LCA evaluation system and benefit analysis of green Highway technology

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Abstract: Aiming at the problem of all kinds of green road technology is difficult to compare with, energy conservation and emissions reduction from the technical feasibility and economic benefits, etc. Build green road technologies LCA evaluation system is put forward, and with G312 Suzhou western engineering comprehensive benefit analysis as an example, the comprehensive benefit of the most significant, have scale, resource investment suitable green road technologies; the breakthrough and innovation of technical bottleneck problem is the fundamental power to promote the development of green highway. The premise of integrating green concept into the whole life cycle of highway construction is not only the preliminary planning layout research according to local conditions, but also the basis of reasonable selection of suitable green highway technology.

1. Introduction
With the concept of green development in highway planning and design in construction operation and maintenance practices continue to expand and in-depth, initially build green transportation system strategic target the important measures of the green road technology as an important carrier green operating the process of highway construction, comprehensive benefit analysis of whole life cycle, which provides decision-making support for highway construction and operation management departments, promote green highway technology popularization and application has important practical significance[1-3].

Life Cycle Assessment (LCA), as an effective part to evaluate the energy consumption emission in highway projects[4-5], has been widely used in the relevant evaluation practice of highway projects at home and abroad. Research institutions at abroad have developed relevant professional LCA software.

According to green technology efficiency analysis, highway construction should not only consider the operating costs, also want to consider the energy conservation and emissions reduction benefits of the technology and the impact on the environment, input and output method for reference, will highway construction (production) and operation (demand) of both, to better understand the green road technology and the building of the relationship between the production and operation demand, laid the theoretical basis for its benefit analysis[6].

2. Green highway technology LCA evaluation system
It provides reference for the construction of green highway technology LCA evaluation system, which is mainly reflected in:(1) green highway evaluation index does not include planning and design related indexes;(2) Both intensity index and process index include related indexes of highway construction period and operation period. Therefore, LCA concept can be adopted to evaluate green highway technology. (3) from the measurement of intensity can be involved in a green road technical resources
of the technical feasibility of the whole life cycle energy consumption impact on the environment and economy, etc. A comprehensive evaluation of input and output method for reference to build green road technologies LCA evaluation body of the evaluation system is mainly from the scope of evaluation boundaries and green highway technology selection and green road technologies LCA evaluation method is presented in three aspects.

2.1. Evaluation limits and scope
Taking the green highway technology of all links in the whole life cycle of highway engineering as the evaluation scope, that is, the whole life cycle from planning and design to construction and operation. The survey and design mainly include the design schemes related to energy conservation, emission reduction, resource recycling, ecological and environmental protection adopted by various majors such as routes, roads, Bridges, culverts and intersections. The construction stage is mainly used in the construction material construction technology and construction machinery, energy-saving emission reduction ecological environmental protection technology and equipment; The operation process is mainly aimed at the monitoring equipment along the lighting building energy conservation and other aspects of the use of information renewable energy technology and equipment.

2.2. LCA evaluation method for green Highway technology
Input-output method, this article is based on economic research to build green road technology LCA comprehensive evaluation model, the discriminant conditions mainly refers to the technical performance as the precondition, with full lifecycle concept respectively from the green technology with conventional technology economy index, energy conservation and emissions reduction benefits index two dimensions transverse comparison, get green road technologies of comprehensive benefit evaluation index, annual average energy conservation and emissions reduction benefits of the technology and its conversion into a year the ratio of the operating cost of investment, construction of units are the ten thousand yuan.

2.2.1. Technical performance index (M)
This indicator is a necessary condition for judging whether to adopt the green highway technology. It is a qualitative indicator for comprehensive comparison and analysis with conventional technology in terms of applicability, advancement, reliability and safety. When M \( \leq 0 \), that is, Y is 0 when the green technology has no obvious advantage over the conventional technology under the comprehensive comparative analysis results of the above factors; When M > 0 has obvious advantages and positive benefits, \( k_1 \) and \( k_2 \) need to be compared comprehensively.

2.2.2. Economic index (\( k_1 \))
This index is a comprehensive evaluation index of construction investment cost, operation maintenance cost, recycling utilization rate and other aspects in the whole life cycle of green technology implementation compared with conventional technology, as detailed below:

\[
k_1 = 1 - \frac{(1 - \beta_e) \cdot y_e \cdot Q_{1e} + \frac{Q_{2e}}{y_e^2} \cdot \eta \left(1 - \frac{1}{(1 + \eta)^y_e}\right)}{(1 - \beta_g) \cdot y_g \cdot Q_{1g} + \frac{Q_{2g}}{y_g^2} \cdot \eta \left(1 - \frac{1}{(1 + \eta)^y_g}\right)}
\]

In the formula, \( \eta \) is the social discount rate, taking the bank's annual loan interest rate of the same period; \( y \) is the service life of a green technology in years (the same below); \( Q_1 \) is the total investment cost of construction, and the unit is ten thousand yuan (the same below); \( Q_2 \) is the cost of operation and maintenance; G is the conventional technology adopted; E refers to the green technology adopted.

2.2.3. Efficiency index of energy conservation and emission reduction (\( k_2 \))
This indicator refers to the comprehensive energy saving and emission reduction benefits generated during the construction period and operation and maintenance period of implementing green
technologies compared with conventional technologies, namely:

\[ k_2 = (E_{1g} - E_{1e}) + (E_{2g} - E_{2e}) \]

\( k_2 \) is benefit index of energy conservation and emission reduction; If \( k_2 > 0 \), represents that the technology has energy saving and emission reduction benefits, and the greater the value is, the more significant the energy saving and emission reduction benefits are, \( M > 0 \); If the \( k_2 < 0 \), represents that the technology has no obvious advantages in reducing emission, namely \( M < 0 \); \( E_1 \) is the direct annual energy consumption or annual carbon dioxide emissions. \( E_2 \) refers to indirect annual energy consumption or annual carbon dioxide emission or investment and operation and maintenance cost reduction.

Referring to the construction of green roads in China and their contribution to the social economy, the weights corresponding to \( E_1 \) and \( E_2 \) were selected, as shown in Table 1.

Table 1: Weight selection of \( E_1 \) and \( E_2 \)

| Types of energy saving and emission reduction benefits | Annual average energy saving and emission reduction \( (E_{1g} - E_{1e}) \) | Average annual amount of alternative fuels | Annual CO₂ emission reduction \( (E_{2g} - E_{2e}) \) | The rest of maintenance costs | subtotal |
|-------------------------------------------------------|-------------------------------------------------|----------------------------------|---------------------------------|-----------------------------|--------|
| Direct annual energy saving and emission reduction \( (E_1) \) | 0.18 | 0.18 | 0.24 | — | 0.6 |
| Indirect annual energy saving and emission reduction \( (E_2) \) | 0.12 | 0.12 | 0.12 | 0.04 | 0.4 |
| total | 0.3 | 0.3 | 0.36 | 0.04 | 1 |

2.2.4. Overall efficiency indicator \((Y)\)

This index is the economic index and energy-saving emission reduction index of the green highway technology, which are converted into the specific value of economic benefit or social benefit respectively:

\[
Y = \frac{(E_{1g} - E_{1e}) \cdot \delta + (E_{2g} - E_{2e}) \cdot \lambda}{\left\{ (1 - \beta_e) \cdot y_e \cdot Q_{1e} + \frac{Q_{2e}}{y_e^2 \cdot \eta} \cdot \left( 1 - \frac{1}{(1 + \eta) y_e} \right) \right\} \cdot \frac{1}{y_e}}
\]

Where, \( Y \) is the comprehensive benefit index of green technology. The higher the \( Y \) value is, the higher the comprehensive benefit of technology and economy evaluation in its life cycle will be, energy saving and emission reduction in energy conservation and emissions reduction benefits to quantitative calculation of project, the \( \delta \) take 600 yuan/tce,800 yuan/toe. \( \lambda \) is the calculated unit price for energy saved or the average unit price for carbon trading.

Table 2: Summary of green highway technology LCA evaluation index results

| Green highway technical name                        | \( M \) | \( k_1 \) index | \( k_1 \) rank | \( k_2 \) index | \( k_2 \) rank | \( Y \) index | \( Y \) rank |
|-----------------------------------------------------|--------|----------------|---------------|----------------|---------------|--------------|-------------|
| Critical path planning selection design             | \( >0 \) | 0.0184         | 9             | 434.68         | 7             | 0.0020       | 15          |
| The implementation scheme of subgrade engineering based on resource balance | \( >0 \) | 0.1553         | 5             | 646.90         | 4             | 2.6686       | 4           |
| Bridge standard prefabricated structure              | \( >0 \) | 0.119          | 7             | 25260.42       | 1             | 2.7748       | 3           |
Prestressing intelligent construction technology  >0  -0.8729  13  1.14  15  0.2671  8
Deck runoff collection system  >0  -3.2654  16  6.28  14  0.2368  9
Road self-illumination signs  >0  -0.2396  12  0.11  16  0.0004  16
Warm mix asphalt technology  >0  -0.0311  10  23.42  11  0.0081  14
Finished rubber asphalt technology  >0  0.3011  3  82.36  9  1.6504  5
Crack resistant water stabilizes the base  >0  0.0728  8  559.21  6  0.2018  10
Low carbon rut resistant asphalt mixture  >0  0.3521  2  626.32  5  0.1015  11
Utilization and regeneration of old pavement structure  >0  0.1344  6  300.34  8  7.6297  2
Low carbon thin layer bridge deck pavement technology  >0  0.1773  4  10.64  13  10.8230  1
Mixing building "oil to gas" technology  >0  -0.1022  11  1610.03  2  0.2812  7
Super energy saving variable information board  >0  -0.9517  14  18.53  12  0.0569  13
LED green lighting technology  >0  0.5123  1  908.72  3  0.2829  6
Insulation technology for building walls  >0  -1.0227  15  29.17  10  0.0638  12

3. LCA evaluation results and analysis of green Highway technology

3.1. LCA evaluation result
According to the above evaluation method, combined with the energy consumption statistical survey data of G312 and relevant design documents, contract invoices and other materials, the results of various indicators are calculated and obtained, as shown in Table 2.

3.2. Analysis of various indicators
It can be seen from Table 2 that all kinds of green technologies adopted in the West Suzhou section of G312 project have certain energy saving and emission reduction benefits due to their technical feasibility, so M > 0; The proportion of $k_1 > 0$ is 56.25%. In addition to LED green lighting technology, the rest ranked 2nd to 7th with good economic performance. All of them have significant resource-friendly characteristics, which will bring significant economic benefits due to the reduction of project amount or initial investment. However, green technologies with poor economy are mainly due to their limited application scale and relatively limited economic benefits.

$k_2 > 375.70$ (that is, the average value after excluding the maximum value and the minimum value) is 43.75%. According to the analysis, the top 7 green technologies in this index all have large application scale. Except for LED green lighting technology and mixing building oil to gas technology, the other green technologies have significant indirect energy saving and emission reduction benefits brought by resource intensification. And no obvious energy conservation and emissions reduction benefits of green technology, mainly because it should use smaller, direct energy conservation and emissions reduction benefits of the poor, and embodies in reducing emissions and other environmental protection category (the economic benefits of these technologies in environmental protection is not fully considered, only saving of resources indirectly measure to reduce carbon emissions, but not to reduce the economic benefits of water pollution caused by atmospheric pollutants to measure).

In addition, $Y > 1.1590$ (the average value after excluding the maximum value and the minimum value) is 31.25%, and its ranking is similar to the economic index of energy conservation and emission
reduction. In other words, the green highway technology ranked in the top ranks is characterized by large application scale, resource conservation and environmental friendliness; In addition to the small scale of application, the technologies at the bottom of the list are also affected by the large investment cost and operation cost, resulting in poor comprehensive benefits.

4. LCA evaluation results and analysis based on application size normalization

Based on the above analysis shows that due to the use of the green field and the actual size is different, resulting in only qualitative evaluation technology of different categories, it is difficult to reflect the green technology comprehensive benefits between high and low. Therefore, according to the actual application scale of various green technologies, this paper normalized $k_2$ to obtain unit energy saving and emission reduction targets.

The $k_2'$ index value of application scale evaluation based on the number of kilometers and the number of surfaces decreases in turn. Among them, technologies such as LED green lighting technology critical path selection, planning and design of standardized prefabricated structures have significant energy saving and emission reduction benefits. Through a comprehensive comparison between $k_2$, $k_2'$ and $Y$, it can be known that three green highway technologies, such as bridge standardized prefabricated structure mixing building oil to gas technology and LED green lighting technology, rank high in the rankings, and these technologies are also widely and successfully applied at present.

5. Conclusion

This paper uses the input-output method for reference to establish the LCA evaluation system of green highway technology from the aspects of technical economy, energy conservation, emission reduction and comprehensive benefit, etc., and analyzes the comprehensive benefit of each green highway technology. The conclusions are as follows:

(1) It has the green highway technology suitable for large-scale resource recovery investment, and its comprehensive benefits in the whole life cycle process are the most significant; On the contrary, technologies with low scale without obvious resource intensive utilization and high investment cost have poor overall life cycle benefits.

(2) Technological innovation is the fundamental driving force for promoting green development. For example, LED lighting technology is more efficient, more environmentally friendly and has a longer service life compared with traditional incandescent fluorescent lamps.

(3) Improving energy consumption structure is in the process of highway construction need to further promote, vigorously promote the development direction of oil to gas such as mixing floor construction machinery used solar wind and geothermal energy and other clean energy and renewable energy use, not only has more obvious advantage in operating costs, environmental advantages of its low emissions and low pollution is also increasingly highlights the need to plan as a whole to solve the technology or equipment, large initial investment recovery cycle is long, restricted by the natural conditions of fuel price linkage mechanism and so on practical problems.

References

[1] Ma Feng, QIN Juze, Fu Zhen. Life cycle assessment (LCA) in Applications in Highway engineering in the United States [J]. Sino-foreign highway, 2014,34(5): 332-337.

[2] Shang Chunjing, ZHANG Zhihui, LI Xiaodong. Highway life cycle energy consumption and Atmospheric emission research [J]. Road traffic technology, 2010,27(8):149-154.

[3] Pan Meiping. Calculation method of highway energy consumption and carbon emission based on LCA Research and application [D]. Guangzhou: South China University of Technology, 2011.

[4] Chen Liwei. Quantification of energy consumption and gas emissions during asphalt pavement operation Analysis [D]. Xi'an: Chang 'an University, 2012.
[5] Cui Can. Based on the life cycle road energy consumption evaluation model establishment analysis and application[D]. Zhengzhou: Zhengzhou University, 2014.

[6] Xiao Y J, Ni F J, et al. Life-cycle cost optimization of highway maintenance and rehabilitation strategies based on integrated maintenance management system[C]. Transportation Portation Research Board 87th Annual Meeting Location: Washington, 2008.