Plant mixed base stabilized soil				
Tire type unloader	0.42	371.08	499.81	1272.19
stabilized soil mixing plant	0.21	131.88	163.27	351.61
Mixing equipment				

Mixing equipment within 100t/h (lime crushed stone)	0.62	346.16	379.66	580.66
Tire type unloader	0.62	312.92	338.16	489.6
Transportation of crushed stone`				
10t dump truck (with a transportation distance of 15km)	20.26	181.63	242.17	605.43
Plant mixed base stabilized soil mixture				
6-8t smooth wheel roller	0.14	35.97	35.97	35.97
Paver within 9.5 meters	0.24	165.74	165.74	165.74
Sprinkler	0.31	9.05	9.05	9.05
Total		1995.61	2275.01	3951.43

Table 3. assembly and disassembly of stabilized soil plant mixing equipment (1 unit)

machine	machine shift	Equivalent Carbon Emission (kg)
Single bucket excavator	5.08	29.14
Concrete mixer within 250L	4.06	142.81
Flat trailer within 20 tons	7.74	247.68
Truck crane within 12 tons	1.88	57.15
Truck crane within 40 tons	11.79	433.87
Total		910.65

4 Calculating Carbon Emission for Road Pavement Layer Construction.

Tables4 to Table 5 display the results of calculating the energy usage during the construction of the layers of roadway pavement.

Table 4. Calculating the carbon emission for road pavement layer

machine	machine shift	Equivalent Carbon Emission (kg)		
		5cm thick	8cm thick	10cm thick
Asphalt concrete mixture mixing				
Motor grader	7	20.58	32.93	41.16
Asphalt mixing equipment 120t/h	3.73	59.50	95.20	119.00
5t dump truck	3.88	0.54	0.86	1.08
Asphalt mixture transportation				
10t dump truck (with a transportation distance of 15km)	26.43	3.68	5.89	7.36
Asphalt mixture pavement paving				

6-8t smooth wheel roller	8.07	123.28	197.24	246.56
12-15t smooth wheel roller	6.05	149.16	238.66	298.32
Paver within 6 meters	4.1	142.43	227.88	284.85
Total		499.16	798.67	998.33

Table 5. Asphalt mixture mixing plant 1 unit's carbon emission during assembly and disassembly (1 Unit)

Asphalt mixture mixing plant	machine shift	Carbon Emission (kg)
Shovel (Fuel consumption 225g/w.h)	20.87	12154
Mixer	6.97	1162
20 ton trailer	10	1043
12 ton truck crane	3.22	319
40 ton truck crane	19.84	2379
75 ton truck crane	19.84	2844
Total	-	19900

5 Calculating Carbon Emission of mining equipment and stone chips.

Table 6 displays the energy consumption results of the mining equipment used to extract stone and chippings.

Table 6. Calculating Carbon Emission of mining equipment and stone chips (1000 m^3)

machine	machine shift	road base and cushion construction carbon emission kg			road pavement layer construction kg		
		8cm thick	20cm thick	50cm thick	8cm thick	20cm thick	50cm thick
Excavation of soil and stones							
9m^3/min air compressor	0.52	39.68	99.18	248.01	11.17	27.93	69.83
Collecting and screening soil and clay							
90kw tracked bulldozer	0.21	40.40	101.00	252.55	11.38	28.44	71.11
Sieve washing sand and machine made sand							
105KW tracked bulldozer	0.64	143.53	358.78	897.18	40.42	101.04	252.61
2m^3 tire loader	0.65	129.65	324.09	810.43	36.51	91.27	228.18
10m belt conveyor	1.37	51.82	129.53	323.89	14.59	36.48	91.19
screening machine	0.68	32.15	80.37	200.98	9.05	22.63	56.59
Mining block stones							
9m^3/min air compressor	3.95	301.39	753.36	1883.88	84.86	212.17	530.42
Mechanical crushed stone							
150 * 250mm electric jaw crusher	7.91	137.15	342.82	857.26	38.62	96.55	241.37
Total		875.77	2189.13	5474.19	246.59	616.51	1541.28

6 Taking a road construction as an example

Main technical standards:(1) design speed: 80km/h;(2) width of subgrade:24.5m;(3) Vehicle load level: Highway - Level I. According to traffic volume analysis, road grade and traffic composition, the traffic lane is designed as a two-way four lane 3.75m first-class highway asphalt concrete pavement, with a design life of 15 years, lane coefficient of 0.5, and standard axle load of BZZ-100. The K498+895-K510+116 is a newly constructed section. The road is paved with 4cm fine-grained modified asphalt concrete (AC-13C)+8cm coarse-grained modified asphalt concrete (AC25C)+32cm cement stabilized crushed stone+16cm cement stabilized crushed stone. The total length is 11.221km, the road width is 24.5 meters, and the construction area is 274914.5m^2. Example of construction carbon emission is 2862057.88kg. Plus the construction of a mixing plant with carbon emissions of 5238kg and 7654kg. The construction of this road generates a total of 2874.95 tons of carbon emissions.

See in figure 1.

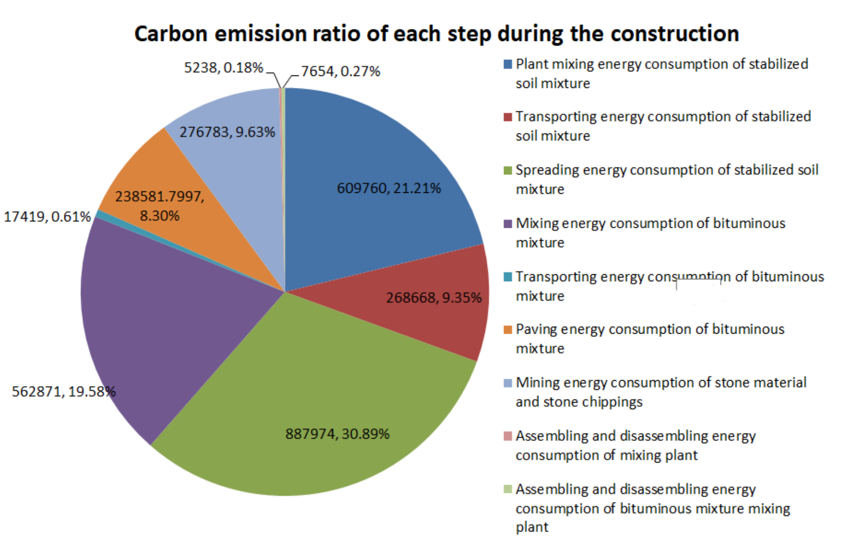

Fig. 1. The calculation results of carbon emissions for each construction stage of the road construction case in this article

7 Conclusion

China has constructed 74.1 thousand km of road in 2022. According to calculating methods and data stated above, the total consumption of energy was 7.30 million tons of SCE and the total carbon emission was 18.99 million tons. According to the calculation example, the steps with the highest carbon emissions are Spreading energy consumption of stabilized soil mixture, Plant mixing energy consumption of stabilized soil mixture and Mixing energy consumption of bituminous mixture, which are important for controlling carbon emissions. This article proposes the unit quota method for the first time and elaborates on the detailed calculation process. It can estimate a single road, multiple roads. This study addresses the issue of not incorporating greenhouse gas emissions into the quantitative measurement and calculation methods and evaluation system for the entire life cycle of Chinese highways in the field of highway transportation. The carbon emission quota calculation method can objectively and comprehensively compare and select specific emission estimates for construction, operation, and maintenance technologies. This study aims to guide and promote the development and progress of energy-saving and emission reduction technologies during the road use stage.

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