Study on Carbon Emission Assessment Index System of Highway Tunnels based on Life-cycle Approach

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Abstract. In this paper, to achieve energy conservation and low carbon in tunnel construction, a tunnel carbon emission assessment method is proposed based on the life-cycle approach. This study focuses on the characteristics of carbon emission sources in the planning & design stage, construction stage and operation stage of tunnels. The aim of achieving green and low-carbon comprehensive value assessment of highway tunnels needs to be determined by quantitative indexes, and particularly, an assessment index system for tunnel carbon emission should be established. The paper provides a standard for evaluating the scientificity and rationality of design schemes of highway tunnels. Finally, a basis is provided for the optimization design of life-cycle carbon emission and the optimization construction technologies of highway tunnels.

Keywords: tunnel engineering; carbon emission; life cycle

1 Introduction

Tunnels are key nodes for the highway traffic safety. Vehicles and electromechanical facilities in tunnels not only cause concentrated carbon emissions, but also determine the visual and air environment which directly affects the physical and mental health of drivers and safe driving. Due to the limited space, special structure, complex facilities and poor air environment, there easily occur the accumulation of carbon emission. It is essential to aware and make a standard and evaluation for carbon emission in tunnels.

As the “throat” of highway traffic, the low carbonization of tunnel directly determines the environmental protection of highway traffic. At present, building green and low-carbon tunnel traffic is important for building green traffic, and low-carbon monitoring through information technologies also expands the application field of intelligent transportation. In this paper, carbon emission calculation and assessment are studied based on the features of tunnel engineering & carbon emissions, the requirements of ecological environment protection and the management of low carbon

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operation. The study is carried from four aspects: characteristics and influencing mechanism of carbon emission from expressway tunnels in mountain areas, carbon emission calculation method, carbon emission assessment technical requirements of highway tunnel design scheme, and carbon emission monitoring technology.

2 Carbon emission sources of highway tunnels

2.1 Carbon emission from highway tunnel planning and design

The carbon emissions in the planning & design stage are typically generated from the daily activities of designers and the consumption of design materials, etc., but they account for a very small proportion of the total emissions in the life cycle of tunnels. In addition, due to the consumption of designers' activities and design documents are difficult to be subdivided and quantified, the detailed calculation of their carbon emissions is not necessary. However, the small amount of greenhouse gas emissions directly generated in the planning & design stage affects the carbon emissions in the later stages of tunnel construction and operation.

2.2 Carbon emission from highway tunnel construction stage

The carbon emission sources in tunnel construction can be divided into three parts: the construction raw materials, energy consumption of machinery, and the production and transportation of materials. Most of construction materials are produced outside the construction site. Common materials include steel, cement, explosive, sand, crushed gravel, water, asphalt, ceramic tiles, etc. For carbon emission of tunnel construction machinery, typical activities that generate carbon emission mainly include shield construction, drilling, blasting, mucking, pavement laying and equipment installation by energy-consumption tunnel construction equipment such as intelligent three-boom drill jumbo, concrete batching plant, air compressor, excavator, drill jumbo, shotcrete machine, AC welder, and tunnel fan. The carbon emission in the production and processing stage of raw materials for tunnel construction and the energy consumption of mobile machinery used in tunnel construction, including trucks, dumpers, loaders and concrete mixers, can be calculated by statistical analysis of the inventory of raw materials used in construction, the consumption of various raw materials and corresponding carbon emission factors and multiplying the consumption by the carbon emission factors.

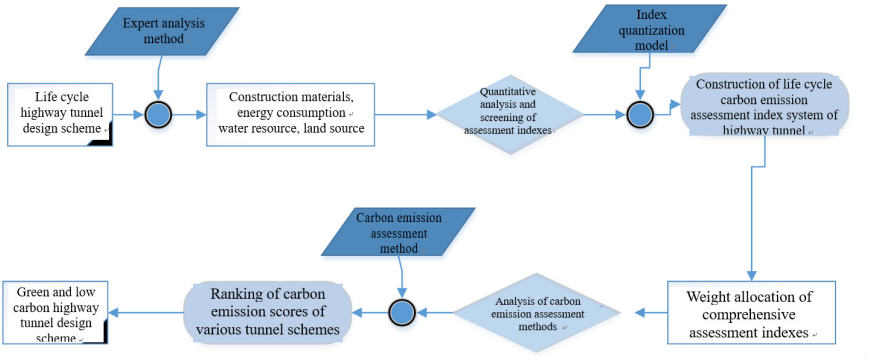

Fig. 1. Highway Tunnel Carbon Emission Assessment Process

2.3 Carbon emission from highway tunnel operation stage

The operation and maintenance stage have the longest influence on carbon emission in the life cycle of highway tunnel, mainly from electromechanical facilities and tunnel maintenance facilities. In the operation and maintenance stage, there are many electromechanical facilities in the tunnel, resulting in concentrated carbon emissions. Electromechanical facilities are also the main fixed source of carbon emissions in the tunnel, mainly including lighting, ventilation, smoke control, indication, monitoring, etc. Tunnel maintenance generates carbon emissions directly or indirectly, so there are endogenous carbon emissions and exogenous carbon emissions. Typical activities of the former are the repair and maintenance of damaged subgrade and pavement, and the replacement and maintenance of various electromechanical facilities directly generating carbon emissions, while the production and transportation of raw materials required for maintenance also generates carbon emissions indirectly.

3 Comprehensive assessment and analysis methods for carbon emissions of highway tunnels

3.1 Assessment principle and method

As early as 1990, the concept of life cycle assessment was put forward for evaluating the impact of product production process and use process on the environment, and the assessment object improving environmental impact. Life cycle assessment of tunnel carbon emission involves the process of tunnel planning and design, construction, and operation and maintenance. At present, the basic structure of life cycle assessment is divided into scope definition, impact assessment and inventory analysis (the most important part).

3.2 Assessment principle and method

To obtain the tunnel engineering design scheme with optimal carbon emission, a systematic and objective analysis was carried out based on the impact effect of tunnel engineering technology, ecological environment and social economy. During the comprehensive assessment of life-cycle carbon emission of highway tunnel based on the concept of green and low carbon, the comprehensive carbon emission assessment method (shown in Figure 1) of highway tunnel was proposed. These helps construct a life cycle comprehensive value assessment index system of extra-long highway tunnel based on the concept of green and low carbon.

3.3 Inventory analysis

Inventory analysis is the abstraction and generalization stage of material and energy flows in the life cycle process. It is the quantitative analysis of data of resources, energy and environmental emissions (including waste gas, waste water, solid waste, etc.) of tunnel construction project in the life cycle. The core of inventory analysis is the input and output of the product system represented by the functional unit of tunnel carbon emission.

4 Construction of highway tunnel carbon emission assessment index system

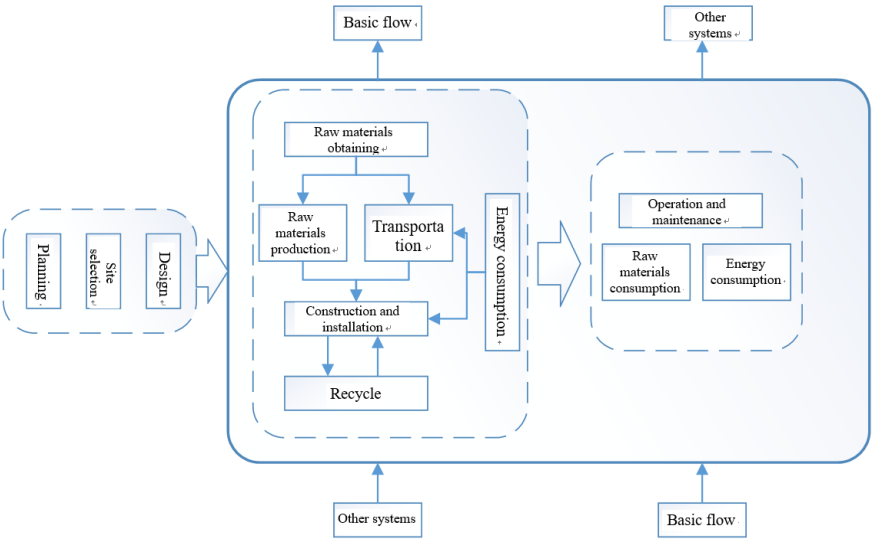

Fig. 2. Highway Tunnel Carbon Emission Inventory Boundary

4.1 Basic principles for the establishment of the assessment system

It should highlight the requirements of "a green four sections", take “land saving, energy saving, water saving, material saving and environmental protection” as the main objectives, implement the national technical and economic policies, and promote the concept of sustainable development in highway transportation. Around the above objectives, multi-level and multi-faceted specific requirements should be put forward.

The process control should be reflected. Highway tunnels generate carbon emissions through their life cycle, which is a systematic engineering including material production, planning, design, construction and operation. The carbon emission assessment of highway tunnel is not only based on the results of the project, the control for the stages of planning, design and construction is also required.

It should combine qualitative and quantitative methods, and list specific values for mature assessment indexes. After comprehensive analysis, specific values should be put forward for assessment indexes that are considered or expected to be achievable. Put forward qualitative requirements for assessment indexes that are lack of relevant basic data, such as energy consumption of materials, CO_2 emission, plant CO_2 fixation, etc.

4.2 Key assessment indexes

It should clarify the basic requirements for carbon emission assessment of highway tunnels, and put forward key carbon emission assessment indexes for tunnels according to rational utilization of resources and energy, environmental protection, etc.

(1) Resource consumption index. Cement and steel are the main resources. Three aspects of saving materials, material selection and using local materials are considered. The word of “material” here involves construction materials, installation materials, decorative materials and temporary engineering materials.

(2) Energy consumption index. Energy conservation, the use of renewable energy and energy optimization are mainly considered. The word of “energy” here involves electricity, oil, coal, etc. Temporary land occupation index. Saving temporary land occupation index is mainly considered.

(3) Investment quota index. According to the investment for main energy consumption and material consumption criteria of various tunnel construction projects given in the tunnel design, the energy consumption and material consumption of each construction investment are measured.

4.3 Construction of assessment index system

Land saving, energy saving, water saving, materials saving and environmental protection within the life cycle of highway tunnels for building green and low-carbon tunnels, as well as meeting the functional requirements of highway tunnels are often contradictory to each other. For example, excessive consumption of materials to achieve single energy-saving index does not meet the requirements of green & low-

carbon tunnels. Lowing the functional requirements and applicability of highway tunnels to reduce resource consumption is also not conformance with green and low-carbon concept. Therefore, the direct relationship between land saving, energy saving, water saving, material saving, environmental protection and tunnel functions must be considered as a whole and properly handled in the life cycle of the tunnel. Attention should also be paid to the application of information technologies, intelligent technologies and new technologies, new products, new materials and new processes of green highway. According to the basic requirements for carbon emission assessment of highway tunnels, a carbon emission assessment index system for tunnels is established based on rational utilization of resources and energy, environmental protection, etc. (as shown in Figure 3).

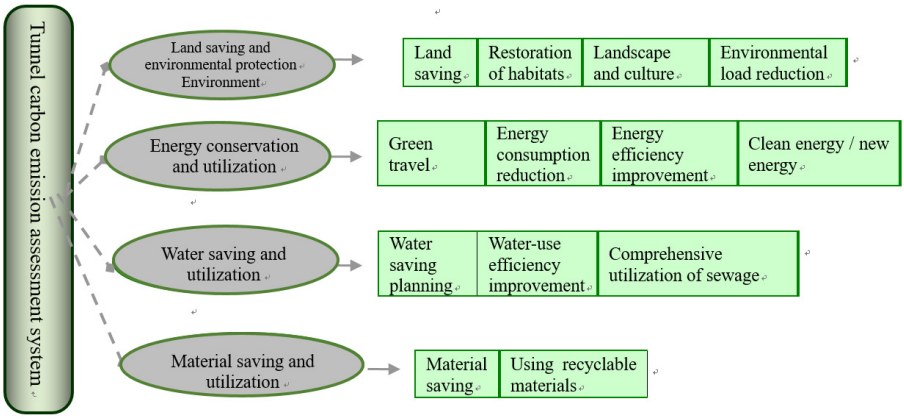

Fig. 3. Assessment Index System

5 Conclusion

From the aspects of land saving, energy saving, material saving and water saving, the impact factors of carbon emission assessment indexes are considered during the construction & operation stage of highway tunnels. The main conclusions can be summarized as follows:

In this study, the principles of systematicness, conciseness, scientificity, operability, typicality, comparability and comprehensiveness are considered. Finally, an assessment index system is obtained according to relevant information of tunnel engineering, relevant specifications and standards. The objective mathematical statistical methods are used such as correlation analysis, index quantitative analysis and expert analysis. It is of great significance to obtain the optimal design scheme of highway tunnel carbon emission in the near and far future.

In terms of the future work, the resource consumption indexes (such as: construction materials, installation materials, decoration materials, energy consumption index-

es including electricity, oil, coal and water) and key assessment indexes (such as: investment quota indexes) should be selected to obtain a life-cycle comprehensive evaluation index system of tunnels through the analysis of the life-cycle comprehensive assessment indexes of tunnels. This system meets the technical feasibility of design, economic and social rationality which also provides basis for constructors and decision maker.

References

1. Hong Kairong, Feng Huanhuan. Development Trends and Views of Highway Tunnels in China over the Past Decade [J]. Chinese Journal of Highway and Transport, 2020,33(12):62-76.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73
2. Liu Yiming, Liu Nianxiong. The Importance of Carbon Emission Calculation in Building Life Cycle Assessment [J]. Design Community 2020(3):46-51
3. Xue Xiaodong. Life Cycle Carbon Emission Assessment of Buildings [J]. Sichuan Cement 2019(12):301
4. Li Qiaosong, Bai Yun, Li Lin. Study of Influential Factors and Measures for Low Carbonization During the Construction of Shield Tunnels [J]. Modern Tunnelling Technology, 2015,52 (03): 1-7
5. Chen Lingjun. Study on Carbon Emission Characteristics and Impact Mechanism of Highway Tunnel Traffic [M]. Chongqing Jiaotong University

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