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A Framework of Indicators for Sustainable Road and Highway Infrastructure Development in Developing Countries: The Ghana Context

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Abstract: There is an increase in global concern about sustainability issues across all industrial sectors. Adopting sustainable highway infrastructure development is thus a crucial step toward achieving sustainable transport. This, in turn, is a key component of several sustainable development goals (SDGs) and targets in the 2030 Agenda for Sustainable Development. Most developing countries face significant sustainability challenges in constructing roads and highway infrastructure because of a lack of a comprehensive framework for sustainable road infrastructure. This study aimed to develop a framework for sustainable road and highway development. The study utilises a questionnaire survey and data were obtained from highway professionals, including contractors, consultants, environmental agencies, road agencies, researchers and academics. Inferential statistics were developed via Statistical Package for the Social Sciences (SPSS) version 26 to identify the critical indicators considered by all highway professional groups. The findings revealed 31 critical indicators, of which reducing material costs, complying with environmental requirements, contract documents and project specifications, and disaster-resilient designs emerged as the top three critical indicators, highlighting the importance of economic efficiency, responsible project execution and infrastructure resilience. In addition to bridging the gap in the literature from developing countries, the developed conceptual framework offers a structured approach to guide future initiatives in highway infrastructure development, emphasising the integration of a range of criteria for a holistic and sustainable approach.

Keywords: Sustainability indicators, Highway development, Climate change resilience, Sustainable road infrastructure, Roads and highway in Ghana

INTRODUCTION

Sustainable transport is an integral component of several sustainable development goals (SDGs) and targets the 2030 Agenda for Sustainable Development. Without sustainable road infrastructure, we cannot achieve sustainable transport (United Nations, 2023). This is envisioned in SDG Target 9.1, which states, "Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all". Notwithstanding this, there is a global rise in concern about sustainability issues across all industrial sectors

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(Owusu-Manu et al., 2023). Most developing countries, including Ghana, face sustainability challenges concerning the development of sustainable roads and highway infrastructure (Nerini et al., 2019; Xiao, D'Angelo and Lê, 2020). These challenges cut across various stages of the development of roading infrastructure (i.e., planning, design, construction, maintenance and operation). All these stages involve multiple stakeholders and require all involved parties to rapidly address sustainability issues in development (Bühler et al., 2023).

The Ghana Highway Authority, the Department of Feeder Roads and the Department of Urban Roads are the three main departments of Ghana Road Infrastructure and are tasked with managing the country's roads and highway development. As of 2017, the total road network size in Ghana was 78,402 km. The Ghana Highway Authority, the Department of Feeder Roads and the Department of Urban Roads had approximately 14,583 km, 48,383 km and 15,462 km of the road network under their jurisdiction, respectively (Frimpong, 2022; Yeboah, 2022). The mandate for these road agencies includes the requisite human and technical resources to ensure the sustainability of roads and highway infrastructure projects. At all stages of road infrastructure development, these road agencies collaborate with state and nonstate actors, who play important roles in highway sustainability. There is, however, a lack of a locally developed framework for sustainable road and highway infrastructure development, a situation not only in Ghana but also in most sub-Saharan African countries. This results in a lack of synergy among the activities of various road stakeholders and various highway professionals attempting to implement what they believe are the best-known sustainability standards. There appear to be different stakeholder interests and multidimensional viewpoints on highway development. According to Mok, Shen and Yang (2015), the inclusion of different perspectives and opinions from stakeholders in a comprehensive manner is necessary when making decisions regarding sustainable highway infrastructure development. The literature indicates that researchers have given little attention to enhancing sustainability in highway infrastructure development, especially in sub-Saharan Africa. Most sustainability frameworks for highway development originate from developed countries (i.e., the United States and Europe, etc.) that have different drivers and indicators compared to African countries such as Ghana. Conceptual frameworks from developed countries are unlikely to be applicable or relevant to developing countries (Polat et al., 2006). In different countries, there are different approaches and priorities for sustainable construction. It is important to incorporate the local and regional characteristics of the physical environment when measuring the level of sustainability (Adler, 1998; Yunus and Yang, 2011).

Against this backdrop, it is important to ascertain the sustainable highway indicators that carry the utmost significance for key stakeholders in their decision-making processes pertaining to sustainable highway development. The primary goal of this study is to establish a framework for the development of sustainable roads and highways. Specifically, this study seeks:

1. To explore the attitudes and perceptions of road and highway professionals toward sustainability indicators.
2. To identify the indicators considered critical by road and highway professionals for sustainable roadway development.

This study is distinct from other studies since it investigates concerns within the framework of a project-level context, encompassing planning, design, construction, maintenance and operations. The study contributes to the knowledge of sustainable highway infrastructure development in developing countries, with a particular focus on the identification of critical indicators of road and highway infrastructure development in developing countries. The study findings serve as a valuable source of information for all stakeholders in the road infrastructure sector of developing countries, offering guidance for effectively implementing sustainable practices and assessing progress in road and highway development.

LITERATURE REVIEW

Concept of Sustainability

In a broad sense, sustainable development can be defined as a form of development that effectively addresses the requirements of the current generation while ensuring that future generations are not hindered in their ability to fulfil their own demands (Brundtland, 1987). The concept of sustainable development pertains to the necessity of incorporating novel integrative methodologies into existing physical development practices. The concept of sustainability has been a subject of considerable interest for a considerable period of time and across several sectors of development, including energy and transportation. The incorporation of this concept within the construction sector is currently in a promising phase (Opoku et al., 2021; Teo and Loosemore, 2003).

Although sustainability logically connects with infrastructure development, there is limited consensus on what constitutes sustainability in the context of infrastructure, as different stakeholders interpret the priorities of sustainability differently (Lim, 2009). The concept of sustainability was based strictly on the economic dimension in the 1970s (Purvis, Mao and Robinson, 2019). Over time, the concept has evolved with an all-encompassing context and growing complexity. Despite these different perspectives, there are three main universally accepted principles of sustainability called the triple bottom line (Babashamsi et al., 2016; Hashemi, Ghoddousi and Nasirzadeh, 2021). These are social, economic and environmental concerns. However, there is a school of thought that sustainability could mean anything that is encapsulated in the equation "bottom line" (Lim, 2009). This is evident in studies (Ferro et al., 2019; Laurell et al., 2019; Lim, 2009; Ugwu and Haupt, 2007; Yunus, 2012) that have extended the triple bottom line principles to cover other criteria.

In the road and highway sector, sustainable road and highway infrastructure development concerns the planning, design, construction, operation and maintenance of roadways in a way that satisfies lifecycle functional requirements for social and economic development while minimising the negative impacts on the environment (Culp, 2011; FHWA [Federal Highway Administration], 2012) and promoting long-term resilience and future adaptability. It is therefore necessary to assess the sustainability characteristics of highway or roadway projects throughout their lifecycle, from planning through construction, operations and maintenance.

Assessment of Road and Highway Infrastructure Development Sustainability

A project's sustainability can be assessed by comparing it to current best practices (Orieno et al., 2024). This approach ensures that the project aligns with the latest and most effective standards in sustainable development, providing a comprehensive measure of its performance against recognised benchmarks. When sustainability is used as a metric, it means an extension of the traditional business reporting framework to account for the three main principles of the triple bottom line. The three main principles do not provide a measurement system for themselves (Culp, 2011; FHWA, 2012). Several organisations, including those in the construction sector, are therefore establishing industry-specific sustainability evaluation systems to address the requirements for sustainable development (Bhyan, Shrivastava and Kumar, 2023).

Evaluation systems or tools for structures, either built or in the process of development, have proliferated in recent years to evaluate the sustainability of infrastructure development (Bhyan, Shrivastava and Kumar, 2023; Bueno, Vassallo and Cheung, 2015). Typically, these entities are established by governmental agencies and non-governmental organisations, and occasionally, they are established in partnership with academic institutions. Various systems employ distinct methodologies to assess sustainability, with each system placing emphasis on different elements related to sustainability (Bhyan, Shrivastava and Kumar, 2023; Lim, 2009). Table 1 summarises existing scholarly works on sustainability criteria for road and highway infrastructure development.

Table 1. Existing scholarly works on sustainability criteria for highway development

No.	Sources	Criteria
1	Proposed criteria for this study	Economics; Environmental; Technical; Project implementation and management; Social equity and culture; Resources utilisation and management
2	Amiril et al. (2014)	Environment; Economic; Social; Engineering and Resource utilisation; Project administration;
3	Ugwu and Haupt (2007)	Economy; Environment; Society; Resource Utilisation; Health and safety; Project management and administration
4	Huang and Yeh (2008)	Ecology; Landscaping; Material; Waste reduction; Water conservation; Energy conservation
5	Montgomery, Schirmer and Hirsch (2014)	Quality of life category; Project leadership; Natural world; Natural resource management; Resilience and greenhouse gas emissions

(*Continued on next page*)

Table 1. *Continued*

No.	Sources	Criteria
6	Lim (2009)	Environmental; Economic; Social; Engineering; Community engagement; Relationship management; Project management; Institutional sustainability; Health and safety; Resource utilisation and management
7	Ametepey, Aigbavboa and Thwala (2022)	Social sustainability; Cultural sustainability; Economic sustainability; Environmental sustainability; Institutional sustainability; Health and safety; Project management; Resource utilisation and management; Engineering performance; Climate change response; Public participation; Stakeholder management
8	Transport for New South Wales (2012)	Environmental category (Greenhouse gas emissions, Water, Pollution control, Noise management, Resource management, Waste management, Material consumption and Biodiversity); Social category (Stakeholders' relationship, Communities and public acceptance and Heritage conservation); Economic category (Corporate sustainability)
9	Suprayoga et al. (2020)	Socio-ecological system integrity; Livelihood security and opportunity; Intra-generational equity; Intergenerational equity; Resource maintenance and efficiency; Socio-ecological civility and democratic governance; Precaution and adaption; Complete staging; Comprehension of pillars; Dimension (time/space)
10	Civil Engineering and Environmental Quality Assessment and Award Scheme (CEEQUAL, 2018)	Project management; Land use; Landscape; Ecology and biodiversity; Historic environment; Energy and carbon; Material use; Waste management; Transport; Effects on neighbours; Relations with the local community and other stakeholders
11	INVEST (FHWA, 2012)	Operations and maintenance; Project development; Systems planning
12	FIDIC's (International Federation of Consulting Engineers) *Project Sustainability Management Guidelines* (2004)	Equity; Health; Human rights; Education; Housing; Security; Population; Culture; Integrity; Atmosphere; Land; Oceans seas and coast; Fresh water; Biodiversity; Economic structure; Consumption and product patterns; Institutional framework

(*Continued on next page*)

Table 1. *Continued*

No.	Sources	Criteria
13	I-LAST (Illinois Department of Transportation, 2009)	Materials; Lighting; Transportation; Water quality; Environmental; Design; Planning
14	BE^{2}ST-in-Highways (Recycled Materials Resource Center, 2012)	Social; Carbon saving; Life cycle cost; Traffic noise; Hazardous waste; Water consumption; Waste reduction (including in-situ materials); Waste reduction (including ex-situ materials); Energy use; Greenhouse gas emissions
15	Greenroads (Muench, Anderson and Söderlund, 2010)	Pavement technologies; Materials and resources; Energy and atmosphere; Construction activities; Access and equity; Environment and water
16	Envision® (Institute for Sustainable Infrastructure, 2024)	Climate; Natural world; Resource allocation; Leadership; Quality of life
17	GreenPave (Lane et al., 2014)	Pavement technologies; Energy and atmosphere; Materials and resources; Innovation and design
18	Green Guide for Roads (Clark et al., 2009)	Mobility for all; Transportation planning; Environmental impact; Energy and atmosphere; Materials and resources; Community impact; Innovation and design
19	GreenLITES (New York State Department of Transportation, 2011)	Innovation and unlisted; Materials and resources; Energy and atmosphere; Water quality; Sustainable sites

The implementation of various assessment methodologies has the potential to increase the sustainability of highway infrastructure development (Lim, 2009; Sandanayake et al., 2023). However, the majority of assessment methodologies are based on Western and developed countries. This might make the assessment methodologies inapplicable to developing countries, including Ghana. In this context, the assertion that advanced country assessment methodologies for sustainability on roads and highways can be learned and implemented by anyone (Sala, Farioli and Zamagni, 2013) is a matter of concern and gives rise to a gap in knowledge.

Some studies prioritise addressing technological challenges (Miyatake, 1996), whereas others prioritise economic and environmental concerns (Santos, Flintsch and Ferreira, 2017). Further studies focus on the effects of implementing sustainable road infrastructure projects in developing countries (Aljboor, Imam and Alawneh, 2023; Ametepey, 2019). However, many such examples lack complete decision-making frameworks encompassing all dimensions of sustainability, including economic, environmental, social equity and culture; technical, project implementation and management; and resource utilisation and management aspects.

The study detailed in this article reviewed the literature from the last 10 years in top construction and related journals, focusing on sustainability in road and highway projects. The review aimed to filter a variety of sustainability outcomes pertinent to road and highway projects. The identification of critical sustainability indicators within the context of road and highway infrastructure development enables the assessment of their capacity to promote sustainability. The goal of each of the developed sustainability indicators is to encourage the construction industry to include sustainable practices in its business plan and daily operations. These sustainability indicators have the advantage of assisting a project's major stakeholders, including planners, decision-makers, designers and project managers, among others, in improving the infrastructure projects delivered towards sustainable development and minimising environmental and social externalities over the course of the project.

RESEARCH METHODOLOGY

Research Design, Survey Instrumentation and Sampling

With the objective of developing a framework for sustainable highways in Ghana, there is a need to identify indicators that are considered critical by highway industry professionals. First, a number of highway sustainability indicators were gathered through a review of the literature and other guidelines (as shown in Table 1). A list of prospective indicators identified was sent to six highway construction professionals and three experts in academia to evaluate their appropriateness and suggest additional indicators suitable for the Ghanaian context. The results of the first stage guided the development of a structured questionnaire, which had two main sections via Google Forms. Section A focused on soliciting the demographic information of the respondents. These included, but were not limited to, their level of education achieved, professional body membership, affiliated organisation and years of experience. Section B of the questionnaire presents several sustainability indicators for highway planning, design, construction, maintenance and operations. For this study, six sustainability criteria were considered. These include economics, the environment, social equity and culture, technology, project implementation and management and resource utilisation and management. Overall, 80 sustainability indicators were considered in this study, with each criterion having several sustainability indicators under it. The respondents were required to express their opinions about the importance of 80 sustainability indicators in enhancing sustainable highway infrastructure development in Ghana via a nominal scale (i.e., "Least Important", "Moderately Important", "Important", "Very Important" and "Extremely Important").

Prior to the main questionnaire survey, a pilot survey was conducted to assess the questionnaire's clarity, comprehensiveness and response time (Ismail et al., 2023) so that any ambiguity or omissions could be found. Cronbach's alpha (α) was utilised to evaluate the sample adequacy, internal reliability and consistency measures of the questionnaire. Cronbach's alpha values exceeding 0.80 for each indicator indicated the reliability of the questionnaire. The alpha reliability coefficient is generally between 0 and 1. A score greater than 0.7 is considered satisfactory; however, values greater than 0.8 are frequently chosen (Bland and Altman, 1997; Laerd Statistics, 2023; Yu, 2001).

Convenience and purposive sampling methods were employed to target key stakeholder organisations, followed by census sampling using the Cochran formula to determine the sample size. The research was primarily conducted in

Accra, Ghana's capital, where the headquarters of these organisations are predominantly located. The total number of relevant highway professionals in the population was identified as 400, according to sources including Ghana Institution of Engineering (2023), Ghana Institution of Surveyors (2021) and Institution of Engineering and Technology (2023). To achieve statistical significance, the sample size was calculated with a 90% confidence level and a 5% margin of error, resulting in a necessary sample of 162 participants. A link to the questionnaire survey with a participation information sheet and advertisement was distributed to 400 participants via email. The target population consisted of stakeholders in the Ghanaian highway industry, including professionals from private highway consultancy firms, government highway consultancy firms, highway construction companies, research and academic institutions, and the environmental protection agency. Respondents with at least two years of experience in Ghana's road and highway industry met the inclusion criteria. The study included 162 completed and submitted questionnaires, accounting for approximately 40.5% of the total responses. Assaad, El-Adaway and Abotaleb (2020) asserted that this response rate (40.5%) is above an acceptable range of 20% to 30%, as per the prevailing industry standard in the construction sector. The low response rate, therefore, does not necessarily invalidate the results. However, the low response rate presents a potential source of sampling bias and may impact the representativeness of our findings. Against this backdrop, efforts were made to reduce sampling and response biases. Sampling biases were controlled by, for example, contacting the gatekeepers of most of the companies to confirm that prospective respondents were comfortable with the survey approach (online) and distribution method. We also monitored and conducted follow-ups on the categories of respondents who did not respond. Furthermore, response biases were controlled by employing methods which included ensuring that all respondent groups understood the purpose of the survey to prevent them from second-guessing the purpose and highlighting the fact that their responses would be treated anonymously and would have no repercussions on them. The submitted responses were extracted in CSV format, examined and cleaned for further analysis.

Data Analysis

After the data were cleaned, the information obtained from the questionnaires was analysed via descriptive and inferential statistics via Statistical Package for Social Sciences (SPSS) version 26. Descriptive statistics were calculated to gain deep insight into the profiles of the respondents. Furthermore, inferential statistics were performed to shed more light on the sustainability criteria and their indicators, helping to identify the critical indicators and how perceptions of the indicators vary among various respondent groups.

To determine the critical indicators, the response options (nominal variables) indicating the level of importance of each indicator in contributing to sustainable highway infrastructure development as perceived by each respondent were coded with numerical values: 1 = "Least Significant", 2 = "Moderately Significant", 3 = "Significant", 4 = "Very Significant" and 5 = "Extremely Significant". The average importance scores of each indicator were then determined to enable the ranking of the indicators.

The average scores were used to identify the critical indicators. For the purpose of this study, a cut-off score of 4 was chosen as the value at or above which an indicator is considered significant or very significant. Kendall's coefficient of concordance was used to measure the extent of agreement among the highway professionals on the rating of the indicators. Furthermore, a one-sample *t*-test (one-tailed) was performed to determine the critical indicators. To perform a one-sample *t*-test (one-tailed), the following hypotheses were formulated:

1. Null hypothesis H0: The mean value of the population is less than or equal to that of the specified value.
2. Alternative hypothesis H1: The mean value of the population is larger than the specified values.

If the *p*-value is greater than 0.05, the null hypothesis H0 is rejected. We proceed to accept alternative hypothesis H1 and conclude that the indicator's population mean score is greater than the specified value (i.e., 4 in this case). The critical indicators were those whose mean scores were significantly greater than 4.

Although an indicator's population mean may be significantly higher than the cut-off value (4), the opinions of various respondent groups may differ significantly. As a result, it was critical to establish a consensus among all respondent groups on the scores of critical indicators for the framework's development. We can use the Kruskal-Wallis H test, also known as the "one-way analysis of variance (ANOVA) on ranks", as a rank-based nonparametric test to identify statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable (Laerd Statistics, 2015a). For the purpose of this research, the Kruskal-Wallis H test was employed to evaluate the heterogeneity among the respondents' group scores. A statistically significant difference in the importance scores of the sustainable indicators for highway infrastructure development exists between the different respondent groups if the *p*-value is ≤ 0.05. We employed the Mann-Whitney U test to identify the groups whose scores significantly differed from each other. Agresti (2013), Hart (2001) and Laerd Statistics (2015b) suggest that we can use such a test to investigate variations in the relative importance of indicators among groups.

RESULTS AND DISCUSSION

Profile of the Respondents

A total of 162 valid responses were imported into the Statistical Package for the Social Sciences (SPSS) version 26 for the purpose of conducting the analysis. Table 2 shows the demographic characteristics of the respondents.

Table 2. Demographic characteristics of respondents

No.	Demographic Profile		Frequency	%
1	Categories of organisation	Contractor	86	53
		Consultants	18	11
		Environmental agencies	6	4
		Road agencies	39	24
		Researchers/Academia	13	8
		Total	162	100
2	Number of years working or practising in Ghana	2 years to 4 years	11	7
		5 years to 7 years	21	13
		8 years to 10 years	28	17
		More than 10 years	102	63
		Total	162	100
3	Professional memberships	Ghana Institution of Engineering	104	64
		Chartered Institute of Building - Ghana Chapter	10	6
		Institution of Engineering and Technology	27	17
		Ghana Institution of Surveyors	6	4
		American Society of Civil Engineers and others	2	1
		None	13	8
		Total	162	100
4	Level of education	Bachelor's degree	54	33
		Diploma	3	2
		Master's and higher degree	105	65
		Total	162	100

Table 2 shows the respondents' various categories of organisation. The majority (53%) of the respondents were contractors, followed by those from road agencies (24%), consultants (11%), researchers/academia (8%) and those from environmental agencies (4%). The distribution of the respondents by the number of years of professional experience in Ghana's highway infrastructure development also indicates that all the respondents have more than two years of professional experience working in the Ghanaian highway infrastructure development industry. The majority (64%) of the respondents are members of the Ghana Institution of Engineering. Furthermore, 17%, 6% and 4% of the respondents are members of the Institution of Engineering and Technology, the Chartered Institute of Building - Ghana Chapter and the Ghana Institution of Surveyors, respectively. The rest are either not members of any professional bodies, part of another membership, or members of the American Society of Civil Engineers. These findings indicate that the data cover opinions from different professionals who come together to contribute to highway infrastructure development from diverse perspectives in Ghana. In terms of education, most of the respondents have either attained a bachelor's or master's degree or above. Specifically, more than half (65%) of the respondents had a master's degree or higher degree. Only 2% have a diploma and the rest have a bachelor's degree. The educational profile depicts respondents who are well educated, can read relatively well and have a greater understanding of the questionnaire with no interpretation.

Indicator Scores by Highway Construction Professionals

The attitudes of highway professionals about the sustainability indicators of highway projects play a key role with respect to whether they will incorporate sustainability into the planning, design, construction and operational stages of the project. Highway professionals rated various sustainability indicators for highway infrastructure development in terms of their perceived importance for achieving sustainable highway infrastructure. The higher the score is, the more the professionals recognise the indicator as a significant indicator. Among the 80 indicators, 51 were rated as significant or very significant (i.e., an average score of 4.0 or higher). To avoid much publication space, only the results of the 51 significant indicators are presented in Table 3.

Table 3. Indicator scores by highway construction professionals

No.	**Sustainability Indicator**	**Average Score**	**Rankings**	**Standard Deviation**	***p*-Value**
Economic Value Criteria					
1	Reduce material costs	4.32	(1) 1	0.81	6.09e-07
2	Reduce construction time	4.20	(2) 4	0.88	0.002174
3	Reduce life cycle costs	4.15	(3) 9	0.93	0.020812
4	Reduce maintenance and operation costs	4.13	(4) 11	0.86	0.028060
5	Provide extra duration for planning, design and material procurement	4.03	(5) 19	0.88	0.332469
6	Reduce the cost of production	4.02	(6) 20	0.87	0.385104
Environmental Impact					
1	Use of environmentally friendly materials	4.17	(1) 7	0.82	0.003877
2	Minimise flood and surface run-off	4.16	(2) 8	0.62	0.000627
3	Environmental monitoring measures after project completion	4.15	(3) 9	0.84	0.010174
4	Dust control	4.13	(4) 11	0.87	0.030061

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Table 3. *Continued*

No.	Sustainability Indicator	Average Score	Rankings	Standard Deviation	*p*-Value
5	Preserve/Improve ecological functions of drainage corridor	4.13	(4) 11	0.83	0.023944
6	Design to reduce traffic noise	4.06	(5) 16	0.88	0.187317
7	Reduce contamination of soil	4.05	(6) 17	0.86	0.233457
8	Pollution control during the construction process	4.03	(7) 19	0.78	0.306597
9	Minimise disturbances to the original ground and scenery: Design/ Construction (effective land use)	4.01	(8) 21	0.83	0.462365
10	Operational energy (e.g., solar-powered traffic lights, solar-powered signals, etc.)	4.01	(8) 21	0.83	0.462365
11	Groundwater management	4.00	(9) 22	0.84	0.500000
12	Restoration of possible vegetation	4.00	(9) 22	0.91	0.500000
13	Use of energy conservation facilities	4.00	(9) 22	0.88	0.500000
Social Equity and Culture					
1	Improve workers' health and safety	4.20	(1) 4	0.72	0.000224
2	Reduction of traffic congestion: Design, construction, operational phase	4.19	(2) 5	0.86	0.003570
3	Safety risk assessment and mitigation during construction	4.14	(3) 10	0.90	0.024710
4	Public participation in the early project phase	4.12	(4) 12	0.82	0.032169
5	Improve working conditions	4.08	(5) 14	0.69	0.069483
6	Increase economic/employment opportunities for local contractors, expertise and local communities	4.07	(6) 15	0.78	0.115633
7	Increase knowledge and exposure to sustainable technology	4.07	(6) 15	0.81	0.144497
8	Reduction of community disturbance	4.04	(7) 18	0.80	0.277041
9	Improve aesthetic impact and appearance	4.02	(8) 20	0.79	0.383169

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Table 3. *Continued*

No.	Sustainability Indicator	Average Score	Rankings	Standard Deviation	*p*-Value
Technical Quality					
1	Disaster (flood) resilient designs	4.23	(1) 3	0.74	3.83E-05
2	Design and construct climate change-resilient roadway infrastructure	4.18	(2) 6	0.78	0.001899
3	Application of durable materials	4.17	(3) 7	0.72	0.001752
4	Durable, cost-effective highway construction	4.16	(4) 8	0.68	0.001486
5	Allow adaptability and flexibility for future changes	4.16	(4) 8	0.78	0.004809
6	Ensuring availability of competent supervisors, labourers, etc.	4.12	(5) 12	0.87	0.040377
7	Incorporate technology in design and construction	4.12	(5) 12	0.73	0.021828
8	Incorporate future needs into the design	4.09	(6) 13	0.74	0.056047
9	Provide ease for construction and design integration for overall requirement	4.07	(7) 15	0.76	0.108435
10	Improve quality control and reduce failures in achieving specifications	4.03	(8) 19	0.93	0.336423
Project Implementation and Management					
1	Comply with environmental requirements, contract documents and project specification	4.25	(1) 2	0.81	4.89E-05
2	Project risk assessment	4.20	(2) 4	0.70	0.000138
3	Meeting project duration (completing the project on schedule)	4.17	(3) 7	0.75	0.002629
4	Provide project control and monitoring guidelines	4.16	(4) 8	0.84	0.008111
5	Accomplish sustainable policy and strategy to improve construction efficiency	4.15	(5) 9	0.83	0.009635
6	Approach/Criteria for a contractor (e.g., prequalification)	4.13	(6) 11	0.72	0.011947
7	Contractor selection	4.13	(6) 11	0.73	0.012777

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Table 3. *Continued*

No.	Sustainability Indicator	Average Score	Rankings	Standard Deviation	*p*-Value
8	Provide a standard size for each element for mass production and reproduction	4.04	(7) 18	0.75	0.232388
9	Governance (Reduce economic and social problems)	4.04	(7) 18	0.79	0.243899
Resource Utilisation and Management					
1	Material quality control	4.16	(1) 8	0.72	0.002616
2	Use of local materials	4.14	(2) 10	0.76	0.010133
3	Use of recycled construction materials	4.14	(2) 10	0.88	0.022265
4	Supply chain management	4.12	(3) 12	0.79	0.027473

Notes: (xx) = Ranking indicators under a criterion; yy = Ranking of all indicators; Average score of the sustainability indicators where 5 = "Extremely Significant", 4 = "Very Significant", 3 = "Significant", 2 = "Moderately Significant" and 1 = "Least Significant". The higher the average score, the more the professionals recognise the indicator as an important indicator.

Economic criteria

Concerning economic criteria, "Material cost reduction" emerged with the highest average score from highway professionals (average score: 4.32). This is an indication that they are aware of the influence that a highway's construction materials have on its long-term sustainability and performance. Generally, highway professionals want to meet the required specifications at the lowest possible cost. This aligns with the findings of Blismas and Wakefield (2009) concerning cost comparisons. It is, therefore, not surprising that highway professionals ranked material costs as the most significant economic indicator for sustainable highway infrastructure. The "Construction time" was the second most significant indicator, with an average score of 4.2. Most project managers, therefore, put in measures to avoid delay because it increases the cost of materials, logistics and overall project costs. This finding corroborates the conclusions of Mahamid, Bruland and Dmaidi (2012). According to highway professionals, the "Life cycle cost", with an average score of 4.15, was also considered critical for sustainable highway infrastructure development. Life cycle cost analysis considers not only financial but also social and environmental costs across the entire life cycle of a project, including design, construction and operation costs (Juni, Adams and Sokolowski, 2008). This finding means that professionals may accept a higher cost of design and construction if lower operating and maintenance costs are attained in the future. Maintenance and operation costs constitute a substantial part of the highway's life cycle cost (Fallah-Fini et al., 2015). "Maintenance and operation costs", with an average score of 4.13, mean that highway professionals emphasise the importance of adopting a holistic, life cycle approach to the development of highway infrastructure. They acknowledge the need for quality construction and the use of durable materials and designs to minimise maintenance and operational costs. "Provide extra duration for planning, design and material procurement" emerged as a significant indicator of sustainable highway infrastructure (average value = 4.03). When highway professionals emphasise this indicator, they are able to undergo thorough preparation and planning, which consequently minimises the likelihood of unexpected issues arising during project implementation. "Cost of production" also emerged as a significant indicator of sustainable highway infrastructure, with an average score of 4.02. This finding means that highway professionals place a strong emphasis on efficient and economical construction processes.

Environmental criteria

In terms of the environmental criteria, highway professionals rated "Use of environmentally friendly materials" as the highest, with an average score of 4.17. This result demonstrates that highway professionals place strong emphasis on the selection and utilisation of materials that reduce environmental degradation while ensuring that highways are resilient and sustainable in the long term. In support of these findings, Jiang, Huang and Sha (2018) reported that the use of eco-friendly materials enhances and diversifies the environmentally friendly features of road pavement. Highway professionals were found to consider "Minimise flood and surface run-off" as a critical indicator (average score = 4.16) for sustainable infrastructure development. This means that they prioritise designs, measures and construction practices that aim to mitigate flooding and stormwater run-off, thereby promoting the environmental and social sustainability of highway projects. The results show that highway professionals recognise the ongoing responsibility to assess and manage the environmental impacts of the highway even after it has been built and is in use. They rated "Environmental monitoring measures after project completion" as a significant sustainability indicator, with an average score of 4.15. Furthermore, highway professionals showed a strong commitment to protecting and restoring habitats for wildlife by rating the "Restoration of possible vegetation" as a significant indicator (average score = 4.13). "Dust control" also emerged as a significant indicator for the provision of sustainable highway infrastructure (average score = 4.13), suggesting that highway professionals are committed to reducing the harmful effects of dust on the environment (Xing et al., 2018) and human health during highway construction and operation.

Social equity and culture criteria

The highway professionals rated "Improving workers' health and safety" as the most significant indicator of sustainable highway infrastructure under social equity and culture criteria, with an average score of 4.20. This indicates that they place high priority on putting down measures to ensure a safe and healthy work environment, adhering to legal obligations and taking proactive steps to safeguard and support the workforce's well-being. Highway professionals consider "Traffic congestion during the design, construction and operational stages" to be a significant indicator (average score = 4.19). The results imply that highway professionals are aware of economic implications, such as increased fuel consumption and decreased productivity and therefore place strong emphasis on design alternatives and construction and operational strategies that seek to minimise congestion. The safety of construction workers and the public, including drivers and pedestrians, may be impacted by highway construction. Sustainable highway infrastructure development, therefore, recognises the importance of safeguarding employee health and safety (Nawaz, Linke and Koç, 2019). In line with this, highway professionals have indicated that "Safety risk assessment and mitigation during construction" are significant indicators of sustainable infrastructure development, with an average score of 4.14. The next significant indicator for sustainable infrastructure development is "Public participation in the early project phase" (average score = 4.12). Road and highway experts highly prioritised public participation in project planning and decision-making from the beginning (Ogryzek, Krupowicz and Sajnóg, 2021; Suprayoga, Witte and Spit, 2020). They do this to consider the requirements and interests of all stakeholders and foster a sense of community ownership and responsibility. The highway professionals selected "Working conditions" and "Economic/employment opportunities for local contractors, expertise and local communities" as significant indicators for sustainable highway infrastructure, with average scores of 4.08 and 4.07, respectively.

Technical quality criteria

Among the technical quality criteria, the indicator highly scored by highway professionals is "Disaster (flood) resilient design" (average score = 4.23). This means that highway professionals are committed to measures in the form of planning, engineering and community engagement to ensure that the highway can withstand and recover from flood-related challenges. "Design and construct climate change-resilient roadway infrastructure" was considered a significant sustainability indicator (average score = 4.18). By doing so, highway professionals have demonstrated that they acknowledge the effects of climate change, such as extreme weather occurrences, increasing temperatures and rising sea levels, on highway infrastructure, which aligns with previous findings (de Abreu, Santos and Monteiro, 2022; Regmi and Hanaoka, 2011). Sustainable highway infrastructure development focuses on the design and construction of highways that reduce the frequency of maintenance and have a longer service life. The use of durable materials is essential to achieve this goal. The highway professionals acknowledge this and, therefore, rate the "Application of durable materials" as a critical indicator for sustainable highway infrastructure, with an average score of 4.17. "Construction of highways that are durable and cost-effective over their design life" was considered a critical indicator for sustainable highway infrastructure development (average score = 4.16). This result suggests that highway professionals prioritise the design and construction of highways that provide long-term operational and safety performance, reduce life cycle costs and have a minimal impact on the environment. Highway professionals rated "Allow adaptability and flexibility for future changes" as a significant indicator (average score = 4.16). They place a strong emphasis on the design and construction of highways so that expansion, new technologies, shifting traffic characteristics and environmental concerns are accommodated, ultimately promoting the long-term sustainability of the infrastructure. The analysis revealed that "Ensuring availability of competent supervisors, labourers, etc.", "Incorporating technology in design and construction" and "Incorporating future needs in design" are significant indicators of sustainable infrastructure, with average scores of 4.12, 4.12 and 4.09, respectively.

Project implementation and management criteria

Under the project implementation and management criteria, the indicator that had the highest score was "Comply with environmental requirements, contract documents and project specification" (average score = 4.25). This reflects the commitment of highway professionals to responsible, open and accountable execution of projects that have direct benefits for contractors working on infrastructure and transportation projects (Elsayegh et al., 2020). With an average score of 4.2, "Project risk assessment" is considered very important in the development of sustainable highway infrastructure. This means that highway professionals prioritise a thorough assessment of the project's potential risks and uncertainties and develop plans and strategies to mitigate and manage the identified risks, which are in line with the findings of El-Sayegh and Mansour (2015). Meeting the project duration has been the aim of most highway project managers and contractors, as this helps control the project budget by avoiding the need for extended labour, equipment rentals and other costs that may accrue if projects run behind schedule. As expected, "Meeting project duration (completing the project on schedule)" had an average score of (average score = 4.17) and was therefore considered a significant indicator of sustainable highway infrastructure development. The highway professionals also rated the provision of project control and monitoring guidelines as a significant indicator of sustainable highway development (average score = 4.16). This indicates that there is a need for norms and guidelines that ensure that projects meet the required standards and specifications. Highway professionals consider sustainable policy and strategy to be significant indicators of achieving sustainable highway infrastructure (average score = 4.15). This implies that the development of policies and strategies that guide decision-making and actions throughout the life cycle of highway projects is of great interest to highway professionals (Ruiz and Guevara, 2020). The "Approach or criteria for a contractor (e.g., prequalification)" had an average score of 4.13. The results showed that highway professionals are very interested in the establishment of rigorous and sustainable methods for selecting contractors.

Resource utilisation and management criteria

Under the resource utilisation and management criteria, the indicator that emerged with the highest score by highway professionals was "Material quality control/ assurance" (average score = 4.16). This means that the need to select, utilise and maintain high material quality throughout the project through robust testing to ensure that the required standards and specifications for the materials are met is highly important to highway professionals (Khan, Azhar and Mahmood, 2008). The results of the analysis also suggest that highway professionals place a strong emphasis on the need to source materials from the immediate region, which essentially supports local businesses and economies, creates jobs and leads to economic growth. They, therefore, scored the "Use of local materials" an average of 4.14. The highway professionals showed a positive attitude toward the "Use of recycled construction materials", with an average score of 4.14. This reflects their commitment to the conservation of resources, waste reduction, economic efficiency and protection of the environment by favouring the use of reclaimed materials from previous construction or demolished projects rather than relying solely on newly extracted or manufactured materials (Segui et al., 2023). "Integration of supply chains: A smooth flow of highway materials and other resources" was considered critical sustainable highway infrastructure development, with an average score of 4.12. Highway professionals, therefore, place a strong emphasis on the well-integrated and efficient movement of materials, equipment and resources, which ultimately reduces the cost of transporting materials delays and optimises project timelines (Prakash and Mohanty, 2015).

Critical indicators of sustainable highway infrastructure development

In this study, critical indicators were those that were rated with an average score significantly greater than 4.0 (*p*-value less than or equal to 0.05). Among the 51 indicators identified in Table 3 as either significant or very significant, 31 were found to be critical (as highlighted in Table 3). Out of the 31 indicators, four were indicators under the economic criteria, five indicators under the environmental impact criteria and four indicators under the social equity and culture criteria. The technical quality criteria and project implementation and management criteria had seven indicators each and resource utilisation and management had four indicators each. Standard deviations depict the extent to which the errors differ from the average value, with the majority falling below 1, indicating acceptable data accuracy in this study. The rankings provide an indication of highway professionals' priorities in the context of sustainable road and highway construction.

On the basis of the analysis, the most important critical indicator (rank first) is "Reducing material costs", with an average score of 4.32. This is not a surprise when the cost of materials greatly affects the overall life cycle cost. Contractors incur the cost of transport in addition to how much material is bought. This finding is consistent with the assertions of previous studies, including Goh and Yang (2010). According to Donyavi and Flanagan (2009), materials can represent approximately 70% of the project cost, so reducing waste and obtaining materials at a reasonable cost are important (Donyavi and Flanagan, 2009). The cost reduction of materials can be focused on by considering the optimisation of material usage (Luo et al., 2021), even at the design phase. The second most important indicator (rank second) is "Complying with environmental requirements, contract documents and project specifications". This implies that highway professionals demonstrate a keen interest in project implementation and management. They ranked "Disaster (flood) resilient designs" third, with an average score of 4.23. Consistent with Uchehara et al. (2022), highway professionals have therefore demonstrated that they place strong emphasis on the construction of highways that are resilient to disasters, such as earthquakes and floods. The incorporation of this indicator enables highway professionals to assess the ability of road infrastructure to withstand shocks and unpredicted events (Suprayoga et al., 2020; Joumard and Nicolas, 2010). With an average score of 4.2, highway construction professionals rank "Construction time", "Workers' health and safety" and "Project risk assessment", all of which secured the fourth position. This is an indication that highway professionals understand the importance of construction time for cost management and on-time project completion. This could be a result of their awareness of the implications of project delays on cost since most road projects in Ghana experience significant delays (Amoatey and Ankrah, 2017). At the same time, they emphasise the importance of protecting the workers involved in the project, as well as the need to identify, assess and mitigate risks throughout the project's lifecycle. This finding corroborates the results of Vijayakumar et al. (2023). This finding contradicts the assertion of Williams, Fugar and Adinyira (2020), who reported that Ghanaian contractors do not see safety as a key business risk despite having health and safety policies and codes of conduct in place. The disparity, however, maybe because the population of Williams, Fugar and Adinyira (2020) had building contractors as the majority and few road contractors, which is completely different from the findings of this study. "Traffic congestion reduction (at the design, construction and operational stages)" and "Climate change-resilient roadway infrastructure design and construction" were ranked fifth and sixth, respectively, in the highway industry. Professionals in the highway industry recognise the importance of designing highway facilities to facilitate seamless operations (Suprayoga et al., 2020). They also highlight the need to take a critical look at the impact of road construction on travellers and reduce construction-related traffic congestion. "Use of environmentally friendly materials" is tied for seventh rank with "Application of durable materials and meeting project duration (completing the project on schedule)", with an average score of 4.17. The positive attitudes of highway professionals toward eco-friendly materials for highway construction is an indication of their acceptance of green construction, which has been the direction of construction globally (Uchehara et al., 2022). Similarly, "Minimising floods and surface run-off", as identified by Suprayoga et al. (2020), is tied eighth with four other indicators, namely, "Durable and cost-effective highway construction", "Adaptability and flexibility for future changes", "Providing project control and monitoring guidelines" and "Material quality control", with each having an average score of 4.16. The positive attitudes of highway professionals toward adaptability and flexibility for future changes could mean that they acknowledge that most of the built civil infrastructure is not capable of adaptively and reliably meeting the needs of users in the face of rapid changes in demand, conditions of service and environmental conditions. Their relative positioning is, therefore, consistent with that of Sánchez-Silva and Calderón-Guevara (2022), as well as Chester and Allenby (2019), who reported that successful projects in the 21st century are those that better adapt to new circumstances as and when they occur. Two other indicators, including "Life cycle cost", were ranked ninth. "Safety risk assessment" and "Mitigation during construction" are considered equally important alongside the "Use of local materials" and "Recycled construction materials", with a ranking of 10th. The importance of the use of local material and recycled construction materials is in line with the suggestions of previous studies, including Ibrahim and Shaker (2019), Yang, Liu and Tran (2018), Uchehara et al. (2022) and Luo et al. (2021), that the use of local material and reuse of materials maximise the benefits of highway projects. "Dust control" and "Preservation or improvement of the ecological functions of drainage corridors" are tied to the 11th position, with an average score of 4.13. The last rank (12th) was a tie between "Public participation in the early project phase" and "Supply chain management", both of which averaged 4.12.

The indicators' similar significance to that of highway experts is demonstrated by the tie-in rankings for several of the indicators. Highway professionals consider those indicators of the same rank to be equally important in the context of sustainable highway infrastructure development. We should address these indicators holistically during highway infrastructure design, construction and operation to ensure that facilities are sustainable and resilient.

Consensus on indicators among highway professionals

Depending on the role played by their organisations and their prior experience managing highway construction projects, their attitudes towards sustainable highway indicators are likely to differ. Kendall's coefficient of concordance was calculated to measure the agreement of highway professionals with the ranked indicators. The results of the analysis have a coefficient value of 0.004 and *p*-value = 0.933, greater than the chosen significance level of 0.05. The small coefficient suggests that the level of agreement among highway professionals could reasonably be due to chance. The *p*-value also indicates that there is not enough evidence to conclude that the observed concordance is statistically significant. Kendall's coefficient of concordance implies that highway professionals, to a large extent, have varied attitudes and even conflicts when determining the most important factors. For an indicator to be included in any framework or guideline, there should be a consensus among the major stakeholders. Notably, Kendall's coefficient of concordance can determine only the level of agreement; it cannot be used to determine whether highway professionals' judgments of the level of indicator importance differ significantly from one professional group to another. We employed the Kruskal-Wallis one-way ANOVA to overcome this limitation. If an indicator has a *p*-value greater than 0.05, it means that the different professional groups rated it differently. On the other hand, a significant difference exists among the ratings of highway professionals if the *p*-value is 0.05 or less.

As shown in Table 4, the Kruskal-Wallis test revealed that there was no significant difference among the highway professional groups concerning how they perceived 29 out of the 31 critical indicators of sustainable highway infrastructure development. There was a consensus on all five highway professional groups' perceptions of the 29 critical indicators. The two indicators that were perceived and rated differently among the highway professionals were the construction of durable and cost-effective highways and project control and monitoring guidelines, with *p*-values of 0.000 and 0.015, respectively. The mean rank in the Kruskal–Wallis test provides information about the relative positioning of each group with the data set. Higher mean ranks indicate that, on average, the observations in that group tend to have higher values than observations in other groups do. Conversely, lower mean ranks indicate lower average values within the group than others do.

Table 4. Kruskal-Wallis H test results

No.	Sustainability Indicator	Mean Rank					Kruskal-Wallis Statistics	*p*-Value
		G1	G2	G3	G4	G5		
1	Material costs	94.19	64.55	87.06	77.67	91.50	8.830	0.066
2	Comply with environmental requirements, project spec	86.00	77.34	81.67	74.19	112.36	4.753	0.314
3	Disaster (flood) resilient designs	107.27	81.32	74.45	96.00	83.93	9.369	0.053
4	Workers' health and safety	87.88	78.18	80.54	87.75	83.36	0.961	0.916

(*Continued on next page*)

Table 4. *Continued*

No.	Sustainability Indicator	Mean Rank					Kruskal-Wallis Statistics	*p*-Value
		G1	G2	G3	G4	G5		
5	Construction time	85.27	72.43	83.83	86.00	83.57	2.203	0.698
6	Project risk assessment	84.36	71.64	83.56	85.47	94.14	3.164	0.531
7	Traffic congestion: Design/Operational phase	78.38	71.11	87.02	78.17	84.43	3.776	0.437
8	Climate change-resilient roadway infrastructure	88.38	75.00	82.20	78.58	102.86	2.941	0.568
9	Environmentally friendly materials	103.31	76.92	78.07	82.22	106.13	6.741	0.150
10	Meeting project duration	72.96	77.92	81.51	89.78	95.36	2.193	0.700
11	Durable materials	90.31	81.74	77.62	86.53	98.64	2.739	0.602
12	Construction of durable and cost-effective highway	122.54	91.18	65.92	99.64	97.50	33.443	0.000
13	Adaptability and flexibility for future changes	98.46	69.26	84.07	84.03	78.36	5.429	0.246
14	Material quality control	94.65	86.39	79.59	67.94	88.79	4.111	0.391
15	Flood and surface run-off	86.00	78.89	75.86	104.00	98.71	9.261	0.055
16	Project control and monitoring guidelines	66.73	68.04	85.83	84.06	122.29	12.407	0.015
17	Life cycle costs	88.23	67.20	85.05	81.50	103.00	6.618	0.158
18	Environmental monitoring measures	75.42	65 .67	86.52	93.22	86.93	7.913	0.095
19	sustainable policy and strategy	69.92	70..09	85.15	84.11	113.36	8.806	0.090
20	Safety risk assessment and mitigation	75.12	77.46	84.66	84.42	69.00	1.688	0.793
21	Use of local materials	95.27	75.21	82.75	76.72	87.00	2.677	0.613
22	Recycled construction materials	84.38	73.01	82.64	94.25	75.43	3.284	0.511
23	Maintenance and operation costs	90.85	68.74	80.55	93.11	115.21	9.257	0.055
24	Dust control	64.35	80.82	85.32	78.17	78.71	2.772	0.597
25	Ecological functions of drainage corridor	79.12	78.96	83.67	72.69	95.64	1.913	0.752
26	Criteria for contractor (e.g., prequalification)	76.73	73.34	83.17	94.33	81.07	3.352	0.501
27	Contractor selection	76.73	80.78	80.26	85.89	98.21	1.499	0.827
28	Availability of competent supervisors, labourers, etc.	106.65	90.55	74.07	83.94	70.14	8.806	0.066

(*Continued on next page*)

Table 4. *Continued*

No.	Sustainability Indicator	Mean Rank					Kruskal-Wallis Statistics	*p*-Value
		G1	G2	G3	G4	G5		
29	Public participation in the early project phase	88.85	69.47	82.45	87.36	106.36	6.130	0.190
30	Integration of supply chains	76.69	65.76	87.61	82.75	97.57	7.862	0.097
31	Technology in design and construction	92.92	76.74	79.23	87.28	99.14	3.225	0.521

Notes: G1 – Researcher/Academia; G2 – Road agencies; G3 – Contractors; G4 – Consultants; G5 – Environmental agencies.

To gain much insight into the differences in attitudes of highway professionals toward the importance of indicators (i.e., construction of durable and cost-effective highways and project control and monitoring guidelines), the Mann-Whitney U test was employed. This test compares the ratings of two groups of highway professionals to determine whether they differ significantly.

Table 5 shows that the attitudes and perceptions of professionals from environmental agencies regarding the importance of project control and monitoring guidelines as sustainable highway indicators are significantly different from those of most other groups, including researchers and academics, road agencies, contractors and consultants ($p < 0.05$). The mean ranks of the environmentalists were found to be higher than those of the other professionals, as shown in Table 4. This finding indicates that environmental agency professionals prioritise the control and monitoring of highway projects more than other professional groups do. Similarly, but quite surprisingly, Table 5 shows that professionals from road agencies and contractors have significantly different attitudes towards the importance of project control and monitoring guidelines (p-value = 0.033). The mean rank of the project control and monitoring guidelines by the contractors was found to be significantly higher than that of the road agencies.

Compared with researchers/academia, road agencies, consultants and environmental agencies, contractors, as shown in Table 5, significantly differ in their attitudes and perceptions about the importance of durable and cost-effective highways as indicators of sustainable highway infrastructure ($p < 0.05$). Table 4 indicates that, surprisingly, the contractors had lower mean ranks than the other groups. This suggests that the other highway professional groups attach more importance to the durability and cost-effectiveness of highway infrastructure than do the contractors. Notably, the perceptions of academics/researchers and road agencies about durable and cost-effective highways also differ significantly from each other (p-value = 0.047). We found that the mean rank of the researchers/academia was higher than that of the road agencies.

Table 5. Mann-Whitney test results on critical indicators

Groups	Project Control and Monitoring Guidelines	Durable and Cost-Effective Highways
G1/G2	0.946	0.047*
G1/G3	0.128	0.000*
G1/G4	0.239	0.121
G1/G5	0.010*	0.138
G2/G3	0.033*	0.001*
G2/G4	0.173	0.589
G2/G5	0.009*	0.837
G3/G4	0.852	0.000*
G3/G5	0.021*	0.007*
G4/G5	0.022*	0.864

Notes: G1 – Researcher/Academia; G2 – Road agencies; G3 – Contractors; G4 – Consultants; G5 – Environmental agencies; * = Significant at 95% confidence level.

Conceptual Framework for Highway Infrastructure Development

The output of the systematic identification of critical sustainability indicators, which has reached a consensus among all professional highway groups, is a conceptual framework for highway infrastructure development. As illustrated in Figure 1, this framework organises the identified critical indicators into six distinct categories, referred to as "Sustainability Criteria". These categories are economic, environmental and technical quality, project implementation and management, social equity and cultural considerations, and resource utilisation and management.

Figure 1. Conceptual framework for indicators for sustainable road and highway infrastructure development

This structured approach to categorising indicators facilitates a comprehensive understanding of the multifaceted nature of sustainability in highway infrastructure projects. The framework forms the foundation and guides the integration of sustainability principles into the planning, design, construction and operation phases of highway development projects in Ghana. The framework not only aims to enhance the environmental sustainability of highway infrastructure but also aims to ensure that road and highway projects contribute positively to economic development, technical excellence, health and safety, effective project management, social inclusiveness and efficient use of resources.

CONCLUSIONS

This study was designed to develop a framework for sustainable highway infrastructure development within the Ghanaian context, focusing on six key dimensions: economic, environmental, social equity and culture, technical, project implementation and management, and resource utilisation and management. Through initial stakeholder interviews and an extensive literature review, 80 sustainability indicators were identified.

The identification of the top three critical indicators—reduction in material costs, compliance with environmental requirements and project specifications and incorporation of disaster-resilient designs—emphasises the importance of economic efficiency, adherence to environmental standards and infrastructure resilience. However, disparities in the valuation of project control and monitoring guidelines, as well as durable and cost-effective highways, particularly between environmental agencies and contractors, indicate the necessity for a decision-making process that embraces diverse perspectives to achieve holistic and sustainable outcomes.

The Kruskal-Wallis test was used to demonstrate a consensus among highway professional groups on 29 critical indicators essential for sustainable highway development. This agreement highlights the collective recognition of the crucial elements necessary for sustainability in highway projects. This study proposes a conceptual framework that outlines a structured method to guide future efforts in highway infrastructure development. It advocates for the integration of various sustainability criteria to ensure a balanced and comprehensive approach. The study recommends increasing public engagement, further research into the use of eco-friendly materials, regular updates to sustainability guidelines and continued emphasis on worker health and safety.

Nevertheless, this study has its limitations. It focuses primarily on the perspectives of contractors, consultants, environmental agencies, road agencies and academic researchers. These groups play a critical role in the development of highway infrastructure, yet the inclusion of additional viewpoints from road users and community members could provide a more rounded understanding of sustainability in highway projects. Another limitation of this study is the low response rate, which may have affected the representativeness of the data. Although efforts have been made to address this, the low response rate could still affect the generalizability of the findings. Future studies should seek to improve response rates or use alternative data collection strategies to ensure more comprehensive data and consequently deepen the dialogue on sustainable highway infrastructure development, enriching the framework with a more comprehensive array of insights and experiences.

ETHICS APPROVAL

We hereby confirm that the manuscript includes a comprehensive description of all necessary ethics approvals. Specifically, the authors detail the approval granted by the Auckland University of Technology Ethics Committee, associated with the institution of Auckland University of Technology, under approval number 22/327.

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