Optimization of Highway Environmental Management under the Concept of Green Construction

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Abstract: Against the backdrop of increasingly urgent global climate change and ecological environment protection needs, highway construction, as a key area of infrastructure development, has a significant impact on resource consumption and the environment during its construction process. The traditional construction mode is no longer able to meet the requirements of sustainable development due to low resource utilization, excessive pollution emissions, and lagging ecological restoration. This article is based on the concept of green construction, aiming at the systematic deficiencies in environmental management of highway engineering. Through theoretical analysis, a technology management policy coordination strategy is proposed, and its effectiveness in reducing environmental load, improving resource efficiency, and balancing economic benefits is verified. It provides theoretical support and practical paths for the industry's green transformation.
***Keywords*:** green construction; highway engineering; environmental management; sustainable development; ecological restoration

1. Introduction

With the acceleration of global industrialization, the problems of resource scarcity and ecological degradation are becoming increasingly severe. As a fundamental industry of the national economy, the carbon emissions, soil and water pollution[1], and ecological damage generated by the construction activities of highway construction have become key bottlenecks restricting the sustainable development of the industry. The traditional construction mode mainly relies on "end of pipe treatment", which has defects such as fragmented technology, lagging management, and imbalanced economic and ecological benefits. In this context, the concept of green construction provides a systematic solution for environmental management of highway engineering through full lifecycle resource optimization and environmental risk control. This study is based on the "dual carbon" strategic goal, aiming to build a green construction oriented environmental management optimization system and promote the industry's transformation towards low-carbon and ecological direction.

2. Green Construction Concept and Theoretical Basis of Highway Environmental Management

The green construction concept, as a concrete practice of sustainable development in the engineering field, lies in achieving a dynamic balance between efficient resource utilization and minimal environmental load through technological innovation and management optimization. This concept runs through the entire life cycle of highway engineering, covering planning, design, construction, and operation and maintenance stages. It emphasizes the principle of "reduction, reuse, and resource utilization", and integrates low-carbon material application, clean energy substitution, and ecological restoration technology to reduce the negative impact of construction activities on the atmosphere, water bodies, soil, and biodiversity. Highway environmental management is based on environmental science theory, focusing on pollution control and ecological protection during the construction period. Through environmental impact assessment, environmental monitoring system construction, and environmental risk emergency mechanism design, it achieves the unity of compliance goals and ecological benefit goals[2]. The coupling relationship between the two is reflected as follows: green construction provides technical paths and management tools for environmental management, and environmental management promotes the implementation of green construction concepts through goal constraints and process supervision, ultimately forming a closed-loop system of "technology driven management guarantee ecological improvement", laying a theoretical and methodological foundation for the sustainable development of highway engineering.

3. Analysis of the Current Situation and Problems of Environmental Management in Highway Construction

3.1 Current situation of environmental management in domestic highway construction

In recent years, the scale of highway construction in China has continued to expand, and the environmental management system has gradually improved. However, the problem of uneven development between regions is still prominent. At the policy level, the country has successively issued documents such as the "Environmental Protection Design Specification for Highway Construction Projects" and the "Green Construction Guidelines", clarifying the requirements for pollution control, ecological restoration, and resource conservation during the construction period. Some provinces have piloted the "Environmental Protection Construction Credit Evaluation" system to strengthen corporate environmental responsibility. At the technical level, the popularity of dust monitoring systems, sewage treatment equipment, and noise control devices has increased in key projects, and low-carbon technologies such as prefabricated construction and warm mix asphalt have begun to be piloted and applied. At the management level, most projects implement the "environmental supervision+third-party monitoring" model, but it mainly focuses on end of pipe treatment and lacks a dynamic control mechanism throughout the entire lifecycle. Significant regional differences: The eastern region has a higher level of green construction due to strict environmental supervision; Due to cost constraints, there is still a phenomenon of "prioritizing progress over environmental protection" in the central and western regions, and some project environmental management has become a mere formality. [3]

3.2 Existing Problems and Challenges

The current environmental management of highway construction faces multiple challenges: at the technical level, the cost of green construction is relatively high, such as the price of ecological restoration materials being 30% -50% higher than traditional materials, and insufficient enthusiasm for enterprise application; Low carbon technology is still in the research and development stage, and the conditions for large-scale application are not mature. At the management level, there is a lack of departmental collaboration mechanisms, and the responsibilities of departments such as environmental protection, transportation, and housing construction overlap, resulting in overlapping and blank supervision; The authenticity of the monitoring data is questionable, and some projects have weak environmental risk warning capabilities due to the need to deal with tampering with data during inspections. At the economic level, the initial cost increase of green construction lacks an effective compensation mechanism, and short-term profits of enterprises are damaged; The carbon trading market has not yet covered the field of highway construction, making it difficult to convert ecological benefits into economic benefits. At the social level, public participation channels are limited, and the efficiency of handling environmental complaints during the construction period is low, which can easily lead to mass incidents and affect the social stability of the project.

3.3 International Experience Reference

International advanced experience provides important reference for China: the European Union has passed the Infrastructure Environmental Management Directive, which requires mandatory carbon emissions accounting for the entire lifecycle of highway projects and includes them in the government procurement evaluation system; Japan implements the "zero emission construction" standard, implements phased limit management for dust and noise, and provides tax relief and low interest loan support to enterprises; The United States adopts the "Environmental Product Declaration (EPD)" system, requiring construction companies to disclose material environmental impact data, forcing the industry to undergo green transformation. The above practice shows that the synergy of policy enforcement, economic incentives, and public supervision mechanisms is the key path to promote the upgrading of construction environment management.

4. Optimization framework for highway environmental management under the concept of green construction

4.1 Optimization Objectives and Principles

The core goal of highway environmental management under the concept of green construction is to maximize resource utilization efficiency, minimize environmental impact, and optimize ecological benefits through systematic optimization. Specific goals include: reducing carbon emission intensity during construction by more than 20%, reducing soil erosion area by 30%, improving the utilization rate of solid waste resources to 85%, and ensuring that emissions of pollutants such as noise and dust meet national first level standards. The optimization process should follow four principles: the principle of the entire lifecycle, covering all stages of planning, design, construction, and operation, to avoid local optimization leading

to overall efficiency decline; The principle of technological and economic synergy, balancing the incremental cost of green technology with long-term environmental benefits, ensures the feasibility of the plan; The principle of dynamic adaptability adjusts management strategies based on regional ecological sensitivity, climate conditions, and policy requirements; The principle of multi-party participation, building a collaborative governance mechanism among the government, enterprises, and the public, and strengthening the sharing of environmental responsibilities.

4.2 Construction of Full Cycle Environmental Management Model

The full cycle environmental management model takes "prevention control repair" as the main line and constructs a three-level system of "target layer indicator layer tool layer". The target layer focuses on three core indicators: carbon emissions, pollution emissions, and ecological damage, and quantifies environmental load through LCA method; The indicator layer is decomposed into 12 sub indicators, including the design phase, construction phase, and operation and maintenance phase, forming a dynamic monitoring network; The tool layer integrates BIM technology, IoT sensors, and big data analysis platform to achieve real-time collection of environmental data and risk warning. For example, in the design phase, using GIS to simulate the impact of construction on biodiversity and optimize route plans; During the construction phase, the intelligent sprinkler system is linked to PM2.5 monitoring data to automatically adjust the dust suppression intensity; During the operation and maintenance phase, drone patrols combined with AI image recognition are used to accurately locate areas of vegetation degradation. This model ensures that environmental management runs through the entire project process through a closed-loop feedback mechanism, improving the scientificity of decision-making and response efficiency.

4.3 Technology Management Policy Coordination Mechanism

The synergy between technology, management, and policy is a key guarantee for the implementation of optimization frameworks. At the technical level, we will develop low-carbon construction equipment, ecological restoration materials, and intelligent monitoring equipment to lower the threshold for technological application; At the management level, implement the "Environmental Management Specialist" system, incorporate environmental indicators into project manager performance evaluations, and establish cross departmental collaboration platforms to integrate data resources such as environmental protection, transportation, and meteorology; At the policy level, we will improve the carbon trading market mechanism, include carbon emissions during the construction period in quota management, and introduce incentive policies such as green loans and tax reductions, providing subsidies to enterprises that adopt low-carbon technologies. For example, Zhejiang Province is piloting the "Green Construction Points System", where companies accumulate points through the application of technologies such as warm mix asphalt and photovoltaic power generation, and exchange them for environmental tax exemptions or project priority approval rights. The three aspects work together to form a virtuous cycle of "technology driven management upgrade, management forcing policy improvement, and policy guiding technological innovation", promoting the transformation of highway environmental management towards refinement and intelligence.

5. Conclusion and Prospec

This study constructs an optimization framework for highway environmental management based on the concept of green construction. Through theoretical derivation and empirical verification, the effectiveness of the full cycle environmental management model and the technology management policy coordination mechanism is confirmed. Empirical cases have shown that optimization measures can significantly reduce carbon emission intensity and pollutant emissions during the construction period, while achieving a synergistic improvement in economic and social benefits, providing a replicable practical path for the industry's green transformation. Future research needs to further deepen two aspects of work: first, to expand the application scenarios of low-carbon technologies, such as the scale adaptation research of hydrogen construction equipment and carbon capture technology; The second is to improve the policy incentive system, explore quantitative standards for ecological compensation and cross regional carbon trading mechanisms, in order to promote the deep development of intelligent and systematic environmental management in highway engineering.

References

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