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Sustainable Highway Construction Assessment Using Value Engineering-AHP Hybrid Technique

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ABSTRACT

This study investigates the imperative for sustainable materials in highway construction, a sector with substantial raw material consumption and environmental impact, representing approximately 40% of global resource use. Using a hybrid Value Engineering (VE) and Analytic Hierarchy Process (AHP) approach, this research rigorously evaluates and ranks sustainable material options by surveying construction professionals across Egypt. The findings highlight Reclaimed Asphalt Pavement (RAP) as the optimal sustainable choice for surface/wearing layers, with Recycled Concrete Aggregate (RCA) identified as the leading material for base layers. Additional materials, including Warm Mix Asphalt, recycled tire rubber, and geosynthetics, are presented as effective solutions for enhancing sustainability across multiple construction layers. By prioritizing environmentally and economically favourable materials, this VE-AHP framework supports a holistic, multi-criteria approach to sustainability in infrastructure projects. The study provides a valuable reference for practitioners and researchers aiming to make strategic, data-driven decisions that align with sustainability goals in highway development.

1. Introduction

The construction industry's nature is unique and complex, always facing chronic problems such as cost overruns, time overruns, waste generation, and the consumption of natural materials, which accounts for about 40% of raw materials globally for new construction alone. It is recognized as one of the most significant pollutants in the environment. Highway construction projects are voracious consumers of energy and materials, resulting in many losses [1]. The history of highway construction has emphasized three factors: cost, time, and quality, without considering human needs, environmental impacts, or social responsibility risks [2]. Highway sustainability must handle the realization that highways are key infrastructure projects [3]. Sustainable highway building begins with a reuse strategy and the practical use of existing resources on the site. The lack of comparable and quantitative methodologies makes it difficult to evaluate the economic and environmental benefits of using recycled materials in construction[2]. Sustainable choices have become the basis and are adopted by many highway authorities in different countries, but more is needed to keep up with the increasing universal demand for resources [4].

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Traditional building procedures and management must be more capable of dealing with the enormous challenges of sustainability. In practice, sustainability in construction is a plan divided into various connected keys with distinct objectives. While the sustainability goals are embedded in the triple bottom line of social justice, economic prosperity, and ecological protection, the better sustainability construction outcomes rest on reducing the ecological impacts of construction processes [5].

In recent decades, significant research has focused on issues related to sustainable construction. By addressing challenges connected to economic, social, and environmental impacts, the construction sector has significant potential to achieve sustainable development. Construction growth is associated with a rapid increase in adverse environmental impacts by using a massive consumption of natural resources, such as materials and energy, and producing construction waste (2016). Sustainable development in the construction industry has become an important issue [6]. Urbanization in developing countries must trigger the growth of infrastructure projects, such as highway construction in Egypt. Despite its economic growth contribution, it also has adverse environmental impacts (resource consumption, waste).

Sustainable roads support community and economic growth while enhancing the environment and conserving natural resources. Project characteristics should be developed and met at all phases of the lifecycle. Sustainability entails examining the project's life cycle from a social, economic, and environmental perspective [7–9]. Value Engineering (VE) is a procedure used to reconcile the multiple values placed by different stakeholders. It enables an organization to progress on its goals using the fewest resources. [10]. VE can be performed in two ways: proactively or reactively. A proactive approach to collecting ideas starts with the design, where all design alternatives are considered, and the most cost-effective one is selected. A reactive approach gathers cost-effective alternatives through design reviews by others, such as contractors and designer engineers [11]. The study aims to put a practical framework to value engineering hybrid with AHP to create materials alternatives in highway construction projects, which maximize sustainability indicators and other owner's criteria.

1.1 Background and Context

Briefly introduce the significance of sustainability in highway construction.

Discuss the growing importance of sustainability criteria and their impact on construction practices.

1.2 Research Objectives

Clearly state the main objectives of the study, emphasizing the need to identify and rank sustainability and owner criteria.

1.3 Research Methodology

Summarize the methodology employed, highlighting the multi-stage process:

Literature Review*:* Overview of the sustainability criteria identified through the review.

Questionnaire Design and Collection*:* Description of the mixed-method approach used to gather expert opinions and the demographics of the respondents.

Application of Value Engineering (VE)*:* Briefly explain the phases of VE and its role in analyzing the sustainability indicators.

Analytical Hierarchy Process (AHP)*: Outline* how AHP was used for weight calculations.

1.4 Structure of the Paper

- **Literature Review** – Detailed discussion of sustainability criteria and their pillars.
- **Methodology** – In-depth explanation of the research design, questionnaire, data collection methods, and statistical analyses.
- **Results and Discussion** – Presentation and interpretation of findings related to the sustainability indicators and owner criteria.
- **Conclusion and Recommendations** – Summary of key findings and implications for future research and practice.

2. Literature Review

Sustainable development satisfies the present requirements without affecting future generations' ability to satisfy their needs [12]. Conventional buildings have a high energy consumption rate that may account for up to 40% of all worldwide energy output, use 12% of the world's clean water supply, and consume 30% of all global resources during the building phase. Additionally, the operation and upkeep of buildings indirectly negatively influence greenhouse gas emissions, which can account for up to 40% of global emissions. By 2030, 30% of these emissions will be expected in Asian nations [13].

Sustainable development issues are fundamentally engineering, such as energy and materials use. Much research on various aspects of sustainability in various industrial sectors has been undertaken, and most of them have focused on a single principle of sustainability rather than encompassing all three components in a single comprehensive model. Some research focused primarily on social issues[14].The environmental aspects are as in[15,16]. The economic aspects are as in [17–19].

Sustainable construction means creating and operating a healthy environment based on ecological design and resource efficiency [20]. The concept of sustainable construction addresses social, economic, and ecological development issues in its community. Further, Sustainable Construction Principles are formulated as a guideline from the design to the construction phase, which covers the project's life cycle [20]. Sustainable construction indicators used in this study were obtained from literature analysis [21,22]. Table (1) shows that the primary indicators from the project stakeholders' perspectives were explored. Sustainability is categorized into environmental sustainability, socio-economic sustainability, and economic sustainability.

Table 1. Highway construction sustainability indexes criteria`s

Index	Factor with codes				
Environmental	Energy use (E1)	Renewable energy (E2)	Water consumption (E3)	Recycling water (E4)	Waste Management (E5)
	Material Recycle/ Reuse (E6)	Land Use for Temporary Site Facilities (E7)	Impact on biodiversity (E8)	Air Pollution (E9)	Water Pollution (E10)
	Noise Pollution (E11)				
Economic	Initial cost (C1)	Maintenance cost (C2)	Operational Cost (C3)	Job Creation (C4)	Long term Savings (C5)
	Equitable Income (C6)	Local Resources (C7)	Employment creation (C8)	Effective Management Practices (S9)	Social Capital and well bing (S17)
Social	Construction Site Safety (S1)	Local Community Safety (S2)	Employee Wellbeing (S3)	Employee Training and Development (S4)	Employee Satisfaction and Retention (S5)
	Impact on Local Community (S6)	Social Responsibility (S7)	Innovation Practices (S8)	Social security (S16)	Social and cultural life (S10)
	Social homogeneity and cohesion (S11)	Integration diversity sense of place (S12)	Communication and participation (S13)	Social Justice and Equity (S14)	Social amenity (S15)
	Social security (S16)	Social Capital and well bing (S17)	Access to goods (S18)	Service and Employment (S19)	Education (S20)
	Training (S21)	Democracy (S22)	Engaged Governance (S23)	System for citizen Engagement (S24)	

2.1 Innovations in Sustainable Materials for Highway Construction

In the last two decades, research has been performed to use sustainable materials in highway construction. Reusing chosen waste materials such as building and demolition waste, glass wastes, waste rubber, fly ash and granulated blast furnace slag (GBFS), colliery spoils, polyethylene terephthalate (PET), mine tailings, shingles, aluminum dross, bio-oils are among the approaches. These have been investigated independently or in conjunction with other waste products as a whole or partial substitute for certain traditional construction materials in roadway construction and rehabilitation[23]. In a real-world example study in a mountainous region, highway alignment was automatically improved, resulting in 3.6 percent lower carbon dioxide emissions and 3.1 percent lower land utilization, respectively [24]. A sustainability index for Egyptian highway projects has been developed to help managers, engineers, and road organizations create systems for sustainable roadway design, construction, operation, and maintenance. Some professionals consider the term "sustainable highways" to be an ironic expression as they have high material consumption and significant impacts on natural resources [25]. However, when carefully considering the triple principles, social and economic benefits demonstrate that highways are a vital part of the infrastructure for society in any country [26].

2.2 Value Engineering in Highway Projects

Value engineering (VE) is a tool used by engineers and management in various sectors to optimize costs and boost profit margins while preserving the product's basic functionalities.VE can assist in making more comprehensive decisions to improve the performance and quality of highway projects, balance project goals, and manage community expectations [27].The VE process aids in generating creative alternatives while balancing cost, time, and scope to help identify better solutions to these issues. Using VE at the right time can save significantly and improve project performance [19]. The primary component of VE analysis is a function, and VE aims to provide the necessary functionalities at the lowest possible cost [28]. Using a two-fold VE and goal programming to maximize the available highway maintenance fund utilization indicated considerable savings of up to 30% [29]. To maximize the use of the available budget, by applying value engineering (VE) to School Model 15 at Al-Khums City in Libya. The key items were saved between 20% and 30%, resulting in a cost decrease in the whole project [30].Incorporating sustainability objectives into a project using the VE tool depends on the owner's enthusiasm and commitment [31].

2.3 Measuring Sustainability in Highway Construction

VE has been used to reduce environmental impact factors by using metal plates instead of the typical existing ones, resulting in double the utilization and cost savings of 12.94% [32].It serves as a tool for measuring sustainability in highway construction and maintenance methods to ascertain the level of sustainability attained in the projects represented by an index. After performing a correlation and reliability analysis on the data to extract the most valuable parameters following the Pareto principle, a pairwise comparison questionnaire that satisfies the requirements of the Analytical Hierarchy Process (AHP) was created to determine the weights of each parameter in the model [25].

2.4 Sustainable Practices in Highway Projects

A methodical approach to assigning sustainable practices in highway projects has been proposed; they created a model used currently in the building and upkeep of highways, not only limited to green buildings but also covering highway sustainability and green activities [25]. The fundamental principles of sustainable development can enhance the conventional highway construction process. The sustainable highways goal is attained by applying best practices in environmental management throughout road planning and construction [33]. The project's sustainability can be assessed using the Penarafan Hijau JKR (pH JKR) tool [34]. Value engineering and sustainable development for best value in construction. Explores the link between construction design and sustainable construction [35]Integration of sustainability and value engineering in construction. Potential to boost project performance and value enhancement [36]. VE strengthens the economic factor, social factor, and environmental components, the three pillars of a road project's sustainability. VE improves the three pillars of road project sustainability: economic factor, social factor, and environmental factor. VE case studies have shown cost avoidance/savings from project costs ranging from 0.03 percent to 1.05 percent, ensuring that the final project cost is within the approved project cost [34]The applicability of sustainable elements on the checklist was assessed on four roadway design projects, indicating that more than 52% of the 60 produced sustainable components were considered, and 50% were included in the design. A framework for creating sustainable elements for highway design was developed by reviewing LEED, GRI, pertinent research, sustainable highway projects, and practitioner interviews [37]. Based on the definition of sustainable development, the project aims, and sustainability evaluation criteria on connotation and impact analysis are proposed. The goal is to spend as little money as possible while preserving the highway, the social-economic environment, and human tranquility [38]. The value describes the link between functions and resources, with three essential factors that must be measured when determining value: function, quality, and cost [32]. VE emphasizes that products are bought for a specific purpose, namely, for what they could do best, including providing the best aesthetic quality to the user [39]. VE has been applied to reduce the impact of environmental factors, and it has been found that using metal plates instead of typical bekisting with double the utilization resulted in cost savings of IDR 252,590,538.00, or as high as 12.94%. By switching to metal decking plates from traditional bekisting, building projects could save money and time while also making significant environmental benefits by producing less trash [32].

Despite the growing interest in sustainability in highway construction, there needs to be more literature on the state of practice in Egypt

This study aims to investigate how to evaluate sustainability criteria with other owner criteria in highway construction using a hybrid of value engineering methodology and the Analytical Hierarchy Process (AHP).

The study proposes a framework to evaluate suitable alternative additives that can be used in highway construction by applying VE.

The investigation also covers barriers to implementing sustainability strategies, generally related to the environment, in the construction industry in Egypt, as applied in the research methodology.

3. Research Methodology

The research methodology comprised several stages, illustrated in Figure 1, aimed at identifying and prioritizing sustainability and other owner criteria. The initial stage included a literature review that outlined sustainability criteria based on its three pillars: environmental, social, and economic. A questionnaire was developed with a mix of qualitative and quantitative questions in both Arabic and English to gather expert insights on the significance of sustainability and other necessary criteria. This phase aimed to identify the most crucial factors through descriptive and inferential statistics.

In the second stage, Value Engineering (VE) was applied to the key sustainability indicators as well as other owner criteria, including construction time, performance, quality, and constructability. VE consists of six phases: information, function analysis, creativity, and evaluation. During this evaluation phase, the Analytic Hierarchy Process (AHP) was utilized twice: first, to calculate the weights for the sustainability indicators and other owner criteria through pairwise comparisons; and second, to determine the weights for each sustainability factor and owner criterion. The study focused on the Eastern and Western Delta regions of Egypt, aiming for sustainable development in highway construction by ranking alternatives for material additives. The final phase of the methodology involved ranking these material additives for the construction layers of the highway.

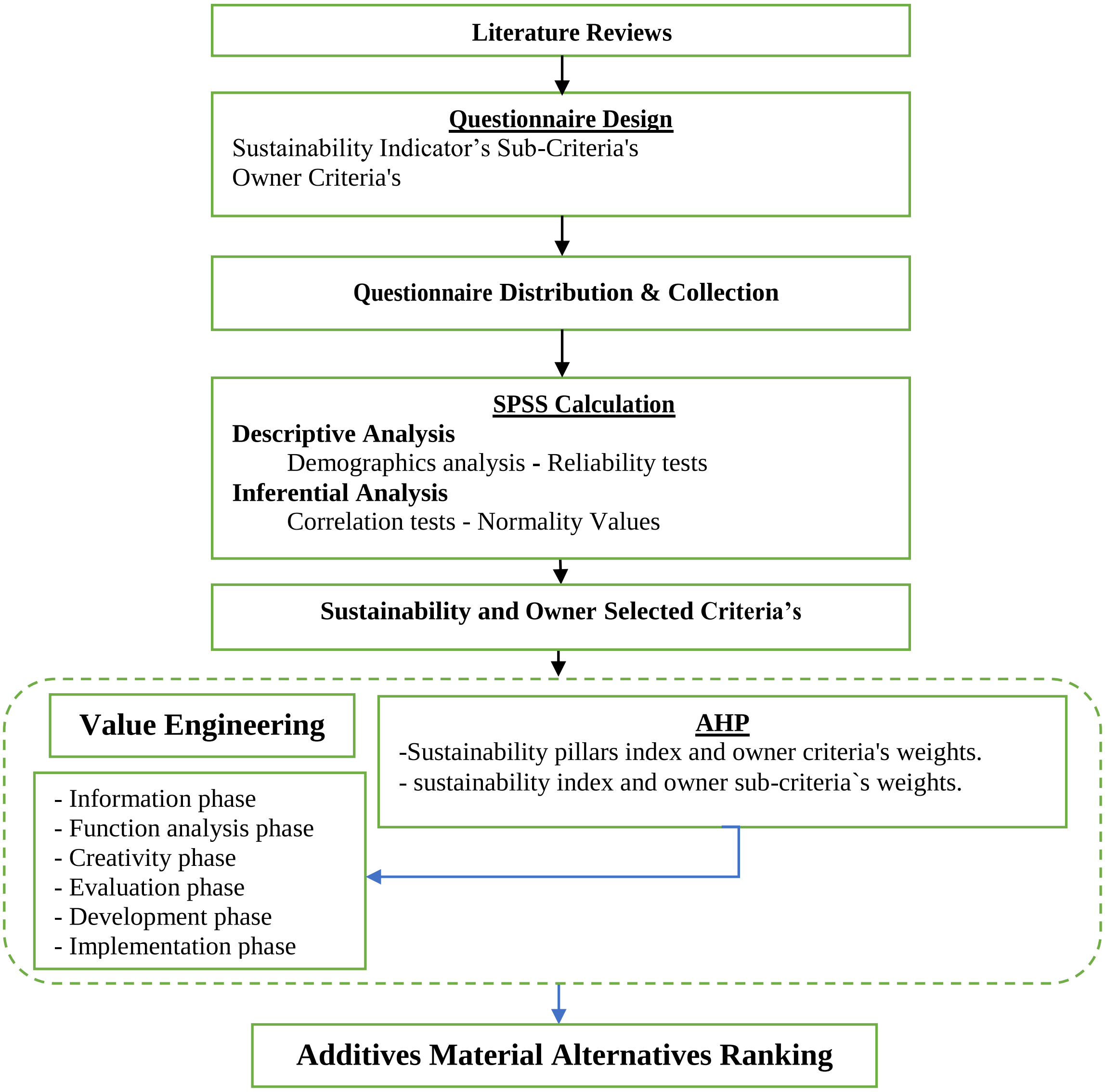

Figure 1: Research methodology chart

3.1 Questionnaire Design

The questionnaire designed for this study aimed to identify the most important factors that affect sustainability in highway construction projects and owner criteria. It used a Likert scale ranging from zero to ten, where zero represented "not important" and ten represented "extremely important." The questionnaire had two sections: closed and open questions. The closed questions focused on the factors that affect sustainability, including 11 factors for the environmental indicator, 8 for the economic indicator, and 24 for the social indicator. The open questions asked about other owner criteria that should be considered in addition to the sustainability factors

3.2 Questionnaire collection

Data for the survey and associated questionnaire were collected from 123 respondents out of 160 invitations sent to participants, resulting in an acceptable response rate of 76.87% [36] **.**

The questionnaire was distributed using Microsoft Forms for convenience. Prior to analysis, the methodology involved applying demographic analysis, reliability, normality, and correlation tests using SPSS statistical software

4. Research Methodology Application Results

4.1 Demographics analysis

Personal identification shows the recipient's education level and experience in construction field, as shown in Table (2). Also, the types of responses organization, his job are shown in Table (3). The organization work value in Egyptian pounds (million) per year was shown in Table (4).

Table 2. Response education level and experience's years

Response	Education level			Experience years					
	BS.c	MS.C	PhD	<5	5-10	10-15	15-20	20-25	>25
Numbers	69	37	17	43	40	22	9	6	3

Table 3. Response organization and job title

Response	Organization type					Job			
	Consultant	Contractors	Education	Government	Owner	Site	Head Office	Academic staff	Technical office
Numbers	42	54	13	3	11	56	49	10	8

Table 4. Annual organization work per year (million)

Organization work value per year (million)	Unknown	<10	10-50	50-100	100-500	>500
Number	68	12	11	8	6	18

4.2 Reliability, Normality, and Correlation tests

The reliability test for collected data done to calculate Cronbach's Alpha for the questionnaire stability as shown in Table (5), which equal .981for all 43 indices' factors it's classified an excellent ratio. Then, the reliability test for environmental factors equals .829 for 11 factors it also classified a good ratio, economic factors the Cronbach's Alpha is .883 for 8 factors and social related factors the Cronbach's Alpha is .986 for 24 factors which classified as Excellent according to [40].

A normality done by Kolmogorov-Smirnov and Shapiro-Wilk tests, showed that ($p < 0.001$), indicating significance, and the value of Statistic was between (1) and (-1), which represented normally distributed data [41]. According to the Spearman correlation theory, all factors at a confidence level between 95% and 99%. The correlated factors were categorized into three environmental factors, four economic factors, and three social factors, totaling 10 factors The strength of the inter-correlation between the factors was assessed using a correlation matrix (R-matrix), which represented the Pearson correlation coefficient between all pairs of factors. The matrix was inspected to test the relationships between factors, and none of the correlation coefficients were less than 0.3 or greater than 0.9.as shown in Table (6).

Table 5. Reliability statistics for sustainability index

Index	Economic	Environmental	Social	All
Cronbach's Alpha	0.883	0.829	0.986	0.981
N of Items	8	11	24	43

Table 6. Sustainability indicators correlated factors

Environmental factors				Social factors				Economic factors				
	E8	E9	E11		S10	S11	S13		C1	C2	C3	C5
E8	1.00	0.388	0.332	S10	1.00	.833	.672	C1	1.00	.450	.423	.588
E9	0.388	1.00	0.639	S11	.833	1.00	.772	C2	.450	1.00	.440	.886
E11	0.332	0.639	1.00	S13	.672	.772	1.000	C3	.423	.440	1.00	.512
								C5	.588	.886	.512	1.00

4.3 VE-AHP methodology application results

The information phase of VE involves gathering all relevant information about the sustainability indicators and owner-required criteria for highway construction projects to determine the most critical factors. From a literature review, a wide range of ideas are collected to select the materials additives for each highway layer to improve the value of the project according to sustainability due to additives.

According to the study methodology, the VE Evaluation phase, Analytical Hierarchy Process (AHP), applies to decide the weights of the group factors, where the ideas generated in the Creativity Phase are evaluated based on a set of criteria and sub-criteria. AHP gives weight between the criteria and sub-criteria, allowing for a more objective and systematic approach to ideas evaluation. AHP was applied twice, firstly calculating the weights for sustainability indicators and other owner criteria using pairs comparison. secondly calculating the weights for sustainability indicators subfactors. Utilizing A 9-point standard scale was used to conduct pairwise comparisons, as shown in Table (7) according to [42].

After the consistency check, criteria weights were determined as in Table (8). The matrix was constructed using the geometric mean of decision-makers' perspectives, and also, equal decision-making power to ensure a balanced comparison, the criteria assigned weights by the weight vector for each matrix. An approximation method (arithmetic mean) was used to compute the matrix weights [43]. The AHP applied in the second step for factors in each indicator as sub-criteria Table (9) shows the result of all sub-criteria. The weights

of sub-criteria selected from the sustainability and owner criteria are represented as shown in Table

(10). It is worth noting that the total weight of sustainability indicators in the Table equals 53.7%, which reflects the country's consideration toward sustainability.

After obtaining the weights criteria and sub-criteria from AHP, a value engineering methodology was applied to evaluate additives for each highway layer. Initial screening for material additives alternatives of highway layers was done, to get a short list of additives alternatives, which have the maximum gain for VE study. In this screening, the evaluator assigns a numerical rating starting by judging an excellent additive worth 5 points; a good additive 4 points; a fair additive 3 points; a poor additive 2 points; a very poor additive 1 point. The screening results shown in Table (11) represent the inputs for the following VE phases. The alternative materials additives for highway Layers, have a ranking from 3 to 5 and are summarized in Table (12) such as the Surface/Wearing layer are Warm Mix Asphalt, Recycled tire rubber, porous asphalt, Reclaimed Asphalt Pavement, Fly Ash, and bio-oils.

Base course layer and Sub Base layer, the alternatives are Fly ash, Lime or cement, Recycled Concrete Aggregate, Pozzolanic materials, Recycled Asphalt Pavement, and Geosynthetics. Sub Grade layer, the alternatives are Fly ash, Lime or cement, Recycled materials, Geosynthetics, and

Chemical stabilizers. While Table (13) represents the Expert's judgement for material alternative's additives weights.

4.3.1 Enhancing Statistical Reliability and Validity

The statistical reliability of the results was ensured through rigorous analysis of Cronbach's Alpha and the consistency of AHP pairwise comparisons. The Cronbach's Alpha values for the questionnaire were exceptionally high (0.981 overall, with subcategories ranging from 0.829 to 0.986), indicating strong internal consistency and reliability of the collected data. This confirms that the responses accurately reflect the underlying sustainability criteria being assessed. Furthermore, the Analytic Hierarchy Process (AHP) used for ranking sustainability indicators and owner criteria demonstrated excellent reliability, with a Consistency Ratio (CR) of 3%, well below the acceptable threshold of 10%. These robust statistical measures reinforce the validity of the study's findings, making the rankings of sustainable materials both dependable and credible.

Table 7. Scale for conduct pairwise comparisons

Value	Equally important	Weak importance	Strong importance	Very strong importance	Absolute importance	Intermediate levels
Relevance	1	3	5	7	9	2,4,6,8

Table 8. Weight for each indicator of sustainability and owner criteria for VE

	Environmental	Economical	Social	Performance	Construction time	Quality	Constructability
Weight %	18.6	27.1	8	17.3	8	13.6	7.4
CIR	0.02817						
IIR	1.32						
CI	0.03719						
λ_{max}	7.2231						
Consistency	3%						

Table 9. Sustainability and owner criteria factors weight

Indicator	Environmental			Economical				Social			Owner criteria's			
W %	100%			100%				100%			100%			
Factor	E8	E9	E11	C1	C2	C3	C5	S10	S11	S13	Performance	Constr. Time	Quality	Constructability
W %	21.3	9.7	69	28.3	52.4	6.3	13	55.7	32	12.3	37.3	17.3	29.5	15.9
CIR	0.01283			0.0415				0.0201			0.045048			
IIR	0.58			0.9				0.58			0.9			
CI	0.00744			0.03735				0.0117			0.04054			
λ_{max}	3.01488			4.112				3.0234			4.1216			
Consistency	1%			4%				2%			5%			

Table 10. Sustainability and owner sub-criteria factors weight

Indicator	Environmental			Economical				Social			Others			
W %	18.6			27.1				8			46.3			
Factor	E8	E9	E11	C1	C2	C3	C5	S10	S11	S13	Performance	Constr.time	Quality	Constructability
W %	3.97	1.8	12.83	7.76	14.2	1.7	3.44	4.45	2.56	0.99	17.3	8	13.6	7.4

Table 11. Additives alternatives for highway layers materials initial screening

Surface/Wearing layer	Rank	Base course layer	Rank	Sub Base layer	Rank	Sub Grade layer	Rank
Warm Mix Asphalt	4	Fly ash	5	Fly ash	5	Fly ash	4
Porous asphalt	3	Lime or cement	3	Geosynthetics	3	Lime or cement	3
Reclaimed Asphalt Pavement	5	Recycled Concrete Aggregate	5	Recycled Concrete Aggregate	5	Recycled materials	5
Fly Ash	4	Pozzolanic materials	3	Pozzolanic materials	3	Geosynthetics	3
Bio-based additives	4	Recycled Asphalt Pavement	4	Recycled Asphalt Pavement	4	Chemical stabilizers	3

Recycled tire rubber	3	Geosynthetics	4	Lime or cement	4	Glass waste	2
PET*	2	Steel slag	2	Waste Rubber tires	2	Coal bottom ash	1
Agricultural waste	2			Cement kiln dust (CKD)	1	Mine and quarry waste	2
Sewage sludge	2						
Waste ceramic	2						
Asphalt shingles.	1						

***PET:** Polyethylene terephthalate plastic bottles

Table 12. Highway layers materials additives alternatives

Surface/Wearing layer	Base course layer	Sub Base layer	Sub Grade layer
Warm Mix Asphalt	Fly ash	Fly ash	Fly ash
Porous asphalt	Lime or cement	Geosynthetics	Lime or cement
Reclaimed Asphalt Pavement	Recycled Concrete Aggregate	Recycled Concrete Aggregate	Recycled materials
Fly Ash	Pozzolanic materials	Pozzolanic materials	Geosynthetics
Bio-based additives	Recycled Asphalt Pavement	Recycled Asphalt Pavement	Chemical stabilizers
Recycled tire rubber	Geosynthetics	Lime or cement	

Table 13. Experts judgement for each highway layer

<u>For alternatives rating:</u> Excellent =5, V.good = 4, Good = 3, Fair = 2 , Poor = 1		Degree of Criterion importance													
		Environmental			Economical				Social			Others			
		Impact on biodiversity	Air Pollution	Noise Pollution	Initial cost	Maintenance cost	Operational Cost	Long term Savings	Social and cultural life	Social homogeneity and cohesion	Communication and participation	Performance	Constr. time	Quality	Constructability
Surface/Wearing Course	Warm Mix Asphalt	3	3	4	4	4	3	5	5	5	4	5	5	5	4
	Porous asphalt	4	3	4	4	3	2	3	4	3	4	4	4	5	4
	Reclaimed Asphalt Pavement	5	4	5	5	4	5	3	5	4	5	5	4	5	4
	Fly ash (FA)	3	3	4	4	2	4	3	2	3	2	3	5	2	3
	Bio-based additives	3	2	4	4	3	3	2	3	2	3	5	3	5	3
	Recycled tire rubber	5	4	4	4	3	3	4	3	4	3	5	5	4	4
Base course.	Fly ash (FA)	4	5	4	5	3	3	4	5	3	4	5	3	4	3
	Recycled Asphalt Pavement	3	3	4	3	2	4	3	3	2	3	3	2	1	3
	Geosynthetics	3	2	3	2	4	3	2	1	3	4	1	2	1	5
	Lime or cement	2	1	2	1	3	2	1	3	2	1	4	2	3	4
	Pozzolanic materials	2	1	3	1	1	2	1	1	4	3	2	4	2	1
	Recycled Concrete Aggregate	4	5	5	5	4	5	4	4	5	5	4	5	5	3
Sub Base	Lime or cement	5	4	4	4	3	3	4	3	4	3	5	5	4	4
	Fly ash (FA)	4	5	4	4	3	2	5	4	1	2	3	4	5	4
	Recycled Asphalt Pavement	5	4	3	3	4	4	1	2	4	3	2	3	1	4
	Geosynthetics	3	2	4	3	2	4	2	3	3	3	3	1	2	3
	Pozzolanic materials	1	2	2	3	2	2	2	3	3	2	3	1	5	3
	Recycled Concrete Aggregate	5	5	4	5	4	3	5	4	1	4	2	1	4	5
Sub Grade	Recycled materials	4	3	2	5	4	4	5	5	4	5	5	4	5	5
	Geosynthetics	3	2	3	4	5	3	4	4	3	4	4	3	4	4
	Fly ash (FA)	5	4	4	3	4	4	2	5	3	4	4	5	3	4
	Lime or cement	2	3	2	2	4	3	1	2	3	2	3	2	4	3
	Chemical stabilizers	3	3	2	3	4	3	3	3	2	3	4	3	2	3

4.3.2 Highway construction layers materials additives evaluation

Firstly, Surface/Wearing layer, Table (14) representing the evaluation and rank for each additive in this layer, comparing between six alternatives. Secondly, Base course layer. Table (15) shows the evaluation and ranking for each additive. Thirdly, sub-Base course layer, Table (16) shows the rank and evaluation for each alternative. Thirdly, Sub Grade layer after Applying the VE methodology to compare between the five additives according to sustainability and the owner criteria's, Table (17) shows the rank and evaluation for each alternative.

Table 14. Surface wearing layer materials additives alternatives ranking

For alternatives rating: Excellent =5, V.good = 4, Good = 3, Fair = 2, Poor = 1		Desired Criteria: Environmental			Economical				Social			Others				Total score	Rank
		Impact on biodiversity	Air Pollution	Noise Pollution	Initial cost	Maintenance cost	Operational Cost	Long term Savings	Social and cultural life	Social homogeneity and cohesion	Communication and participation	Performance	Construction time	Quality	Constructability		
Item: Surface/Wearing Course in pavement.																	
Weight of Importance 0 ® 100%		E8	E9	E11	C1	C2	C3	C5	S10	S11	S13	A	C	D	F		
		3.97	1.8	12.83	7.76	14.2	1.7	3.44	4.45	2.56	0.99	17.3	8	13.6	7.4		
Warm Mix Asphalt	w. rating	11.91	5.4	51.32	31.04	56.8	5.1	17.2	22.25	12.8	3.96	86.5	40	68	29.6	441.9	2
	Rating	3	3	4	4	4	3	5	5	5	4	5	5	5	4		
Porous asphalt	w. rating	15.88	5.4	51.32	31.04	42.6	3.4	10.32	17.8	7.68	3.96	69.2	32	68	29.6	388.2	4
	Rating	4	3	4	4	3	2	3	4	3	4	4	4	5	4		
Reclaimed Asphalt Pavement	w. rating	19.85	7.2	64.15	38.8	56.8	8.5	10.32	22.25	10.2	4.95	86.5	32	68	29.6	459.16	1
	Rating	5	4	5	5	4	5	3	5	4	5	5	4	5	4		
Fly Ash	w. rating	11.91	5.4	51.32	31.04	28.4	6.8	10.32	8.9	7.68	1.98	51.9	40	27.2	22.2	305.1	6
	Rating	3	3	4	4	2	4	3	2	3	2	3	5	2	3		
Bio-based additives	w. rating	11.91	3.6	51.32	31.04	42.6	5.1	6.88	13.35	5.12	2.97	86.5	24	68	22.2	374.6	5
	Rating	3	2	4	4	3	3	2	3	2	3	5	3	5	3		
Recycled tire rubber	w. rating	19.85	7.2	51.32	31.04	42.6	5.1	13.76	13.35	10.2	2.97	86.5	40	54.4	29.6	407.93	3
	Rating	5	4	4	4	3	3	4	3	4	3	5	5	4	4		

Table 15. Base course layer materials additives alternatives ranking

For alternatives rating: Excellent =5, V.good = 4, Good = 3, Fair = 2 , Poor = 1		Desired Criteria														Total score	Rank
		Environmental			Economical				Social			Others					
		Impact on biodiversity	Air Pollution	Noise Pollution	Initial cost	Maintenance cost	Operational Cost	Long term Savings	Social and cultural life	Social homogeneity and cohesion	Communication and participation	Performance	Construction time	Quality	Constructability		
Item: Base course.																	
Weight of Importance 0 ® 100%		E8	E9	E11	C1	C2	C3	C5	S10	S11	S13	A	C	D	F		
		3.97	1.8	12.83	7.76	14.2	1.7	3.44	4.45	2.56	0.99	17.3	8	13.6	7.4		
Fly ash	w. rating	15.88	9	51.32	38.8	42.6	5.1	13.76	22.25	7.68	3.96	86.5	24	54.4	22.2	397.5	2
	Rating	4	5	4	5	3	3	4	5	3	4	5	3	4	3		
Lime or cement	w. rating	7.94	1.8	25.66	7.76	42.6	3.4	3.44	13.35	5.12	0.99	69.2	16	40.8	29.6	267.7	3
	Rating	2	1	2	1	3	2	1	3	2	1	4	2	3	4		
Recycled Concrete Aggregate	w. rating	15.88	9	64.15	38.8	56.8	8.5	13.76	17.8	12.8	4.95	69.2	40	68	22.2	441.84	1
	Rating	4	5	5	5	4	5	4	4	5	5	4	5	5	3		
Pozzolanic materials	w. rating	7.94	1.8	38.49	7.76	14.2	3.4	3.44	4.45	10.2	2.97	34.6	32	27.2	7.4	195.9	6
	Rating	2	1	3	1	1	2	1	1	4	3	2	4	2	1		
Recycled Asphalt Pavement	w. rating	11.91	5.4	51.32	23.28	28.4	6.8	10.32	13.35	5.12	2.97	51.9	16	13.6	22.2	262.6	4
	Rating	3	3	4	3	2	4	3	3	2	3	3	2	1	3		
Geosynthetics	w. rating	11.91	3.6	38.49	15.52	56.8	5.1	6.88	4.45	7.68	3.96	17.3	16	13.6	37	238.3	5
	Rating	3	2	3	2	4	3	2	1	3	4	1	2	1	5		

Table 16. Sub-base layer materials additives alternatives ranking

For alternatives rating: Excellent =5, V.good = 4, Good = 3, Fair = 2 , Poor = 1	Desired Criteria														Total score	Rank
	Environmental			Economical				Social			Others					
	Impact on biodiversity	Air Pollution	Noise Pollution	Initial cost	Maintenance cost	Operational Cost	Long term Savings	Social and cultural life	Social homogeneity and cohesion	Communication and participation	Performance	Construction time	Quality	Constructability		
Item: Sub Base.																
Weight of Importance	E8	E9	E11	C1	C2	C3	C5	S10	S11	S13	A	C	D	F		

0 ® 100%		3.97	1.8	12.83	7.76	14.2	1.7	3.44	4.45	2.56	0.99	17.3	8	13.6	7.4		
Fly ash	w. rating	15.88	9	51.32	31.04	42.6	3.4	17.2	17.8	2.56	1.98	51.9	32	68	29.6	374.3	2
	Rating	4	5	4	4	3	2	5	4	1	2	3	4	5	4		
Geosynthetics	w. rating	11.91	3.6	51.32	23.28	28.4	6.8	6.88	13.35	7.68	2.97	51.9	8	27.2	22.2	265.5	6
	Rating	3	2	4	3	2	4	2	3	3	3	3	1	2	3		
Recycled Concrete Aggregate	w. rating	19.85	9	51.32	38.8	56.8	5.1	17.2	17.8	2.56	3.96	34.6	8	54.4	37	356.39	3
	Rating	5	5	4	5	4	3	5	4	1	4	2	1	4	5		
Pozzolanic materials	w. rating	3.97	3.6	25.66	23.28	28.4	3.4	6.88	13.35	7.68	1.98	51.9	8	68	22.2	268.3	5
	Rating	1	2	2	3	2	2	2	3	3	2	3	1	5	3		
Recycled Asphalt Pavement	w. rating	19.85	7.2	38.49	23.28	56.8	6.8	3.44	8.9	10.2	2.97	34.6	24	13.6	29.6	279.8	4
	Rating	5	4	3	3	4	4	1	2	4	3	2	3	1	4		
Lime or cement	w. rating	19.85	7.2	51.32	31.04	42.6	5.1	13.76	13.35	10.2	2.97	86.5	40	54.4	29.6	407.9	1
	Rating	5	4	4	4	3	3	4	3	4	3	5	5	4	4		

Table 17. sub grade layer materials additives alternatives ranking

For alternatives rating: Excellent =5, V.good = 4, Good = 3, Fair = 2 , Poor = 1		Desired Criteria														Total score	Rank
		Environmental			Economical				Social			Others					
		Impact on biodiversity	Air Pollution	Noise Pollution	Initial cost	Maintenance cost	Operational Cost	Long term Savings	Social and cultural life	Social homogeneity and cohesion	Communication and participation	Performance	Construction time	Quality	Constructability		
Item: Sub Grade.																	
Weight of Importance		E8	E9	E11	C1	C2	C3	C5	S10	S11	S13	A	C	D	F		
0 ® 100%		3.97	1.8	12.83	7.76	14.2	1.7	3.44	4.45	2.56	0.99	17.3	8	13.6	7.4		
Fly ash	w. rating	19.85	7.2	51.32	23.28	56.8	6.8	6.88	22.25	7.68	3.96	69.2	40	40.8	29.6	385.6	2
	Rating	5	4	4	3	4	4	2	5	3	4	4	5	3	4		
Lime or cement	w. rating	7.94	5.4	25.66	15.52	56.8	5.1	3.44	8.9	7.68	1.98	51.9	16	54.4	22.2	282.9	5
	Rating	2	3	2	2	4	3	1	2	3	2	3	2	4	3		
Recycled materials	w. rating	15.88	5.4	25.66	38.8	56.8	6.8	17.2	22.25	10.2	4.95	86.5	32	68	37	427.5	1
	Rating	4	3	2	5	4	4	5	5	4	5	5	4	5	5		
Geosynthetics	w. rating	11.91	3.6	38.49	31.04	71	5.1	13.8	17.8	7.68	3.96	69.2	24	54.4	29.6	381.5	3
	Rating	3	2	3	4	5	3	4	4	3	4	4	3	4	4		
Chemical stabilizers	w. rating	11.91	5.4	25.66	23.28	56.8	5.1	10.3	13.35	5.12	2.97	69.2	24	27.2	22.2	302.5	4
	Rating	3	3	2	3	4	3	3	3	2	3	4	3	2	3		

5. Research Finding Analysis

Applying the proposed methodology for study, which includes value engineering and AHP technique, to the addition of various materials for the construction of Highway projects, we found the following for each layer.

5.1 Surface/Wearing pavement

We discovered that Reclaimed Asphalt Pavement is ranked first in terms of sustainability, as Reduced material and transportation costs, as well as overall environmental benefits, have raised interest in using RAP in pavements, notably as base materials for highway building projects [44]. Higher RAP recycling rates enhance pavement durability and reduce environmental impacts, making RAP integration crucial for sustainable pavement construction and achieving significant reductions in embodied GHG emissions [45] . demonstrates that integrating waste PET with high RAP content enhances pavement performance, reduces costs by 17%, and lowers CO2 emissions by 53%, promoting sustainable infrastructure [46]. Secondly, Warm Mix Asphalt is considered sustainable due to its ability to resist high temperatures of asphalt mixtures with aggregates from different sources, including natural and inorganic materials. Furthermore, improved resistance to high temperatures of asphalt mixtures with waste glass as an aggregate, compared to mixtures with stone aggregate (SA) [47]. WMA technology significantly reduces energy consumption by 16.5% to 47.4% and carbon emissions during production and construction, demonstrating its effectiveness in energy savings and emission reduction [48] WMA reduces asphalt production temperatures, energy consumption, and emissions. WMA supports sustainable development in pavement construction[49]. Recycled tire rubber provides outstanding water resistance, great soundproofing, thermal insulation, good acid resistance, and the ability to absorb plastic energy and substantial impact resistance[50]. Waste rubber in asphalt mixtures for sustainable pavement infrastructure. Evaluation of CR-SMA mix design, performance characteristics, and improvement areas [51]. Assessing RARP mixtures with different rejuvenation schemes through mechanical tests. Recycling RARP can save GHG emissions and cost in Hong Kong[52]. Porous asphalt is also considered sustainable due to its sound absorption capability[53]. Bio-based additives producing softening effect that results in an improvement in low-temperature behaviour and fatigue resistance compared to the control bitumen, despite an increased likelihood of permanent deformation [54]. while Fly Ash ranks last[55].

5.2 Base and Sub base layer

Recycled Concrete Aggregate is ranked first for base layer and third for sub-base layer due to its ability to improve the mechanical properties of the mixture, where the unconfined compressive strength (UCS) is an important quality indicator [56]. Fly ash is ranked second in both layers, as the immobilization of all heavy metals and metalloids from APC is achieved by the pozzolanic effect of the cement mortar [57]. Lime is ranked first in sub-base and third in base layer, as it shows that the addition of 2% and 3% of lime or cement was enough to change the soil workability and mechanical strength. Additionally, mechanistic analyses supported the soil modification technique as a valuable practice with low elastic strains in the asphalt layer when applied in pavement base layers [58]. Recycled Asphalt Pavement is ranked fourth in both layers as it has a high resilient modulus, the development of higher residual strains under repeated loading due to the addition of RAP contents may be detrimental to the life of the road pavement structure [59]. Geosynthetics are ranked fifth in the base layer and sixth in sub base layer, as it has been utilised to increase recycled aggregates' mechanical qualities and long-term durability[60]. and increase in the compression strength of reinforced specimens compared to unreinforced soil samples [61]. The effect of geosynthetic inclusion reduces by increasing the subbase thickness. Lastly, Pozzolanic materials are ranked sixth in base layer and fifth in sub base [62].

5.3 Grade layer

Recycled materials are ranked first, as it is more appropriate to blend the Recycled Concrete Aggregates (RCA) with natural materials rather than to use them in their pure form. In general, it is appropriate to use 50% of RCAs in the mixtures. It was observed that if the concrete compressive strength is as high as in RCA1 (18.5 MPa), RCA can be used even in the mixture at a ratio of 75% [63]. Fly ash is ranked second[64]. while geosynthetics are ranked third[65]. Chemical stabilizers are ranked fourth, as it shows impressive regression for sets of models [66]. Lime is ranked lasts[67]. Summarizing the results in figure to simplify the presentation for decision maker (project owner) as shown in Figure 2.

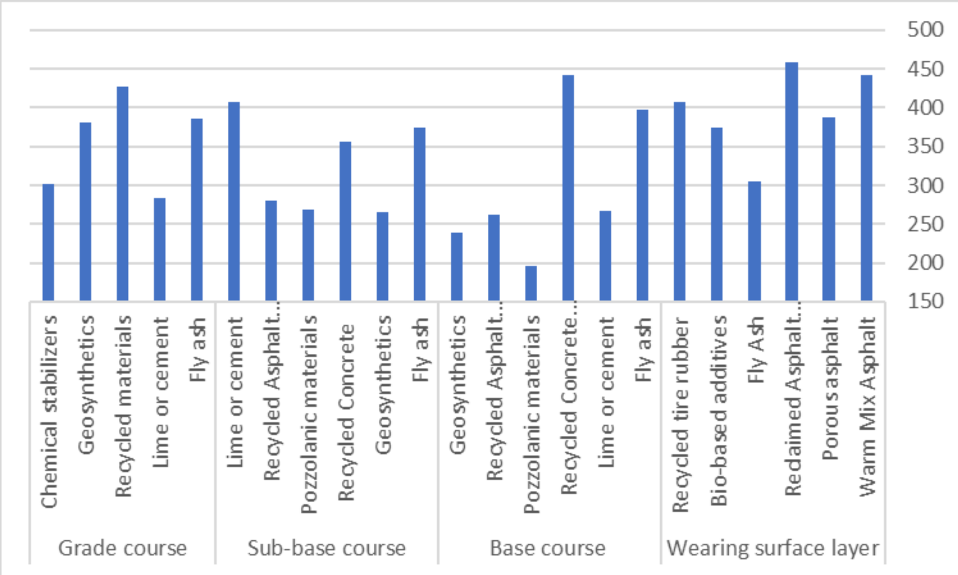

Figure 2: Highway Construction Materials Additives Alternative Ranking

Fig 3. The bar chart shows the sustainability scores of various highway construction materials. Reclaimed Asphalt Pavement (RAP) leads with the highest score, followed by Warm Mix Asphalt (WMA) and Recycled Tire Rubber, reflecting their strong sustainability performance. Materials like Porous Asphalt and Bio-based Additives also score well, while Fly Ash has the lowest score. Overall, the chart highlights RAP and WMA as the top sustainable options for highway projects.

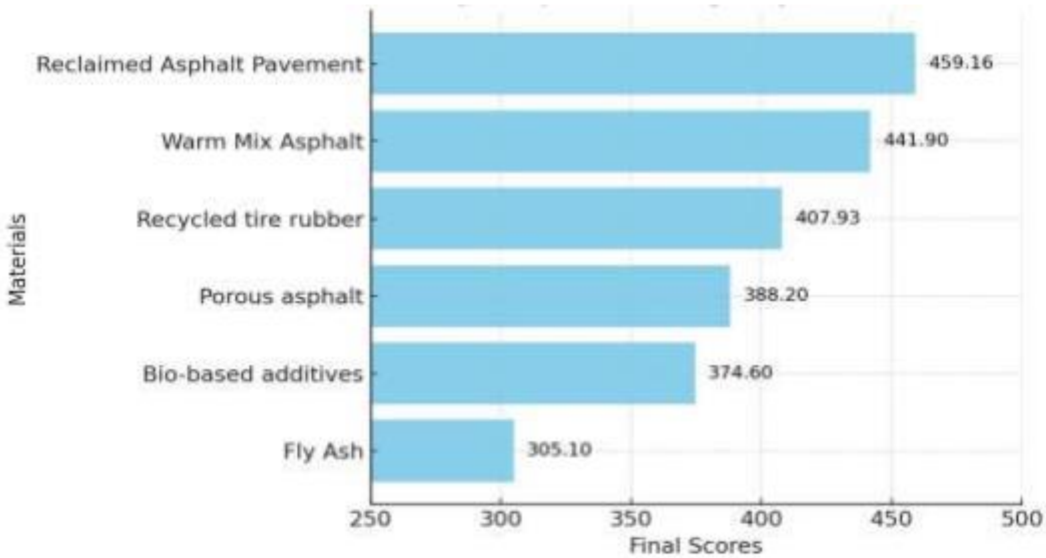

Figure3. Comparison of sustainability scores for highway construction material

6. Results Validation

6.1 Surface/Wearing pavement

We have found that Reclaimed Asphalt Pavement (RAP) ranks first in terms of sustainability, as documented by [68]. This conclusion was drawn from the use of a 20% RAP mixture, assessed in terms of materials and related to cost analysis. It was reported that a total cost reduction of 14% was achieved using RAP compared to conventional materials. This assessment was conducted in a case study on the Lahore–Islamabad Motorway (M-2), which spans a length of 354 km. Additionally, Warm Mix Asphalt (WMA), as indicated by [69], offers several advantages over conventional asphalt concrete mixtures. These advantages include reduced energy consumption, decreased emissions, improved or more uniform binder coating of aggregate, which should reduce mix surface aging, and an extended construction season in temperate climates. Regarding recycled tire rubber, as researched by [70], introducing crumb rubber in the production of asphalt mixtures contributes to the pavement's environmental sustainability. It allows for the reduction of tire/road noise emissions, classifying crumb rubber modified asphalt concrete as a construction material that enhances the three dimensions of sustainability. Porous asphalt, according to [71], has been studied for its sound absorption coefficient in asphalt pavements to reduce traffic and environmental noise. It has been observed that the sound absorption coefficient in the asphalt layer can be increased with the use of a porous asphalt layer, thereby enhancing sound absorption performance and reducing environmental noise levels. Lastly, bio-based additives, according to [72], offer an environmentally friendly and cost-effective alternative to imported granular fills, concrete, costly hauling of materials, or export to a landfill. Similarly, [73] found that fly ash serves as an alternative solution for pavement stabilization, saving natural resources typically used as wearing course materials.

6.2 Base and Sub base layer

Recycled Concrete Aggregate (RCA) has been ranked first for the base layer and third for the sub-base layer, according to the study by [74]. Their research, conducted in a recently completed project for constructing a new access road on the premises of a former Jute Mill, demonstrates the technical viability of using recycled concrete aggregates in new concrete construction. This approach not only achieves cost savings but also aligns with policies promoting sustainable development. Fly ash has been ranked second in both layers, as indicated by [75]. Their study focuses on assessing the environmental stability of fly ash for use as a subbase material in flexible pavements. Laboratory investigations confirmed that the minimum strength criteria required for a material to be used as a subbase layer in a flexible pavement were met. The case study conducted by the Indian Road Congress (IRC) involved constructing six different test sections with fly ash in the subbase layers, comparing them with one section constructed using conventional granular subbase (GSB). Lime has been ranked first in the sub-base layer and third in the base layer, according to [76]. The investigation, conducted on the roads of the rice region of Merin Lake in Uruguay, evaluated the performance of a full-scale test section of pavement with a base layer of local silty clay soil stabilized with lime. This approach offers a technical and economical alternative for base layers of low-volume roads, contributing to a significant improvement in the rural road network with associated socioeconomic benefits. Recycled Asphalt Pavement (RAP) has been ranked fourth in both layers, according to [77]. Their research highlights the reduced cost for materials and transportation, overall environmental benefits, and other advantages associated with utilizing RAP in pavements, including as base materials for highway construction projects. Experimental data support the conclusion that RAP materials can be effectively utilized as a base material, contributing to pavement sustainability, as emphasized by [78]. Geosynthetics have been ranked fifth in the base layer and sixth in the sub-base layer, as per [79]. Geosynthetics offer sustainable solutions for geotechnical and geoenvironmental problems when used with natural materials. The study demonstrates the feasibility and environmental benefits of combining geosynthetics with unconventional or alternative construction materials, aligning with the trend towards a circular economy and sustainable development. Pozzolanic materials have been ranked sixth in the base layer and fifth in the sub-base layer, according to [62].

Road Cem, a soil stabilizer, provides a cost-effective and environmentally friendly source of materials for road construction when used with in-situ material. This approach reduces the required pavement thickness, resulting in cost savings and addressing the declining availability of imported materials.

6.3 Grade layer

Recycled materials are ranked first, particularly in the context of recycling construction and demolition wastes (CDW) into subgrade materials. This approach, exemplified by a CDW subgrade construction case in Beijing, offers significant environmental and economic benefits. [80] conducted life cycle assessments (LCA) of two treating schemes of CDW to analyze their environmental benefits: recycling utilization as subgrade materials and direct landfilling. Utilizing recycled CDW aggregates in the subgrade can lead to a large consumption of CDW, thereby significantly reducing environmental impacts such as eutrophication and ecotoxicity. Fly ash is ranked second in importance, as highlighted by [67]. Fly ash stabilization can be economically engineered for long-term performance, offering cost savings of up to 50% by reducing material costs. Geosynthetics are ranked third, according to [81]. Their use in various railway applications, exemplified by a high-speed railway project completed in Malaysia, provides safe and cost-effective solutions to various geotechnical engineering challenges. Chemical stabilizers are ranked fourth, as indicated by [82], particularly in the geotechnical section of the Kyoto Protocol. This study aimed to investigate and compare the effect of chemical and biological stabilization of clay subgrade soil. Chemical stabilization, utilizing polymers such as cationic polyelectrolyte (CPE) and Nicoflok, was found to be economically feasible. Meanwhile, biological stabilization using biopolymers was deemed environmentally suitable for the studied soil. Lastly, lime is ranked last, according to [67].

7. Conclusion and Recommendation

The selection of sustainable materials through value engineering is crucial for reducing the environmental impact and improving the efficiency of highway construction projects. From the findings of this study, it is evident that Reclaimed Asphalt Pavement (RAP) and Warm Mix Asphalt (WMA) are the most sustainable materials for surface/wearing and base/sub-base layers, respectively.

Recycled Concrete Aggregate, bio-based additives, recycled tire rubber, and porous asphalt are other sustainable options for surface/wearing layers. Recycled Concrete Aggregate, fly ash, geosynthetics, and chemical stabilizers are also sustainable materials for base/sub-base and sub-grade layers. recycled tire rubber. This research can inform the development of best practices for integrating sustainable materials into highway construction project management processes.

By adopting these recommendations, project managers and engineers can contribute to the development of a more sustainable and environmentally friendly transportation infrastructure. This can result in significant benefits for society, including reduced environmental impact, improved public health, and increased economic sustainability. Ultimately, the application of value engineering through the selection of sustainable materials can lead to more successful highway construction projects and a more sustainable future for all.

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