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Research Paper

# Assessing sustainability performance by applying the TOPSIS method in road construction projects

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ABSTRACT

The sustainability of road development projects must be evaluated holistically. These guarantees roads are constructed to endure fluctuating climatic circumstances and decreasing overall costs and environmental implications. Establishing a comprehensive methodology and framework to evaluate the sustainability level of infrastructure investment projects is crucial. This study presents a methodology that combines the Life Cycle Approach with the TOPSIS technique to conduct a comprehensive assessment of the sustainability level. The social, conventional environmental, and economic implications were initially evaluated through a life cycle method. The TOPSIS technique was subsequently utilized to rank the alternatives according to the metrics obtained from these evaluations. For validation, three pavement options in a project are compared to select the most sustainable alternative by using the proposed integrated TOPSIS technique. The results signify that option Y3 has superior sustainability performance relative to Y1 and Y2. Consequently, option 3 (normal Asphaltic Concrete) emerges as the most sustainable selection among the evaluated choices.

## 1 Introduction of the research

Nowadays, the construction sector significantly supports and improves the overall quality of human living. This improvement in infrastructure boosts the growth of the economy, so some countries identify infrastructure development as an essential goal for economic growth. However, road construction investment projects are responsible for a significant amount of damage to sustainable development, such as material and energy consumption, CO2 emissions, and social issues [1].

The sustainability of road investment projects must be evaluated holistically. This guarantees roads are constructed to endure fluctuating climatic circumstances, including the effects of climate change, minimizing the requirements for regular repairs or replacements, hence decreasing overall costs and environmental implications. Certain research underscores the

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significance of sustainable development in road construction investment projects [2-5]. Sustainability denotes a comprehensive strategy that harmonizes economic development, environmental conservation, and social welfare (commonly called the triple bottom line). It seeks to guarantee that development satisfies current needs without jeopardizing future generations.

In conclusion, it is essential to establish a mechanism for evaluating sustainability levels throughout the construction phase/building phase in infrastructure projects. An effective strategy for sustainable development must incorporate economic viability, environmental stewardship, and social inclusivity to establish a balanced assessment.

## 2 Literature review

In [6], sustainability is defined as a concept that assesses, controls, and integrates social, environmental, and economic dimensions to guarantee long-term welfare for current and forthcoming generations. *Life cycle cost analysis (LCC)* offers numerous advantages in assessing the financial aspects of road infrastructure projects. At first, the LCC approach can be employed in the initial stage to monitor and control expenses throughout the construction phase. Second, this LCC method determines the long-term worth by deconstructing the construction procedure into several consecutive activities and considering the principle and characteristics of the time value of money. *Life Cycle Assessment (LCA)* is a systematic approach for assessing all stages with the objective of identifying and alleviating environmental issues [4, 5]. LCA assesses the environmental effect of highway construction projects across their entire life cycle, encompassing construction material extraction, building, operation, maintenance, and demolition. This evaluation encompasses aspects including resource depletion, energy usage, greenhouse gas emissions, and waste generation [7]. *Social Life Cycle Assessment (Social LCA)* provides a framework for assessing the social impacts associated with construction investment projects throughout their entire lifecycle. It evaluates factors such as labor conditions, community well-being, and human rights from the planning phase to demolition or recycling. The implementation of Social LCA in construction can inform decision-making to achieve more socially responsible and equitable project results. [8, 9].

The project life cycle approach often addresses social, environmental, and economic elements of sustainable development principles in isolation. This separation limits its ability in order to provide an extensive view of the integrated and interdependent nature of sustainability outcomes [8, 10, 11]. Life Cycle Sustainability Assessment (LCSA) amalgamates the approaches of Social LCA, LCC, together with typical LCA to deliver a thorough assessment and controlling road infrastructure projects. This integrated method developed and provides a comprehensive methodology for evaluating the overall sustainability level of highway construction projects by concurrently examining social, environmental, and economic aspects. This comprehensive framework assists decision-makers in choosing solutions that conform to sustainable development objectives within the building sector [8, 10, 11]. It entails the methodical organization of pertinent data and the presentation of conclusions in a clear and structured format to facilitate decision-making. A major problem in LCSA is the amalgamation of social, ecological, and economic performance levels in a cohesive score, particularly due to the intricacies involved in quantifying social variables. To tackle this difficulty, numerous academics have utilized the Analytic Hierarchy Process (AHP) instrument to integrate various sustainability elements. The application of AHP facilitates the prioritization and integration of the varied results from Social LCA, LCA, and LCC results, hence improving the rigor and transparency of sustainability assessments [12, 13]. The AHP technique relies significantly on questionnaire responses to conduct the requisite pairwise comparisons for decision-making. The dependence on subjective input may generate biases, thus impacting the accuracy and consistency of the estimation procedure.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is recommended for synthesizing the results of Social LCA, typical LCA, together with LCC to evaluate sustainability level during the building phase of road infrastructure projects. TOPSIS considers various criteria simultaneously; hence, this technique is suitable for complex decision-making situations where various factors need to be taken into account. It also allows decision-makers to assess alternatives based on different attributes or objectives, providing a comprehensive evaluation framework.

## 3 Methodology

Evaluating the performance level of sustainability of a highway infrastructure project necessitates a thorough assessment encompassing social, ecological, and economic factors.

*Economic dimension*

The detailed steps of the Life Cycle Costing (LCC) process are outlined in ***Fig. 1*** below:

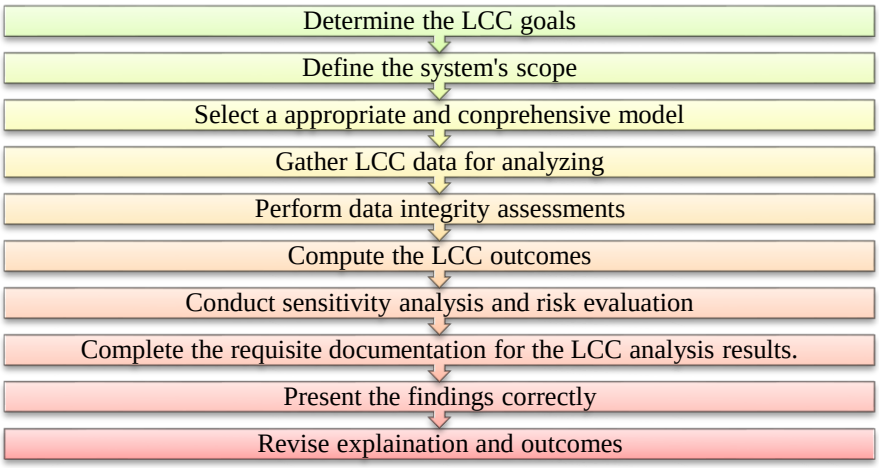


***Fig. 1 - Proposed procedure for analysis steps [14-19]***

*Environmental dimension*

Life Cycle Assessment (LCA) offers an extensive perspective on environmental performance, encompassing the extraction of raw construction materials and recycling [20]. The four main steps of typical LCA are illustrated as below:

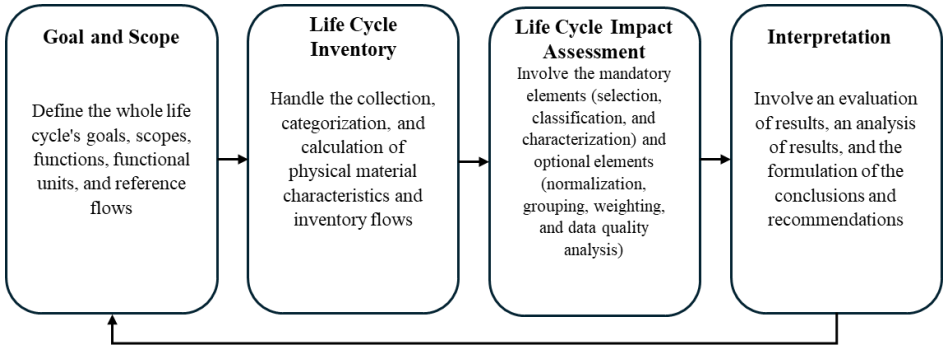


***Fig. 2 – Detailed LCA steps***

*Social dimension*

The social dimension is an essential element of sustainability, emphasizing human welfare, and societal effects. The process comprises four primary steps: establishing objectives and parameters, evaluating the inventory of the Social LCA, assessing Social LCA impacts, and interpreting the findings to inform socially responsible decision-making [21-23].

$$I_c = \sum_s I_{c,s} \quad (1)$$

where:

$I_c$ denotes the result of Social LCI analysis type c during the building/construction phase;

$I_{c,s}$ denotes the result of Social LCI analysis type c in phase s crossing the construction phase.

In this study, the social dimensions of the triple bottom line are evaluated by Equation 1. Qualitative ecological and social criteria evaluate the potential consequences of a project on natural ecosystems, biodiversity, and environmental resources. They can be assessed based on loss of habitats or critical ecosystems (e.g., wetlands, forests, coral reefs), changes in species populations due to pollution or land use changes, or health risks from pollution, hazardous materials, or accidents.

*TOPSIS method for Social LCA, LCA, and LCC methods*

The conventional TOPSIS method was developed in 1981 and applied as an important method in making decision concerning multiple criteria. It was designed to identify the most suitable option from a large number of alternatives by comparing their distances to an ideal solution (the best possible outcome) and a negative ideal solution (the worst possible outcome) [24, 25]. The TOPSIS technique is able to select the best sustainable road infrastructure investment projects.

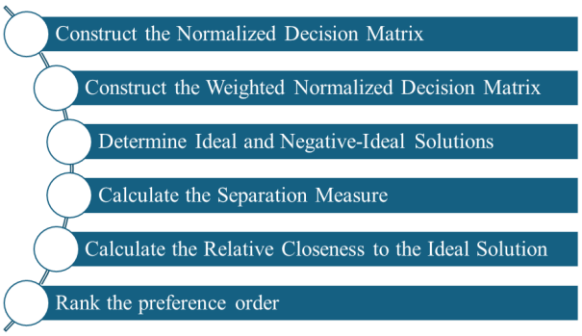


***Fig. 3 – Detailed TOPSIS steps***

### *3.1 Construct the Normalized Decision Matrix:*

The first stage in the TOPSIS approach entails transforming the attribute dimensions into non-dimensional values to facilitate standardized comparison. The normalization process generates the Normalised Decision Matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{2}$$

where:

- m denotes the number of given road construction investment projects
- $r_{ij}$ represents the non-dimensional attribute of project i in relation to the specific economic, environmental, or social criterion j. The selection and quantity of these criteria are guided by the research objectives, ensuring a tailored approach to sustainability assessment.
- $x_{ij}$ represents the original impact factor of project i concerning the specific economic, environmental, or social sustainability criterion j. These values form the basis for further analysis and normalization in the sustainability assessment process.

### *3.2 Build and develop the Weighted Normalized Decision Matrix*

This step involves developing the weighted normalized decision matrix by multiplying each normalized attribute by its corresponding criterion weight: $V = [v_{ij}] = [w_j r_{ij}]$.

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1j} & \cdots & v_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ v_{i1} & v_{i2} & \cdots & v_{ij} & \cdots & v_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mj} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_j r_{1j} & \cdots & w_n r_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ w_1 r_{i1} & w_2 r_{i2} & \cdots & w_j r_{ij} & \cdots & w_n r_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_j r_{mj} & \cdots & w_n r_{mn} \end{bmatrix} \tag{3}$$

where:

- $w_j$ is the weighting of corresponding economic, environmental, or social criterion j

### *3.3 Define and select Ideal and Negative-Ideal Solutions for TOPSIS*

The ideal solution signifies the optimal outcomes for each criterion, whereas the negative-ideal solution denotes the least favorable outcomes. These solutions function as benchmarks to assess and prioritize the alternatives according to their closeness to the ideal and their remoteness from the negative ideal

$$\begin{aligned} A^* &= \{(\max - v_{ij} / j \in J), (\min - v_{ij} / j \in J'), i = 1,2,3,\dots,m\} = \{v_{1^*}, v_{2^*}, \dots, v_{n^*}\} \\ A^- &= \{(\min - v_{ij} / j \in J), (\max - v_{ij} / j \in J'), i = 1,2,3,\dots,m\} = \{v_{1^-}, v_{2^-}, \dots, v_{n^-}\} \end{aligned} \quad (4)$$

where:

- The variable $n$ represents the total number of sustainability criteria considered in the analysis. It encompasses all selected economic, environmental, and social factors relevant to the decision-making process.
- J= {j=1,2,3,…,n and j represents *advantage* criteria}
- J'= {j=1,2,3,…,n and j represents *disadvantage* criteria}

### *3.4 Calculate the Separation Measure*

In this phase, the developed measure is computed by assessing the distance of each alternative/option from both ideal solutions. These distances measure the proximity of each option to the optimal conclusion and its deviation from the least favorable situation.

$$\begin{aligned} S_i^* &= \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \\ S_i^- &= \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \end{aligned}, i = 1,2,3,\dots,m \quad (5)$$

### *3.5 Evaluate the Relative Closeness (RC) to the Ideal Solution*

The formula compares a project's proximity to the ideal solution against its total distance from both solutions

$$C_{i*} = \frac{S_i^-}{S_i^* + S_i^-} \text{ , where } 0 < C_i < 1 \text{ and } i=1,2,3,\dots,m \quad (6)$$

Project $A_i$ is closer to the ideal solution as $C_{i*}$ approaches to 1. In contrast to that, $A_i$ is closer to the negative-ideal solution as $C_{i*}$ approaches to 0.

### *3.6 Rank the preference order*

The TOPSIS technique enables the systematic evaluation and ranking of proposals based on their $C_{i*}$, arranged in descending order of preference. This ranking process facilitates the selection of the most sustainable infrastructure investment project according to its social, ecological, and economic performance. In addition to identifying the optimal option, the method offers a systematic framework for evaluating and contrasting various design or construction alternatives. Utilizing this methodology enables decision-makers to make more informed selections that correspond with sustainability objectives and enhance project results.

## 4 Case study

Three pavement options in the project "Construction project from Km43-Km80 and upgrading section Km18-Km80, National Highway 4B" are compared to select the most sustainable alternative. For validating the proposed method, the selected pavement structure performs the best sustainability performance in the construction phase when it ranks highest in the TOPSIS method. In this project, three alternatives are different from the pavement structure: Normal Concrete with Cement (Y1), Asphalt Concrete (with Dense-Graded Polymer) (Y2), and normal Asphaltic Concrete (Y3). The construction phase is the physical process, including some activities such as building, transporting, and lifting. In this phase, the

contractor performs the construction tasks and delivers the project as designed with some important activities, such as grading and excavation. The activities should be considered when evaluating the economic, environmental, and social impact factors. For example, some machines, such as Concrete Mixers, Concrete Pumps, Concrete Vibrators, and Concrete Batching Plants, may be used for Cement Concrete (Y1).

For economic impact indicators, the total costs that were incurred directly (labeled as B1) and indirect costs (labeled as B2) were calculated. Then, the summarized costs were discounted to the present value (normally year 0). Besides, the total amount of CO2 emission (B3) and the percentage or rate of recycled construction materials (B4) have been chosen as the ecological impact criteria. The total amount of CO2 emission was computed by summing up all the amount of CO2 emissions from construction equipment and working labor. The number of jobs that were created (B5) and the average monthly wage (B6), respectively, are the two variables that are used to quantify the social impact (see Table 1). The number of created jobs was predicted according to similar construction works in previous projects.

**Table 1 – LCC, LCA, and Social LCA results**

| | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** |
|---|---|---|---|---|---|---|
| **Y1** | 2,323,923.00 | 485,228.15 | 137,007 | 0.34 | 830.00 | 560.00 |
| **Y2** | 2,132,356.00 | 449,670.95 | 111,816 | 0.36 | 840.00 | 575.00 |
| **Y3** | 1,906,245.00 | 436,301.10 | 114,201 | 0.35 | 816.00 | 535.00 |
| **Sum of Squares of criteria** | 3,685,285.63 | 792,470.17 | 210,512 | 0.606 | 1,435.3 | 964.59 |

Table 1 illustrates the values of sustainable level criteria and their relevant weightings, though no specific weighting requirements were imposed by the sponsors for this project. After calculating the social, environmental, and economic impact indicators, the project alternatives are ranked by using the conventional TOPSIS method. The process began with the construction of the Normalized Decision Matrix based on the results of these sustainability-level indicators (see Table 2).

**Table 2 - Normalized Decision Matrix of sustainable-level indicators**

| | **B1 (no unit)** | **B2 (no unit)** | **B3 (no unit)** | **B4 (no unit)** | **B5 (no unit)** | **B6 (no unit)** |
|---|---|---|---|---|---|---|
| **Y1** | 0.6306 | 0.6123 | 0.6508 | 1.7835 | 1.7294 | 1.7225 |
| **Y2** | 0.5786 | 0.5674 | 0.5312 | 1.6844 | 1.7088 | 1.6776 |
| **Y3** | 0.5173 | 0.5506 | 0.5425 | 1.7325 | 1.7591 | 1.8030 |

The Weighted Normalised Decision Matrix was subsequently developed to integrate the criteria weightings. This matrix was subsequently employed to ascertain the Solutions (both Ideal and Negative-Ideal Solutions) for the purpose of ranking all options. The Ideal Solutions (IS) and Negative-Ideal Solutions (NIS) denote the optimal (highest benefit) and sub-optimal (lower benefit) values, respectively, selected from the weighted normalized impact indicators. These values function as standards for comparison. Then, the RC to the Ideal Solution was subsequently assessed for each project, forming the foundation for ranking the options by preference.

**Table 3 – Relative Closeness of given alternatives**

| | **IS** | **NIS** | **RC** | **Order/Rank** |
|---|---|---|---|---|
| **Y1** | 0.1958 | 0.1107 | 0.3612 | 3 |
| **Y2** | 0.1792 | 0.1380 | 0.4350 | 2 |
| **Y3** | 0.0522 | 0.2213 | 0.8091 | 1 |

As shown in the table above, the RC values for Y1, Y2, and Y3 are 0.3612, 0.4350, and 0.8091, respectively. Since Y3 has the highest RC, it outperforms Y1 and Y2 in terms of sustainability. Therefore, option 3 demonstrates the best sustainable performance among the alternatives.

A sensitivity study was performed to address any possible data ambiguity in the assessment process. This examination evaluates the resilience of the rankings by examining the influence of fluctuations in the input data on the ultimate outcomes. The sensitivity analysis explores how changes in input data affect the model's conclusions by examining the

correlations between diverse data and outcomes. Specifically, the analysis adjusts the material quantities by increasing them by 10% (worst-case scenario) and decreasing them by 10% (best-case scenario). This approach helps to assess the impact of unclear data and assumptions on sustainability rankings. By altering the material quantities, the study assesses the variations in the Relative Closeness values for each alternative. The goal is to understand how sensitive the model is to fluctuations in material quantities, which could significantly impact the overall rankings (see Table 4).

**Table 4 – The sensitivity check of RC in scenarios**

| | **The best scenario** | | | **The original scenario** | | | **The worst scenario** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **IS** | **NIS** | **RC** | **IS** | **NIS** | **RC** | **IS** | **NIS** | **RC** |
| **Option Y1** | 0.30 | 0.4 | 0.60 | 0.19 | 0.11 | 0.36 | 0.29 | 0.45 | 0.61 |
| **Option Y2** | 0.56 | 0.15 | 0.21 | 0.17 | 0.13 | 0.43 | 0.56 | 0.14 | 0.19 |
| **Option Y3** | 0.07 | 0.53 | 0.87 | 0.05 | 0.22 | 0.80 | 0.07 | 0.53 | 0.87 |

According to the results, the ranks of RC are not changed in all three scenarios. It can be seen that in all three scenarios, option three still has priority over the others in this project.

## 5 Conclusion

Road construction is essential for the maintenance and improvement of transportation infrastructure; it can also result in adverse sustainable consequences, including air pollution, noise pollution, erosion, and habitat destruction. This study presents a methodology that combines the Life Cycle Approach with the TOPSIS technique to conduct a comprehensive assessment of the sustainability level. The social, conventional environmental, and economic implications were initially evaluated through a life cycle method. The TOPSIS technique was subsequently utilized to rank the alternatives according to the metrics obtained from these evaluations. For validation, three pavement options in a project are compared to select the most sustainable alternative by using the proposed integrated TOPSIS technique. The results signify that option Y3 has superior sustainability performance relative to Y1 and Y2. Consequently, option 3 emerges as the most sustainable selection among the evaluated choices. Finally, normal Asphaltic Concrete is selected according to the integrated Life Cycle Approach-TOPSIS method.

This approach encounters an issue related to data management. The suggested method employs a life cycle approach, necessitating the analysis of substantial data sets. Furthermore, the normal TOPSIS technique has specific limitations, referred to as rank reversal. The order of preference among alternatives is modified when an option is introduced or removed from the decision-making process.

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