Research on the Characteristics and Evaluation Metrics of Green Highway Corridors

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Abstract: This paper reviews the key characteristics and the progress of research on the evaluation metrics for green highway corridors. Initially, it defines the concept of green highway corridors. Subsequently, the paper thoroughly discusses the multidimensional metrics used to evaluate the success of these corridors. Finally, it suggests recommendations for optimizing the design and evaluation methods of green highway corridors. This review aims to serve as a reference for researchers in the fields of highway engineering and environmental science, and to promote the development of green transportation infrastructure.

1. Introduction

Green transportation is an essential characteristic and inherent requirement of a strong transportation nation. Since the 19th national congress, a series of new ideas, requirements, goals, and deployments for ecological civilization and green development have been proposed by the party and the country. The "outline for building a transport-strong nation" has set the theme of "promoting green development" and emphasized the main directions such as "continuously deepening the battle for pollution prevention and control" and "strengthening the protection and restoration of the transportation ecological environment." among them, "construction technology of green transportation corridors" is one of the main directions. For the development of a "strong transportation nation" with the goal of satisfying the people, how to minimize the ecological environmental impact of transportation infrastructure to the greatest extent possible, and achieve sustainable coordination and symbiosis between transportation infrastructure and sensitive ecological environments, are key scientific issues that urgently need to be addressed in the construction of ecological highway networks and green transportation corridors.

Currently, some countries are actively developing green highways, emphasizing considerations such as landscape along the roads, energy conservation and environmental protection, and reducing greenhouse gas emissions during construction[1-4].

However, the construction of highways only considers the effects of individual factors, without taking into account the combined effects of many influencing factors, resulting in a relatively single positioning for green highway construction.

European and American countries have an early start in the field of green highway design. They balance the requirements of highway safety, speed, environmental protection, and aesthetics through FLEXIBILITY INHIGHWAY DESIGN and CONTEXT SENSITIVE DESIGN· They achieve rainwater management and green highway design through LOW IMPACT DEVELOPMENT, beautify the landscape along the highways, and create sustainable transportation corridors for habitat connectivity[5-10].

In 2009, the United States introduced THE GREENROADS RATING SYSTEM, which defined the attributes of road sustainability and established a quantitative evaluation method for road sustainability levels. The rating system includes 11 mandatory requirements, 37 scoring items, and up to 2 custom items for the evaluation of highway engineering projects. Upon meeting all mandatory requirements, the green level of highway engineering projects is determined based on the scoring values. In 2010, the federal highway administration of the United States proposed the INFRASTRUCTUREVOLUNTARY EVALUATION SUSTAINABILITY TOOL, (INVEST). This system defines the sustainable characteristics of highways from three aspects: social, economic, and environmental. It evaluates highway projects from three stages: road network planning, project design and construction, and project operation management. This is the biggest difference between INVEST and the GREEN ROADS evaluation system.

In 2019, the Joint Research Center of the European Union published a policy report titled "THE FUTURE OF ROAD TRANSPORT IMPLICATIONS OF AUTOMATED, CONNECTED, LOW-CARBON AND SHARED MOBILITY"; in December 2020, the European Commission issued the "sustainable and smart mobility strategy", proposing to promote the green and digital transformation of the transportation sector in the next 30 years, and make full efforts to build a sustainable and smart transportation system to reduce carbon emissions.

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The goal is to reduce greenhouse gas emissions in the EU transportation sector by 90% by 2050. Intelligent and green maintenance of highway infrastructure is one of the important measures in this regard. France is promoting low-carbon transportation. In November 2021, French President Emmanuel Macron signed the "France 2030" investment plan, involving multiple fields such as transportation and energy, with an investment amount of 30 billion euros, aimed at enhancing France's ability to achieve economic growth through innovation. In the field of transportation, approximately 4 billion euros are planned to be invested, with the goal of producing 2 million pure electric and hybrid vehicles by 2030, and producing the first low-emission aircraft before 2030.

Currently, environmental pollution problems such as air, water, and soil pollution in China are still severe. Strengthening pollution prevention and control, continuously improving the quality of the ecological environment, and meeting the increasingly growing demand of the people for a beautiful ecological environment have become the most important livelihood issues valued by the party central committee and the state council. The transportation industry is a fundamental, leading, and strategic industry that supports the sustained and rapid development of the national economy. China's various types of transportation equipment holdings and the turnover volume of passenger and freight transportation rank among the top in the world, and have maintained a rapid growth trend for many years. Currently, the number of motor vehicles and ships in China has become the largest in the world. In many large and medium-sized cities, emissions from motor vehicles have become one of the main sources of air pollution.

2. Green Development Objectives of Road Construction

2.1. Connotation of Green Highway Corridors

The concept of green roads originated from green construction, known as sustainable construction abroad, which refers to the construction of a diverse urban transportation system that is people-oriented, convenient, fast, safe, highly efficient, low-pollution, and conducive to ecological and environmental protection, promoting the sustainable development of cities. As a sub-concept of green transportation, green highways refer to highways that maintain harmonious relationships with other factors within the transportation system (such as vehicles, pedestrians) and external factors. Compared to green highways, greened highway corridors undergo three transformations in their connotations: firstly, shifting from focusing on the functional factors of highways and emphasizing economic benefits to considering the overall regional economic, environmental, and social systems. Secondly, transitioning from simple evaluation methods that solely prioritize the economic rationality and technical feasibility of highways to a comprehensive evaluation system that considers multiple objectives such as economy, energy conservation, environmental protection, landscape, and sustainable development. Thirdly, moving from focusing on immediate interests and intra-generational equity to prioritizing the protection of the ecological environment, reducing energy costs, and promoting material recycling to address long-term benefits, balancing intergenerational and intra-generational fairness.

2.2. Characteristics of Green Highway Corridors

Green highway corridors are an integral part of the overall concept of green transportation and should participate in the material and energy cycles of natural ecosystems. Summarily, the main characteristics of green roads can be categorized as "three highs and three lows": the "three highs" refer to "high efficiency, high integration, and high quality", while the "three lows" denote "low energy consumption, low emissions, and low pollution".

(1) High Efficiency, High Integration, High Quality

High Efficiency: Throughout the entire lifecycle of green highway corridors, the modernization of the comprehensive governance system and governance capacity of highways is significantly enhanced.

High Integration: Optimizing the effective regulation and structural optimization of resource demand and supply during highway construction, maximizing the utilization of resources within highway corridors to meet the maximum service demands of highways.

High Quality: Achieving the organic integration of green and beautiful highway corridors, service enhancement, safety, and durability, maximizing comprehensive benefits, thereby promoting the reduction of highway construction costs.

(2) Low Energy Consumption, Low Emissions, Low Pollution

Low Energy Consumption: Refers to the emphasis on minimizing the use of resources such as land, water, energy (including electricity, oil, natural gas), and building materials along the highway.

Low Emissions: During the construction of green highways, efforts are made to reduce or even eliminate the emissions of various waste materials (including wastewater, exhaust gases, noise, and solid waste), aiming for minimal pollution emissions, or even zero emissions.

Low Pollution: During the construction phase of green highways, attention is paid to strengthening the prevention and control of land degradation, water pollution, and air pollution, emphasizing ecological balance and biodiversity, minimizing the ecological environmental damage caused by highway construction.

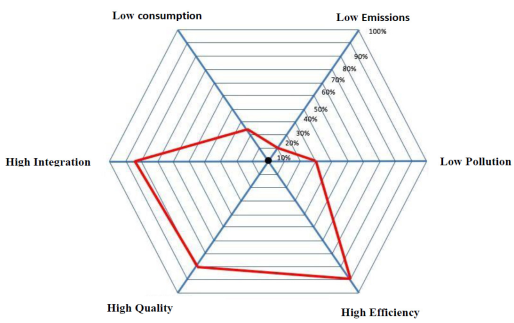

Figure 1 Radar Chart of Characteristics of Green Highway Corridors

2.3. Philosophy of Green Highway Corridors Construction

(1) Innovation philosophy. Innovation serves as the primary driving force for the high-quality development of green highway corridors. It is the foremost momentum for the high-quality development of transportation and a pivotal focus for green highway development, shaping new competitive advantages in the field.

(2) Coordination Philosophy. Green highway corridors lead to balanced development. With their long routes and extensive coverage, green highway corridors help balance regional transportation resources.

(3) Green philosophy. Green embodies the core essence of harmonious development between humans and nature. It alleviates conflicts between humans and the land, intensively and efficiently utilizes nature, protects the environment, and minimizes disturbances caused by human activities.

(4) Open philosophy. With the implementation of environmental "three simultaneities" and the completion of environmental self-inspection supervision mechanisms, intelligent management platforms for the highway industry are gradually introduced, enhancing platform data availability.

(5) Sharing philosophy. Green highway corridors are an inevitable focus in promoting common prosperity. Integration of transportation and tourism: highway development allows for the shared use of ecological landscapes and green products between urban and rural areas.

3. Top-Level Design of Green Highway Corridors Evaluation System

3.1. Principles for Selecting Key Characteristic Evaluation Indicators

(1) Scientific principle. The key feature assessment system of green highway corridors should scientifically reflect the impact of various components and equipment systems on transportation operations. It should primarily consist of quantitative evaluation indicators, supplemented by some qualitative evaluation indicators. The indicator system should systematically reflect aspects such as safety, economy, and environmental protection of green highway corridors.

(2) Importance principle. When selecting indicators, consideration should be given to the importance of the key features of green highway corridors on the impact of transportation infrastructure and vehicle operations. A clear hierarchy should be established, choices made appropriately, and emphasis placed on selecting indicators that prominently reflect the design and control of key features of green highway corridors. Radar Chart of Characteristics of Green Highway Corridors is shown in Figure 1.

(3) Systematic principle the diversity of factors contributing to carbon emissions determines that the design of low-carbon energy systems is influenced by many factors. It is also affected by the external environment, resulting from the combined effects of many factors. These factors have a certain degree of correlation with each other, either promoting or constraining each other.

(4) General and specific principles. In the design process of green highway corridors, comparability is affected by the content, spatial scope, time frame, calculation criteria, and methods of the indicators. It is essential to consider the unique characteristics of some evaluation indicators in conjunction with the socio-economic and environmental conditions of the area where the transportation system is located.

3.2. Establishment and selection methods of evaluation indicators

In actual comprehensive evaluation activities, more indicators do not necessarily mean better, nor does fewer mean better. The key lies in the impact of the evaluation indicators during the evaluation process. The following methods are commonly used for indicator selection in practical applications.

1) Expert Survey Method (Delphi Method)

Evaluators can list a series of evaluation indicators based on the evaluation objectives and characteristics of the evaluated objects in the designed survey form, consult experts' opinions on the designed evaluation indicators, then conduct statistical processing and provide consultation results. The biggest advantage of expert survey method is its simplicity and intuitiveness, while the main disadvantage of expert survey method is that it can only make qualitative evaluations.

2) Importance Indicator Selection

After obtaining experts' opinions on the importance and size of the indicators through the Delphi method, the next step is to perform importance indicator selection based on these opinions. The advantage of indicator method is the quantification of objectives, but the disadvantage is that it may overlook some difficult to quantify factors.

(1) Ranking method

Assuming there are N indicators P1, P2…PN for evaluating the planning and design of self-consistent energy facilities for highway traffic, with respective importance levels X1, X2…XN. Here, X values are all positive numbers, where larger values indicate greater importance for the corresponding indicators. To select important indicators and eliminate unimportant ones from the N indicators, follow these steps:

Arrange X1, X2…X in descending order and denote them accordingly$\boldsymbol{x} = \sum_{i=1}^{n} \boldsymbol{x}$. Find the smallest value of M that satisfies the following equation:

$$\frac{\sum_{i=1}^{n} x}{x} \geq \mathbf{a} \quad (1)$$

Where: A is a constant smaller than 1, known as the importance constant.

At this point, the indicators P1, P2…PN corresponding to X1, X2…X become the indicators of importance. The selection of A is not quantitatively defined and should depend on the actual situation. In general A≥0.7, a value of 0.7 is considered appropriate based on experience.

(2) minimum mean square method

For N predetermined evaluation objects (or systems) S1, S2...SN, each evaluation object can be represented by M observation values XIJ (I=1, 2 …N; J=1, 2, …M) of indicators. It is clear that if the values of N evaluated objects for a certain evaluation indicator are similar, even if this evaluation indicator is very important, it does not affect the evaluation results of these N objects.

Therefore, to reduce computational complexity, this evaluation indicator can be removed. This inspires us to establish the minimum mean square screening principle as follows:

$$S_j = \left(\frac{1}{n}\sum_{i}^{m}(x_{ij}-\bar{x}_j)^2\right)^{\frac{1}{2}}, \quad j=1,2,\dots m \qquad (2)$$

Where, SJ is the sample mean square deviation of the evaluation indicator for N evaluated objects. Among them:

$$\bar{x}_j = \frac{1}{n}\sum_{i=1}^{m} x_{ij}, \quad j=1,2,\dots m \qquad (3)$$

Is the sample mean value of the evaluation indicator for the N evaluated objects.

If there exists $k_0 \in (1<k_0<m)$ such that the following equation holds:

$$S_{k_0} = \min_{1<j<m}\{S_j\} \qquad (4)$$

And $\boldsymbol{S_{ko}} \approx \mathbf{0}$

Then the corresponding evaluation indicatorXK0 can be deleted along with$\boldsymbol{S_{ko}}$.

(3) extreme difference method

Firstly, calculate the maximum deviation RJ of each evaluation indicator XJ, that is,

$$r_0 = \min_{1\le i,k\le m}\{|x_{ij}-x_{kj}|\} \qquad (5)$$

Then calculate the minimum value of RJ, let

$$r_0 = \min_{1\le j\le m}\{r_j\} \qquad (6)$$

When R0 approaches zero, the evaluation indicator corresponding to R0 can be deleted.

3.3. Framework of Evaluation Indicator System for Green Highway Corridors

An analysis of the factors influencing traffic infrastructure within green highway corridors and other facilities is conducted to construct a comprehensive system architecture covering various aspects such as transportation infrastructure, service facilities, ecological conservation facilities, and energy transmission facilities. This system aims to establish evaluation indicators for green highway corridors from multiple aspects including green operation, management, and operation[11-15]. Evaluation Indicator System for Green Highway Corridors is shown in Figure 2.

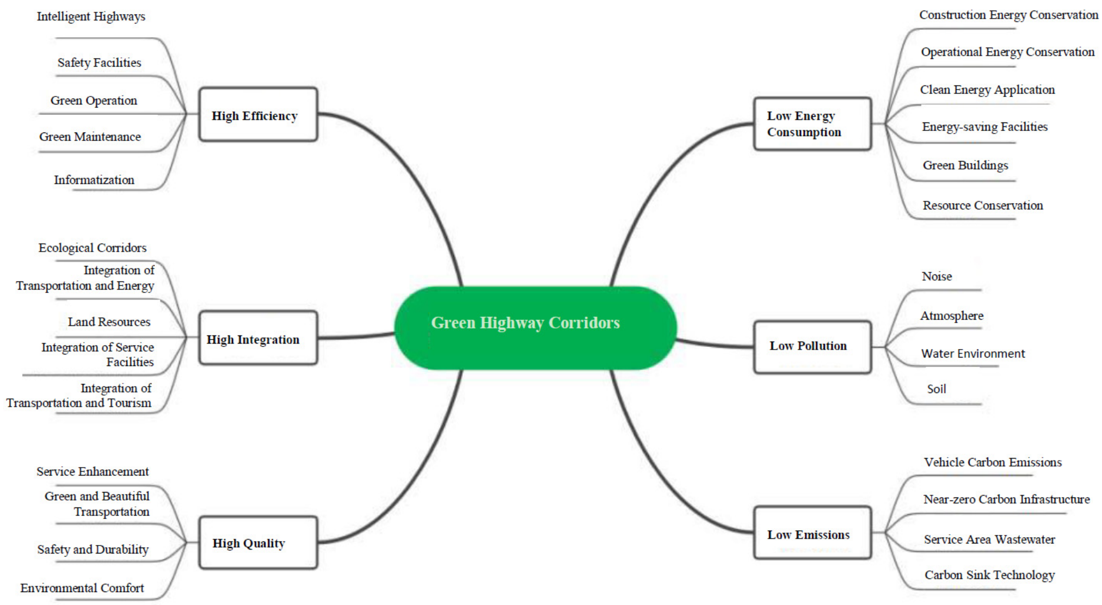

Figure 2 Evaluation Indicator System for Green Highway Corridors

3.4. Evaluation Methods for Green Highway Corridors

Following the construction method of the evaluation index system described above and the established procedures, the constructed evaluation index system for the scoring items of green highway corridors is shown in Table 1.

Table 1 Evaluation Index System

Index	Index Type	Index Attribute
High Energy Efficiency	Green Operation	Qualitative
	Green Maintenance	Qualitative
	Intelligent Highway Construction	Quantitative
	Information Systems	Quantitative
	Safety Facilities	Quantitative
High Integration	Ecological Environmental Protection	Qualitative
	Energy Facility Construction	Quantitative
	Comprehensive Utilization of Land Resources	Qualitative
	Development and Sharing of Service Facilities	Qualitative

	Integration of Transportation and Tourism	Qualitative
	Integration Design of Carbon Sink Green	Qualitative
High Quality	Safety and Durability	Qualitative
	Fine Construction	Qualitative
	Service Enhancement	Qualitative
	Environmental Comfort	Qualitative
Low Energy Consumption	Construction Energy Conservation	Qualitative
	Operational Energy Conservation	Qualitative
	Proportion of Clean Energy	Quantitative
	Green Buildings	Quantitative
	Resource Conservation	Qualitative
Low Pollution	Atmospheric Pollution Control	Qualitative
	Noise Control	Qualitative
	Water Environment Protection	Qualitative
	Land Resource Protection	Qualitative
Low Emissions	Near-Zero Carbon Service Area	Qualitative
	Near-Zero Carbon Tunnel	Qualitative
	Road Area Carbon Emission Monitoring	Qualitative
	Carbon Sink Technology	Qualitative

In the expandable cloud model evaluation, differences in dimensionalities of quantitative indicators are allowed. Next, quantitative indicators will be graded and quantified. The evaluation index system of green highways consists of quantitative and qualitative indicators. For quantitative indicators, they can be directly calculated using the following calculation methods, while qualitative indicators need to be quantified.

3.5. Determination of Weight of Evaluation Indicators for Green Highway Corridors

The combination weighting method takes into account both subjective and objective weighting, allowing for the combined analysis of qualitative and quantitative aspects, thus avoiding deviations from the true results caused by a single weighting. This method applies statistical methods to establish data analysis and invites experts to perform value calculations. It can not only maximize reliance on scientific methods for verification but also bring the results closer to reality, ultimately obtaining precise and reasonable indicator weights. The preliminary determination of the weights of evaluation indicators for green highway corridors was proposed using the expert scoring method. Weights of Evaluation Indicators for Green Highway Corridors is shown in Table 2.

Table 2 Weights of Evaluation Indicators for Green Highway Corridors

Index	Index Type	Weight
High Energy Efficiency (0.25)	Green Operation	0.05
	Green Maintenance	0.05
	Intelligent Highway Construction	0.04
	Information Systems	0.05
	Safety Facilities	0.06
High Integration (0.2)	Ecological Environmental Protection	0.03
	Energy Facility Construction	0.04
	Comprehensive Utilization of Land Resources	0.05
	Development and Sharing of Service Facilities	0.03
	Integration of Transportation and Tourism	0.02
	Integration Design of Carbon Sink Green	0.03
High Quality (0.15)	Safety and Durability	0.03
	Fine Construction	0.04
	Service Enhancement	0.05
	Environmental Comfort	0.03
Low Energy Consumption (0.2)	Construction Energy Conservation	0.04
	Operational Energy Conservation	0.04
	Proportion of Clean Energy	0.05
	Green Buildings	0.04
	Resource Conservation	0.03
Low Pollution (0.1)	Atmospheric Pollution Control	0.02
	Noise Control	0.02
	Water Environment Protection	0.03
	Land Resource Protection	0.03
Low Emissions (0.1)	Near-Zero Carbon Service Area	0.03
	Near-Zero Carbon Tunnel	0.03
	Road Area Carbon Emission Monitoring	0.02
	Carbon Sink Technology	0.02

4. Policy Recommendations for Green Highway Corridors

4.1. Main Tasks

The first task is to adhere to ecological priority and construct green ecological highway corridors. Accelerate the formation of green transportation corridors that are coordinated with ecological protection redlines and adapted to the carrying capacity of resources and environment, and construct a lifelong, all-element, and all-round green ecological highway corridor.

The second task is to achieve green and low-carbon, and rapidly construct green transportation infrastructure. Optimize the spatial layout of transportation infrastructure and integrate the concept of ecological protection throughout the entire process of transportation infrastructure planning, construction, operation, and maintenance.

The third task is to promote the integration of transportation and energy and create transportation and energy corridors. Improve the flexible system and capacity building of transportation energy, promote the intelligent interaction between energy supply and transportation infrastructure, and establish a multi-source and multi-type energy supply system.

The fourth task is to coordinate corridor resources and promote intensive and efficient use of resources. Integrate the concept of ecological protection throughout the entire process of transportation infrastructure planning, construction, operation, and maintenance, intensively utilize land and other resources, and reasonably avoid or relocate land with important ecological functions.

The fifth task is to green the appropriate areas and construct beautiful green transportation corridors.

Combining the characteristics of the comprehensive transportation industry, while ensuring safe operation, scientifically and finely allocate plants, construct sustainable and low-maintenance plant community landscapes, enhance the increment of ecological carbon sinks, and assist in reducing carbon emissions and achieving carbon peaking in the transportation sector.

4.2. Key Tasks

1. Strengthen top-level institutional research. Around the coordinated development needs of reducing carbon emissions, reducing pollution, expanding greenery, and promoting highways and corridors, propose policy recommendations for the green and low-carbon development of highways and corridors guided by the goal of peaking carbon emissions.

2. Initiate the formulation of relevant standard systems. Carry out the top-level design of the construction of standard specification systems for green highway corridors, and guide the construction of green highway corridors for key highway engineering projects.

3. Promote the construction of demonstration projects. Carry out the creation of green highway demonstration projects under the concept of dual carbon during the “14th five-year plan” period, and give priority support to green highway construction demonstration projects within the 7 corridors and 8 channels. By implementing pilot demonstrations, establish benchmarks for the construction of green highway corridors in China, and radiate and drive the comprehensive greening of national highway construction.

4. Build demonstration projects integrating corridor green energy and highway transportation. Accelerate the promotion and application of new energy and clean energy, build an integrated industrial system of energy and transportation combining centralized, distributed, charging piles, and battery swapping stations, and promote the integrated development of energy and transportation.

5. Encourage the research and development of carbon sink and evaluation new technologies for highway corridors. Most of the carbon emission control, ecological benefit monitoring, and evaluation new technologies for highway corridors currently under research and development at home and abroad are still in the research and development stage. The industry should increase technology tracking and encourage technological innovation.

5. Conclusion

Experience from developed countries also indicates that emissions from transportation sources will continue to grow rapidly and become the largest contributor to urban areas in the later stages of industrialization. The transportation industry has become an important area for energy conservation, emission reduction, and ecological environmental protection in China. In the future, energy consumption, carbon emissions, and pollutant emissions in the industry will continue to grow. Therefore, it is necessary to effectively carry out energy conservation and emission reduction in the industry and promote a significant reduction in pollutant emissions.

We propose that the green highway corridors should be guided by the concept of green ecological civilization, with the goal of reducing pollution, lowering carbon emissions, increasing greenery, and synergistically increasing efficiency. It involves coordinating the layout of highway corridors and resources along with achieving the greening and upgrading of highway operation, management, and operation, integrating multiple elements such as green highway corridors, ecological corridors, natural systems, energy corridors, and cultural corridors, and establishing a green, efficient, safe, and comfortable highway transportation system.

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