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A Life Cycle Assessment Of Energy-saving And Carbon Reduction Potential ——Empirical research On A Road Reconstruction Project In China

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Abstract: A life cycle standardized assessment module of energy-saving and carbon reduction is established based on the current road cost management software. The assessment module combines the domestic road material consumption quota and the main LCA database CLCD in China. Quantitative energy-saving and carbon reduction benefits of material and technical alternative measures could be calculated autocratically. Empirical project data shows that reducing concrete, reducing mixing temperature and reusing material of the old road are essential measures. It is possible to reduce carbon by 22-28% and save energy by 45-50%.

1. Introduction

With the requirement of energy conservation and carbon reduction, road reconstruction design become important such as the use of new materials, energy and masonry reduction design measures[1]. In 1999, Piantanakulchai took the lead in assessment of carbon emissions for a highway[2].Yue Huang measuring the carbon footprint[3].The life-cycle carbon of asphalt paving proves reducing waste is important [4,5].It is also found that context up to 34% of GHG emissions can be avoided based on current technology[6].

An empirical research is conducted on a road reconstruction project in Hainan province, China. The assessment module is set based on the cost management software in which the material consumption is calculated using a unified social average labor quota in China. Thus the assessment method could be copied and popularized easily.

2. Energy consumption and carbon emissions assessment

2.1 assessment scope and method

The assessment module of energy consumption and carbon emission is the basis of optimal design[7]. Generally, the ISO14040 life cycle evaluation standard is adopted from cradle to grave evaluation perspective, including raw materials, construction, maintenance, and abandonment stages[8].

Firstly, the bill of three stages and 18 materials are selected to represent the material consumption which covers 99.2% of the road reconstruction project as shown in Table 1. Considering the error rate of in environmental is up to 25% from different databases[9], the application of recognized local databases CLCD is the key method to ensuring the applicability and comparability of assessment results.

Table 1 Carbon and Energy Coefficients of Road Reconstruction

stages	Materials	Coefficients		Data sources
		f_i (carbon)	p_i (Energy)	
Raw material production	Steel reinforcement	2.64	39.05	CLCD
	Asphalt	0.86	56.00	
	Steel pipe	2.84	42.27	
	Coal	0.21	25.98	
	Electric	0.97	12.79	
	Steel plate	2.91	43.72	
	Heavy oil	0.66	40.82	
	Aluminium alloy	23.86	281.42	
	Clay	0.003	0.03	

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	Gasoline	0.93	50.61	
	Cement	0.74	4.50	
	Water	0.0002	0.003	
	Crushed stone	0.002	0.03	
	Diesel oil	0.80	47.34	
	Iron piece	2.36	29.08	
	Sand	0.003	0.04	
	Natural gas	0.28	15.49	
Construction and operation	Coal	1.9	20.91	Domestic specifications
	Heavy oil	3.17	41.82	
	Gasoline	2.93	43.07	
	Diesel oil	3.1	42.65	
	Natural gas	2.16	38.93	
Abandonment	Construction waste of old road	0.01	0.18	ELCD

Note:data corms from China Life Cycle Core Database of Sichuan University,General Principles for the Calculation of Comprehensive Energy Consumption (GB/T 2589-2020) and the Guidelines for the Preparation of Provincial Greenhouse Gas Inventory (FGBG [2011] No. 1041).

Secondly, the bill is imported into the Energy consumption and carbon emissions assessment module based on the cost management software. Then the coefficients of carbon or primary energy consumption set in the software module could be used to account the GWP and PED according to formula (1) and (2).

$$\sum_{i=1}^{n} GWP = Q_i \times f_i \tag{1}$$

$$\sum_{i=1}^{n} PED = Q_i \times p_i \tag{2}$$

GWP is the carbon emissions, with the unit kg CO2 eq/kg. PED is the primary energy consumption, with the unit MJ/kg. Q_i is the inventory quantity of i materials. f_i is the carbon coefficients of i materials. p_i is the primary energy consumption coefficients of i materials.

2.2 Assessment result

According to the assessment result, the total carbon emission of the project is 1.8e6kgCO2eq/km, which is mainly concentrated in the raw material production stage, assessment for 83%, followed by 10% in the construction stage and 5% in the original road abandonment stage, and 2% in the maintenance stage. The primary energy consumption is 2.58E+07MJ/km. The main energy consumption and carbon emission is the construction stage.

Reducing concrete is the key to carbon reduction, as shown in Fig. 1. Cement raw materials produce a large amount of carbon dioxide in the production process of calcination. The cement consumption is mainly reflected in the pavement base by 19%, bridge and culvert structures by 36% and concrete ditches by 12% that do have alternative technical measures and materials. From the perspective of primary energy consumption in Fig. 2, asphalt is the highest by 40% in Fig. 3, mainly because asphalt mixing uses a hot mixing process, which consumes much energy.

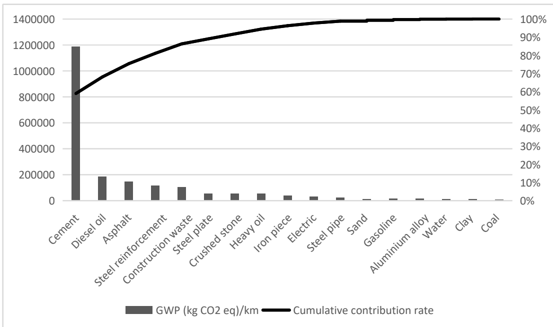

Fig. 1 Cumulative contribution of carbon (left)

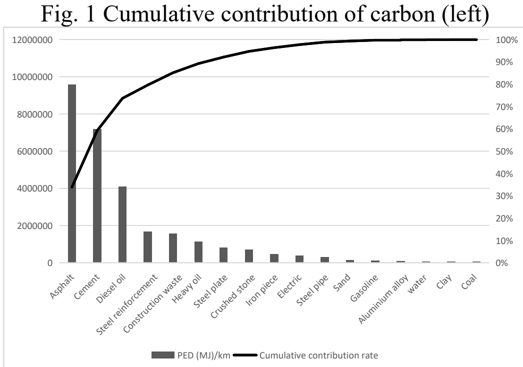

Fig. 2 Cumulative contribution of primary energy(right)

3. Application of optimized design

The goal of the assessment is to guide the optimization of road design to lower energy consumption and carbon emission.The comparison of energy conservation and carbon reduction measures show that warm mix asphalt is the most effective measure for energy conservation. At the same time, concrete replacement is the effective measure for carbon reduction, as shown in Table 2. Other measures include such as replacing oil with gas in the mixing station, reusing old road materials, and arranging material transportation which contribution less compared with the main materials as pavement and slope protection measures.

Table 2 energy conservation and carbon reduction contribution

measures	GWP	PED	Implied in the provincial road	Introduction
Foam warm mix asphalt	3%	28%	0	Future possible
Rubble concrete replacing foam light soil protection	17%	9%	0	Future possible
Mortar rubble protection replacing rubble concrete	11%	6%	0	possible
25% Plant mixed hot regeneration dosage	0	9%	0	possible
Rubble concrete ditch replaced by rubble concrete ditch	3%	1%	0	possible
Changing oil to gas in mixing station	1%	3%	100%	
Reuse of old road as sub-base	1%	1%	30%	
Granular material reuse to abutment backfill	1%	1%	100%	
Reuse of mortar rubble	1%	1%	100%	
Reuse of waste excavation in backfill	1%	1%	100%	
Optimize transportation organization	1%	1%	100%	

(1) Comparison and selection of pavement measures

The carbon emission of the concrete measure are much higher than that of the asphalt measure because the carbon of the cement product itself is amplified, and the cement structure has poor reprehensibility, which will be abandoned after the design life,shown in Table 3.

Table 3 Energy saving and carbon reduction of pavement measures

	Asphalt	Cement concrete	25%Asphalt plant mixing hot regeneration	Foam asphalt cold regeneration
GWP (kg CO2 eq/m2)	30	91	30	24
PED (MJ/m2)	1212	736	981	485
Cost per square meter	134	145	94	137
GWP contribution	16%	50%	16%	13%
PED contribution	46%	28%	37%	18%
	Implementation		Conservative optimization	

(2) Comparison and selection of slope protection measures

Rubble structure is superior to concrete structure from the carbon reduction aspect in Table 4.Considering the construction inefficiency of rubble structure, increasing the labour subsidy of mortar rubble can increase the use of rubble structure.

Table 4 Energy saving and carbon reduction of the protection measure

	Rubble concrete+8% foam light soil	Rubble	Rubble concrete	foam light soil
GWP (kg CO2 eq/m3)	218	80	211	309
PED (MJ/m3)	1542	551	1503	1994
Cost per cubic meter	746	400	750	700
GWP contribution	21%	8%	21%	30%
PED contribution	11%	4%	10%	13%
	Implementation	Conservative optimization		

According to different implementation scenarios including "no energy conservation and carbon reduction measures"、 "Implied in the provincial road " 、 "conservative optimization" and "future optimization" as shown in Fig. 3. Based on the existing engineering technology, the "conservative optimization" scenario is expected to further reduce carbon by 17-22% and energy consumption by 13-16%. It is expected to reduce carbon by 22-28% and save energy by 45-50% in future.

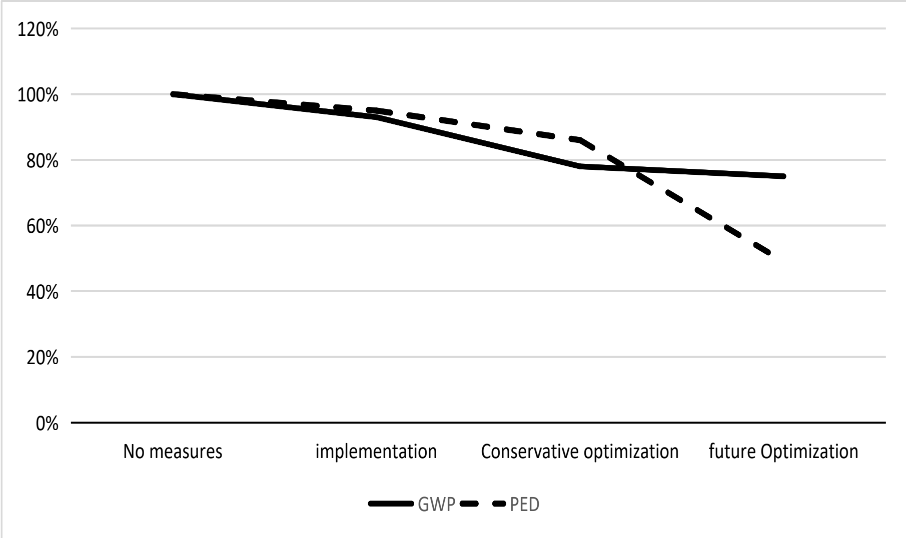

Fig. 3 Prediction of Energy Conservation and Carbon Reduction Scenarios

4. Conclusion

A life cycle standardized assessment module of energy-saving and carbon reduction is established based on the current road cost management software. The assessment module combines the domestic road material consumption quota and the main LCA database in China. Quantitative energy-saving and carbon reduction benefits of material and technical alternative measures could be calculated autocratically.

Reducing concrete, reducing mixing temperature and reusing material are essential measures that reduces energy consumption and carbon emissions throughout the life cycle of the road reconstruction . In addition, the optimized technical measures include using new energy, reusing old road waste, and arranging material transportation, are also essential measures to reduce energy consumption and carbon.It is possible to reduce carbon by 22-28% and save energy by 45-50%.

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