

**Developing an enhanced framework of sustainability
deliverables in Ghanaian highway construction
projects**

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Abstract

It is the responsibility of the construction sector to meet the sustainability demands of our society. The integration of sustainability principles into road and highway infrastructure development in Ghana, addressing a critical gap in existing research and practice within the context of developing countries. It advanced the guidelines aim to optimize the discourse on sustainable construction by identifying and evaluating the relative importance of sustainability indicators, examining professional perceptions towards these indicators, and formulating decision-support guidelines to enhance sustainable outcomes in road and highway projects.

Grounded in a comprehensive literature review, the study first identifies a broad range of potential sustainability indicators relevant to the construction of roads and highways. This foundational work underpins the subsequent empirical research phases, which employ both quantitative and qualitative methods to refine and contextualize these indicators within Ghana's specific development challenges and opportunities. Through a questionnaire survey, the research rigorously assesses the perceptions of key stakeholders—comprising engineers, project managers, contractors, consultants, and environmental consultants—on the criticality of identified sustainability indicators. This quantitative phase, analysed through Inferential statistical analysis, isolates 29 critical indicators, underpinning the development of a conceptual model that categorizes these indicators into six main sustainability pillars: economic value, environmental impact, social equity and culture, technical quality, project implementation and management, and resource utilization and management. Semi-structured interviews with industry professionals further reveal the practical implications, challenges, and strategies related to the integration of these sustainability indicators into road and highway projects. Through thematic analysis, these qualitative findings yielded comprehensive action plans across all critical indicators, with policy development, capacity building and training, stakeholder engagement and collaboration are the key implementation strategies. This qualitative inquiry not only validates the empirical findings from the survey but also deepens the understanding of sustainability's multifaceted nature in infrastructure development. One of the thesis's key contributions is the development of decision-support guidelines that leverage the SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis framework. These guidelines offer a novel approach for project managers and designers to systematically evaluate and incorporate sustainability considerations into

their projects. By facilitating an in-depth assessment of internal and external project factors, the guidelines aimed to optimize sustainability outcomes across the six identified pillars. The research reveals a complex interplay between sustainability indicators and project outcomes, highlighting the crucial role of strategic planning, stakeholder engagement, and the adoption of innovative practices and technologies in promoting sustainable infrastructure development. Moreover, it emphasized the need for comprehensive policy support and capacity building among industry professionals to embed sustainability deeply within Ghana's road and highway construction sector.

In conclusion, this thesis made significant contributions to academic knowledge by expanding the understanding of sustainability in road and highway infrastructure development, particularly in the context of Ghana and, by extension, similar developing countries. It also offered practical contributions by providing actionable guidelines for industry practitioners, aiming to bridge the gap between sustainability theory and practice. The research findings and developed guidelines served as a critical resource for policymakers, project managers, and designers committed to advancing sustainable infrastructure development in Ghana and beyond.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

.....
George Okyere Dokyi

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Starting a PhD has been an amazing educational adventure that has involved a wide range of experiences, relationships, knowledge, and happiness. This journey has been profoundly transformative, revealing to me my true self, my strengths, and my weaknesses, beyond the academic achievement of earning a PhD degree. Today, I stand stronger, more self-confident, independent, healthier, fitter, happier, and significantly improved from who I was at the onset. It is with great pleasure that I express my heartfelt gratitude to the many individuals who played pivotal roles in my journey to success.

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Dedication

To

My Father (Sam Dokyi Yeboah)

My Mother (Grace Adomaa)

My life has been nourished by your effort, sacrifices, and unwavering support.

Ethics Approval

The ethics application for this research project was approved by the Auckland University of Technology Ethics Committee, AUTEK Reference number 22/327.

Chapter 1 : Introduction

1.1 Introduction

The introduction chapter establishes the foundation for this research by presenting the background, defining the research questions and objectives, and highlighting the study's significance. It outlines the research methodology, clarifies the scope and limitations, and concludes with an overview of the thesis structure. This chapter sets the stage for the detailed exploration that follows, providing readers with a clear roadmap of the investigation's approach and anticipated contributions.

1.2 Research Background

The importance of sustainable development in road and highway infrastructure, especially in developing countries, is widely recognised as crucial for promoting economic growth, environmental conservation, and social inclusiveness. Ghana's road and highway sector, integral to the national development strategy, exemplifies the challenges and opportunities inherent in embedding sustainability into infrastructure projects. The sustainability of road and highway infrastructure in Ghana summarises a comprehensive approach aimed at minimizing environmental impacts, ensuring economic viability, and enhancing societal welfare throughout the infrastructure lifecycle, necessitating a framework adaptable to Ghana's unique circumstances (Jones et al., 2013; Lartey & Glaser, 2024).

Despite Ghana's road sector's pivotal economic role, it encounters numerous challenges such as funding shortfalls, environmental issues, and maintenance concerns, highlighting the urgent need for sustainable development practices (Oppong, 2014; Pinard, 2012). However, the practical application of these sustainable principles, especially in the planning, design, and construction phases, remains limited, with a notable gap in a comprehensive framework tailored to the needs of developing countries like Ghana (Ametepey et al., 2023; Kissi, Babon-Ayeng, et al., 2023).

This research aimed to bridge this gap by proposing a sustainability framework specifically designed for Ghana's road and highway infrastructure development, guiding stakeholders towards sustainability-aligned practices. The proposed framework integrated economic, environmental, technical, and social considerations, alongside project management and resource utilization aspects, offering a holistic approach to

sustainable infrastructure development in Ghana and potentially serving as a model for similar contexts in other developing nations.

Moreover, this study explores the attitudes of Ghanaian highway professionals towards sustainability criteria and their impact on climate action support within the highway sector. This exploration is crucial for understanding how professional attitudes influence the integration of sustainability practices in highway projects and for identifying targeted strategies to enhance sustainability within the sector (Lachapelle et al., 2012; Oti, 2020). By examining the dynamics between sustainability attitudes and climate action support, this research contributes to the broader discourse on sustainable infrastructure development, offering insights for policymakers, engineers, and other stakeholders committed to advancing sustainable highway projects in Ghana and beyond.

1.3 Research Problem Statement

In developing nations, such as Ghana, the establishment and improvement of road and highway infrastructure play a pivotal role in promoting economic growth and improving social welfare. Traditional approaches to infrastructure projects often emphasize immediate benefits, overlooking the imperative for long-term sustainability. This tendency leads to adverse outcomes such as environmental degradation, social inequalities, and economic inefficiencies (Anarfi, 2020; Kaiser & Barstow, 2022). The escalating challenges posed by rapid urbanization, population growth, and constrained resources in Ghana emphasize the need for integrating sustainable practices into infrastructure development efforts (Appau et al., 2024).

Despite the acknowledged importance of sustainability in infrastructure projects, there is a noticeable gap in literature regarding frameworks specifically designed for sustainable road and highway development in developing countries contexts, particularly in Ghana. Current studies tend to focus predominantly on economic factors, often overlooking essential environmental and social considerations. Additionally, these frameworks rarely address the distinct contextual challenges faced in Ghana, such as socio-economic disparities, environmental sensitivities, and institutional capabilities (Adugbila et al., 2023; Antwi-Agyei et al., 2018; Fuseini & Kemp, 2015).

This identified gap poses a significant impediment to the sustainable development of road and highway infrastructure in Ghana. A lack of comprehensive understanding regarding the details of sustainable infrastructure development could lead to the perpetuation of

unsustainable practices, thereby jeopardizing the long-term efficacy and resilience of infrastructure projects (Adams, 2024; Javidroozi et al., 2023). The research problem, therefore, centres on the absence of a detailed framework for sustainable road and highway infrastructure development in Ghana that encompasses environmental, economic, technical, social, project management, and resource utilization considerations.

Further complicating the landscape of infrastructure development is the intersection between sustainability criteria and climate action support among highway professionals. While the construction industry increasingly recognizes the importance of sustainable practices, there's a notable lack of understanding regarding how professionals' attitudes towards sustainability influence their support for climate action. This gap is particularly significant among highway professionals, whose decisions can significantly impact the environmental, economic, and social fabric of infrastructure projects (Liu & Xu, 2024; Mahabubul Bari, 2023).

This study aims to bridge this knowledge gap by investigating highway professionals' attitudes towards sustainability criteria and their correlation with support for climate action initiatives. By clarifying this relationship, the research seeks to contribute to the formulation of strategies that enhance the sustainability of road and highway infrastructure projects, with broader implications for policy development, educational programs, and construction industry practices.

To systematically address this aim, the research is structured around three principal questions:

1. What are the criteria and indicators used to assess sustainability in highway construction projects that are critical to highway professionals?
2. How do the perceptions of highway construction professionals about the sustainability criteria and indicators relate to their support for climate action?
3. What would guide the decisions of highway construction professionals for sustainable road and highway construction?

By answering these questions, the research endeavours to offer an in-depth understanding of the dynamics at play in the adoption of sustainable practices in Ghana's road and highway sector, ultimately guiding stakeholders towards more environmentally responsible, economically viable, and socially equitable infrastructure development initiatives.

1.4 Research Aim and Objectives

The aim of this study is to develop a comprehensive framework and guideline for integrating sustainability into the highway infrastructure development in Ghana. This involves identifying critical sustainability indicators used in the planning, design, and construction phases of highway infrastructure development and examining the relationship between these sustainability criteria and climate action initiatives from the perspective of professionals in the field. Ultimately, this research sought to deepen understanding and enhance the promotion of the synergies between climate action and sustainable development within the road and highway construction industry.

To effectively fulfil the research aim, and adequately address the previously posed research questions, it was important to undertake the following objectives:

Objective 1: To identify critical sustainability indicators for road and highway infrastructure development that are of primary concern to key stakeholders in making decisions in respect of road and highway construction.

- i. Reviewing the current decision tools and performance attributes to road and highway infrastructure development.
- ii. Identifying the sustainability indicators for road and highway infrastructure development.
- iii. Identifying the critical indicators that are significant in improving sustainability efforts for road and highway infrastructure development.
- iv. To analyze highway professionals' expectations to establish a shared understanding that can improve the sustainability outcomes of road and highway projects.

Objective 2: To examine the perceptions of highway construction professionals about the sustainability criteria and indicators relate to their support for climate action.

- i. To explore the interconnections between sustainability criteria in highway construction and climate action efforts, aiming to enhance the effectiveness of these synergies.

Objective 3: Develop decision support guidelines to enable the highway construction professionals (designers) to enhance the sustainable deliverables in road and highway infrastructure development.

- i. Identifying the action plans and available strategies to improve sustainability for each critical indicator identified, as well as.
- ii. Developing guidelines for decision-making with regards to sustainability in road and highway infrastructure development.

1.5 Significance of the study

It is crucial to emphasise the significance of sustainable development in relation to road and highway infrastructure in Ghana. This study makes substantial contributions to both the theoretical and practical realms of sustainable infrastructure development, with a keen focus on the Ghanaian context. Amidst the global thrust towards the Sustainable Development Goals (SDGs) set by the United Nations in 2015, the transportation sector, particularly road and highway infrastructure, emerges as a pivotal area for intervention to foster economic growth, environmental stewardship, and social equity. The imperative for a sustainable approach to road and highway infrastructure development in Ghana is emphasized by a host of challenges, including but not limited to, environmental degradation, social inequities, and economic inefficiencies. These challenges are further compounded by Ghana's rapid urbanization, population growth, and constrained resources, presenting a compelling case for integrating sustainability into infrastructure projects (Anarfi, 2020; Kaiser & Barstow, 2022).

Despite the critical need for sustainability, there is a notable gap in the literature and practice concerning the adoption of sustainable frameworks tailored to the infrastructure sector in developing countries like Ghana. This research addresses this gap by proposing a comprehensive framework for sustainable road and highway infrastructure development, specifically designed to meet Ghana's unique socio-economic and environmental needs landscape. This framework was intended to guide policymakers, planners, engineers, and other stakeholders towards best practices that align with global sustainability goals while considering local contexts.

By focusing on the identification of key sustainability criteria and indicators relevant to the Ghanaian highway sector and examining the attitudes of highway professionals towards these criteria and their support for climate action, this study aimed to enhance understanding and promotion of synergies between climate action and sustainable development. This is particularly critical in the domain of highway engineering and management, where decisions and practices have profound implications for environmental sustainability, economic efficiency, and social equity. The anticipated

contributions of this research are manifold. Firstly, it enriches the body of knowledge on sustainable highway infrastructure development by pinpointing critical sustainability indicators pertinent to Ghana. Secondly, it seeks to elevate the awareness and knowledge of highway professionals, influencing their decision-making towards sustainability. Moreover, the study offers a practical guiding framework for sustainable highway projects in Ghana, potentially serving as a model for similar contexts in other developing countries. This framework is aimed at promoting sustainable development while mitigating negative impacts across economic, social, and environmental dimensions.

Ultimately, the outcomes of this research were expected to directly contribute to the achievement of several SDGs, including SDGs 9 (Industry, Innovation, and Infrastructure), 11 (Sustainable Cities and Communities), and 13 (Climate Action). Additionally, it lays a foundational platform for future research endeavours aimed at advancing sustainable highway infrastructure development. This study not only marks a significant stride towards sustainable development in Ghana's highway sector but also highlights the critical interplay between infrastructure development and global sustainability efforts.

1.6 Research Methodology Overview

This research uses a sequential explanatory research design that combines both the logical positivism and hypothetico-deductive model approaches to test and explore hypotheses within the framework of sustainable road and highway infrastructure development. The research adheres to the principles of logical positivism, prioritizing the verification of empirical data through measurable evidence and assessing sustainability indicators through quantifiable insights. Sequentially, the hypothetico-deductive model helps to come up with hypotheses based on existing theories. These hypotheses are mostly about how professionals in highway construction perceive sustainability criteria in relation to their support for climate action. These hypotheses are then empirically tested, enhancing the investigation.

The questionnaire emerges as the primary method employed in surveys, facilitating the collection of extensive data from a large number of respondents within a short timeframe (Lund, 2023). Following questionnaire preparation, a preliminary evaluation, often referred to as a "pre-test," is conducted to gauge its clarity, comprehensiveness, and acceptability (Jacobs et al., 2023). Subsequently, a survey was conducted to identify critical sustainable road and highway indicators.

Semi-structured interviews complemented the survey, providing deeper insights into the potential impacts of critical indicators on sustainability. By examining both the drawbacks and benefits of each indicator, effective strategies were devised to align with sustainability goals. Additionally, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was employed to inform the decision-making process.

In summary, this study incorporates a literature review, a survey, semi-structured interviews, and data analysis techniques. By utilising both quantitative and qualitative methods, the perceptions of highway professionals about sustainable road and highway infrastructure were leveraged to develop a decision-making framework. The resulting guidelines were anticipated to foster integrated approaches to decision-making, particularly during the planning and design stages, promoting the implementation of sustainable, climate-resilient strategies.

1.7 Research Limitations and Scope

The scope of this study was limited to the construction industry sector, which focuses primarily on road and highway infrastructure development. This research involves the phases of road and highway planning, design, and construction. However, the guidelines aided the highway professional (designer) in decision-making. Using information gathered from key stakeholders, this research identifies the critical sustainability indicators for sustainable highway infrastructure development. Road agencies, contractors, consultants, environmental agencies, and researchers are the main participants in this study. Liu et al. (2023) stated that it is essential to include a variety of respondents from various backgrounds in order to minimize the possibility of bias. Even though this set of guidelines was developed for highway designers, the contributions of other key stakeholders are crucial to the success of the construction project.

1.8 Thesis Outline

This thesis contains seven chapters. A concise overview of each chapter is provided below.

Chapter 1 (Introduction): This chapter contains the introduction, which establishes the orientation of the research. The identification of critical issues comes before the formulation of research problems and objectives. In addition, it provides an overview of the research methodology and outlines the limitations of the research scope.

Chapter 2 (Literature Review): Explains the current state of knowledge by reviewing the existing literature. The areas covered include an overview of sustainable highway infrastructure development, the benefits of developing sustainable highway infrastructure, the current implementation of sustainable highway construction, and the development of a decision support system. From the synthesis of this information, the research gaps are identified.

Chapter 3 (Research Methodology): Describe the research methodology utilized in this study. Before discussing the research design, the research philosophy is initially explained. The questionnaire and semi-structured interview tools are used for collecting quantitative and qualitative data, respectively.

Chapter 4 (Questionnaire Surveys: Report of Findings): Describe the analysis of the data and questionnaire results. The questionnaire layout, instruments, response rate, and survey validity are discussed. Each distinct stakeholder's perspective is presented. The principal finding is analysed, and the conceptual framework is presented.

Chapter 5 (Semi-Structured Interviews: Report of Findings): Describes the data analysis and the outcomes of the interviews. Along with the instruments, format, and structure, the selection of participants and their backgrounds are briefly discussed. The results are tabulated, and the data is presented. Additionally, the interpretation of the results is discussed.

Chapter 6 (Research Findings and General Discussion): Discusses the results and outcomes of the questionnaire and semi-structured interviews used for data collection. Consequently, the investigation results are presented.

Chapter 7 (Conclusions and Recommendations): Examines the research questions and process of development. Each research query and issue are discussed in light of the research's findings and accomplishments. The conclusions summarize the findings and explain the research contributions in detail. In addition, recommendations for future research and research limitations are provided.

1.9 Summary

This introductory chapter has laid the groundwork for understanding the complexities of developing sustainable road and highway infrastructure, particularly within the Ghanaian context. It has established the critical relationship between sustainability practices and the

construction of highways, spotlighting the research questions that guide this study. The chapter has clearly articulated the research aims and set forth the expected significance and outcomes, positioning the study within the broader discourse on sustainable development in road and highway construction.

Furthermore, the methodology employed in this research is outlined, demonstrating the approach taken to achieve the stated objectives. By defining the scope and acknowledging the limitations, this chapter ensures a focused investigation into the pertinent issues surrounding sustainable road and highway infrastructure development.

The next chapter details a comprehensive literature review, providing a thorough exploration of the existing body of knowledge related to this study's thematic concerns. This established a solid foundation for the subsequent analysis and discussions, contributed to the overarching aim of enhancing sustainability within the road and highway infrastructure sector in Ghana.

Chapter 2 : Literature Review

2.1 Introduction

The purpose of this chapter is to examine the existing literature on sustainable road and highway infrastructure development, with a specific emphasis on the approaches used in Ghana. It explores current development practices, sustainability assessment tools, criteria and indicators for road and highway projects, and the interplay between climate action and sustainable development goals. Additionally, the impact of climate change on road and highway sustainability is discussed, identifying a gap in Ghana's highway construction industry's sustainability practices. This foundation aims to inform the development of a comprehensive framework for sustainable road and highway infrastructure in Ghana.

2.2 Definitions and Concepts of Sustainability

Sustainability in road and highway infrastructure development embodies a strategic approach designed to balance and integrate the core dimensions of environmental stewardship, economic viability, and social equity. This integrative perspective aims to ensure that present infrastructure development practices do not compromise the capacity of future generations to meet their own needs, a principle first articulated in the Brundtland Report (1987). The application of sustainability within the domain of infrastructure, specifically roads and highways, necessitates a holistic view that extends beyond the immediate environmental impacts to include long-term considerations of resource efficiency, economic benefits, and the promotion of equitable social outcomes (Kabashkin & Sansyzybayeva, 2024; Lim, 2009). The concept of sustainability in this context is multifaceted, involving the selection of sustainable materials, the incorporation of green design and planning principles, the adoption of environmentally friendly construction methodologies, and the implementation of sustainable maintenance and operation practices. These practices are aimed at minimizing the ecological footprint of infrastructure projects, maximizing resource utilization, and ensuring that the economic and social benefits of such projects are equitably distributed (Akadiri & Olomolaiye, 2012; Radzi et al., 2023).

Another critical aspect of sustainable infrastructure development is resilience, which pertains to the ability of road and highway systems to withstand, adapt to, and recover from various external stresses and shocks, such as climatic changes, economic

fluctuations, and social transformations. This resilience is increasingly important in the Ghanaian context, where infrastructure must be robust enough to handle a wide range of environmental and socio-economic challenges, thereby ensuring its long-term functionality and serviceability (Barajei et al., 2024; Francis & Bekera, 2014).

Furthermore, the evolution of sustainability frameworks and models offers practical tools for assessing and improving the sustainability performance of infrastructure projects. These frameworks typically feature a comprehensive set of indicators and metrics that evaluate projects across environmental, economic, and social dimensions, providing benchmarks for sustainable development. In Ghana, the challenge involves adapting these global sustainability models to align with the nation's unique environmental conditions, economic imperatives, and social fabric. This adaptation process is crucial for developing locally relevant and effective sustainability strategies that can guide policymakers, planners, engineers, and other stakeholders in making informed decisions that contribute to the broader goals of sustainable development (Anarfi, 2020; Kissi, Aigbavboa, et al., 2023; Owusu-Manu et al., 2023).

The intersection of sustainability principles with road and highway infrastructure development in Ghana presents a complex but essential endeavour. By navigating the in-depths of sustainability, stakeholders can forge pathways toward infrastructure projects that not only meet current needs but also safeguard the environmental integrity, economic prosperity, and social well-being of future generations.

2.3 Scope in developing countries' sustainability.

In the realm of sustainability research, it becomes evident that developing countries encounter distinct issues that are different from those encountered by developed nations. Factors like the economy, population, and culture significantly influence how sustainability is approached in these regions (Spaargaren, 2011). Strategies for sustainability, often discussed at international meetings mostly attended by developed countries, might not fit well in developing countries because they require complex systems, proper monitoring, government action, and companies acting responsibly. There are doubts whether these strategies can work in places facing issues like corruption, unequal income distribution, and poverty (Frieden, 2017; Hope, 2017). Clark (2007) points out that in developing economies, where resources are scarce, governments often prioritize economic growth and feeding the hungry over taking care of the environment. This has led to a development path where the focus is on growth first and solving

environmental problems later, described by Rock & Angel (2007) as a "grow first, clean up later" attitude. Despite attempts by organizations like the United Nations Environment Programme (UNEP) to push for sustainable development through cleaner technologies, sustainable business strategies, and eco-friendly product design (Montalvo Corral, 2003; Mungkung et al., 2012; Wong et al., 2016), these efforts haven't fully succeeded due to governance challenges (Schroeder, 2014).

Wang et al. (2019) highlight that cultural differences, stages of economic development, and political processes are key factors that differentiate how developed and developing countries achieve sustainability. They suggest building cooperative relationships between these groups to make a positive impact and call for more research to understand better the different frameworks, themes, and commonalities relevant to sustainability in developing areas (Wang et al., 2019). This literature review emphasizes the specific sustainability issues faced by developing countries, pointing out the need for approaches that consider their particular economic, social, and environmental situations. It suggests that understanding and collaboration between developed and developing nations are essential for creating sustainable development practices that are both practical and suitable for the context.

Despite the clear frameworks and extensive discussions on sustainability, developing countries encounter numerous challenges in implementation, including limited financial resources, inadequate technological access, and insufficient data for informed decision-making (Ikram, Ferasso, et al., 2021; Ikram, Sroufe, et al., 2021; Vanegas Cantarero, 2020). However, these challenges also present opportunities for innovation and partnerships. International cooperation and knowledge exchange can play significant roles in overcoming these barriers, as developing countries can learn from each other's experiences and adapt solutions that have been effective elsewhere.

2.4 Infrastructure Development Sustainability Concepts

To fully understand sustainability in infrastructure development, it is essential to thoroughly examine its complex definitions and underlying conceptual frameworks. Originating from the Brundtland Commission, sustainability is defined as the ability to meet present needs without compromising future generations' capacities Brundtland (1987), emphasizing intergenerational equity. In infrastructure development, this extends beyond environmental considerations to include economic, social, and institutional

sustainability, where practices ensure long-term project viability, equitable benefits distribution, and sustainable governance structures (Spangenberg, 2002).

Conceptual frameworks like the Triple Bottom Line (TBL) evaluate sustainability through environmental, economic, and social lenses, integrating non-financial metrics into sustainability assessments (Elkington, 1997). Additionally, the Green Infrastructure (GI) framework merges natural systems with engineered solutions to enhance resilience, climate adaptation, and biodiversity, advocating for multifaceted sustainability benefits (Matsler et al., 2021). The United Nations' Sustainable Development Goals (SDGs) further expand the sustainability narrative by setting objectives to combat global challenges, including poverty and environmental degradation. The SDGs emphasize the indispensable role of sustainable infrastructure in achieving these comprehensive goals, emphasizing its contribution to sustainable, resilient, and inclusive communities (Opoku, 2016).

This evaluation consolidates these varied viewpoints, highlighting the necessity of a holistic approach that incorporates environmental, economic, social, institutional, and managerial considerations in infrastructure development. Through these lenses, the study seeks to contribute to a deeper understanding of sustainability, advocating for integrated strategies that promote sustainable, resilient, and equitable infrastructure projects.

2.5 Sustainable Road and highway development

According to Sarsam (2015) and cited in Ibrahim & Shaker (2019), sustainable road and highway development involves enhancing the natural environment, minimising natural resource consumption, and promoting community and economic progress. This comprehensive approach recognizes the crucial function of roads and highways in the transportation infrastructure, vital for catering to sustainable human needs, including accessibility, people and goods movement, and the provision of safe and comfortable modes of transportation like walking, cycling, and public transit (FHWA, 2023; Umer et al., 2016). According to Bueno et al. (2015) as cited in Suprayoga et al. (2020), transportation development, particularly in roads and highways, aligns with the principles of sustainability when it supports economic development and meets societal transportation demands without compromising environmental integrity.

Sustainable road and highway development projects are those that incorporate the core tenets of sustainable development: social, economic, and environmental sustainability

(Aljboor et al., 2023). The concept of sustainable road transportation is described as meeting society's natural and reasonable mobility demands in the most efficient way possible, minimizing costs related to society, economy, environment, and resources. It aims for a balanced development alongside other social and economic sectors. The characteristics of sustainable road and highway transportation systems can vary across different regions and times, influenced by available resources and environmental constraints (Hu et al., 2010). This section emphasizes the importance of integrating sustainability principles into road and highway development to ensure that transportation infrastructure not only supports economic and community development but also conserves the environment and optimizes the use of natural resources.

2.6 Infrastructure Development: Sustainability Concerns

The necessity to integrate sustainability into the realm of infrastructure development has become progressively evident in light of the complex interaction between worldwide environmental issues, economic constraints, and social disparities. This necessity is especially pronounced in the context of road and highway infrastructure, where the pursuit of sustainable development encompasses a comprehensive approach that ensures projects not only mitigate environmental impacts but also bolster economic growth and social welfare, thus achieving resilience and inclusivity for current and future societal needs (Esfandi et al., 2024; Robertson, 2021). The significance of sustainability in the road and highway sector is further emphasized by its considerable environmental implications, which include, but are not limited to, substantial greenhouse gas emissions, extensive habitat disruption, and considerable resource utilization. These factors necessitate a strategic focus on reducing environmental footprints, while simultaneously enhancing economic efficiency and social well-being, to ensure infrastructure projects contribute positively to societal development and quality of life (Cervero, 2014; Mehmood et al., 2024).

In Ghana, the imperative for sustainable infrastructure development is highlighted by unique challenges and opportunities presented by the nation's rapid infrastructure growth needs amidst environmental degradation, economic transition demands, and the quest for social inclusion. The integration of sustainability principles into the lifecycle of road and highway projects—from planning and design through to construction and maintenance—emerges as a critical strategy not only for aligning with international sustainability ambitions but also for addressing local environmental concerns, such as soil erosion and

deforestation, and for improving access to transportation and economic opportunities for the populace (Aboagye et al., 2022). Moreover, the resilience of infrastructure to climate change impacts is a paramount consideration within the sustainability discourse. Sustainable infrastructure inherently incorporates adaptability and resilience features, making it better equipped to withstand the challenges posed by climate variability and change. This adaptability is crucial for ensuring infrastructure's long-term serviceability and reducing the financial burdens associated with repairs and rebuilds, thus safeguarding the nation's investment in its road and highway network against the unpredictable consequences of climate change (Mitoulis et al., 2023).

This section reveals the indispensable role of sustainability in the development of road and highway infrastructure in Ghana. It highlights the necessity for adopting sustainable practices that mitigate environmental damage, promote economic and social benefits, and incorporate climate adaptation measures to enhance infrastructure resilience. The integration of these sustainability principles is vital for advancing Ghana's infrastructure sector towards achieving broader developmental goals and environmental sustainability, thereby contributing to a more sustainable and equitable future.

2.7 Sustainable Global Highway Infrastructure Development.

The global importance of sustainable development in road and highway infrastructure is fuelled by the need to address environmental, social, and economic challenges. This has led to a shift in how infrastructure projects are viewed, not just as solutions for immediate transport needs but as opportunities to contribute to long-term sustainability goals (Bühler et al., 2023; Thacker et al., 2019). This shift sees the adoption of new methods, materials, and technologies aimed at reducing harm to the environment, making projects more cost-effective, and improving social outcomes. One key area is reducing carbon emissions by using environmentally friendly materials and construction methods. In places like the United States, Japan, China, and the European Union, there has been progress in using recycled materials and low-carbon concrete in road construction, showing a commitment to lowering greenhouse gas emissions (Chen et al., 2023). Also, innovative projects like solar roadways in the Netherlands show how infrastructure can produce energy sustainably (Lampropoulos et al., 2020). Another important aspect is water management, with countries like Singapore developing advanced drainage systems to reduce flood risks and use water more efficiently. These systems are designed to make roads more resistant

to climate change and extreme weather (Chan et al., 2018; de Abreu et al., 2022; Kim et al., 2022).

Social sustainability, which includes fairness and accessibility, is also crucial. For example, Canada has shown how involving indigenous communities and the public in planning and designing highway projects can ensure that the development meets local needs and respects cultural values (Caron, 2022). Economically, sustainability is about making projects cost-effective in the long run and supporting sustainable economic growth. Germany's multimodal transport networks are a good example of how infrastructure can help diversify the economy, reduce traffic jams, and improve transportation (Reichenbach & Fleischer, 2023; Schönharting et al., 2003). These examples from around the world highlight the need for a well-rounded approach to integrating sustainability into road and highway infrastructure development. They offer valuable lessons and practices that can inform the development of a sustainability framework in Ghana, tailored to its unique environmental, social, and economic conditions. Learning from these global experiences can help Ghana adopt strategies that promote sustainable infrastructure development.

2.8 Ghanaian Highway Infrastructure Development Practices.

In exploring Ghana's road and highway infrastructure, it's evident that this sector plays a pivotal role in the country's developmental agenda, serving as a conduit for economic growth, enhancing regional connectivity, and improving access to essential services. The Ghanaian government, primarily through the Ministry of Roads and Highways along with its affiliated agencies, leads the charge in infrastructure development, focusing on both the expansion of access in underserved areas and the upgrading of roads to accommodate rising traffic volumes (Ministry of Roads and Highways, 2018). The Ghana Highway Authority details a comprehensive national highway network designed to optimize connectivity across the nation, as demonstrated in figure 1.



Figure 1: Ghana's National Highway Network, Source: (Wikipedia, 2023)

Despite the strategic importance of road and highway infrastructure, challenges such as funding limitations, maintenance deficits, and the need for enhanced local engineering capacities persist. These challenges highlight the critical need for sustainable and efficient development practices within the sector (Akinradewo et al., 2019). The global shift towards sustainable construction practices in road and highway projects reflects an acknowledgment of the essential role these infrastructures play in national development and the necessity of aligning construction processes with broader goals of sustainability (Fei et al., 2021). Ghana faces a notable infrastructure deficit, exacerbated by insufficient investment in expansion and maintenance. Innovative financing mechanisms are increasingly being explored to bridge this gap. An estimated annual investment of \$1.5 billion is required to meet Ghana's infrastructure needs, suggesting a need for diversified funding sources beyond traditional government expenditure (Owusu-Manu et al., 2019; Tenkorang et al., 2022).

While policies have been enacted to reduce the financing gap, the integration of sustainability in construction processes is imperative for achieving long-term benefits.

Despite the recognized importance of sustainability, there appears to be a gap between acknowledgment and action among stakeholders, with many prioritizing immediate project metrics over environmental sustainability (Buertey & Asare, 2014; Jones et al., 2013; Owusu-Manu et al., 2023). In this assessment, the intricate terrain of road and highway infrastructure development in Ghana is emphasised. It highlights the critical need for a concerted effort towards sustainable practices, innovative financing, and capacity building to address the challenges faced by the sector. By drawing insights from both the local context and global best practices, this research aims to contribute to the development of a sustainable framework and guideline for Ghana's road and highway infrastructure sector.

2.9 Identified Ghanaian highway infrastructure stakeholders.

The development of road and highway infrastructure in Ghana involves a complex network of stakeholders, each contributing unique perspectives, expertise, and interests to the planning, design, construction, and maintenance phases. Understanding the roles and interrelations of these stakeholders is paramount for the successful implementation of sustainable practices within the sector (Damoah et al., 2022). The stakeholder landscape in Ghana's road and highway sector is diverse, encompassing government entities, private sector participants, non-governmental organizations (NGOs), and the local communities affected by infrastructure projects.

Government and Regulatory Bodies: The Ghanaian government, through the Ministry of Roads and Highways (MRH), spearheads the development and maintenance of road and highway infrastructure. The road agencies Ghana Highway Authority (GHA), Department of Urban Roads, Department of Feeder Roads are under the MRH, is specifically tasked with the planning, development, and management of the national trunk road network. Regulatory bodies, including the Ghana Standard Authority (GSA), the Forestry Commission, the Water Resource Commission, the District/Municipal/Metropolitan Assemblies, the Environmental Protection Agency (EPA), play a crucial role in ensuring that road and highway projects comply with national environmental standards and sustainability criteria (Babon-Ayeng et al., 2022).

Local Communities: Local communities are vital stakeholders, directly affected by road and highway projects. Their involvement is crucial for identifying local needs, mitigating adverse impacts, and enhancing the socio-economic benefits of infrastructure projects. Community engagement processes are essential for incorporating local knowledge and

ensuring the social acceptability of projects (Agyekum et al., 2023; Babon-Ayeng et al., 2022).

Contractors and Consultants: Contractors and consultants in the construction industry are responsible for the physical realization of road and highway projects. Their expertise in sustainable construction methods, materials selection, and project management is critical for integrating sustainability principles into infrastructure development (Agyekum et al., 2022).

Financiers and Donors: The financing of road and highway projects in Ghana often involves a mix of government funding, loans, and grants from international donors and development banks. These financiers and donors not only provide the necessary capital but also influence the prioritization of sustainability through funding criteria and project evaluation guidelines (Badu et al., 2011).

Academic and Research Institutions: Universities and research institutions contribute to the development of road and highway infrastructure by conducting research on sustainable materials, design innovations, and impact assessments. They play a key role in advancing knowledge and providing evidence-based recommendations for policy and practice (Mensah & Gordon, 2020; Murunga et al., 2020).

Non-Governmental Organizations (NGOs) and Civil Society Organizations (CSOs): NGOs and CSOs advocate for environmental conservation, social equity, and accountability in infrastructure development projects. They are instrumental in raising awareness about sustainability issues and ensuring that the voices of marginalized groups are heard in the decision-making process (Asogwa, 2023; Naaikuur et al., 2022).

The effective collaboration among these stakeholders is crucial for addressing the multifaceted challenges of road and highway infrastructure development in Ghana. Through a coordinated approach, stakeholders can ensure that infrastructure projects are economically viable, socially equitable, and environmentally sustainable (Lawer, 2019).

2.10 Sustainable Highway Infrastructure Benefits

The recognition of the importance of highway construction in the more comprehensive framework of sustainable development is growing due to its substantial influence on the attainment of the Sustainable Development Goals (SDGs) by the year 2030. This sector, a cornerstone of the construction industry, is instrumental in driving sustainable initiatives

across its lifecycle, influencing everything from land use and resource management to waste production and labour practices (Fei et al., 2021; Iyer-Raniga et al., 2021). Goubran (2019) highlights the industry's potential to extend its sustainability efforts beyond environmental concerns to encompass social and economic aspects, advocating for a more inclusive approach to sustainable development.

The integration of sustainability principles in road and highway construction not only addresses environmental impacts but also weaves social and economic considerations into project planning and execution. Such integration results in improved efficiency, minimized project disruptions, and notable social and economic returns, while also enhancing biodiversity through landscape and green space integration within highway projects (Fei et al., 2021; Ngampravatdee et al., 2023). Opoku (2016) further elaborates on the contribution of sustainable road and highway projects to achieving broader societal objectives, such as education, innovation, access to clean energy, sustainable communities, climate action, and economic growth through infrastructure development and job creation.

The role of organizational learning and innovation within the construction industry is emphasized as vital for maintaining competitive standards in road and highway infrastructure development, crucial for economic prosperity through reliable and efficient transportation networks (Shatz et al., 2011). In the context of Ghana, the expansion of sustainable transportation infrastructure, especially in rural regions, is pivotal for economic development and improving living standards. Sustainable road and highway projects have been linked to increased household incomes, agricultural productivity, motorized vehicle usage, market access, and access to educational and healthcare services, all while reducing transportation costs (Asomani-Boateng et al., 2015). This highlights the comprehensive benefits of sustainable road and highway infrastructure development, showcasing its critical role in achieving holistic growth and sustainability objectives. The need for a sustainable approach in road and highway construction aligns with global and national sustainable development agendas, emphasizing the essential integration of environmental, social, and economic dimensions to foster inclusive and long-lasting development outcomes.

2.11 The Development of Sustainability Rating Systems

The utilisation of sustainability rating systems is crucial within the domain of infrastructure development, as they offer a systematic methodology for integrating

sustainability across the various stages of design, building, and operation. These systems simplify the integration of sustainable practices into infrastructure projects, enhancing their appeal to policymakers, developers, and end-users alike (Andreas et al., 2010). By offering a point-based certification process, they facilitate the communication, marketing, and ultimately, the broader adoption of sustainability features within projects.

Moreover, sustainability rating systems play a crucial role in decision-making throughout a project's lifecycle, ensuring the consistent integration of sustainability from start to finish (Poveda & Lipsett, 2011). Their influence extends beyond buildings to impact transportation and land development, enabling the assessment of transportation policies, plans, and projects through the lens of sustainability (Brodie et al., 2013). These tools not only guide decisions towards sustainability objectives but also reshape stakeholder perspectives and promote effective infrastructure project management strategies (Kim & McCarthy, 2022). Grounded in fundamental sustainability pillars such as site selection, water management, energy efficiency, material utilization, and environmental protection, these rating systems emphasize the significance of reducing noise, protecting water quality, and preventing pollution. The benefits of adopting these systems are diverse, leading to improved public health, operational efficiency, waste reduction, and cost savings via green infrastructure (Munagala & Jothilakshmy, 2023).

The crucial role of sustainability rating systems in advancing sustainable infrastructure development, highlighting their potential to foster comprehensive environmental, economic, and social benefits. Through the structured evaluation and certification of projects, these systems support the widespread adoption of sustainable practices, highlighting the necessity of integrating sustainability principles across all stages of infrastructure project development. Examples of prominent sustainability rating systems are summarized in table 1. Table 1: A table showing some prominent sustainability rating systems

Transportation systems			
Year	Rating Systems	Description	Application
2007	Greenroads	A third-party rating system used both domestically and internationally to evaluate projects related to the design and construction of roadways. These projects are graded based on	Roadway design and construction
	Developed by the University of Washington and CH2MHILL.		

		their ability to meet modern sustainability standards.	
2008	GreenLITES	Self-certification program which integrates NYSDOT sustainability principles into project and practice choices. Scoring is based on criteria and certification levels are determined accordingly.	All projects and practices at the DOT level
	Developed by NYSDOT and modeled on USGBC LEED and Green roads		
2010	Greenpave	The Ministry's contractors and consultants use this rating system to advance sustainable pavement design and construction practices.	Pavement projects
	Developed by the Ontario Ministry of Transportation in Ontario, Canada.		
2012	INVEST	Web-based tool to help transportation agencies achieve their sustainability goals. Rates three project phases (planning, development, operations and maintenance) based on developed criteria.	Life cycle of transportation projects
	Developed by the Federal Highway Administration.		
2012	Envision	Developed for self-assessment to enhance performance and resilience of various physical infrastructure. Rating is based on meeting a minimum number of points in each category.	All infrastructure projects
	In development by Institute for Sustainable Infrastructure.		
2003	CEEQUAL	Improve sustainability and performance of civil engineering projects by assessing and rating their performance against a range of criteria including environmental and social impacts, economic considerations, and stakeholder engagement.	Tools applicable to all sectors
	Developed by BRE		

Other systems

2009	LEED-ND Developed by USGBC LEED.	Assesses sustainable development using smart growth, urbanism, and sustainable construction principles, employing a credit system for certification.	Neighborhood-scale planning and development
2001	CASBEE	Evaluating and rating the environmental performance of buildings and the built environment	Buildings and the environment
1990	BREEAM developed by BRE	A science-based suite of validation and certification systems for a sustainable built environment.	Built environment
	Green Star developed by GBCA	Provide a means of certification for building design and construction, operation, fit outs and communities	Building design and construction
	GBTool	Used for the assessment of potential energy and environmental performance of buildings	Buildings

Source: (Brodie et al., 2013; Bueno et al., 2015; Griffiths et al., 2018; Poveda & Lipsett, 2011)

2.12 Sustainability Assessment of Highway Infrastructure

Development

Sustainability frameworks guide how decisions are made to achieve sustainability goals, with notable examples including the United Nations Global Compact (UNGC) and the Sustainable Development Goals (SDGs) (Rage, 2023). These frameworks help evaluate the sustainability of road and highway projects by looking beyond traditional measures to consider social, environmental, and economic impacts together, known as the Triple Bottom Line (TBL). However, this broad view of sustainability often lacks precise ways to measure progress directly within its main ideas (Culp, 2011; FHWA, 2023). To address the need for specific measures of sustainability in construction, various sectors are creating their own evaluation tools. These tools, developed by groups ranging from government bodies to universities, use different methods to judge how sustainable a project is, focusing on aspects like environmental effects, fairness, and cost-effectiveness (Bhyan et al., 2023; Bueno et al., 2015).

However, applying sustainability assessment tools from more developed countries to places like Ghana can be problematic. These tools might not fit well with the unique challenges and opportunities of developing nations, pointing out a gap in our knowledge (Sala et al., 2013). While some research has emphasized new technologies (Miyatake, 1996), or economic and environmental issues (Santos et al., 2017), there's a lack of comprehensive frameworks that consider all aspects of sustainability in developing countries. This includes not just the environment and economy but also social, technical, institutional, and managerial factors. Identifying sustainability indicators specific to road and highway projects is crucial for promoting sustainable practices within the construction industry. These indicators guide project stakeholders in making choices that align with sustainability goals, reducing negative impacts on the environment and society (Lim, 2009; Sandanayake et al., 2023). Table 2 summarizes existing scholarly works of Sustainability Criteria for Roads and Highway Infrastructure development. Table 2: Sustainability Criteria for Roads and Highway Infrastructure Development

S/N	Source	Criteria
1	Proposed Criteria for this study	Economics, Environmental, Technical, Project Implementation & Management, Social Equity & Culture, Resources Utilization & Management
2	Amiril et al. (2014)	Environment, Economic, Social, Engineering & Resource Utilization, Project Administration
3	Ugwu & Haupt, (2007)	Economy, Environment, Society, Resource Utilization, Health and Safety, Project Management & Administration
4	Huang and Yeh (2008)	Ecology, Landscaping, Material, Waste Reduction, Water Conservation, Energy Conservation.
5	Montgomery et al., (2014)	Quality of life category, Project leadership, Natural world, Natural resource management, Resilience and greenhouse gas emissions.
6	Lim (2009)	Environmental, Economic, Social, Engineering, Community engagement, Relationship management, Project management, Institutional sustainability, Health and safety, Resource utilization and management.

7	Ametepey et al., (2022)	Social Sustainability, Cultural Sustainability, Economic Sustainability, Environmental Sustainability, Institutional Sustainability, Health & Safety, Project Management, Resource utilization and Management, Engineering Performance, Climate Change Response, Public Participation, Stakeholder management.
8	Transport for New South Wales, (2012)	Environmental category (GHG emissions, water, pollution control, noise management, resource management, waste management, material consumption, and biodiversity); Social category (stakeholders' relationship, communities & public acceptance and heritage conservation), Economic category (corporate sustainability).
9	Suprayoga et al., (2020)	Socio-ecological system integrity, opportunity and security of livelihood, intra- and intergenerational equity, resource maintenance and efficiency, precaution and adaptation, full staging, understanding of pillars, and dimension (time, space).
10	CEEQUAL – Civil Engineering and Environmental Quality Assessment and Award Scheme	Project Management, Land Use, Landscape, Ecology & Biodiversity, The Historic Environment, Energy and Carbon, Material Use, Waste Management; Transport; Effects on Neighbours, Relations with the Local Community and other Stakeholders.
11	INVEST	Operations and Maintenance, Project Development, Systems Planning.
12	FIDIC's Project Sustainability Management (PSM) Guidelines	Equity, Health, Human rights, Education, Housing, Security, Population, Culture, Integrity, Atmosphere, Land, Oceans Seas & Coast, Fresh Water, Biodiversity, Economic Structure, Consumption & Product Patterns, Institutional Framework
13	I – LAST	Materials, Lighting, Transportation, Water Quality, Environmental, Design, Planning.

14	BE2ST-In-Highways	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	Pavement Technologies, Materials and Resources, Energy and Atmosphere, Construction Activities, Access and Equity, Environment and Water,
16	EnvisionTM	Climate, Natural World, Resource Allocation, Leadership, Quality of Life.
17	GreenPave	Pavement Technologies, Energy and Atmosphere, Materials and Resources, Innovation and Design.
18	Green Guide for Roads	Mobility for All, Transportation Planning, Environmental Impact, Energy and Atmosphere, Materials and Resources, Community Impact, Innovation and Design.
19	GreenLITES	Innovation & Unlisted, Materials and Resources, Energy and Atmosphere, Water Quality, Sustainable Sites.

Source: Modified from Ametepey et al. (2019)

2.13 Sustainable highway infrastructure development indicators

The formulation of decision-making guidelines for sustainable road and highway infrastructure development is predicated on the identification and combination of key performance indicators (KPIs). Ensuring the long-term effectiveness of these indicators necessitates incorporating feedback from primary stakeholders from the project's outset. This participatory approach ensures that the indicators are both relevant and grounded in the practical realities of road and highway infrastructure projects.

This study reviewed literature from the last ten years in top construction and related journals, focusing on sustainability in road and highway projects. This review aimed to filter a variety of sustainability outcomes pertinent to road and highway projects. Based on this extensive review, the indicators identified were systematically categorized to reinforce the sustainability criteria proposed in this study. These categories are instrumental in providing a structured framework for assessing and enhancing sustainability in road and highway infrastructure development. They include:

Economic Criteria: Encompassing cost-effectiveness, lifecycle cost analysis, and economic viability, these indicators assess the financial sustainability of infrastructure projects.

Environmental Criteria: Focused on minimizing environmental impact, these indicators include measures for reducing carbon emissions, enhancing biodiversity, and promoting the use of sustainable materials.

Technical Criteria: Addressing the durability, reliability, and technical soundness of infrastructure, ensuring that projects are designed and constructed to last and perform efficiently.

Project Implementation and Management Criteria: Covering aspects of project delivery, such as adherence to timelines, budget management, stakeholder engagement, and the integration of sustainability goals into project management practices.

Social Equity and Culture Criteria: Emphasizing the importance of inclusivity, community engagement, and preserving cultural heritage, these indicators seek to ensure that projects contribute positively to social welfare and equity.

Resource Utilization and Management Criteria: Concentrating on the efficient use of resources, waste reduction, and recycling, to promote sustainability throughout the project's lifecycle.

By leveraging these categorized indicators, stakeholders can systematically evaluate and enhance the sustainability of road and highway infrastructure projects. This approach not only facilitates the achievement of sustainability goals but also contributes to the broader agenda of sustainable development within the infrastructure sector. Table 3 is an overview of possible indicators that contribute to the improvement of sustainable outcomes in road and highway infrastructure development

Table 3: An overview of possible indicators

<i>S/N</i>	<i>Sustainability Indicator (s)</i>	<i>References</i>	<i>Sources</i>
<i>Economic Criteria</i>			
1.	Life cycle costs	(Babashamsi et al., 2016)	Pavement Research and Technology
2.	Material costs	(Lee et al., 2013)	Construction Engineering and management
3.	Construction time	(Aziz & Abdel-Hakam, 2016)	Alexandria Engineering Journal
4.	Maintenance and operation costs	(Babashamsi et al., 2016)	Pavement Research and Technology
5.	Labour costs	(Persyn et al., 2022)	Transport Policy
6.	Cost of Production	(Gschösser & Wallbaum, 2013)	Environmental Science & Technology
7.	Disposal costs	(Li et al., 2019)	Cleaner Production
8.	Extra duration for planning, design & met. Proc.	(Choudhari & Tindwani, 2017)	Construction Innovation
9.	Limit variation costs	(Mostert et al., 2017)	Transportation Business & Management
10.	Initial construction costs	(Babashamsi et al., 2016)	Pavement Research and Technology
11.	Return on investment.	(Mishra et al., 2013)	Research in Transportation Economics
12.	Cost of Resettlement	(Babatunde et al., 2017)	Engineering, Design and Technology
<i>Environmental Criteria</i>			
1	Design to reduce vehicle emission.	(Llopis-Castelló et al., 2018)	Transportation Research Part D
2	Vehicle emission – construction	(Hanson & Noland, 2015)	Transportation Research Part D
3	Dust Control	(Sanders et al., 2015)	Transportation Engineering
4	Design to reduce traffic noise	(Vaitkus et al., 2017)	Construction and Building Materials

5	<i>Reduce construction noise and vibration.</i>	<i>(Heutschi et al., 2016)</i>	<i>Transportation Research Part A</i>
6	Ground and scenery Design / Construction	(Freudenberger et al., 2013)	Landscape Ecology
7	Pollution control	(Loganathan et al., 2013)	Environmental Science and Technology
8	Excavation and earthmoving	(Liu & Lu, 2015)	Construction Engineering and Management
9	Water-permeable slope shapes	(Ndon, 2017)	Civil & Environmental Engineering
10	Water-permeable pavement design	(Ahammed, 2017)	Sustainable Water Resources Management
11	Direct infiltration design	(Liu, 2015)	Road Materials and Pavement Design
12	Water storage infiltration design	(Lin et al., 2018)	Sustainable Water in the Built Environment
13	Design slope vehicle energy consumption	(Levin et al., 2014)	Transportation Research Board
14	Energy conservation facilities	(Lv & Shang, 2023)	Green Technologies and Sustainability
15	Use of natural energy or reuse of waste heat	(Aziz et al., 2015)	Construction and Building Materials
16	Use of environmentally friendly materials	(Araújo et al., 2014)	Transport and Environment
17	Restoration of possible vegetation	(Yang et al., 2016)	Ecological Engineering
18	Destruction of animal habitat	(Davey et al., 2017)	Transportation Research Part C
19	Preservation and reuse of topsoil	(Celauro et al., 2015)	Transportation Research Part D
20	Ecological functions of drainage corridor	(Brunen et al., 2020)	Environmental Management
21	Environmental monitoring	(Gallardo et al., 2016)	Environmental Assessment Policy & Mgt.
22	Contamination of soil	(Kibblewhite, 2018)	Environmental Pollution
23	Groundwater management	(Uliasz-Misiak et al., 2022)	Science of the Total Environment
24	Operational Energy	(Mukta et al., 2020)	Transportation Research Board
25	Energy consumption during construction phase	(Barandica et al., 2013)	Cleaner Production
26	Flood and surface run-off	(Kia et al., 2021)	Construction Material

Technical Criteria

1	Application of durable materials	(Kamal & Bas, 2021)	Materials Today: Proceedings
2	Incorporate future needs in design	(Chen et al., 2015)	Applied Energy
3	Disaster (flood) resilient designs	(Aydin et al., 2018)	Int. Journal Disaster Risk Reduction
4	Ease for construction and design integration	(Tong et al., 2015)	Transportation Research Part B
5	Quality control	(Gautam et al., 2018)	Construction and Building Materials
6	Durable and cost effective over the design life	(Li et al., 2019)	Journal of Cleaner Production
7	Design and construct climate change resilient	(Schweikert et al., 2014)	Transport Policy
8	Technology in design and construction	(Castañeda et al., 2024)	Construction and Building Materials
9	Adaptability and flexibility for future changes	(Pompigna & Mauro, 2022)	Engineering Science and Technology
10	Competent Supervisors, labours	(Gharouni Jafari & Noorzai, 2021)	Construction Engineering and Management
<i>Project Implementation and Management Criteria</i>			
1	Procurement system simplification	(Dabarera et al., 2019)	Built Environment Project and Asset Mgt.
2	Standard size for mass production	(Lo Presti, 2013)	Construction and Building Materials
3	Comply with contract documents.	(Elsayegh et al., 2020)	Legal Affairs in Eng. & Construction
4	Project control and monitoring guidelines	(Liu et al., 2016)	Automation in Construction
5	Sustainable policy and strategy	(Berg et al., 2017)	Development studies
6	Governance – economic and social problems	(Skorobogatova & Kuzmina-Merlino, 2017)	Procedia Engineering
7	Delivery system	(Tran & Molenaar, 2015)	Construction Engineering and Management
8	Type of contract	(Noorzai, 2020)	Journal of Infrastructure System
9	Inclusion of sustainability clauses	(Sanchez et al., 2015)	Environmental Planning and Management
10	Meeting sustainability performance	(Amiril et al., 2014)	Procedia – social and behavioural science
11	Completing project on schedule	(Demetracopoulou et al., 2020)	Engineering and Construction
12	Project risk assessment	(Carbonara et al., 2015)	Transport Reviews

13	Prequalification of contractors	(Le et al., 2020)	Journal of Management in Engineering
14	Contractor selection	(El-Abbasy et al., 2013)	Construction Engineering and Management
<i>Social Equity and Culture Criteria</i>			
1	Safety risk assessment and mitigation	(Serrone et al., 2023)	Transportation Research Procedia
2	Knowledge in sustainable technology	(Huang et al., 2018)	Renewable and Sustainable Energy Reviews
3	Improve working conditions	(Wang et al., 2018)	Journal of Cleaner Production
4	Job creation	(Chakrabarti, 2018)	Transport Policy
5	Improve workers health and safety	(Hughes et al., 2016)	Accident Analysis & Prevention
6	Reduction of community disturbance	(Abdel-Raheem & Ramsbottom, 2016)	Procedia Engineering
7	Traffic congestion – design / operational phase	(Lee et al., 2005)	Journal of Infrastructure Systems
8	Traffic congestion – construction	(Fei et al., 2016)	Physical A: Statistical Mechanics
9	Aesthetic impact and appearance	(Tee & Ekpivhre, 2019)	Quality and Reliability Management
10	Public participation in project	(Cascetta & Pagliara, 2013)	Procedia – Social and Behavioural Sciences
11	Economy opportunities to local communities	(Holl, 2016)	Journal of Urban Economics
12	Cultural heritage elements	(Broere, 2016)	Tunnelling and Underground Space Tech.
<i>Resource Utilization and Management Criteria</i>			
1	Integration of supply chains	(Karlsson et al., 2020)	Renewable and Sustainable Energy Reviews
2	Use of local materials	(Alsalman et al., 2017)	Construction and Building Materials
3	Use of prefabricated materials	(Fang et al., 2022)	Traffic and Transportation Engineering
4	Material quality control	(Zhou et al., 2017)	Road Materials and Pavement Design
5	Supply chain management	(Islam et al., 2013)	Research in Transportation Economics
6	Use of recycled construction materials	(Silva et al., 2019)	Journal of Cleaner Production

2.14 Sustainability Considerations and Climate Action Support

In the quest to enhance sustainability in road and highway infrastructure development in Ghana, understanding the perceptions of highway construction professionals regarding sustainability criteria and indicators emerges as a pivotal aspect. This understanding is not only fundamental in aligning infrastructure projects with sustainability objectives but also in fostering a culture that supports climate action. The integration of sustainability criteria into the planning, design, construction, and maintenance of road and highway projects is crucial for mitigating environmental impacts, promoting social equity, and ensuring economic viability. As such, the perceptions of professionals who are directly involved in these projects play a critical role in shaping the sustainability outcomes of infrastructure development efforts.

2.14.1 Perceptions of Highway Construction Professionals

Understanding the perceptions of highway construction professionals regarding sustainability practices is pivotal in developing and implementing an enhanced framework of sustainability deliverables in Ghanaian road and highway infrastructure. These perceptions significantly influence the decision-making process, the adoption of sustainable construction methods, and ultimately, the success of sustainability initiatives within the sector (Stanitsas & Kirytopoulos, 2023; Tokbolat et al., 2020). Research indicates a broad spectrum of perceptions among construction professionals concerning sustainability. A study by Giddings et al. (2002) highlighted that while there is a general awareness of sustainability concepts, the depth of understanding varies significantly, with a tendency towards prioritizing immediate economic benefits over long-term environmental and social impacts. This inclination often results in the superficial adoption of sustainability practices, lacking in comprehensive integration and optimization within projects (Fathalizadeh et al., 2022; Vitale et al., 2019).

Moreover, the literature reveals a gap in the alignment of perceptions between different levels of professionals - from project managers to on-ground engineers - regarding the importance and implementation of sustainability criteria (Ayokunle Olubunmi et al., 2014). While project managers may recognize the value of sustainable practices, engineers and on-site workers often face practical challenges in their execution, stemming from a lack of clear guidelines, resources, and training (Choudhry & Fang, 2008; Damnjanovic & Rispoli, 2014).

Another critical gap identified in the literature is the limited research on the influence of cultural and organizational factors on professionals' perceptions of sustainability in the Ghanaian context. For instance, Etse et al. (2022) call for more in-depth studies into how organizational culture, leadership, and policy frameworks within Ghanaian construction firms shape sustainability attitudes and practices. Additionally, there is a noted scarcity of empirical studies focusing on the specific sustainability indicators that highway construction professionals in Ghana consider most critical and feasible for implementation. Such insights are essential for developing targeted interventions and educational programs to shift perceptions and encourage the adoption of sustainable practices (Aboagye et al., 2022).

2.14.2 Climate Action and Sustainable Development Goals

Climate action commitments under the Paris Agreement and the 2030 Agenda for Sustainable Development are vital to global efforts to solve environmental issues and promote sustainable growth. Recent studies in specific areas have shed light on the complex relationship between global climate commitments and the pursuit of sustainable development goals (SDGs). These studies reveal both the positive interactions and the difficulties that climate change introduces, particularly in relation to objectives like enhancing agricultural productivity, reducing poverty, and eliminating hunger (Fuso Nerini et al., 2019; Gjorgievski et al., 2022). Janetschek et al. (2020) provide a pivotal analysis of the Nationally Determined Contributions (NDCs) to illustrate the extensive overlap between climate action plans and the 17 SDGs. NDCs, which outline national strategies for mitigation and adaptation, inherently encompass a broad spectrum of sustainable development initiatives, thereby underlining the capacity of climate action to contribute directly to the SDGs. This analysis emphasizes the potential for realizing mutual benefits through the successful implementation of NDCs.

Coenen et al. (2022) further explore the connections between climate actions, as outlined in 72 transnational initiatives, and the specific targets of the 17 SDGs. Their findings reveal that the vast majority of these initiatives support the achievement of 16 SDGs, thereby generating significant co-benefits and reinforcing the integral role of climate action in sustainable development. Additionally, Morton et al. (2019) argue that strategies aimed at long-term mitigation of climate change—such as reducing car usage, decreasing meat consumption, increasing renewable energy use, enhancing biodiversity, and promoting sustainable land and soil management—also yield immediate health benefits. These include increased physical activity, improved air quality, reduced calorie and

saturated fat intake, and greater exposure to natural environments, all of which contribute to enhanced physical, mental, and community health.

The intersection of climate action with the eradication of hunger (SDG 2) is particularly notable, as climate change adversely impacts all sectors of the economy, with the agricultural sector being significantly affected worldwide (Zahid et al., 2022). Stevenson et al. (2021) assessed 89 climate-relevant policies in the UK, finding that the majority align closely with SDGs 11 (Sustainable Cities and Communities) and 7 (Affordable and Clean Energy). In addition, the Industrial Strategy and the 25-Year Environment Plan are connected to various Sustainable Development Goals (SDGs), indicating that focused climate policies can promote cooperation among multiple SDGs, including SDG 3 (Good Health and Well-being), SDG 7, SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 11, SDG 14 (Life Below Water), and SDG 15 (Life on Land).

2.14.3 Sustainable highway infrastructure and climate change

The increasingly difficult problems caused by climate change have significant consequences for the development of infrastructure, particularly in the field of road and highways. The vital importance of sustainable road and highway infrastructure development emerges as a critical response to mitigate these impacts. Lee et al. (2013) highlights the significance of adopting sustainable materials and practices in road and highway construction. Their advocacy for the utilization of recycled materials aims at curtailing carbon emissions and minimizing the environmental footprint of road and highway projects. This approach not only addresses environmental sustainability but also aligns with economic considerations by potentially reducing construction costs and promoting resource efficiency. Egilmez & Tatari, (2012) extend the discourse by highlighting the necessity of developing strategies focused on fuel efficiency, the enhancement of public transportation systems, and the integration of electric vehicles. These strategies are pivotal in influencing policymaking towards sustainable infrastructure, demonstrating a comprehensive approach that encompasses both the construction phase and the operational life of road and highway infrastructure.

Leijstra et al. (2018) draw attention to the vulnerabilities of road and highway infrastructure in the face of climate change, including the risks posed by extreme weather

conditions such as heatwaves, droughts, and increased precipitation. They advocate for a proactive adaptation strategy to safeguard the longevity and sustainability of road and highways. This entails not only the development of new, more resilient infrastructure but also the maintenance and refurbishment of existing assets. Additionally, the implementation of advanced traffic management systems is proposed as a means to accommodate the exigencies of climate change. Furthermore, Rattanachot et al. (2015) emphasize the importance of dynamic adaptation strategies that evolve in response to emerging knowledge about climate change. This perspective advocates for a flexible approach to infrastructure planning and development, one that can adjust to unforeseen challenges and leverage new insights to enhance resilience and sustainability.

While significant strides have been made in understanding the intersection of climate change and highway infrastructure sustainability, gaps remain in specific methodologies for assessing climate impacts and the cost-effectiveness of adaptation strategies. This research focus on explores the interconnections between sustainability criteria in road and highway construction and climate action efforts, aiming to enhance the effectiveness of these synergies. The challenges posed by climate change to road and highway infrastructure in Ghana emphasize the need for a strategic focus on sustainable development practices. By integrating resilience into planning, design, and maintenance, Ghana can enhance the sustainability of its highway infrastructure, contributing to broader environmental, social, and economic objectives.

2.14.4 Impacts of climate change on highway infrastructure development

The susceptibility of transportation infrastructure to extreme weather events and gradual shifts in hydrogeological conditions presents a formidable challenge to its sustainability. The vulnerability of transportation networks, including road and highways, is shaped by a myriad of factors such as infrastructure type, geographic location, design specifications, and construction methodologies. These elements collectively heighten the risk and complicate the conventional practices involved in the planning, design, construction, and operation of transport infrastructure (Rattanachot et al., 2015). The consequences of climate change on the sustainability of road and highway infrastructure development manifest through various channels including precipitation changes, temperature fluctuations, sea-level rise, and increased frequency of storms (de Abreu et al., 2022; Meyer & Weigel, 2011; Regmi & Hanaoka, 2011; Wang et al., 2020) These factors are known to adversely affect concrete pavement construction practices, exemplified by issues such as thermal expansion at bridge joints and a reduction in the lifespan of

materials due to climate-induced temperature rises. Similarly, the stiffness and strength of asphalt layers are compromised, among other impacts.

Particularly in developing countries like Ghana, one of the significant repercussions of climate change is the escalated costs associated with the maintenance and repair of existing road networks due to damage inflicted by climate-related events (Twerefou et al., 2015; Twerefou et al., 2014). The financial strain imposed by these increased maintenance requirements highlights the economic dimensions of climate change impacts on road and highway infrastructure.

The reality and significance of climate change impacts on transportation infrastructures are undeniable (Rattanachot et al., 2015). It is essential for transportation agencies globally to acknowledge the potential effects of climate change on their infrastructure assets and to devise appropriate adaptation strategies. These strategies are critical not only for addressing immediate challenges but also for ensuring the resilience and sustainability of transportation networks in the face of future climatic uncertainties.

2.14.5 Climate actions for sustainable highway infrastructure development

In the quest for sustainability within the road and highway sector, it is essential to identify and implement climate actions that enhance the resilience and sustainability of road and highway infrastructure. Regmi & Hanaoka (2011) advocate for a multi-faceted approach to bolster sustainable road and highway development. This includes increasing stakeholders' awareness of climate change impacts, re-evaluating road and highway design standards and construction practices with climate impacts in mind, implementing assessment guidelines for climate change effects, establishing dedicated organisational units for executing adaptation strategies, and fostering coordination among stakeholders to develop resilient road infrastructure. Notable strategies encompass adopting climate-responsive design standards, utilizing sustainable construction materials, and ensuring diligent maintenance of road and highway infrastructure. Additionally, Rattanachot et al. (2015) propose specific measures to improve the resilience of roadways, such as transitioning pavement materials from asphalt to concrete, enhancing subgrade foundations during road reconstructions or repairs, and upgrading roadside drainage systems to better manage water flow and prevent damage.

Auerbach & Herrmann (2016) emphasize the importance of conducting risk analyses, like vulnerability assessments for bridges and tunnels or evaluations of road drainage systems'

designs in the context of climate change. Such analyses are crucial for anticipating the impacts of climate change and formulating mitigation strategies accordingly. Moreover, the adaptation of climate actions tailored to specific climatic conditions has been explored by researchers such as de Abreu et al. (2022) and Meyer & Weigel (2011). Innovations like installing cooling systems within roadbeds to counteract thawing and improving pavement irrigation systems to mitigate high temperature effects exemplify targeted responses to climatic challenges.

Wang et al. (2020) further introduce climate adaptation frameworks specifically designed for the transportation sector, such as blueprinting (Niemeier et al., 2015), Dynamic Adaptive Planning (Wall et al., 2015), and Adaptive Systems Management (Meyer & Weigel, 2011). These frameworks offer structured approaches to integrating climate resilience into transportation infrastructure planning and management, ensuring that road and highways can withstand and adapt to the changing climate.

2.14.6 Sustainability Perceptions and Climate Action Support

Examining the relationship between highway construction professionals' assessments of sustainability criteria and their support of climate action is a critical area of research in the context of sustainable development in road and highway infrastructure. This literature review examines how the perceptions of these professionals, regarding environmental, economic, technical, social equity and culture, project implementation and management, and resource utilization and management criteria, relate to their advocacy and support for climate action.

- **Environmental Criteria:** Environmental sustainability in road and highway construction involves minimizing the negative impacts on the natural environment through the adoption of eco-friendly practices and materials. Research by Agyeman & Evans (2003), underlines the significance of environmental considerations in fostering support for climate action, suggesting that professionals who prioritize environmental criteria are more likely to advocate for and implement climate-resilient measures in their projects.
- **Economic Criteria:** Economic sustainability involves ensuring that road and highway infrastructure projects are cost-effective and provide value for money over their lifecycle. While economic considerations are often seen as at odds with environmental goals, studies by Pearce (2003) have highlighted a growing recognition among professionals that economic and environmental sustainability

can be synergistic, potentially enhancing support for climate action through the demonstration of long-term cost savings and financial benefits.

- **Technical Criteria:** Technical sustainability focuses on the adoption of innovative and efficient construction techniques and materials that contribute to the longevity and resilience of infrastructure. The work of Zou et al. (2007) indicates that a technical understanding of sustainable practices is crucial for incorporating climate action into road and highway projects, as professionals with a strong grasp of technical criteria are more inclined to support and implement adaptive and mitigation strategies against climate change.
- **Social Equity and Culture Criteria:** This dimension emphasizes the social implications of road and highway infrastructure projects, including impacts on communities, equity, and cultural preservation. The study by Beatley & Manning (1997) suggests that social considerations are integral to gaining public support for sustainable infrastructure projects, with a direct correlation between social equity-focused professionals and their support for inclusive climate action initiatives.
- **Project Implementation and Management Criteria:** Effective project management ensures that sustainability and climate action goals are integrated into every stage of infrastructure development. According to Silvius & Schipper (2014), professionals who value project management criteria are more effective in embedding climate action into their practices, highlighting the role of structured implementation strategies in promoting sustainability.
- **Resource Utilization and Management Criteria:** This criterion involves the efficient use of materials and resources, promoting recycling, and minimizing waste. Research by Ofori (2000), demonstrates that a focus on resource management not only contributes to environmental sustainability but also enhances the propensity of professionals to support and advocate for climate action, recognizing the interdependencies between resource efficiency and climate resilience.

The literature illustrates a complex but discernible relationship between the perceptions of highway construction professionals regarding various sustainability criteria and their support for climate action. While individual criteria contribute uniquely to this relationship, the overarching theme is that a holistic understanding and prioritization of

sustainability across all dimensions can significantly enhance climate action support among professionals in the field.

2.14.7 Theory of Sustainability Considerations and Climate Action Support

The theoretical underpinnings of how highway construction professionals' perceptions of sustainability criteria and indicators correlate with their support for climate action can be explored through various conceptual lenses. Central to this investigation is the Theory of Planned Behaviour (TPB) by Ajzen (1991), which posits that an individual's behaviour is directly influenced by their intention to perform the behaviour, which is in turn influenced by their attitude towards the behaviour, subjective norms, and perceived behavioural control. In the context of sustainable road and highway infrastructure development, this theory suggests that professionals' support for climate action may be shaped by their attitudes towards sustainability practices, the social pressures they perceive, and their perceived ability to implement these practices.

Additionally, the Value-Belief-Norm (VBN) theory proposed by Stern et al. (1999), provides a framework for understanding the link between individuals' deeper held values and their environmental behaviours. The theory suggests that personal values influence environmental beliefs, which in turn inform personal norms about environmental responsibility, ultimately motivating behaviour that supports environmental outcomes. Applied to highway construction professionals, this theory suggests that those with stronger biospheric values are more likely to perceive sustainability criteria as important and thus more likely to support climate action.

The Diffusion of Innovation theory by Rogers (2003), also offers insights into how new ideas, practices, or technologies spread within a community or an organization. In the context of sustainable road and highway infrastructure, this theory can help explain how innovative sustainability practices and indicators become adopted by professionals within the construction industry. The theory emphasizes the roles of perceived attributes of innovations, the communication channels used, time, and the social system in influencing the adoption process. Professionals' perceptions of the relative advantages, compatibility, complexity, trialability, and observability of sustainability practices can influence their support for these practices and, by extension, climate action.

Furthermore, the concept of Triple Bottom Line (TBL) Elkington (1997), provides a foundational framework for assessing sustainability in infrastructure projects by

emphasizing the need for balancing economic, social, and environmental objectives. This approach aligns with the sustainability criteria and indicators in road and highway construction, suggesting that professionals' support for climate action is integral to achieving sustainability in the sector.

When integrating these theories, it becomes evident that the perceptions of highway construction professionals about sustainability criteria and indicators and their support for climate action are multifaceted and influenced by a combination of personal values, social norms, perceived control, and the perceived attributes of sustainability practices. Understanding these theoretical frameworks provides a basis for exploring the empirical relationship between professionals' perceptions and their support for climate action in the context of Ghanaian road and highway infrastructure development.

2.15 Sustainability Research Gap

Despite increasing emphasis on sustainability across various sectors, a notable gap persists in the application and understanding of sustainability principles within road and highway infrastructure development, particularly in Sub-Saharan Africa. While substantial research has advanced sustainability methods and decision tools within the building industry (Huang & Yeh, 2008; Liu et al., 2023), the transportation infrastructure sector, notably road and highways, has received less attention (Dasgupta & Tam, 2005; Tsai & Chang, 2012). This oversight is critical, considering the significant environmental, socio-economic, and geographical ramifications of road and highway infrastructure projects. A limited number of sustainability evaluation tools are tailored to the road and highway sectors with minimal exploration of their application (Brent & Labuschagne, 2004; CEEQUAL, 2008; Dasgupta & Tam, 2005). Although these tools have underpinned sustainable development, their relevance and applicability to road and highway infrastructure sustainability are insufficiently explored. While some studies have introduced sustainability indicators for roads (Ametepey, 2019; Chiu, 2002), a holistic approach to embedding these indicators in practical road and highway infrastructure development remains undeveloped.

Additionally, the diverse perceptions and concerns regarding sustainability among stakeholders highlight a significant gap between theoretical frameworks and practical implementation of sustainability in road and highway infrastructure development (Erkul et al., 2016; Hariram et al., 2023). This gap signals the need for a sustainability framework that not only synthesizes findings from previous research but also addresses specific

stakeholder concerns in road and highway infrastructure projects, with a focus on practical application. Recent literature identifies the absence of strategies for integrating sustainable indicators with road and highway infrastructure development needs Suprayoga et al. (2020), and the lack of financial assessments of sustainability aspects in road and highway projects (Goh & Yang, 2010). These gaps highlight the necessity for a comprehensive approach that includes economic, environmental, technical, project implementation, resource utilization, and social indicators in the sustainability evaluation of road and highway projects.

A profound literature gap exists in the exploration of highway construction professionals' perceptions of sustainability criteria and their alignment with climate action. This gap is especially pronounced in Ghana, where infrastructural challenges and climate vulnerability present unique intersections (Asibey et al., 2024). Moreover, empirical evidence on the practical implementation of sustainability practices in Ghana's road and highway construction is scarce, with little examination of the effectiveness of existing sustainability indicators and the real-world application of sustainability policies (Anarfi, 2020; Mensah et al., 2017). The role of traditional knowledge in enhancing sustainability in infrastructure development is often overlooked. In the Ghanaian context, where local knowledge systems are abundant, integrating this wisdom could offer innovative and culturally appropriate sustainability solutions (Gbedemah, 2023). Furthermore, there is a notable deficiency in quantitative analysis related to climate action support among highway construction professionals in Ghana, with existing research heavily reliant on qualitative assessments (Amegavi et al., 2024). Addressing these gaps requires targeted research that bridges global sustainability frameworks with the realities of local implementation, fostering truly sustainable infrastructure development in alignment with Ghana's developmental goals.

2.16 Summary

Infrastructure projects represent some of the most substantial investments globally, with road and highway infrastructure projects in Ghana exemplifying a critical area where demand significantly surpasses supply. These projects are pivotal for fostering economic growth and human development. As such, it is a need to ensure a holistic approach to road and highway infrastructure development, one that achieves a harmonious balance among economic viability, social equity, and environmental sustainability.

Previous research within the realm of infrastructure development has predominantly focused on performance metrics, assessment methodologies, and policy frameworks, with limited attention given to embedding sustainability in the road and highway infrastructure sector. This oversight is notable given the sector's profound influence on economic dynamics, societal well-being, and environmental integrity. This study aims to enrich the existing body of knowledge by reviewing and synthesizing research on sustainable infrastructure development, particularly within the context of road and highway infrastructure development.

Through a comprehensive analysis of literature on sustainability evaluation tools and consultations with industry professionals and academic experts, this work has unearthed critical sustainability dimensions pertinent to the highway construction sector. These dimensions include economic, environmental, technical, social equity and culture, project implementation and management, and resource utilization and management aspects.

The derivation of a conceptual framework for constructing sustainable road and highway infrastructure in Ghana, grounded in sustainability principles and highway development processes, is a key outcome of this research. This framework is intended to guide future studies in this domain, facilitating the integration of sustainability considerations into the planning, design, and execution of road and highway projects. By doing so, it seeks to address identified gaps in the literature and emphasize the importance of sustainable road and highway infrastructure as a cornerstone for achieving broader development goals.

Chapter 3 : Research Methodology

3.1 Introduction

The development of a sustainability framework and guideline tailored for the Ghanaian road and highway construction industry presents a formidable challenge, necessitated by the unique socio-cultural dynamics of the region. To effectively address this challenge, it is essential to employ a comprehensive and rigorous approach to data collection and analysis. This chapter presents the research methodology employed in this study, offering a detailed methodological framework that underpins the investigation into sustainable road and highway infrastructure development practices within Ghana.

A sequential explanatory design, characterized by its two-phase approach of quantitative followed by qualitative analysis, is adopted to facilitate a comprehensive understanding of sustainability in road and highway infrastructure development. This mixed methods research approach allows for a holistic examination of the topic, integrating numerical data with contextual insights to inform the development of sustainability guidelines. The objectives of the study and the criteria for evaluating the research design's effectiveness are thoroughly discussed, ensuring clarity and coherence in the methodology.

Finally, the chapter addresses ethical considerations, highlighting the importance of conducting research responsibly and with respect for participants and the broader community. This includes considerations related to confidentiality, informed consent, and the ethical use of data, ensuring that the research adheres to the highest standards of academic integrity and contributes positively to the field of sustainable road and highway infrastructure development in Ghana.

3.2 Methodological Framework

The methodological framework is a systematic model that outlines the overall research strategy and design. It is led by a philosophical foundation that informs and justifies the approach used to address the research questions of the study (Alankarage et al., 2023). This framework is essential in providing a coherent rationale for the selection of specific research methodologies, techniques, and procedures, ensuring that the inquiry is both systematic and purposeful (Pfister et al., 2023). At the core of the methodological framework is the philosophical foundation, which sets the tone for the entire research process. It encompasses ontological and epistemological considerations, reflecting on the

nature of reality being investigated and the means through which knowledge about this reality can be acquired and understood (Asokan et al., 2020). Upon establishing this philosophical stance, the framework guides the selection of an appropriate research methodology that aligns with the study's objectives and research questions. This methodology, in turn, influences the choice of specific research techniques and methods, ranging from data collection and analysis to the interpretation of findings.

The methodological framework, therefore, serves as a blueprint for the research process, articulating the logical flow from philosophical assumptions to practical research actions. It ensures that the study's design is systematically aligned with its theoretical underpinnings, facilitating a coherent and integrated approach to addressing the research objectives.

3.3 Research Philosophy

Research philosophy is a foundational element that underpins the methodological choices and approaches within scholarly investigations. It encompasses the examination and application of established theories to deepen the understanding of a specific domain (Kuchinke, 2023). This philosophical inquiry is instrumental in guiding researchers through the myriad of theoretical frameworks available, facilitating informed decisions regarding the most appropriate methodological paths (Antwi & Hamza, 2015; Sefotho, 2015). The significance of research philosophy extends beyond theoretical contemplation; it directly influences the quality and design of research endeavours (Easterby-Smith et al., 2012). A clear articulation of a study's philosophical stance is essential, as it shapes the entire research process, from the initial drafting stages to the final conclusions drawn (Al-Ababneh, 2020). Therefore, identifying and defining the philosophical orientation of a research project is of paramount importance.

Within the broad spectrum of research philosophies, positivism and interpretivism emerge as the primary paradigms, each representing distinct approaches to knowledge acquisition and interpretation. Positivism, with its roots in empirical observation and quantifiable evidence, contrasts with interpretivism, which emphasizes understanding through the subjective interpretation of social phenomena (Easterby-Smith et al., 2012; Iovino & Tsitsianis, 2020). These paradigms are often conceptualized as occupying opposite ends of a continuum that encompasses a diverse range of philosophical perspectives, including postpositivism and pragmatism (Masuku, 2023). The choice among these paradigms is guided by the researcher's epistemological (nature of

knowledge), ontological (nature of reality), and axiological (value systems) positions, which collectively inform the methodological approach of the study (Creswell, 2007). The importance of these three philosophical tenets is briefly covered in the following subsections.

3.3.1 Ontology

The research is grounded in a critical realist ontological perspective, which acknowledges both the existence of a single objective reality and multiple subjective interpretations of that reality (Mukumbang, 2023). This ontological stance recognizes that while the indicators for sustainable road and highway infrastructure development represent tangible, measurable phenomena, their interpretation and application in decision support guidelines are often socially constructed and culturally mediated through stakeholder values, local practices, and community priorities. These dual realities coexist in infrastructure development, where objective engineering principles meet subjective societal needs and cultural contexts.

3.3.2 Epistemology

The epistemological foundation of this study pertains to how knowledge is acquired, validated, and applied (Becker & Niehaves, 2007; Moon et al., 2021). The research adopts a pragmatist epistemological approach, which asserts that knowledge is constructed through practical inquiry, focusing on real-world outcomes and the effectiveness of actions in addressing specific problems (Kelly & Cordeiro, 2020). This pragmatic stance aligns with the critical realist ontology by acknowledging both objective measurements and subjective interpretations in knowledge creation.

In the context of sustainability in road and highway infrastructure development in Ghana, this combined philosophical approach embraces both subjective stakeholder perspectives and cultural interpretations while emphasizing the importance of generating knowledge that is directly applicable to solving practical challenges (Barak et al., 2024; Raelin, 2007). This foundation supports a mixed-method sequential explanatory approach, which systematically combines quantitative and qualitative methods to capture both objective and subjective insights.

The quantitative phase initiates the research by measuring objective realities through comprehensive surveys among highway professionals. This phase serves multiple purposes: identifying critical sustainability indicators, examining the relationships

between sustainability criteria and climate action, and providing measurable, generalizable findings that form the foundation for further investigation. Building upon these quantitative insights, the qualitative phase employs in-depth interviews to explore subjective interpretations and provide deeper understanding of stakeholder perspectives. This phase contextualizes the quantitative findings within local cultural and social frameworks, capturing understanding of sustainability challenges specific to Ghana's infrastructure development context.

The integration of these complementary approaches enables several key outcomes. First, it allows recognition of both singular and multiple realities in sustainability assessment. Second, it provides flexibility in understanding sustainability from multiple angles, ensuring comprehensive coverage of all relevant aspects. Third, it facilitates the development of guidelines that effectively combine objective metrics with subjective experiences. Finally, it bridges the critical gap between abstract sustainability concepts and their practical application in the Ghanaian context. This methodological approach ensures that the resulting sustainability guidelines are firmly grounded in measurable, objective criteria while remaining sensitive to local perspectives and cultural contexts. The guidelines are designed to be adaptable to the dynamic nature of road and highway projects, making them practically relevant to Ghana's infrastructure development needs. This comprehensive approach ensures that the developed framework not only meets rigorous academic standards but also provides practical value for infrastructure development practitioners in Ghana.

By combining critical realist ontology with pragmatist epistemology, this study creates a robust foundation for developing sustainability guidelines that are both scientifically rigorous and contextually appropriate. This approach facilitates the integration of sustainability principles into the planning, design, and implementation phases of highway infrastructure development, while acknowledging both the objective realities of infrastructure development and the subjective interpretations of various stakeholders.

3.3.3 Axiology

The axiological aspect of a research paradigm concerns itself with the value systems that underpin a study, including the roles of the researcher's values in the research process and the value-laden nature of the information being gathered. For the study titled "Developing an enhanced framework of sustainability deliverables in Ghanaian highway construction projects," an understanding of axiology is essential to appreciate how the researcher's

position as an outsider influences the approach to understanding sustainability practices within the Ghanaian context.

This research adopts an axiological stance that emphasizes objectivity, while acknowledging the inherent values associated with sustainability in road and highway infrastructure development. Given the researcher's position as an outsider, there is a deliberate attempt to minimize bias and ensure that the findings are reflective of the participants' perspectives rather than the researcher's preconceptions (Solbue, 2011). This approach necessitates a transparent and reflexive methodology, where the researcher's influence on the data collection and analysis processes is critically examined and clearly articulated. In aligning with this axiological perspective, the study employs methods that facilitate the unbiased collection and interpretation of data. Technique such as a semi-structured interview was designed to elicit rich, detailed insights from a different group of stakeholders involved in Ghanaian road and highway infrastructure development. These stakeholders include government officials, construction workers, engineers, and environmental advocates, among others, each bringing their own values and understandings of sustainability to the research (Amoako et al., 2023). The value of sustainability in this context is seen not just in environmental terms, but also through social, economic, technical, managerial, and cultural lenses, reflecting the multidimensional nature of sustainability in infrastructure development. By acknowledging the varied values and interests of these stakeholders, the research aims to develop guidelines for sustainability deliverables that are not only comprehensive and practical but also culturally sensitive and inclusive.

The axiological commitment of this study to objectivity and value awareness highlights the importance of a balanced and ethical approach to research. It ensures that the developed guideline for sustainability deliverables is grounded in the authentic experiences and values of those directly involved in and affected by road and highway construction projects in Ghana.

3.4 Research Paradigm

Interpretivism and pragmatic techniques are widely employed in the field of construction management research (Posillico et al., 2023). However, Amadi (2023) posits that no single methodology suffices to comprehensively address the details of construction management research, advocating for a multifaceted methodological design to enhance understanding within the construction management industry (including road and highway

infrastructure development). This perspective is further supported by Manoharan et al. (2023), who emphasize the importance of employing a multiple methodology design for an in-depth exploration of construction management practices. Considering the multidisciplinary scope of construction industry research, which spans the fields of both social and natural sciences, it is advisable to employ a mixed-methods approach, integrating both quantitative and qualitative methodologies (Khan et al., 2022). This study, aimed at investigating sustainable road and highway infrastructure development in Ghana and proposing recommendations to improve sustainability outcomes, is informed by an extensive review of existing literature and insights from interviews with road and highway construction professionals. The research acknowledges the multiplicity of realities and perspectives within the field, thereby rendering the positivist philosophy, with its emphasis on singular, observable realities, inapplicable to this context.

The range of expert opinions regarding the challenges and opportunities for enhancing sustainability in road and highway infrastructure development has led to the adoption of a mixed methods approach. This methodological choice aligns with the pragmatic paradigm, which is particularly suited to this study due to its flexibility in combining quantitative and qualitative research techniques within a singular investigative framework. Pragmatism, as articulated by Hampson & McKinley (2023), is grounded in the construction of knowledge and truth as determined by practical outcomes and what effectively addresses the research questions (Mayumi & Ota, 2023). By embracing pragmatism, this research adopts variables, units of analysis, and approaches that are optimally aligned with the objectives of the study, ensuring a comprehensive understanding of the sustainability challenges and opportunities in Ghanaian road and highway infrastructure development (Chi-Kuan et al., 2023). The pragmatic paradigm's endorsement of methodological pluralism facilitates a more in-depth and holistic comprehension of the research problem, achieved through the sequential collection and analysis of both quantitative data and qualitative insights.

3.5 Research Design

Adopting a pragmatic stance on knowledge claims, this study utilizes a mixed methods approach, characterized by its flexibility in combining quantitative and qualitative enquiry strategies. This methodology facilitates comprehensive data collection through either concurrent or sequential processes Aramide (2023), thereby enhancing the depth and breadth of understanding concerning the research problem. The dual nature of data

collection in this method, encompassing both numerical data and textual information, ensures that the outcomes of the study are enriched with insights derived from both quantitative and qualitative perspectives.

The research employs an explanatory sequential research design, which is particularly suited for investigations that aim to establish the prevailing conditions within a field and subsequently seek to unearth new insights through diverse lenses. This design was chosen to explore the multifaceted nature of sustainability in Ghanaian road and highway infrastructure development. It begins with the collection and analysis of quantitative data to give explanation the current state of sustainability practices. This is followed by qualitative enquiries designed to explore deeper into the findings, offering a richer, more in-depth understanding of the sustainability indicators from various stakeholder perspectives.

This study emphasizes the critical importance of reaching consensus among key stakeholders and recognizes the significance of integrating sustainable indicators that reflect a wide range of viewpoints. Through this iterative process of data collection and analysis, the study identifies pertinent variables and lays the groundwork for formulating hypotheses for future research endeavours (Fellows & Liu, 2008). This explanatory sequential design not only facilitates a comprehensive examination of the research problem but also ensures that the findings are robust, actionable, and reflective of the complex interplay of factors influencing sustainability in the context of road and highway infrastructure development in Ghana.

3.5.1 Research Methods Selection

The selection of research methods is a cornerstone of scientific investigation, guiding the systematic exploration of a study's questions and challenges. According to Gümüšoğlu et al., (2023), research methodology encompasses the rules and procedures of logical reasoning applied within a scientific context. This study on enhancing sustainability in Ghanaian road and highway infrastructure development necessitated a diverse array of research techniques to assess the current state, understand the context, and devise solutions to identified challenges. Emphasizing sustainability within road and highway infrastructure development requires considering the perspectives of all industry stakeholders to foster a collective understanding. In line with this, the study adopted a mixed methods approach, as previously mentioned, to thoroughly address the research questions through both quantitative and qualitative analyses. The chosen methods reflect

the subject matter and are executed within the designated timeframe, ensuring a comprehensive examination of the initial research problems (Tzagkarakis & Kritas, 2023).

A sequential explanatory design, as highlighted by Jackson-Gordon & Plano Clark (2023), integrates quantitative and qualitative data to provide a holistic analysis. Creswell & Plano Clark (2011), detail this approach, which begins with collecting and analyzing quantitative data to identify critical indicators. This is followed by qualitative data collection and analysis to further reveal the quantitative findings, thus offering deeper insights into sustainability indicators and stakeholder perceptions within road and highway infrastructure development. The utilization of questionnaires facilitated the gathering of broad responses, while subsequent interviews with knowledgeable professionals provided in-depth feedback on study concerns. This structured approach allowed for a seamless integration of research phases, addressing the questions effectively. Creswell & Plano Clark (2011), proposed the research sequential methodologies applied in this study, as illustrated in Figure 2:



Figure 2: The Explanatory Sequential Design. Adopted from: (Creswell & Plano Clark, 2011)

The explanatory sequential design outlined by Creswell & Plano Clark (2011), prioritizes quantitative data analysis to highlight critical sustainability indicators. Subsequent qualitative analysis deepens the understanding of these indicators, exploring the synergy between climate actions and sustainable development in highway infrastructure. Statistical testing was employed to identify significant indicators, followed by qualitative interviews to detail action plans for each indicator. Guidelines were formulated based on in-depth exploration through semi-structured interviews, addressing both the positive and negative aspects of sustainability enhancement. Telephone interviews served as a means of validation and verification, clarifying the comprehensive range of processes, actions, and activities necessary for bolstering sustainability in road and highway construction.

3.5.2 Plan of this Research

In constructing the methodology for this study, a structured plan was developed to systematically explore sustainability deliverables in Ghanaian road and highway infrastructure development. The research approach is segmented into four principal phases, ensuring a comprehensive investigation that encompasses both the theoretical framework and empirical analysis. These phases are intricately designed to build upon one another, facilitating a deepened understanding and practical insights into the subject matter, as illustrated in figure 3.

Literature Review: The initial phase involves an extensive review of existing literature to establish a solid theoretical foundation for the study. This comprehensive examination encompasses relevant theories, previous research findings, and established practices related to sustainability in road and highway infrastructure. The literature review aims to identify gaps in current knowledge and set the stage for empirical investigation.

Data Collection 1 and Analysis 1: Following the literature review, the first round of data collection is conducted through a questionnaire survey. This method is chosen for its efficiency in gathering quantitative data from a wide range of respondents, enabling the assessment of prevalent sustainability practices and perceptions within the industry. The subsequent analysis of this data provides initial insights and identifies key themes and trends.

Data Collection 2 and Analysis 2: The second phase of data collection involves conducting interviews. This qualitative approach allows for in-depth exploration of complex issues uncovered in the initial analysis, offering in-depth understanding and perspectives from industry professionals. The analysis of interview data further refines the study's findings, contributing to a richer, more comprehensive understanding of sustainability in road and highway construction.

SWOT Analysis and Recommendations: Utilizing the insights gained from both quantitative and qualitative analyses, a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis is performed. This strategic assessment informs the development of targeted recommendations for enhancing sustainability practices within the sector. The recommendations are designed to address identified challenges and leverage opportunities for improvement.

Validation and Verification: To ensure the reliability and applicability of the findings, a phone interview is conducted as a final step. This interview serves to validate and verify the decision-making rules and recommendations proposed by the study, ensuring their relevance and practicality for stakeholders in the Ghanaian road and highway infrastructure development industry.

The culmination of these phases results in the presentation of findings and the proposition of recommendations for advancing sustainability in road and highway construction projects. Additionally, the study outlines areas for further research, highlighting opportunities for continued exploration and improvement of sustainability guidelines in the context of Ghanaian infrastructure development. This structured research plan sets a clear and methodical approach to investigating sustainability in road and highway infrastructure development, from literature review through data collection and analysis, to the formulation and validation of actionable recommendations.



Figure 3: Research Plan

3.6 Research Main Activities

3.6.1 Review of Literature

The initial phase of this study is characterized by an exhaustive review of the literature on sustainability in the context of road and highway infrastructure development. This fundamental step aims to equip the researcher with a comprehensive background understanding of the subject matter, enriching the research with contextual insights. Mbanaso et al. (2023), emphasize that the purpose of conducting a literature review is twofold: it not only deepens the researcher's grasp of the topic at hand but also demonstrates an awareness of the latest and most pertinent research endeavours in the field. Furthermore, a critical literature review serves to identify existing gaps within the current body of knowledge and theoretical frameworks, thereby guiding the direction of the new research. Jiang et al. (2023), assert that literature reviews are essential in ensuring that no significant indicators relevant to the research problem are overlooked, as these indicators, identified from previous studies, are likely to influence the outcomes of the current investigation. To address the first research objectives outlined in the preceding chapter, this study embarked on an examination of relevant literature, drawing from a diverse array of sources. These included academic books, peer-reviewed journal articles, conference papers, theses and dissertations, government regulations, and articles from magazines and newspapers.

Through this comprehensive literature review, the frameworks for this research were outlined, and the critical components necessary for the investigation were identified. This process not only informed the development of the research methodology but also laid the groundwork for exploring sustainability within the Ghanaian road and highway construction industry. The literature review thus serves as a cornerstone of the study, providing the necessary theoretical and contextual foundation upon which the research is built. The frameworks for this research were discovered by the literature review, and the essential components were:

- The importance of sustainability in Infrastructure Development
- Sustainability in global road and highway infrastructure development
- Overview of road and highway infrastructure development practices in Ghana
- Benefits derived from developing sustainable highway infrastructure.
- Climate actions for sustainable road and highway infrastructure development

In order to improve and reinforce the theoretical foundation of this research, all publications, including academic and non-academic works, newspapers, and commercial online databases, were reviewed. The integration and comparison were performed using sustainable development tools such as the BREEAM Infrastructure (formerly CEEQUAL) Assessment Tool, and Leadership in Energy and Development (LEED). Also evaluated and analysed were research papers, publications, and other materials relating to road and highway construction and sustainability, and previously published sustainable performance criteria. This mechanism was used to help accomplish the first objective. The researcher would be better able to pinpoint the benefits of road and highway construction and how this approach may perhaps improve sustainable construction with more knowledge of highway and construction sustainability. Additionally, this system's drawbacks were examined. After identifying the obstacles to sustainable highway construction adoption, a correlation between sustainability and highway design was established.

3.6.2 Questionnaire Survey – Phase One Approach

In pursuit of developing a comprehensive framework for sustainable road and highways in Ghana, and to clarify the relationship between highway professionals' perceptions of various sustainability criteria and their support for climate action, it became crucial to discern the indicators deemed critical by industry professionals. Consequently, a structured questionnaire was designed to gather insights on the opinions and perceptions of these professionals regarding a set of indicators derived from the literature review and existing sustainability guidelines. Given the extensive scope of data required and the varied pool of respondents, the questionnaire survey emerged as an effective method to achieve consensus among participants. Inusah et al. (2023), support this approach, advocating for questionnaire surveys as an efficient means of collecting substantial information to explore respondents' views and experiences concerning a specific subject. The collected data underwent rigorous analysis to pinpoint indicators pertinent to the local context, thereby facilitating sustainable development within the Ghanaian highway infrastructure sector.

Before launching the questionnaire survey, the researcher identified indicators related to sustainable road and highway infrastructure development. This preparatory step was followed by a pilot survey, aimed at assessing the questionnaire's effectiveness and feasibility, ensuring the reliability and validity of the instrument for the main survey. This methodological approach, as illustrated in Figure 4, establishes a direct linkage between

the questionnaire survey and the study's initial research questions, highlighting the survey's role in addressing the core objectives of the research.

What are the criteria and indicators used to assess sustainability in highway construction projects that are critical to highway professionals?

How do the perceptions of highway construction professionals about the sustainability criteria and indicators relate to their support for climate actions (SDG 13)?

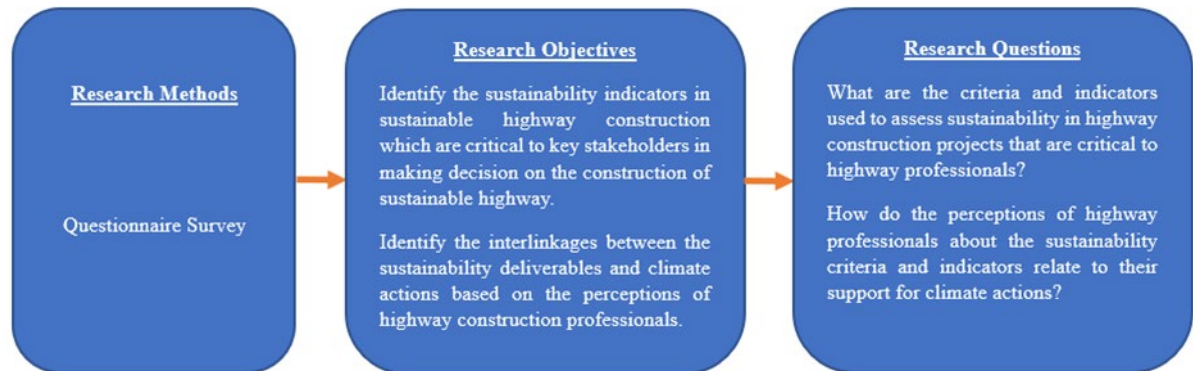


Figure 4: Questionnaire Survey Purpose

3.6.2.1 Sampling Size and Method

The selection of participants for the quantitative phase of this research on sustainable road and highway infrastructure in Ghana was guided by specific criteria, focusing on the qualifications and experience of individuals in road and highway planning, design, and construction within the Ghanaian context. Convenience and purposive sampling methods were employed to target key stakeholder organizations, 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 organizations are predominantly located. The total number of relevant highway professionals in the population was identified as 280, according to sources including GhIE (2023), GhIS (2021), and IET-GH (2023). To achieve statistical significance, the sample size was calculated with a 95% confidence level and a 5% margin of error, resulting in a necessary sample of 162 participants.

The questionnaire survey was distributed to 280 participants across various sectors of the Ghanaian road and highway industry, with an inclusion criterion of at least two years of industry experience. Of these, 162 responses were received, reflecting a 57.9% response rate, which is considered above the typical range for construction sector surveys (20% to 30%) according to Assaad et al. (2020).

3.6.2.2 Data Collection using the Questionnaire.

In this study, the decision to utilize a questionnaire as the primary tool for data collection was made strategically. The objective was to assess the level of agreement among professionals in the highway construction industry regarding decision-making procedures pertaining to sustainable road and highway infrastructure development in Ghana. The target participants were identified based on their roles in the planning, design, and construction phases of road and highway projects and were sourced from a variety of stakeholder organizations within the sector. Initial contact was established via publicly accessible email addresses listed on these organizations' websites, followed by an invitation to partake in the study through a link to a Qualtrics survey.

The design of the questionnaire was designed to mirror the sustainability indicators outlined through the literature review, segmented into five distinct sections. Section A gathered demographic information from respondents, including their educational background, professional affiliations, organizational affiliations, and years of experience in the sector. Section B queried participants on a series of sustainability indicators relevant to the planning, design, and construction of road and highways. Participants were requested to assess the importance of these indicators in fostering sustainable road and highway infrastructure development in Ghana, utilizing a nominal scale ranging from "least important" to "extremely important," as depicted in Figure 5.

Q8. Below are a number of sustainability indicators for highway planning, design and construction. With your experience, please express your opinion on the importance of the following sustainability indicators in enhancing sustainable highway infrastructure development in Ghana by ticking the appropriate scale.

	Least Important	Moderately Important	Important	Very Important	Extremely Important
Reduce Life cycle costs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduce Labour costs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduce Material costs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 5: A typical example of how indicators were presented.

Section C shifted the focus towards Sustainable Development Goal 13 (Climate Action), probing respondents' viewpoints on mitigation and adaptation strategies pertinent to road and highway infrastructure. This section required participants to indicate their agreement or disagreement with a set of statements related to climate change actions, with examples of these statements and their response options illustrated in Figure 6.

Q9. There is strong evidence of synergies between the targets of all Sustainable Development Goals and climate actions (e.g., mitigation and adaptation). Please indicate your level of agreement/disagreement with the following statements of actions against climate change.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I support road designs that harness local topography to reduce energy requirements during the construction phase.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I encourage the use of appropriate network data and hazard assessments by highway designers and planners with a focus on vulnerable communities for rapid recovery during disasters.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 6: Depicts example of Statement presented.

Section D allowed for the provision of additional comments or suggestions, encouraging an open-ended dialogue. The concluding section, Section E, inquired about the respondents' willingness to participate in follow-up interviews to gather deeper insights into the research findings and contribute to the development of the ensuing guideline. This section also included an option for participants to submit their email addresses if they wished to receive a summary of the survey findings. This methodological approach to questionnaire design was instrumental in ensuring a thorough assessment of professional perspectives on sustainability within the Ghanaian road and highway construction context. It facilitated the collection of both quantitative data regarding sustainability indicators and qualitative feedback on the actual application of sustainable practices within the industry.

3.6.2.3 Survey Instrumentation

To guarantee the effectiveness and accuracy of the questionnaire used in this study, a pilot survey was executed, aimed at evaluating the instrument's clarity, comprehensiveness, and the time required by respondents to complete it (Reda Ismail et al., 2023). This initial step was instrumental in identifying and correcting any potential issues within the questionnaire, such as ambiguities or omissions. A select cohort of potential participants was involved in this phase, whose feedback was analyzed and incorporated into the final version of the questionnaire to improve its utility.

The use of the internet and email as channels for survey distribution has gained substantial traction since the late 1990s, offering a compelling alternative to conventional survey methodologies (Hoonakker & Carayon, 2009). The benefits of online surveys, as outlined

by Melis Cin et al. (2023), include cost-effectiveness, efficiency in time, expanded access to a diverse array of participant groups, and the safeguarding of respondent anonymity. Moreover, online survey platforms provide immediate reporting features, allowing researchers to track crucial metrics such as participation rates and the amount of time respondents spend on the questionnaire. These platforms are customizable to meet specific research goals, thus amplifying the effectiveness of the study. The questionnaire survey for this research was carried out from March 6, 2023, to March 31, 2023, via an internet-based platform. "Qualtrics Survey Software" was chosen for its capabilities in survey creation and distribution, recognized for its comprehensive suite of web-based tools that support survey design, customization, and response management and tracking. This choice was motivated by Qualtrics' robust functionality in facilitating the analysis and visualization of the gathered data. The user interface of the Qualtrics Survey Software, exemplified in the study, highlights its suitability for this research, with Figures 7 and 8 depicting the software's homepage and answer interface, respectively.



Figure 7: The homepage of Qualtrics Survey Software

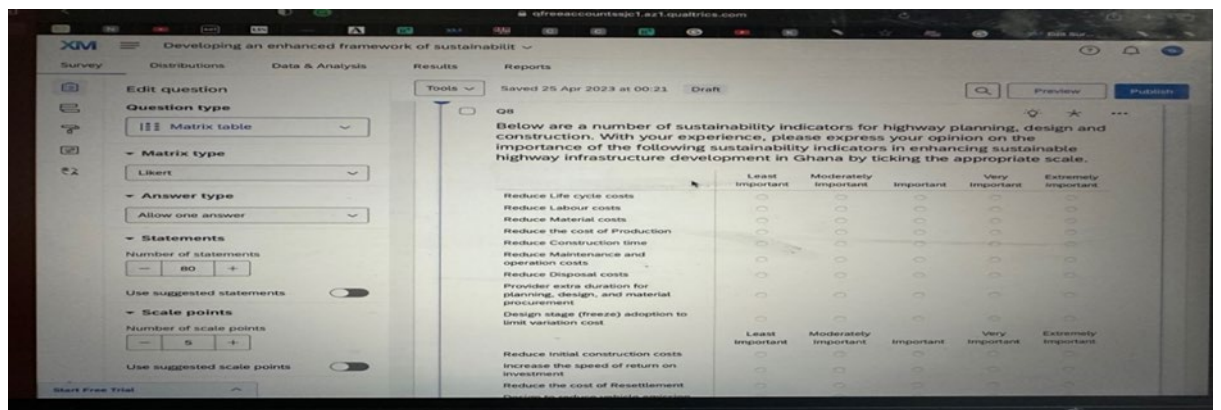


Figure 8: Exemplifies the answer interface for the Qualtrics Survey

3.6.2.4 Survey Validity and Response Rate

In order to gather insights on sustainability practices from stakeholders within the Ghanaian road and highway industry, a comprehensive set of 400 questionnaires, accompanied by a detailed participant information sheet, were disseminated via email. The inclusion of the participant information sheet was pivotal for communicating the study's objectives and upholding confidentiality, thereby adhering to ethical research standards. The survey targeted a comprehensive range of professionals from diverse fields including private and public road and highway consultancy firms, road and highway construction companies, academic and research institutions, and regulatory agencies such as the Environmental Protection Agency, Ghana Standards Authority, Water Resources Commission, Road Agencies, and Forestry Commission. A criterion for participation was established, requiring respondents to have at least two years of experience in the Ghanaian road and highway sector.

The process of participant recruitment involved a systematic review of websites and official directories belonging to applicable stakeholder organizations. To enhance the likelihood of a higher response rate, a specific timeframe for submitting responses was defined, and follow-up reminder emails were politely sent (Röhr et al., 2023). At the conclusion of the designated response period on March 31, 2023, a total of 162 questionnaires were collected.

Subsequently, the responses underwent an extraction process into CSV format, followed by a detailed review and cleaning phase. This phase was crucial for identifying and discarding responses that did not satisfy quality criteria, such as consistent scoring across items or evidence of insufficient experience in road and highway construction. After this validation process, the final response rate was determined to be 57.9%. According to Assaad et al. (2020), this response rate is notably commendable, surpassing the standard acceptance threshold for research within the construction sector, which generally lies between 20% to 30%.

3.6.2.5 Data Analysis (Quantitative phase)

After cleaning the collected data, the questionnaire responses were subjected to both descriptive and inferential statistical analyses using SPSS Statistics. This software is distinguished for its robust data analysis features, facilitating ease in data interpretation (Kline, 2018). Descriptive statistics provided an in-depth overview of respondent demographics, whereas inferential statistics shed light on the sustainability criteria and their indicators, highlighting those deemed essential and exploring perception variations among different respondent groups.

To identify the key indicators for sustainable road and highway infrastructure development, responses were numerically coded according to their perceived importance level: 1 for "least important," increasing to 5 for "extremely important." The mean importance score for each indicator was calculated to determine their ranking, using the formula:
$$\frac{Sum}{Count} \text{-----} (1)$$

With the average scores, critical indicators were presented, using a threshold score of four (4) to qualify an indicator as significant. This approach is consistent with the methodologies utilized by researchers such as Ekanayake & Ofori (2004), Muller et al. (2023), and Wong & Li (2006), who have applied the one-sample t-test in their studies.

The t-test was employed to validate the significance of the critical indicators under the following hypotheses:

- **Null hypothesis (H₀):** The mean value of the population is less than or equal to that of the specified value.
- **Alternative hypothesis (H₁):** The mean value of the population is larger than the specified values.

A p-value greater than 0.05 necessitates rejecting the null hypothesis (H₀), thereby accepting the alternative hypothesis (H₁), and concluding that the indicator's population average score is significantly above 4. Indicators exceeding this benchmark were classified as critical.

Given the potential for substantial variability in perceptions across different stakeholder groups, reaching a consensus on the importance scores of critical indicators was crucial for the framework development. The Kruskal-Wallis H test, a non-parametric method suited for assessing statistical differences across multiple groups on continuous or ordinal variables (Laerd, 2015a), was applied to examine score heterogeneity among groups. A p-value of 0.05 or less signified significant differences in importance scores among the respondent groups. Further analysis to identify specific groups with significantly differing scores utilized the Mann-Whitney U test, following recommendations by Agresti (2013), Hart (2001), and Laerd (2015b), to investigate variations in the perceived importance of indicators.

3.6.2.6 Conceptual Framework and Hypotheses Development

Climate change poses a significant global challenge, exerting its influence on nations worldwide, encompassing all continents. It has detrimental effects on human lives, economies, and imposes considerable financial burdens on individuals, communities, and nations, both currently and in the future. In response, Goal 13 of the United Nations' 2030 Agenda for Sustainable Development calls for urgent action to combat climate change and its impacts, highlighting the integral role of climate action in achieving the Sustainable Development Goals (SDGs) (United Nations, 2023a). The literature emphasizes a significant synergy between climate action and other sustainable development dimensions (Fairbrother, 2022), with a universal call to stakeholders at all levels to mitigate climate change effects (United Nations, 2023b). Jones et al. (2023) categorize support for climate action into two types: stated support, which refers to positive attitudes towards climate action, and active support, which involves actual

environmentally responsible behaviour. Public opinion significantly influences government actions concerning climate change (Anderson et al., 2017; Schaffer et al., 2022), with individual factors largely determining the level of stated and active support for environmental policies (Ajzen, 1985; Stern et al., 1999). Although there is a recognized link between climate actions and sustainable development goals (Coenen et al., 2022; Thapa et al., 2023), the correlation between environmental concerns and support for climate actions and policies is not straightforward. Environmental concern is defined as awareness of, support for, and willingness to actively contribute to resolving environmental issues (Dunlap & Jones, 2002), acting as either a specific attitude influencing intentions or a broader attitude/value orientation (Bamberg, 2003).

This research extends the discourse to other sustainability dimensions, questioning whether a relationship exists between stakeholders' support for climate actions and their perceived importance of other sustainable development dimensions within the road and highway industry. It explores the potential synergies between highway professionals' support for climate action and their attitudes towards sustainable road and highway infrastructure development dimensions. The investigation focuses on how attitudes towards sustainable road and highway infrastructure development dimensions (e.g., economics, environment, technical aspects, project implementation, social equity and culture, and resource utilization) influence support for climate action. Recognizing potential trade-offs between sustainability dimensions and climate action, this study examines whether support for climate action influences the prioritization of sustainability dimensions within road and highway development.

The research hypothesizes a bidirectional relationship between attitudes towards sustainable road and highway infrastructure development dimensions and support for climate actions, suggesting that climate actions contribute towards achieving broader sustainability goals. Figure 9 presents the conceptual framework, linking sustainable road and highway infrastructure development dimensions with supported climate actions. The subsequent section details this framework and introduces the hypotheses formulated for further exploration.

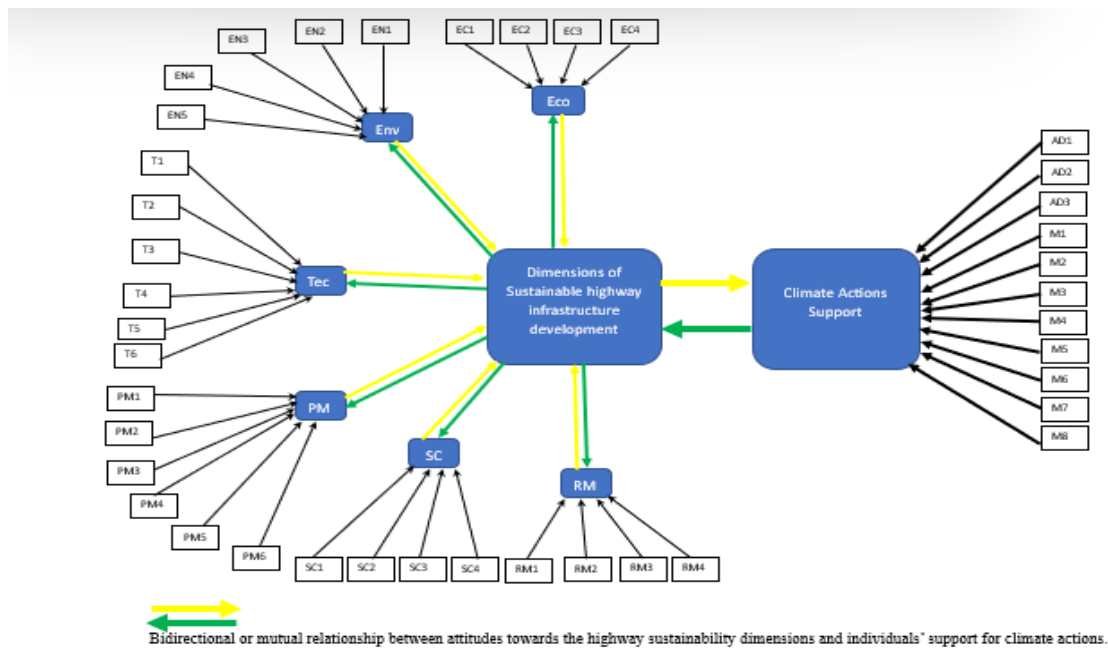


Figure 9: Conceptual framework.

3.6.2.6.1 Hypotheses Development: Economic Dimension

The convergence of economic considerations and climate action in infrastructure development highlights the significance of integrating climate change consequences into the economic assessments of projects. Monasterolo (2020) in "Climate Change and the Financial System" emphasizes the need to align economic interests with climate initiatives, advocating for investments in sustainable transportation. This view suggests that recognizing the long-term economic benefits of sustainable infrastructure investments, such as decreased maintenance costs and job creation, may increase individuals' willingness to support climate actions promoting sustainable and cost-efficient transportation solutions. However, the emphasis on the economic aspects of highway infrastructure development does not automatically ensure support for climate actions. Public perception, as described by Drews & van den Bergh (2016), often leans towards a scepticism that environmental and climate policies might negatively affect the economy, which could reduce support for such policies (Shwom et al., 2010). In contrast, when climate actions are perceived as pathways to economic benefits, like generating green jobs or lowering long-term operational expenses, there may be a heightened inclination to prioritize economic dimensions in sustainable infrastructure projects. While some individuals may accept higher immediate costs for achieving climate goals, others might focus on the long-term economic gains, viewing sustainable infrastructure as inherently cost-effective.

Given these considerations, the following hypotheses are formulated to examine the impact of the economic dimension on support for climate action within road and highway infrastructure development:

- **H_{1a}:** The perceived importance of the economic dimension will significantly and positively influence support for climate action. This hypothesis suggests that acknowledging the economic advantages of sustainable infrastructure development enhances individuals' likelihood to support climate action initiatives.
- **H_{1b}:** Individuals supporting climate actions will place greater importance on the economic dimension of road and highway infrastructure development. This hypothesis indicates a reciprocal relationship where support for climate actions heightens the focus on the economic benefits of sustainable infrastructure, potentially leading to a prioritization of economic over environmental considerations.

These hypotheses are designed to unravel the complex relationship between economic considerations and support for climate action, highlighting the complex interplay between recognizing the economic benefits of sustainable practices and advocating for climate-oriented policies in road and highway infrastructure development.

3.6.2.6.2 Hypotheses Development: Environmental Dimension

The Intergovernmental Panel on Climate Change (IPCC, 2007) highlights the urgent necessity for environmentally sustainable practices in infrastructure development. It advocates for the adoption of green materials, energy-efficient designs, and strategies to reduce emissions. These practices are crucial not only for mitigating the impacts of climate change but also for advancing climate-friendly transportation initiatives, as exemplified by the "Green Highways Partnership" of the Environmental Defence Fund (EDF). This highlights the intrinsic connection between environmental attitudes and support for climate action, suggesting that a commitment to environmentally sustainable road and highway development aligns with broader climate change mitigation objectives. It is proposed that individuals expressing support for climate actions are likely to harbour positive attitudes toward implementing environmentally friendly practices in road and highway infrastructure development. This encompasses a preference for projects emphasized by environmental sustainability, which include measures aimed at emission reduction and conservation of natural resources. Consequently, the importance attributed

to the environmental dimension of sustainability in infrastructure projects is anticipated to be significantly high among these individuals.

Based on this premise, the following hypotheses are developed to investigate the relationship between the environmental dimension of sustainable road and highway infrastructure development and support for climate actions:

- **H_{2a}:** There exists a significant positive relationship between the importance attributed to the environmental dimension and the level of support for climate actions. This hypothesis indicates that individuals prioritizing environmental sustainability in road and highway infrastructure are more inclined to support broader climate action initiatives.
- **H_{2b}:** Support for climate actions correlates with an increased focus on the environmental dimension within road and highway infrastructure development. This hypothesis suggests that individuals advocating for climate change mitigation measures also tend to prioritize environmental considerations in the planning and implementation of road and highway infrastructure projects.

These hypotheses aim to clarify the bidirectional influence between environmental sustainability priorities and support for climate actions, emphasizing the essential role of environmental attitudes in fostering a supportive framework for climate-friendly infrastructure development.

3.6.2.6.3 Hypotheses Development: Technical Dimension

The research conducted by Markolf et al. (2019) titled "Transportation Resilience to Climate Change and Extreme Weather Events – Beyond Risk and Robustness" highlights the indispensable role of technical competence in the development of climate-resilient transportation infrastructure. It stresses the need for technical competence to effectively implement climate adaptation measures, highlighting that trust in technical knowledge is crucial for successfully enhancing transportation systems' resilience to climate change and extreme weather phenomena. Professionals in the road and highway sector who value the technical aspects of sustainable road and highway infrastructure development are likely to recognize the importance of infrastructure capable of withstanding climate change impacts. This recognition often manifests as a supportive attitude towards climate actions, including adopting measures to improve road and highway projects' climate resilience. However, it is essential to understand that a positive technical attitude does not automatically result in support for climate actions. Conversely, professionals advocating

for climate action, particularly in terms of developing climate-resilient facilities, are expected to place significant importance on the technical dimension of infrastructure projects. Such individuals are predisposed to endorse climate-resilient design standards, materials, and construction techniques, acknowledging the essential role of technical proficiency in creating infrastructure that can endure the effects of climate change. Considering these insights, the following hypotheses are formulated to investigate the relationship between the technical dimension of sustainable road and highway infrastructure development and support for climate actions:

- **H_{3a}:** A significant positive relationship exists between the importance placed on the technical dimension and the level of support for climate actions. This hypothesis indicates that individuals emphasizing technical aspects in road and highway development are more likely to support climate action measures that enhance infrastructure resilience.
- **H_{3b}:** Support for climate actions affects the perceived importance of the technical dimension in road and highway infrastructure development. This hypothesis suggests that individuals favouring climate action measures tend to prioritize technical aspects of infrastructure projects, recognizing the need for integrating climate-resilient features.

These hypotheses are designed to clarify the bidirectional relationship between technical considerations in road and highway infrastructure development and support for climate actions. By examining how technical attitudes influence support for climate action and vice versa, this research aims to emphasize the indispensable role of technical expertise in promoting climate-resilient infrastructure projects.

3.6.2.6.4 Hypotheses Development: Project Implementation and Management Dimension

Arif & Bayraktar (2012), in their influential study "Theoretical Framework for Transportation Infrastructure Asset Management Based on Review of Best Practices," highlight the critical importance of effective project management in infrastructure development. Their research reveals the increasing presence of climate-related regulations in infrastructure projects, suggesting that adherence to these requirements is essential for achieving project goals successfully. Professionals who value effective project management are likely to acknowledge the significance of these climate mandates and, as a result, support climate actions that are in line with regulatory standards and

project success criteria. Additionally, it is proposed that individuals advocating for climate actions possess favourable views towards comprehensive project planning and management practices (ACTION, 2013). Such attitudes are crucial for implementing climate mitigation and adaptation strategies within infrastructure projects, with the integration of effective project management practices being key to fulfilling both project success and climate resilience objectives. In light of this background, the following hypotheses are proposed to investigate the relationship between project implementation and management practices and support for climate actions among highway professionals:

- **H_{4a}:** Highway professionals who highly value effective project implementation and management are more likely to support climate actions. This hypothesis indicates a direct link between the emphasis on project management excellence and the inclination to support climate-related initiatives within infrastructure projects.
- **H_{4b}:** Support for climate actions among highway professionals is linked to a stronger focus on effective project implementation and management. This hypothesis suggests that individuals committed to climate action measures inherently appreciate the principles of effective project management, recognizing its importance in successfully incorporating climate resilience strategies.

These hypotheses are designed to explore the connection between the focus on project implementation and management practices and the level of support for climate actions within the context of road and highway infrastructure development. By assessing the mutual influence between project management priorities and climate action advocacy, this research aims to highlight the essential role of effective project management in promoting climate resilience goals in infrastructure projects.

3.6.2.6.5 Hypotheses Development: Social Equity and Culture Dimension

The World Bank's 2006 report, "Social Analysis in Transport Projects: Guidelines for Incorporating Social Dimensions into Bank-Supported Projects," highlights the essential role of integrating social equity considerations into infrastructure development. This integration not only aligns with the Sustainable Development Goals (SDGs) but also supports the aims of climate action initiatives. Highway professionals who are mindful of the importance of social equity and cultural factors in infrastructure projects are aware of the increased vulnerabilities of certain communities to climate change effects. These vulnerabilities often originate from socio-economic disparities, cultural backgrounds, or

geographic locations. A strong commitment to social equity and cultural preservation among these professionals usually leads to substantial support for climate actions designed to address the unique needs and reduce the vulnerabilities of these communities. The advocacy for climate policies and infrastructure projects thus focuses on protecting culturally significant sites and practices while enhancing climate resilience. Highway professionals supporting climate actions demonstrate a deep understanding of the need to overcome disparities and ensure equitable access to climate resilience measures, fostering a positive view towards the social equity and culture dimension in infrastructure development. In light of these insights, the study proposes the following hypotheses to investigate the relationship between the social equity and culture dimension and support for climate actions among highway professionals:

- **H_{5a}:** Highway professionals who emphasize the social equity and culture dimension in infrastructure development are more likely to support climate actions. This hypothesis suggests a direct link between prioritizing social equity and cultural aspects and advocating for climate action measures that mitigate community vulnerabilities.
- **H_{5b}:** Support for climate actions among highway professionals is expected to increase attention to social equity and cultural considerations within infrastructure projects. This hypothesis posits that advocating for climate action initiatives leads to a stronger commitment to social equity and cultural preservation, acknowledging their critical role in addressing the impacts of climate change on disadvantaged communities.

These hypotheses are designed to clarify the bidirectional relationship between the emphasis on social equity and cultural preservation and the support for climate actions in road and highway infrastructure development. By exploring the connection between these vital dimensions, the research aims to highlight the significance of social equity and cultural considerations in promoting climate resilience and advancing climate action objectives.

3.6.2.6.6 Hypotheses Development: Resource Utilization and Management

Dimension

The United Nations Environment Programme (UNEP, 2016) report, “Resource Efficiency: Potential and Economic Implications,” emphasizes the significant benefits of resource efficiency in infrastructure development, highlighting economic and

environmental gains. It posits that highway professionals who emphasize resource utilization and management within sustainability frameworks are likely to have a heightened awareness of efficient resource use's role in climate change mitigation. This awareness is anticipated to engender strong support for climate actions, acknowledging the vital link between judicious resource management and the reduction of environmental impacts in road and highway projects. Professionals dedicated to climate action typically aim for broader objectives, including greenhouse gas emission reductions, natural resource conservation, and promoting environmental sustainability. This dedication translates into an acute awareness of the interplay between resource utilization, management practices, and their effects on carbon emissions, resource conservation, and overall sustainability. Viewing responsible resource management as key to achieving climate goals, these professionals are inclined to endorse practices that minimize waste and promote recycling in road and highway construction and maintenance. In light of this backdrop, the study proposes the following hypotheses to investigate the relationship between the resource utilization and management dimension of sustainability and support for climate actions among highway professionals:

- **H_{6a}:** Highway professionals who highly value the resource utilization and management dimension are more likely to support climate actions. This hypothesis posits that a focus on efficient resource management is associated with advocating for climate measures designed to lessen environmental impacts.
- **H_{6b}:** Professionals showing support for climate actions are expected to emphasize the resource utilization and management dimension in road and highway infrastructure projects. This hypothesis suggests that a commitment to climate action motivates a concentration on resource management practices that are consistent with sustainability and climate goals.

These hypotheses are designed to explore the bidirectional relationships between the valuation of resource utilization and management in infrastructure projects and the willingness to support climate actions. By examining these interactions, the research aims to feature the essential role of resource management in advancing sustainable development and climate action initiatives within the road and highway construction sector.

3.6.2.7 Factor Analysis

To determine the relationship between highway professionals' perceptions and attitudes toward various sustainability criteria and their support for climate action, a comprehensive model was constructed. This model merges essential criteria identified from the conceptual framework—namely, Economics, Environmental, Technical, Project Implementation and Management, Social Equity and Culture, and Resource Utilization and Management—alongside support for climate action. These criteria, acting as research constructs, encompass specific indicators deemed critical for sustainable road and highway infrastructure development. Higher scores across these constructs, except for the climate action support construct, indicate a higher perceived importance in sustainable road and highway infrastructure development. Conversely, for the climate action support construct, higher scores reflect an increased endorsement of climate action initiatives. The operationalization of these constructs through a series of indicators is detailed in Table 4, with the Economics construct evaluated via four items (EC1-EC4), the Environmental construct through five items (EN1-EN5), and the technical construct by six items (T1-T6). The Project Implementation and Management construct was assessed with six items (PM1-PM6), while the Social Equity and Culture, and Resource Utilization and Management constructs were each evaluated using four items (SC1 – SC4) and (RM1 – RM4) respectively. The Climate action support construct was measured through eleven items (AD1 – AD3 and M1 – M8).

Following Gallagher et al. (2008) guidance, Structural Equation Modeling (SEM) using a two-step approach was applied for data analysis through SPSS AMOS. SEM's widespread application in multivariate analysis within psychological and behavioural sciences affirms its appropriateness for this study. Confirmatory factor analysis conducted using the maximum likelihood estimation method as recommended by Hair et al. (2014), facilitated the construction of the measurement model and the assessment of the reliability and validity of the measurement items, assuming data continuity and multivariate normality (Rhemtulla et al., 2012).

After validating the measurement model, the structural model was developed to test the proposed hypotheses. Bootstrap analysis, recognized for its enhanced statistical power and capability for parsimonious analysis without assuming multivariate normality (Mallinckrodt et al., 2006), was utilized to assess the significance of indirect effects. The criteria for identifying mediating roles followed (Nitzl et al., 2016), highlighting significant relationships between independent variables and mediators, and distinguishing

between full and partial mediating effects based on the significance of relationships with the dependent variable.

This factor analysis segment of this section of the methodology defines a structured approach to understanding the complex connections between sustainability criteria perceptions, attitudes, and climate action support among highway professionals, employing statistical analysis to validate the proposed conceptual framework and hypotheses. Table 4: Measurement variables for constructs

<i>Criteria (Construct)</i>	<i>Indicators</i>
<i>Economics</i>	Life cycle costs
	Material costs
	Construction time
	Maintenance and operation costs
<i>Environmental</i>	Dust control
	Environmentally friendly materials
	Ecological functions of drainage corridor
	Environmental monitoring measures after project completion
<i>Technical</i>	Flood and surface run-off
	Durable materials
	Disaster (flood) resilient designs
	Climate change resilient roadway infrastructure
	Technology in design and construction
	Adaptability and flexibility for future changes
<i>Project Implementation & Mgmt</i>	Availability of competent supervisors, labours, etc
	Comply with environmental requirements, contract documents and project specification
	Sustainable policy and strategy
	Meeting project duration
	Project risk assessment
	Criteria for contractor
<i>Social Equity & Culture</i>	Contractor selection
	Safety risk assessment & mitigation
	Worker's health and safety
	Traffic congestion - design/operational phase
<i>Resource Utilisation & Mgmt</i>	Public participation in early project phase
	Integration of supply chains
	Use of local materials
	Material quality control
	Recycled construction materials

3.6.3 Interview – Phase Two Qualitative Approach

The concluding objective of this research was to formulate decision-support guidelines to materialise the framework for sustainable criteria and indicators within the context of road and highway infrastructure development. To this end, a qualitative approach, specifically through the conduct of interviews, was adopted to gather insights and perspectives from key stakeholders. This section presents the methodologies and

procedures employed to execute the interviews and the subsequent qualitative data analysis.

3.6.3.1 Interviews of Highway Professionals

The qualitative component of this study was designed to gain a deeper understanding of the critical indicators identified from the questionnaire survey's quantitative analysis. Out of the respondents who participated in the questionnaire survey, thirty-five (35) individuals volunteered their contact details, expressing willingness to engage further in the research. From this pool, fourteen (14) respondents were purposefully selected to ensure a diverse representation of experiences and perspectives across the key stakeholder groups identified in the construction of road and highways. This selection aimed to foster a consensus on sustainability practices and challenges among professionals whose organizational affiliations matched the groupings outlined in Section A of the questionnaire.

A semi-structured interview guide was crafted to facilitate in-depth exploration of the critical indicators while maintaining the relevance and coherence of the discussion. This format was chosen for its flexibility, enabling the interviewer to probe deeper into specific areas of interest while allowing respondents the freedom to express detailed insights within the structured framework of the interview. The semi-structured nature of the interviews ensured focused discussions aligned with the study's objectives, encouraging respondents to share comprehensive responses and recommendations. The interview guide was organized into three main sections:

1. **Introduction:** This section set the stage for the interview, outlining the expected duration, confidentiality protocols, and the overall structure of the session.
2. **Main Interview:** The core of the interview focused on extracting detailed information about each critical indicator across five thematic areas:
 - i. Strengths of the indicators
 - ii. Weaknesses and challenges associated with the indicators.
 - iii. Opportunities presented by the indicators.
 - iv. Threats to the implementation of the indicators
 - v. Potential action plans for addressing identified issues.
3. **Demographics:** The concluding section of the interview collected demographic information about the interviewees, including their affiliation, years of

experience, and qualifications. For a comprehensive overview of the interview guide refer to Appendix I [C].

In preparation for the interviews, a consent form and the framework derived from the quantitative questionnaire analysis was shared with the selected interviewees via email, allowing ample time for review and preparation. The interviews were conducted using two primary methods: face-to-face meetings and telephone calls, the latter employed when geographical constraints or personal preferences necessitated remote communication. Each interview was audio-recorded with the consent of the participants and subsequently transcribed verbatim to facilitate detailed qualitative analysis. This phase was critical in achieving the third research objective by gathering rich, qualitative data to complement and expand upon the findings from the questionnaire survey, offering a holistic view of the sustainability criteria and indicators pertinent to road and highway infrastructure development.

3.6.3.2 Data Analysis (Qualitative Phase)

This study followed Creswell's (2009) recommended workflow for data analysis during the qualitative phase. A systematic approach was essential for interpreting the subtle and complex data collected through semi-structured interviews with highway professionals. Figure 10 offers a schematic overview of the data analysis process, illustrating the steps from data collection to the formulation of insights.

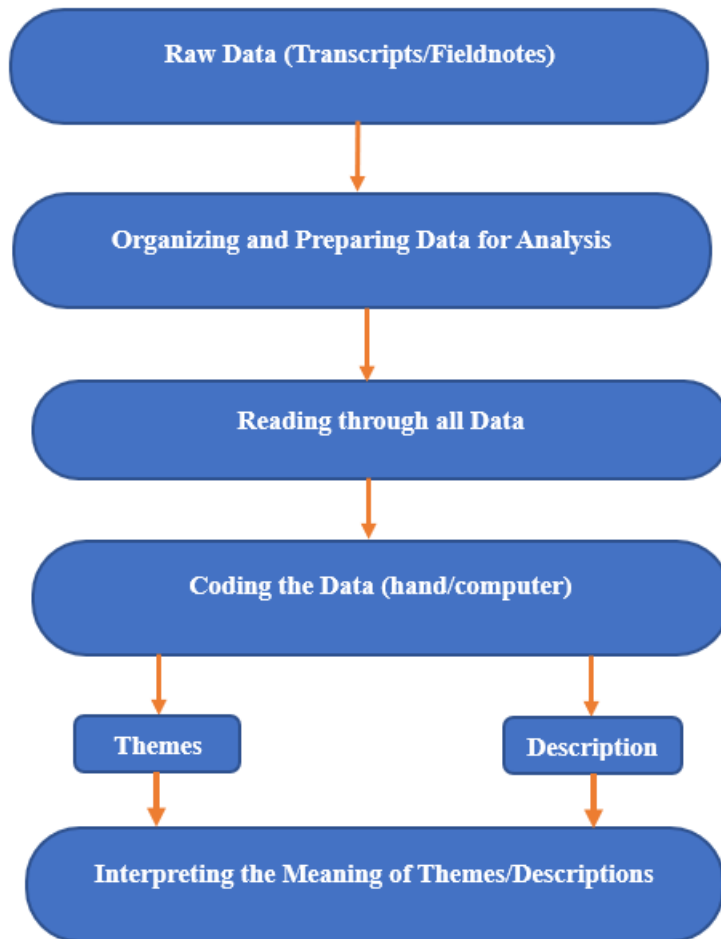


Figure 10: Data Analysis in Qualitative Research, Modified from Creswell, (2009).

For the analysis, ATLAS.ti, a leading qualitative data analysis software, was utilized. ATLAS.ti facilitates a deep and structured examination of qualitative data by allowing researchers to organize, code, and sift through vast amounts of textual information efficiently. This tool is particularly adept at handling coded data at specific nodes, enabling researchers to review the coded content comprehensively, contextualize the findings within the broader dataset, and refine interpretations of the results (Hwang, 2008; Mastrobattista et al., 2024).

One of the key analytical techniques employed in this phase was the examination of SWOT (Strengths, Weaknesses, Opportunities, and Threats) data related to the critical indicators identified in the framework resulting from the quantitative analysis. This SWOT analysis aimed to outline the strategic dimensions of each indicator, providing a balanced overview of internal and external factors that could influence the successful implementation of sustainable practices in road and highway infrastructure development. The insights derived from the SWOT analysis were instrumental in developing a decision-making framework, guiding stakeholders in prioritizing and addressing sustainability

criteria and indicators effectively. The subsequent sections will explore the outcomes of the SWOT analysis and the implications for constructing a decision-support framework for sustainable road and highway infrastructure development. This qualitative analysis not only adds to the quantitative results, but it also adds to the research with contextual, first-hand information from professionals working in the field. This makes the proposed sustainability framework stronger and more useful.

3.6.3.2.1 SWOT Analysis

SWOT analysis, a fundamental tool in strategic planning and decision-making, provides a robust framework for organizations to assess various data elements crucial for aligning business strategies across different scenarios. This methodology, which stands for Strengths, Weaknesses, Opportunities, and Threats, enables a systematic process where management teams identify both internal and external factors impacting a project or organization's success (GÜREL, 2017; Ibraheem, 2023).

Internal Factors: Strengths and Weaknesses

- Strengths are internal, positive attributes and resources that give an organization or project a competitive edge, facilitating the achievement of its objectives (Kamran et al., 2020).
- Weaknesses represent internal constraints or challenges that hinder an organization's or project's ability to reach its goals. These areas necessitate improvement to enhance performance (Kamran et al., 2020).

External Factors: Opportunities and Threats

- Opportunities are external environmental factors that an organization or project can leverage to meet its objectives, presenting avenues for growth and development (Kamran et al., 2020).
- Threats encompass external, negative factors that could impede or delay achieving set goals, requiring strategic management to mitigate potential impacts (Kamran et al., 2020).

For this research, the focus shifted from traditional applications of SWOT analysis towards examining sustainable indicators within the developed framework for road and highway infrastructure development. The adaptation of SWOT components in this context was as follows:

- Strengths of the indicators highlighted the advantages and positive aspects that promote sustainable road and highway infrastructure development.
- Weaknesses and challenges related to aspects of the indicators that limit their positive impact on sustainable road and highway infrastructure development, pointing to areas needing enhancement.
- Opportunities identified external factors that offer positive potential for applying the indicators to foster sustainable road and highway infrastructure development.
- Threats considered external factors that could negatively affect the application of the indicators in sustainable road and highway infrastructure development.

The SWOT analysis in this study utilized a group-wise approach to synthesize relevant information, define key objectives, and clarify any ambiguities among stakeholders (Madras, 2023). This method proved instrumental in focusing discussions on sustainable deliverables for road and highway development and in formulating the proposed guidelines. This research chose SWOT analysis for its evaluation of internal and external factors, which aids in enhancing sustainability in road and highway infrastructure development while considering the perspectives of key stakeholders. By leveraging this approach, the study aimed to outline the benefits and limitations of sustainable roads and highways, facilitating the development of informed, stakeholder-aligned sustainability guidelines.

3.6.3.2.2 Guidelines Development

The culmination of this research is the development of decision-making guidelines aimed at enhancing sustainability deliverables in road and highway infrastructure development. This section outlines the methodological steps undertaken to formulate these guidelines, as illustrated in Figure 11. The approach draws inspiration from the methodologies described by Lim (2009) and Yunus (2012), who developed guidelines focusing on sustainability criteria for Australian road infrastructure and Malaysia's industrialised building systems, respectively. However, this study uses SWOT analysis as a key part of the "text sorting" process. It differs from previous frameworks by including a strategic early-phase analysis to encourage long-term sustainability in road and highway construction.

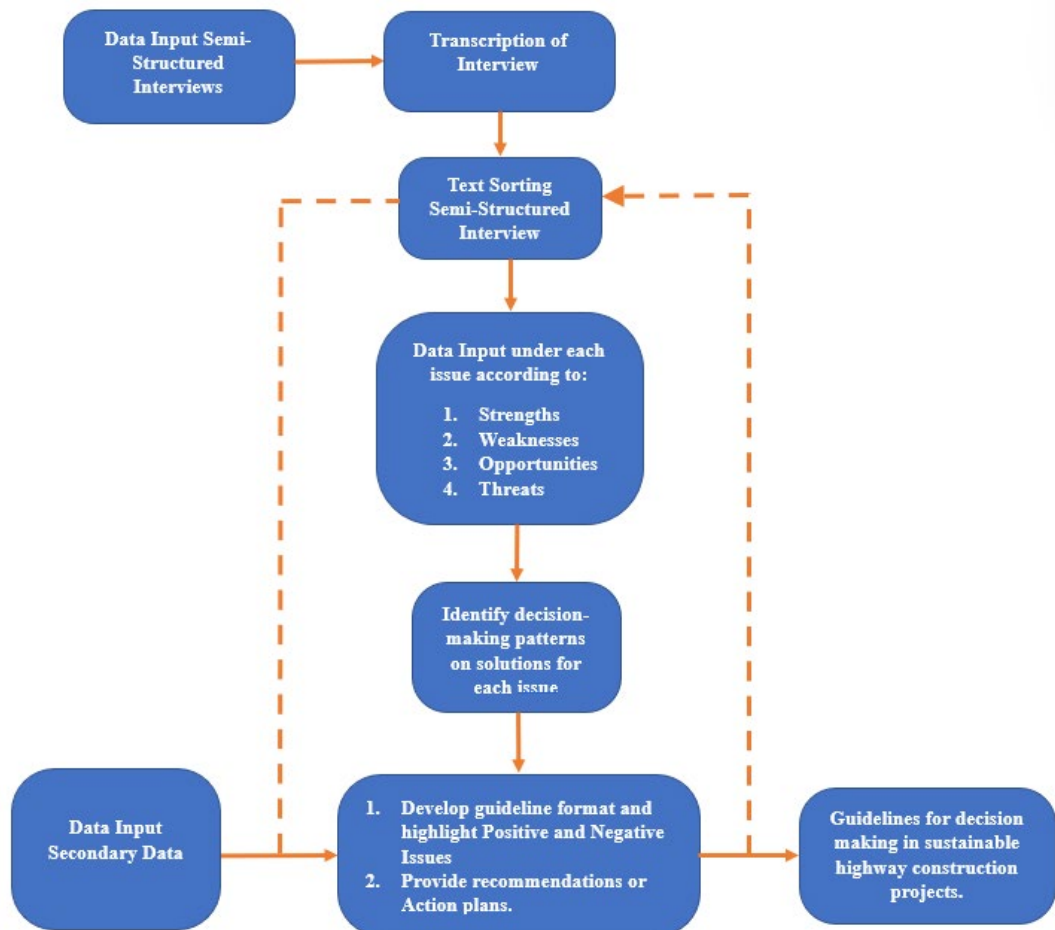


Figure 11: Process of Guideline development, modified from Lim, (2009).

Upon transcription of interviews, the data were organised for streamlined referencing. Utilizing ATLAS.ti, the interview content was systematically coded according to the SWOT framework, encompassing strengths, weaknesses, opportunities, and threats. This coding process facilitated a detailed thematic analysis, enabling the identification of recurring themes, pivotal insights, and decision-making patterns within the data. The findings from this thematic analysis were subsequently organized into a matrix (refer to Figure 12), which served as the foundational structure for the guidelines' formulation process in sustainable road and highway infrastructure development. The matrix showcases the outcomes of the SWOT analysis, categorising data into boxes based on their internal vs. external and positive vs. negative characteristics. Recommendations are formulated based on a comprehensive review of the content within each category.

	Internal	External
Positive (+)	Strength	Opportunities
Negative (-)	Weakness	Threats
Recommendations: Actions towards Sustainability		

Figure 12: SWOT Analysis template for action guidelines.

This critical examination was necessary to distil significant insights and accurately reflect the current state and prospects of the road and highway construction sector in terms of sustainability. The final section of the guidelines presents a series of systematic steps that project stakeholders should follow to achieve sustainable outcomes in road and highway infrastructure development. This analytical process applies to each of the 29 critical indicators discovered through research. This approach not only facilitated the generation of specific recommendations for each indicator but also allowed for comparison across different projects to highlight universally applicable actions. The development of these guidelines represents a significant step towards operationalizing sustainability in road and highway construction, offering stakeholders a comprehensive and strategic framework to navigate the complexities of integrating sustainability into their projects effectively.

3.7 Ethical Consideration

This study received ethical approval from the Auckland University of Technology Ethics Committee (AUTEK), affirming compliance with the guidelines for the approval of ethics committees in New Zealand. Ethical considerations in this research were centred on safeguarding the rights and welfare of participants across both employed research methods: the questionnaire and the semi-structured interview. Participation in this study was entirely voluntary. Respondents were assured that their decision to participate or decline would not influence their current or future relationship with Auckland University of Technology or any external entities. It was clarified to respondents that while they might not directly benefit from the project, their involvement contributes significantly to

the broader body of knowledge in sustainable development within road and highway infrastructure. This, in turn, aims to enhance stakeholder awareness and understanding, highlighting the critical role of sustainability in decision-making processes. The ultimate goal is to foster sustainable development that positively impacts the economy, society, and environment.

To ensure informed participation, cover letters, consent forms, and questionnaires were provided to all potential respondents. These documents served multiple purposes: they offered comprehensive details about the study, outlined the benefits of participation, and highlighted the significance of their contributions. By furnishing this information, the intention was to empower respondents with a thorough understanding of their role in the research, foster confidence in the study's objectives, and interpret the broader implications of their involvement. Participants who consented to partake in the study were asked to sign and return the provided consent form, thereby formalizing their agreement to contribute to the research under the outlined ethical guidelines. These ethical protocols were designed to ensure that the research not only adheres to the highest standards of ethical conduct but also respects and values the contributions of each participant, thereby enriching the study with wide-ranging insights while promoting the principles of sustainable development in the context of road and highway infrastructure projects.

3.8 Summary

This research adopts a pragmatic approach, aligning perfectly with the study's objective to address specific problems by generating actionable knowledge towards sustainable solutions. Pragmatism, as a research paradigm, champions the use of mixed methods to tackle problems by considering actions, situations, and their resultant outcomes. This methodology is particularly suited to this study's aim of identifying critical sustainability indicators and developing a comprehensive framework and guideline for their application within sustainable road and highway infrastructure development. The process of identifying and integrating these sustainability indicators follows an inductive approach, beginning with the exploration and identification of industry perspectives, and their support for climate action, followed by their analysis and synthesis into a cohesive interrelationship model. Conversely, the strategy for enhancing sustainability through decision-making guidelines employs a deductive approach, utilizing SWOT analysis as a structured method to propose practical actions.

Data collection in this study was conducted through survey methods, providing a broad base of responses to inform the research. This chapter has outlined the research philosophy underpinning the study, presented the research design, and justified the chosen methodology. The development of the research approach has been detailed, setting the stage for the subsequent presentation of data analysis and results in the following chapter. This approach ensures a robust framework for addressing the research questions, offering a balanced mix of theoretical insight and practical application tailored to advancing sustainable practices in road and highway infrastructure development.

Chapter 4 : Questionnaire Survey

4.1 Introduction

This chapter presents a detailed analysis of the results obtained from the questionnaire survey conducted as part of this study. The results of the analysis reveal the critical sustainability indicators for the development of sustainable road and highway infrastructure and contribute to the formulation of a preliminary framework for this study. Once more, the assessment of the perceptions of highway professionals and the interconnectedness between sustainability criteria and climate actions was determined.

4.2 Descriptive Statistics

4.2.1 Respondents' Profiles

This segment sets out the demographic characteristics of the respondents, covering their educational qualifications, affiliations with professional bodies, organizational categories, and extent of professional experience. The classification of respondents, as derived from their responses in the questionnaire, facilitated their division into five principal groups:

- i. Contractors
- ii. Consultants
- iii. Environmental Agencies
- iv. Road Agencies (i.e. Ministry of Road and Highways, Ghana Highway Authority, Department of Urban Roads, and Department of Feeder Roads)
- v. Researchers/Academia

Contractors constituted the majority of respondents, accounting for 53% of the total. Majority (63%) of the respondents had more than 10 years of experience, ensuring a depth of knowledgeable insights. Professional affiliations among the respondents were predominantly with the Ghana Institution of Engineers, capturing 64% of the total. The educational background of respondents highlighted a high level of academic attainment, with 65% holding a master's degree or higher qualification. This indicates the respondents' capacity to provide informed responses to the survey questions. Table 5 summarizes the details of the demographic characteristics of the respondents.

Table 5: Details of the demographic characteristics of the respondents

<i>S/N</i>		<i>Demographic Profile</i>	<i>Frequency</i>	<i>Percent (%)</i>
1	Respondents Categories of Organisation	Contractor	86	53%
		Consultants	18	11%
		Environmental Agencies	6	4%
		Road Agencies	39	24%
		Researchers / Academia	13	8%
		162	100%	
2	Number of years working or practicing in Ghana	2 – 4 years	11	7%
		5 – 7 years	21	13%
		8 – 10 years	28	17%
		Above 10 years	102	63%
			162	100%
3	Respondents Professional Memberships	Ghana Institution of Engineers	104	64%
		CIOB – Ghana	10	6%
		Institution of Engineering and Technology	27	17%
		Ghana Institution of Surveys	6	4%
		American Society of Civil Engineers & Others	2	1%
		Not a member of any Professional	13	8%
			162	100%
4	Level of Education of the Respondents	Bachelor's degree	54	33%
		Diploma	3	2%
		Master's degree and above	105	65%
		162	100%	

4.2.2 Reliability of the Questionnaire

To ascertain the internal consistency and reliability of the questionnaire scales, the Cronbach alpha coefficient was calculated using SPSS Statistics. This statistical measure ranges from 0 to 1, with a coefficient greater than 0.7 typically deemed acceptable for research purposes. However, for enhanced reliability, values above 0.8 are often preferred (Taber, 2018; Waqar et al., 2023).

In this study, the Cronbach alpha scores for the scales measuring sustainable road and highway infrastructure indicators and the construct of support for climate action were found to be 0.721 and 0.899, respectively. These scores indicate that the questionnaire possesses excellent internal consistency, suggesting that the data collected through this instrument is reliable. The specific Cronbach alpha values for each scale are detailed in Table 6.

Table 6: Cronback alpha score

<i>Criteria</i>	<i>Cronbach's Alpha</i>
<i>Economics</i>	0.721
<i>Environmental</i>	0.749
<i>Technical</i>	0.785
<i>Project Implementation & Management</i>	0.816
<i>Social Equity & Culture</i>	0.754
<i>Resource Utilisation & Management</i>	0.744

The reliability assessment features the robustness of the questionnaire design and the validity of the responses obtained, ensuring that the findings derived from this study are based on consistent and dependable data. This level of reliability is critical for the accurate identification of sustainability indicators and the assessment of climate action support within the context of sustainable road and highway infrastructure development.

4.3 Scores and Ranking of Indicators

The perspectives of highway professionals on sustainability indicators for road and highway infrastructure development are crucial in determining the integration of sustainable practices into the planning, design, construction, and operational phases of these projects. Variations in attitudes towards these sustainability indicators can be influenced by the specific roles their organizations play in road and highway construction and their prior experiences in managing such projects. Table 7 presents a comparative analysis of how professionals within the highway sector have evaluated various sustainability indicators in terms of their perceived importance for fostering sustainable road and highway infrastructure. An indicator's score reflects its perceived significance, with higher scores indicating greater recognition of its importance. This section reveals on the indicators that gained an average score exceeding 4.0, highlighting those deemed by professionals as critical to the achievement of sustainable road and highway infrastructure. The emphasis on indicators with scores above this threshold highlights their key role in guiding sustainable development within the road and highway construction industry. By analyzing these high-scoring indicators, the research sheds light on the priorities and consensus areas among professionals regarding essential sustainability practices and considerations in road and highway infrastructure projects.

4.3.1 Economic Criteria

When assessing the economic criteria for sustainable road and highway infrastructure, highway professionals ranked "material cost reduction" as the most significant indicator, with an average score of 4.32. This highlights a widespread acknowledgment among road and highway professionals of the substantial impact that the cost and selection of construction materials have on the long-term sustainability and performance of road and highway projects. The pursuit of meeting project specifications economically, without compromising quality, resonates with Blismas & Wakefield's (2009) discussion on cost efficiency in construction materials. "Construction time" emerged as the second most critical economic indicator, receiving an average score of 4.2. This highlights the

consensus among project managers on the importance of timely project delivery. Delays, as noted, not only escalate material and logistical costs but also inflate overall project expenditures, a sentiment echoed by Mahamid et al. (2012). The "life cycle cost" indicator, with an average score of 4.15, was also deemed crucial by road and highway professionals, indicating a preference for projects that, while possibly more expensive upfront, promise reduced operational and maintenance costs over time. This approach aligns with Juni et al.'s (2008) emphasis on comprehensive cost assessments that incorporate financial, social, and environmental considerations throughout the project's life span.

With an average score of 4.13, "maintenance and operation costs" were highlighted, suggesting a strategic focus on quality construction, durable materials, and efficient designs to curb future expenditures. This supports the perspective that a holistic, life-cycle approach to road and highway infrastructure development is essential for sustainability, as pointed out by Fallah-Fini et al. (2015). The indicator "extra duration for planning, design, and material procurement," scoring an average of 4.03, signifies the value placed on extensive preparation and planning. By prioritizing this indicator, road and highway professionals aim to mitigate the risk of unforeseen challenges during project execution. Lastly, the "cost of production" emerged as a significant indicator, with an average score of 4.02. This finding indicates a strong emphasis on optimizing construction processes to be both efficient and cost-effective, emphasizing the industry's commitment to sustainable development practices that are economically viable.

4.3.2 Environmental Criteria

Regarding environmental criteria for sustainable road and highway infrastructure development, road and highway professionals placed a premium on the "use of environmentally friendly materials," which garnered an average score of 4.17. This emphasizes a collective commitment to selecting and employing materials that not only minimize environmental harm but also bolster the resilience and sustainability of roads and highways over time. Echoing this sentiment, Jiang et al. (2018) highlighted the pivotal role of eco-friendly materials in augmenting the environmental sustainability of road pavements. The indicator "minimize flood and surface runoff" was deemed critically important, with an average score of 4.16, indicating a priority on integrating designs and construction methodologies that effectively address flood risks and manage stormwater runoff. This approach underlines an effort to enhance both the environmental integrity and social sustainability of road and highway projects. Professionals in the field also

emphasize the importance of "environmental monitoring measures after project completion," reflected in an average score of 4.15. This underlines the recognition of a continuous responsibility to evaluate and mitigate the environmental impacts of road and highways throughout their operational life. Additionally, there is a strong resolve among highway professionals to promote ecological conservation, as evidenced by the importance placed on "restoration of possible vegetation" with an average score of 4.13. This indicates a concerted effort to rehabilitate wildlife habitats potentially affected by road and highway development. "Dust control" also emerged as a significant environmental sustainability indicator, scoring an average of 4.13. This suggests a dedicated focus on mitigating the adverse effects of dust pollution on both the environment and public health during the construction and operational phases of road and highway projects, aligning with the findings of Xing et al. (2018).

Together, these scores and rankings reflect a comprehensive and proactive approach among road and highway professionals towards embedding environmental sustainability into every facet of road and highway infrastructure development. By prioritizing these indicators, the sector demonstrates a strong commitment to advancing eco-friendly practices that ensure the long-term viability and minimal ecological footprint of road and highway projects.

4.3.3 Social equity and culture criteria

With regard to social equity and culture criteria, highway professionals identified "improve workers' health and safety" as the paramount indicator for sustainable road and highway infrastructure, evidenced by an average score of 4.20. This underlines a prioritization of initiatives aimed at creating a safe and healthy working environment, fulfilling legal mandates, and proactively enhancing the wellbeing of the workforce. Traffic congestion during the design, construction, and operational phases emerged as another critical indicator, with an average score of 4.19. This finding suggests that professionals are aware of congestion's economic ramifications, such as increased fuel consumption and reduced productivity, and therefore emphasize the need for design solutions and strategies that mitigate congestion. Highlighting the significance of construction safety, the professionals also deemed safety risk assessment and mitigation during construction as crucial, with an average score of 4.14. This reflects an understanding that the safety of construction workers and the public, including drivers and pedestrians, is integral to sustainable road and highway infrastructure development, aligning with insights from Nawaz et al. (2019). Public participation in the early stages

of projects was identified as another vital indicator, scoring an average of 4.12. This prioritization of stakeholder engagement in the planning and decision-making processes echoes the literature (Ogryzek et al., 2021; Suprayoga, et al., 2020), emphasizing the importance of considering diverse interests and fostering community ownership and accountability.

Furthermore, the professionals emphasized the importance of working conditions and economic/employment opportunities for local contractors, expertise, and communities as significant to sustainable road and highway infrastructure, with scores of 4.08 and 4.07, respectively. These scores illustrate a comprehensive approach to sustainability that extends beyond environmental considerations to include social equity, cultural sensitivity, and economic inclusivity in the development of road and highway infrastructure.

4.3.4 Technical quality criteria

In assessing the technical quality criteria for sustainable road and highway infrastructure, highway professionals have placed the highest importance on “disaster (flood) resilient design” with an average score of 4.23. This emphasizes a commitment to integrating planning, engineering solutions, and community engagement strategies that enhance the highway’s resilience to flooding, ensuring infrastructure can withstand and recover from flood-related adversities. The indicator “Design and construct climate change-resilient roadway infrastructure” received a significant endorsement, scoring an average of 4.18. This reflects a widespread recognition among professionals of the critical impacts of climate change, including extreme weather events, increased temperatures, and rising sea levels, on road and highway infrastructure. Such an acknowledgment is in accord with research by de Abreu et al. (2022) and Regmi & Hanaoka (2011), highlighting the need for climate-adaptive infrastructure planning. The “application of durable materials” was highlighted as a crucial indicator for sustainable road and highway development, with an average score of 4.17. This indicates an understanding that the longevity and reduced maintenance frequency of roads and highways are contingent upon the use of durable construction materials. Moreover, professionals emphasized the importance of constructing highways that are “durable and cost-effective over their design life,” which garnered an average score of 4.16. This perspective advocates for roads and highways that deliver long-term operational efficiency, safety, minimal environmental impact, and reduced life-cycle costs.

“Allow adaptability and flexibility for future changes” also emerged as a significant indicator with an average score of 4.16. Professionals advocate for road and highway designs that can accommodate future expansions, integrate new technologies, adapt to changing traffic patterns, and address evolving environmental concerns, ensuring long-term infrastructure sustainability. Analysis further revealed that professionals consider the “ensuring availability of competent supervisors, labourers, etc.,” “incorporation of technology in design and construction,” and “incorporating future needs in design” as significant indicators, with average scores of 4.12, 4.12, and 4.09, respectively. These scores reflect a holistic approach towards sustainable road and highway infrastructure development, emphasizing workforce competency, technological integration, and forward-thinking design principles.

4.3.5 Project Implementation and Management Criteria

In the area of project implementation and management criteria, "compliance with environmental requirements, contract documents, and project specifications" emerged as the top-rated indicator, achieving an average score of 4.25. This score signifies the dedication of highway professionals to executing projects in a manner that is transparent, accountable, and adheres to stipulated environmental and contractual guidelines, reinforcing the importance of responsible project management as highlighted by Elsayegh et al. (2020). "Project risk assessment" earned an average score of 4.20, highlighting its critical role in sustainable road and highway infrastructure development. This rating reflects a consensus among professionals on the necessity of conducting comprehensive evaluations of potential project risks and uncertainties and formulating mitigation and management strategies, aligning with El-Sayegh & Mansour's (2015) findings on risk assessment in highway construction projects in the UAE. Achieving the projected completion timeline, denoted by "meeting project duration (completing the project on schedule)," received an average score of 4.17, indicating its significance in controlling project costs by minimizing the need for prolonged labour, equipment rental, and other accruing expenses due to delays. This aligns with the prioritization of timely project delivery to manage budgets effectively.

The "provision of project control and monitoring guidelines" was rated with an average score of 4.16, pointing to the recognized necessity for establishing standards and protocols to ensure project compliance with the desired quality and specifications. Sustainable policy and strategy formulation was deemed a significant indicator, with an average score of 4.15. This suggests a keen interest among highway professionals in

developing comprehensive policies and strategies that guide decision-making and operational practices throughout the lifecycle of road and highway projects, as supported by Ruiz & Guevara (2020). Additionally, the "approach or criteria for contractor selection (e.g., prequalification)" achieved an average score of 4.13. This outcome indicates a strong preference for the implementation of thorough and sustainable contractor selection processes among highway professionals, highlighting the value placed on ensuring that contractors meet high standards of sustainability and technical proficiency.

4.3.6 Resource Utilization and Management Criteria

In the area of resource utilization and management criteria, "material quality control/assurance" was identified as the paramount indicator by highway professionals, with an average score of 4.16. This underlines the critical importance of selecting, using, and maintaining high-quality materials throughout the project lifecycle. Rigorous testing to ensure compliance with required standards and specifications for materials is deemed essential for achieving sustainable road and highway infrastructure, resonating with findings from Khan et al. (2008). The survey results further indicate a significant emphasis on supporting local economies through the "use of local materials," which garnered an average score of 4.14. This approach not only fosters local business growth and job creation but also contributes to overall economic development, highlighting the professionals' preference for sourcing materials from the immediate region.

Additionally, the "use of recycled construction materials" received a positive reception, with an average score of 4.14. This reflects a strong commitment among highway professionals to resource conservation, waste reduction, and environmental protection. Favouring reclaimed materials from prior construction or demolition projects over new materials features an environmentally responsible construction practice, aligning with the sustainable goals outlined by Segui et al. (2023). The "integration of supply chains for a smooth flow of highway materials and other resources" was recognized as crucial, scoring an average of 4.12. This indicates the professionals' focus on ensuring an efficient, well-integrated movement of materials and resources. Effective supply chain integration can lead to reduced transportation costs, minimized delays, and optimized project timelines, supporting the efficiency of sustainable road and highway infrastructure development as discussed by Prakash & Mohanty (2015).

Table 7: Rating of sustainability indicators for highway infrastructure development

No	Sustainability Indicator	ALL						
		Ranking	Average Score	Consultant xx (yy)	Contractor xx (yy)	Environmental Agencies xx (yy)	Research/Academic Institution xx (yy)	Road Agencies xx (yy)
<i>Economic Value Criteria</i>								
1	Reduce Material costs	1	4.32	4.00(11)	4.01(8)	4.14(10)	4.08(3)	3.50(3)
2	Reduce Construction time	2	4.20	4.11(1)	4.20(1)	4.29(6)	4.00(5)	3.45(5)
3	Reduce Life cycle costs	3	4.15	4.11(4)	3.98(9)	4.43(1)	4.31(1)	3.58(2)
4	Reduce Maintenance and operation costs	4	4.13	4.17(2)	4.07(5)	4.43(2)	4.31(2)	3.71(1)
5	Provide extra duration for planning, design, and material procurement	5	4.03	4.06(10)	4.15(2)	4.43(4)	3.46(11)	3.42(6)
6	Reduce the cost of Production	6	4.02	4.06(9)	4.13(3)	4.29(5)	4.00(4)	3.34(8)
7	Design stage (freeze) adoption to limit variation cost	7	3.89	4.11(5)	4.06(6)	4.29(7)	3.46(12)	3.47(4)
8	Increase the speed of return on investment	8	3.88	4.11(6)	4.06(7)	4.29(8)	3.57(9)	3.39(7)
9	Reduce Disposal costs	9	3.82	4.00(12)	4.09(4)	4.43(3)	3.46(10)	3.13(12)
10	Reduce the cost of Resettlement	10	3.81	4.11(7)	3.97(12)	4.14(12)	3.77(7)	3.29(9)
11	Reduce Initial construction costs	11	3.80	4.17(3)	3.98(11)	4.14(11)	3.62(8)	3.21(10)
12	Reduce Labour costs	12	3.78	4.06(8)	3.98(10)	4.14(9)	3.77(6)	3.16(11)
<i>Environmental impact criteria</i>								
1	Use of environmentally friendly materials	1	4.17	4.22(4)	4.19(9)	4.51(2)	4.46(1)	3.89(5)
2	Minimize flood and surface run-off	2	4.16	4.22(5)	4.13(16)	4.71(1)	3.92(11)	3.82(10)
3	Environmental monitoring measures after project completion	3	4.15	4.33(3)	3.98(26)	4.43(8)	4.08(5)	4.05(2)
4	Dust control	4	4.13	4.39(1)	4.03(22)	4.14(17)	3.92(9)	3.87(7)

5	Preserve/Improve ecological functions of drainage corridor	5	4.13	4.39(2)	4.29(1)	4.29(11)	3.85(14)	3.82(9)
6	Design to reduce traffic noise	6	4.06	4.06(15)	4.23(3)	4.00(20)	3.77(15)	4.08(1)
7	Reduce contamination of soil	7	4.05	4.06(15)	4.22(5)	4.43(6)	3.92(10)	4.00(3)
8	Pollution control during the construction process	8	4.03	3.83(26)	4.24(2)	4.00(21)	4.00(6)	3.79(11)
9	Operational energy (e.g., solar powered traffic light, solar powered signals etc)	9	4.01	4.17(11)	4.13(15)	4.43(7)	3.77(17)	3.84(8)
10	Minimize disturbances to the original ground and scenery -Design / Construction (effective land use)	10	4.01	3.83(27)	4.09(19)	4.00(22)	4.08(3)	3.97(4)
11	Groundwater management	12	4.00	3.94 (22)	4.16(11)	4.14(13)	3.92(8)	3.68(14)
12	Restoration of possible vegetation	12	4.00	4.22(6)	4.10(17)	4.29(12)	3.77(18)	3.71(13)
13	Water-permeable pavement design as alternative stormwater management practices	13	4.00	4.06(16)	4.20(8)	3.86(26)	4.08(4)	3.53(19)
14	Design slopes to reduce vehicle energy consumption	14	4.00	4.00(18)	4.22(4)	4.29(10)	3.54(20)	3.58(16)
15	Reduce construction noise and vibration	15	3.99	3.89(24)	4.21(6)	4.43(4)	3.54(19)	3.61(15)
16	Use of natural energy or reuse of waste heat	16	3.99	4.00(19)	4.21(7)	3.71(27)	3.77(16)	3.58(17)
17	Reduce the destruction of animal habitat and migration routes "flora and fauna	17	3.98	4.11(14)	3.98(25)	4.43(5)	3.85(13)	3.89(6)
18	Preservation and reuse of topsoil	18	3.98	3.94(23)	4.14(14)	4.57(3)	3.38(23)	3.71(12)
19	Design to reduce vehicle emission	19	3.98	3.94(21)	4.09(18)	4.29(9)	4.15(2)	3.50(21)
20	Minimize energy consumption during construction phase	20	3.95	4.22(7)	4.06(21)	4.14(18)	3.54(21)	3.55(18)
21	Vehicle emission- construction	21	3.92	3.83(25)	4.17(10)	4.00(19)	3.85(12)	3.37(23)
22	Minimization of excavation and earthmoving	22	3.91	4.17(8)	4.00(24)	4.14(14)	3.46(22)	3.42(22)
23	Water storage infiltration design	23	3.85	4.11(13)	4.16(12)	4.14(16)	3.15(26)	3.13(25)

24	Use of highly water-permeable slope shapes as stormwater management practices	24	3.83	4.17(9)	4.02(23)	4.14(15)	3.23(25)	3.11(26)
25	Direct infiltration design	25	3.77	4.00(17)	4.08(20)	3.86(25)	3.00(27)	3.03(27)
26	Use of energy conservation facilities	26	3.73	4.11(12)	3.94(27)	3.86(24)	3.31(24)	3.13(24)
<i>Social Equity and Culture</i>								
1	Improve workers health and safety	1	4.20	4.33(1)	4.21(3)	4.29(8)	4.31(1)	4.08(1)
2	Reduction of traffic congestion - design/operational phase	2	4.19	4.22(5)	4.33(1)	4.29(9)	4.08(4)	3.87(5)
3	Safety risk assessment and mitigation during construction	3	4.14	4.17(6)	4.15(6)	3.86(12)	3.77(11)	3.97(3)
4	Public participation in early project phase	4	4.12	4.28(2)	4.08(10)	4.57(2)	4.23(2)	3.74(9)
5	Improve working conditions	5	4.08	4.11(8)	4.08(9)	4.29(7)	4.15(3)	4.00(2)
6	Increase economic/employment opportunities to local contractors, expertise, and local communities	6	4.07	4.28(3)	4.13(7)	4.57(3)	4.00(7)	3.79(7)
7	Increase knowledge and exposure in sustainable technology	7	4.07	4.22(4)	4.16(5)	4.29(6)	4.00(6)	3.76(8)
8	Reduction of community disturbance	8	4.04	4.06(10)	4.21(4)	4.43(4)	3.92(9)	3.61(12)
9	Improve aesthetic impact and appearance	9	4.02	4.06(11)	4.12(8)	4.71(1)	3.85(10)	3.71(10)
10	Reduction of traffic congestion - construction	10	3.99	4.17(7)	4.22(2)	4.29(10)	4.08(5)	3.79(6)
11	Preserve cultural heritage elements	11	3.99	4.06(12)	4.08(11)	4.43(5)	4.00(8)	3.68(11)
12	Job creation	12	3.95	4.11(9)	4.00(12)	4.14(11)	3.54(12)	3.87(4)
<i>Technical Quality</i>								
1	Disaster (flood) resilient designs	1	4.23	4.50(1)	4.16(2)	4.29(7)	4.54(3)	4.16(2)
2	Design and construct climate change resilient roadway infrastructure	2	4.18	4.17(10)	4.16(3)	4.57(2)	4.92(1)	3.79(9)
3	Application of durable materials	3	4.17	4.28(6)	4.14(4)	4.43(3)	4.31(6)	4.08(4)

4	Construct highways that are durable and cost effective over the design life	4	4.16	4.44(2)	3.98(9)	4.43(5)	4.77(2)	4.18(1)
5	Allow adaptability and flexibility for future changes	5	4.16	4.22(9)	4.22(1)	4.14(9)	4.46(4)	3.89(7)
6	Ensuring availability of competent supervisors, labours, etc	6	4.12	4.33(5)	4.01(8)	4.00(10)	4.31(8)	4.11(3)
7	Incorporate technology in design and construction	7	4.12	4.22(8)	4.10(6)	4.43(6)	4.31(7)	3.97(5)
8	Incorporate future needs in design	8	4.09	4.39(3)	4.02(7)	4.71(1)	4.23(9)	3.95(6)
9	Provide ease for construction and design integration for overall requirement	9	4.07	4.22(7)	4.14(5)	4.14(8)	4.15(10)	3.82(9)
10	Improve quality control, reduce failures in achieving specifications	10	4.03	4.39(4)	3.94(10)	4.43(4)	4.38(5)	3.87(8)
<i>Project Implementation and Management</i>								
1	Comply with environmental requirements, contract documents and project specification	1	4.25	4.22(8)	4.31(1)	4.71(2)	4.31(1)	4.03(3)
2	Project risk assessment	2	4.20	4.28(7)	4.26(4)	4.43(7)	4.23(4)	4.00(4)
3	Meeting project duration (completing project on schedule)	3	4.17	4.33(2)	4.19(6)	4.43(6)	4.00(7)	4.05(2)
4	Provide project control and monitoring guidelines	4	4.16	4.28(4)	4.28(2)	4.86(1)	3.77(11)	3.84(7)
5	Accomplish of sustainable policy and strategy to improve construction efficiency	5	4.15	4.28(5)	4.26(3)	4.71(3)	3.85(8)	3.87(6)
6	Contractor selection	6	4.13	4.22(9)	4.12(9)	4.43(8)	4.08(6)	4.08(1)
7	Approach / Criteria for contractor (eg., prequalification)	7	4.13	4.33(3)	4.17(8)	4.14(13)	4.08(5)	3.95(5)
8	Provide standard size for each element for mass production and reproduction	8	4.04	4.39(1)	4.17(7)	4.57(4)	3.69(12)	3.61(13)

9	Governance (Reduce economic and social problems)	9	4.04	4.06(13)	4.21(5)	4.43(5)	3.85(9)	3.66(10)
10	Inclusion of sustainability clauses	10	3.94	4.17(11)	3.91(13)	4.00(14)	4.23(3)	3.82(8)
11	Procurement system simplification of documentation and provision of clear information	11	3.93	4.17(10)	4.01(10)	4.29(9)	3.54(13)	3.71(9)
12	Incentives for meeting sustainability performance	12	3.90	4.28(6)	3.90(14)	4.14(12)	4.31(2)	3.55(14)
13	Type of contract	13	3.88	4.11(12)	3.92(12)	4.29(10)	3.85(10)	3.63(12)
14	Choice of delivery system (e.g., design and construct, BOT)	14	3.87	4.06(14)	4.01(11)	4.14(11)	3.31(14)	3.63(11)
<i>Resource Utilization and Management</i>								
1	Material quality control	1	4.16	4.00(4)	4.16(1)	4.29(6)	4.38(2)	4.13(1)
2	Use of local materials	2	4.14	4.00(3)	4.09(4)	4.29(4)	4.38(1)	3.87(2)
3	Integration of supply chains- smooth flow of highway materials and other resources	3	4.14	4.11(1)	4.12(2)	4.43(1)	3.85(3)	3.61(4)
4	Use of recycled construction materials	4	4.12	3.94(5)	4.06(6)	4.43(2)	3.69(4)	3.63(3)
5	Supply chain management	5	3.93	4.10(2)	4.07 (5)	4.30(3)	3.45(5)	3.39 (5)
6	Use of prefabricated materials	6	3.87	3.94(6)	4.12(3)	4.29(5)	3.31(6)	3.37 (6)

xx = Average score of each indicator, yy = Ranking indicators under a criterion,

4.4 Critical indicators of sustainable highway infrastructure development

In this study, critical indicators are defined as those with an average score statistically significantly greater than 4. Utilizing the methodology outlined, indicators with p-values less than or equal to 0.05 were determined to have average scores significantly above 4, rendering them critical for sustainable road and highway infrastructure development. Table 8 describes these critical indicators across each sustainability criterion, as identified through one-sample t-tests (one-tailed).

A comprehensive analysis revealed a total of 31 indicators classified as critical, characterized by their p-values being less than or equal to 0.05. The distribution of these indicators across the various criteria is as follows: four indicators fall under the economic criteria, five under the environmental impact criteria, and four within the social equity and culture criteria. The technical quality criteria and project implementation and management criteria each contributed seven critical indicators, while resource utilization and management criteria accounted for four indicators.

The standard deviations associated with these indicators, predominantly falling below 1, emphasize the precision of the data gathered in this research. This level of deviation signifies that the variability around the average scores is minimal, enhancing the reliability of the identified critical indicators. This identification process ensures that the focus is directed towards those aspects most pivotal for fostering sustainable practices in road and highway infrastructure development.

Table 8: One Sample T Test

NO	SUSTAINABILITY INDICATOR	RANKING	AVERAGE SCORE	STD DEVIATION	NUMBER	HYPOTHESIZED MEAN	P - VALUE
ECONOMIC VALUE CRITERIA							
1	Reduce Material costs	1	4.32	0.81	162	4	6.09E-07
2	Reduce Construction time	2	4.20	0.88	162	4	0.002174
3	Reduce Life cycle costs	3	4.15	0.93	162	4	0.020812
4	Reduce Maintenance and operation costs	4	4.13	0.86	162	4	0.02806
5	Provide extra duration for planning, design, and material procurement	5	4.03	0.88	162	4	0.332469
6	Reduce the cost of Production	6	4.02	0.87	162	4	0.385104
ENVIRONMENTAL IMPACT CRITERIA							
1	Use of environmentally friendly materials	1	4.17	0.82	162	4	0.00387664
2	Minimize flood and surface run-off	2	4.16	0.62	162	4	0.00062652
3	Environmental monitoring measures after project completion	3	4.15	0.84	162	4	0.01017443
4	Dust control	4	4.13	0.87	162	4	0.03006142
5	Preserve/Improve ecological functions of drainage corridor	5	4.13	0.83	162	4	0.0239442
6	Design to reduce traffic noise	6	4.06	0.88	162	4	0.18731651
7	Reduce contamination of soil	7	4.05	0.86	162	4	0.23345701
8	Pollution control during the construction process	8	4.03	0.78	162	4	0.30659691
9	Minimize disturbances to the original ground and scenery -Design / Construction (effective land use)	9	4.01	0.83	162	4	0.46236517
10	Operational energy (e.g., solar powered traffic light, solar powered signals etc)	10	4.01	0.83	162	4	0.46236517

11	Groundwater management	11	4.00	0.84	162	4	0.50000000
12	Restoration of possible vegetation	12	4.00	0.91	162	4	0.50000000
13	Use of energy conservation facilities	13	4.00	0.88	162	4	0.50000000
SOCIAL EQUITY AND CULTURE							
1	Improve workers health and safety	1	4.20	0.72	162	4	0.000224
2	Reduction of traffic congestion - design/operational phase	2	4.19	0.86	162	4	0.00357
3	Safety risk assessment and mitigation during construction	3	4.14	0.90	162	4	0.02471
4	Public participation in early project phase	4	4.12	0.82	162	4	0.032169
5	Improve working conditions	5	4.08	0.69	162	4	0.069483
6	Increase economic/employment opportunities to local contractors, expertise, and local communities	7	4.07	0.78	162	4	0.115633
7	Increase knowledge and exposure in sustainable technology	8	4.07	0.81	162	4	0.144497
8	Reduction of community disturbance	9	4.04	0.80	162	4	0.277041
9	Improve aesthetic impact and appearance	10	4.02	0.79	162	4	0.383169
TECHNICAL QUALITY							
1	Disaster (flood) resilient designs	1	4.23	0.74	162	4	3.83E-05
2	Design and construct climate change resilient roadway infrastructure	2	4.18	0.78	162	4	0.001899
3	Application of durable materials	3	4.17	0.72	162	4	0.001752
4	Durable cost effective highway construction	4	4.16	0.68	162	4	0.001486
5	Allow adaptability and flexibility for future changes	5	4.16	0.78	162	4	0.004809
6	Ensuring availability of competent supervisors, labours, etc	6	4.12	0.87	162	4	0.040377

7	Incorporate technology in design and construction	7	4.12	0.73	162	4	0.021828
8	Incorporate future needs in design	8	4.09	0.74	162	4	0.056047
9	Provide ease for construction and design integration for overall requirement	9	4.07	0.76	162	4	0.108435
10	Improve quality control, reduce failures in achieving specifications	10	4.03	0.93	162	4	0.336423
PROJECT IMPLEMENTATION AND MANAGEMENT							
1	Comply with environmental requirements, contract documents and project specification	1	4.25	0.81	162	4	4.89E-05
2	Project risk assessment	2	4.20	0.70	162	4	0.000138
3	Meeting project duration (completing project on schedule)	3	4.17	0.75	162	4	0.002629
4	Provide project control and monitoring guidelines	4	4.16	0.84	162	4	0.008111
5	Accomplish of sustainable policy and strategy to improve construction efficiency	5	4.15	0.83	162	4	0.009635
6	Approach / Criteria for contractor (eg., prequalification)	6	4.13	0.72	162	4	0.011947
7	Contractor selection	7	4.13	0.73	162	4	0.012777
8	Provide standard size for each element for mass production and reproduction	8	4.04	0.75	162	4	0.232388
9	Governance (Reduce economic and social problems)	9	4.04	0.79	162	4	0.243899
RESOURCE UTILIZATION AND MANAGEMENT							
1	Material quality control	1	4.16	0.72	162	4	0.002616
2	Use of local materials	2	4.14	0.76	162	4	0.010133
3	Use of recycled construction materials	3	4.14	0.88	162	4	0.022265

4	Supply chain management	4	4.12	0.79	162	4	0.027473
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4.4.1 Ranking of critical sustainable highway infrastructure development indicators

The ranking of critical indicators for sustainable road and highway infrastructure development, as depicted in Table 9, reflects the priorities of highway professionals within the field of sustainable construction. The rankings, derived from average importance scores, highlight the critical aspects deemed most vital by these professionals.

Table 9: Ranking of the 31 sustainability indicators for highway construction

No	Sustainability Indicator	Average Score	Std Deviation	P - Value	Ranking
1	Reduce Material costs	4.32	0.81	6.09E-07	1
2	Comply with environmental requirements, contract documents and project specification	4.25	0.81	4.89E-05	2
3	Disaster (flood) resilient designs	4.23	0.74	3.83E-05	3
4	Reduce Construction time	4.20	0.88	0.0022	4
5	Improve workers health and safety	4.20	0.72	0.0002	4
6	Project risk assessment	4.20	0.70	0.0001	4
7	Reduction of traffic congestion - design/operational phase	4.19	0.86	0.0036	5
8	Design and construct climate change resilient roadway infrastructure	4.18	0.78	0.0019	6
9	Use of environmentally friendly materials	4.17	0.82	0.0039	7
10	Application of durable materials	4.17	0.72	0.0018	7
11	Meeting project duration (completing project on schedule)	4.17	0.75	0.0026	7

12	Minimize flood and surface run-off	4.16	0.62	0.0006	8
13	Durable cost-effective highway construction	4.16	0.68	0.0015	8
14	Allow adaptability and flexibility for future changes	4.16	0.78	0.0048	8
15	Provide project control and monitoring guidelines	4.16	0.84	0.0081	8
16	Material quality control	4.16	0.72	0.0026	8
17	Reduce Life cycle costs	4.15	0.93	0.0208	9
18	Environmental monitoring measures after project completion	4.15	0.84	0.0102	9
19	Accomplish of sustainable policy and strategy to improve construction efficiency	4.15	0.83	0.0096	9
20	Safety risk assessment and mitigation during construction	4.14	0.90	0.0247	10
21	Use of local materials	4.14	0.76	0.0101	10
22	Use of recycled construction materials	4.14	0.88	0.0223	10
23	Reduce Maintenance and operation costs	4.13	0.86	0.0281	11
24	Dust control	4.13	0.87	0.0301	11
25	Preserve/Improve ecological functions of drainage corridor	4.13	0.83	0.0239	11
26	Approach / Criteria for contractor (eg., prequalification)	4.13	0.72	0.0119	11
27	Contractor selection	4.13	0.73	0.0128	11

28	Public participation in early project phase	4.12	0.82	0.0322	12
29	Ensuring availability of competent supervisors, labours, etc	4.12	0.87	0.0404	12
30	Incorporate technology in design and construction	4.12	0.73	0.0218	12
31	Supply chain management	4.12	0.79	0.0275	12

“Material Cost” emerges as the utmost critical indicator (Rank 1), scoring an average of 4.32. The emphasis on material cost give emphasis to the significant impact of material expenses on the overall project lifecycle cost. Given the logistics and economic fluctuations affecting material sourcing, this focus aligns with practical considerations in road and highway construction. “Compliance with environmental requirements, contract documents, and project specifications” ranks second, illustrating the professionals' dedication to adhering to regulatory and specification standards in project implementation and management. “Disaster-resilient design” holds the third rank with an average score of 4.23, signifying a pronounced commitment to constructing road and highways capable of withstanding disasters such as floods and earthquakes.

Ranked fourth, “Construction time”, “Worker health and safety”, and “Project risk assessment” all share an average score of 4.20. This indicates a balanced recognition of the importance of efficient construction timelines, safety protocols, and risk management strategies in project success. “Traffic congestion reduction” and “Climate change-resilient roadway infrastructure design and construction” are ranked fifth and sixth, respectively, highlighting the professionals' focus on operational efficiency and climate adaptability in road and highway projects. “Use of environmentally friendly materials”, “Application of durable materials”, and “Meeting project duration” are jointly ranked seventh with an average score of 4.17, reflecting a growing commitment to eco-friendly practices and durable construction within stipulated timelines.

Tied for the eighth rank with an average score of 4.16 each are indicators related to “Flood and surface run-off minimization”, “Durable and cost-effective construction”, “Adaptability for future changes”, “Project control and monitoring”, and “Material quality control”. “Life cycle cost” along with two other indicators, secures the ninth rank,

emphasizing the importance of comprehensive cost analysis encompassing all project phases. Ranked tenth, “Use of local materials” and “Recycled construction materials” emphasize the professionals’ endorsement of sustainable material sourcing practices. “Dust control” and “Ecological functionality of drainage corridors” tie for eleventh rank with an average score of 4.13, indicating a concern for environmental impact mitigation. “Public participation in early project phases” and “Supply chain management” are tied for the twelfth rank with an average score of 4.12, point out the importance of stakeholder engagement and efficient resource management.

These rankings reveal an in-depth understanding among highway professionals of the multifaceted nature of sustainability in road and highway infrastructure development. The indicators’ close scores and shared rankings indicate a comprehensive approach to sustainability, where various indicators are integrated into the planning, design, construction, and operational phases to ensure resilient and sustainable road and highway projects.

4.4.2 Consensus on indicators among highway professionals

To ascertain the level of consensus among highway professionals regarding the importance of ranked sustainability indicators, Kendall's coefficient of concordance was employed. The analysis yielded a coefficient value of 0.004 and a p-value of 0.933, surpassing the predetermined significance threshold of 0.05. This minimal coefficient suggests that the observed agreement among professionals might merely be coincidental, and the high p-value further emphasizes the lack of statistically significant concordance. This indicates wide-range perspectives and potential disagreements among professionals regarding the prioritization of sustainability indicators.

Given the objective of achieving a unified perspective on critical indicators for incorporation into frameworks, it is essential to establish broad consensus among key stakeholders. While Kendall's coefficient effectively measures agreement levels, it does not discern whether the significance of indicators' importance varies across different professional categories. To address this limitation and explore group-specific valuation differences, the Kruskal-Wallis one-way ANOVA was applied. This test examines if varying professional groups have distinct ratings for indicators, with p-values exceeding 0.05 suggesting disparate evaluations among groups. Conversely, p-values at or below 0.05 indicate a significant consensus on the ratings.

According to the outcomes depicted in Table 10, the Kruskal-Wallis's test demonstrated negligible variance among the professional groups for 29 out of the 31 critical sustainability indicators. This signifies a comprehensive consensus among the diverse professional categories on the valuation and expectations tied to these indicators. However, exceptions were noted for two indicators: "construction of durable and cost-effective highways" and "project control and monitoring guidelines," which recorded p-values of 0.000 and 0.015, respectively. These findings highlight differing perceptions and ratings among the professional groups for these two indicators, underscoring the necessity for further deliberation and alignment to ensure cohesive and comprehensive sustainable highway infrastructure development guidelines.

Table 10: Kruskal-Wallis's test among the highway professional groups

S/N	Sustainability Indicator	Scale details.		Mean Rank					Kruskal-Wallis Statics	P-Value
		Mean	SD	G1	G2	G3	G4	G5		
1	Material costs	4.32	0.81	94.19	64.55	87.06	77.67	91.50	8.830	0.066
2	Comply with environmental requirements, project spec	4.25	0.81	86.00	77.34	81.67	74.19	112.36	4.753	0.314
3	Disaster resilient designs	4.23	0.74	107.27	81.32	74.45	96.00	83.93	9.369	0.053
4	Workers' health and safety	4.20	0.72	87.88	78.18	80.54	87.75	83.36	0.961	0.916
5	Construction time	4.20	0.88	85.27	72.43	83.83	86.00	83.57	2.203	0.698
6	Project risk assessment	4.20	0.70	84.36	71.64	83.56	85.47	94.14	3.164	0.531
7	Traffic congestion - design/operational phase	4.19	0.86	78.38	71.11	87.02	78.17	84.43	3.776	0.437
8	Climate change resilient roadway infrastructure	4.18	0.78	88.38	75.00	82.20	78.58	102.86	2.941	0.568
9	Environmentally friendly materials	4.17	0.82	103.31	76.92	78.07	82.22	106.13	6.741	0.150
10	Meeting project duration	4.17	0.75	72.96	77.92	81.51	89.78	95.36	2.193	0.700
11	Durable materials	4.17	0.72	90.31	81.74	77.62	86.53	98.64	2.739	0.602
12	Construction of durable and cost-effective highway	4.16	0.68	122.54	91.18	65.92	99.64	97.50	33.443	0.000*
13	Adaptability and flexibility for future changes	4.16	0.78	98.46	69.26	84.07	84.03	78.36	5.429	0.246
14	Material quality control	4.16	0.72	94.65	86.39	79.59	67.94	88.79	4.111	0.391
15	Flood and surface run-off	4.16	0.62	86.00	78.89	75.86	104.00	98.71	9.261	0.055
16	Project control and monitoring guidelines	4.16	0.84	66.73	68.04	85.83	84.06	122.29	12.407	0.015*
17	Life cycle costs	4.15	0.93	88.23	67.20	85.05	81.50	103.00	6.618	0.158
18	Environmental monitoring measures	4.15	0.84	75.42	65.67	86.52	93.22	86.93	7.913	0.095
19	sustainable policy and strategy	4.15	0.83	69.92	70.09	85.15	84.11	113.36	8.806	0.090
20	Safety risk assessment and mitigation	4.14	0.90	75.12	77.46	84.66	84.42	69.00	1.688	0.793

21	Use of local materials	4.14	0.76	95.27	75.21	82.75	76.72	87.00	2.677	0.613
22	Recycled construction materials	4.14	0.88	84.38	73.01	82.64	94.25	75.43	3.284	0.511
23	Maintenance and operation costs	4.13	0.86	90.85	68.74	80.55	93.11	115.21	9.257	0.055
24	Dust control	4.13	0.87	64.35	80.82	85.32	78.17	78.71	2.772	0.597
25	Ecological functions of drainage corridor	4.13	0.83	79.12	78.96	83.67	72.69	95.64	1.913	0.752
26	Criteria for contractor (e.g., prequalification)	4.13	0.72	76.73	73.34	83.17	94.33	81.07	3.352	0.501
27	Contractor selection	4.13	0.73	76.73	80.78	80.26	85.89	98.21	1.499	0.827
28	Availability of competent supervisors, labours, etc	4.12	0.87	106.65	90.55	74.07	83.94	70.14	8.806	0.066
29	Public participation in early project phase	4.12	0.82	88.85	69.47	82.45	87.36	106.36	6.130	0.190
30	Integration of supply chains	4.12	0.79	76.69	65.76	87.61	82.75	97.57	7.862	0.097
31	Technology in design and construction	4.12	0.73	92.92	76.74	79.23	87.28	99.14	3.225	0.521

NB: G1 – Researcher/Academia, G2 – Road Agencies, G3 – Contractors, G4 – Consultants, and G5 – Environmental Agencies

4.4.3 Differences Between Highway Professional Groups

The examination of variance in the attitudes of highway professionals towards sustainability indicators for highway infrastructure development utilized the Mann-Whitney U test to assess if two distinct groups of professionals significantly deviate in their assessments. The results of the Mann-Whitney U test depicted in Table 11.

Table 11: Mann-Whitney Test results on Critical Indicators (P values)

<i>Groups</i>	<i>Project control and Monitoring guidelines</i>	<i>Durable and cost-effective highways</i>
<i>G1/G2</i>	0.946	0.047*
<i>G1/G3</i>	0.128	0.000*
<i>G1/G4</i>	0.239	0.121
<i>G1/G5</i>	0.010*	0.138
<i>G2/G3</i>	0.033*	0.001*
<i>G2/G4</i>	0.173	0.589
<i>G2/G5</i>	0.009*	0.837
<i>G3/G4</i>	0.852	0.000*
<i>G3/G5</i>	0.021*	0.007*
<i>G4/G5</i>	0.022*	0.864

*G1 – Researcher/Academia; G2 – Road Agencies; G3 – Contractors; G4 – Consultants and G5 – Environmental Agencies. * = significance difference*

According to the findings presented in Table 11, the analysis underlines a notable disparity in the valuation of project control and monitoring guidelines as a critical sustainability indicator, particularly among environmental agency professionals compared to their counterparts in researchers and academia, road agencies, contractors, and consultants. Notably, environmental agency professionals assigned a higher priority to project control and monitoring guidelines, suggesting a more pronounced focus on the governance and oversight of road and highway projects within this group. Additionally, a marked contrast was observed between road agency professionals and contractors in their appreciation of project control and monitoring guidelines. Here, contractors exhibited a higher mean rank than road agencies, indicating a stronger emphasis on project governance among contractors.

A further variance was identified in the attitudes towards the sustainability indicator of durable and cost-effective roads and highways. Contractors demonstrated significantly different views from those held by researchers and academia, road agencies, consultants, and environmental agencies, with contractors displaying lower mean ranks. This finding suggests that, in contrast to other professional groups, contractors may place less emphasis on the durability and cost-effectiveness of roads and highways, potentially prioritizing other aspects of sustainability or project delivery.

Moreover, the study revealed significant differences between the perceptions of researchers and academia versus road agencies regarding durable and cost-effective highways, with researchers and academia assigning a higher importance to this indicator compared to road agencies. This variation highlights the wide-ranging priorities and considerations that different professional groups bring to the discourse on sustainable road and highway infrastructure development, emphasising the need for an in-depth understanding of these perspectives in the formulation of comprehensive sustainability guidelines.

4.5 Conceptual Framework for highway infrastructure development

The formulation of a preliminary conceptual framework for sustainable road and highway infrastructure development, as depicted in Figure 13 and Table 12, was accomplished following the comprehensive identification and consensus on critical sustainability indicators across all groups of highway professionals. These pivotal indicators have been organized into six distinct categories referred to as sustainability criteria, which include economics, environmental impact, technical quality, project implementation and management, social equity and culture, and resource utilization and management. This framework lays the groundwork for crafting guidelines aimed at fostering sustainable practices in the development of road and highway infrastructure within Ghana. It acts as a blueprint for integrating sustainability considerations throughout the lifecycle of highway projects, from initial planning and design phases through to construction and ongoing operations.

To enrich this framework and ensure its practical applicability, semi-structured interviews were conducted. These discussions were instrumental in pinpointing specific strategies and actionable guidelines that could facilitate the incorporation of identified sustainability indicators into the actual practices of planning, designing, constructing, and managing road and highway infrastructure in Ghana. Through this process, the framework evolves

from a theoretical construct into a tangible set of principles, guiding stakeholders towards achieving sustainability objectives in highway infrastructure projects.

Table 12: Construct for the framework

Criteria (Construct)	Indicators
<i>Economics</i>	Life cycle costs
	Material costs
	Construction time
	Maintenance and operation costs
<i>Environmental</i>	Dust control
	Environmentally friendly materials
	Ecological functions of drainage corridor
	Environmental monitoring measures after project completion
<i>Technical</i>	Flood and surface run-off
	Durable materials
	Disaster (flood) resilient designs
	Climate change resilient roadway infrastructure
	Technology in design and construction
	Adaptability and flexibility for future changes
<i>Project Implementation & Mgmt</i>	Availability of competent supervisors, labours, etc
	Comply with environmental requirements, contract documents and project specification
	Sustainable policy and strategy
	Meeting project duration
	Project risk assessment
	Criteria for contractor
<i>Social Equity & Culture</i>	Contractor selection
	Safety risk assessment & mitigation
	Worker's health and safety
	Traffic congestion - design/operational phase
<i>Resource Utilisation & Mgmt</i>	Public participation in early project phase
	Integration of supply chains
	Use of local materials
	Material quality control
	Recycled construction materials



Figure 13: A preliminary conceptual framework.

4.6 Climate action supports and sustainable criteria and indicators.

This section explores the relationship between highway professionals' perceptions of sustainability criteria's importance and their support for climate action using structural equation modelling (SEM). The analytical process was divided into two primary phases: the development of the measurement model followed by the formulation of the structural model. The maximum likelihood estimation method was chosen for this study due to its prevalent application in SEM. This method is renowned for enhancing parameter estimates by minimizing a specific fit function, especially when the data conforms to assumptions of normality (Myung, 2003; Steg, 2023).

The methodology and findings from this sophisticated modelling approach are detailed below, offering insights into how the professionals' valuation of various sustainability criteria correlates with their engagement and support for initiatives aimed at mitigating climate change. Through SEM, the aim is to uncover latent patterns and infer

relationships, providing an in-depth understanding of the dynamics at play within the context of sustainable road and highway infrastructure development and climate action advocacy among highway professionals.

4.6.1 Confirmatory Factor Analysis (CFA) Results and Measurement

Model Validation

The result of the CFA is the measurement model, which defines how measured items (indicators), and constructs (latent dimensions) are related to each other. It provides the link between scores on the measured items and the underlying constructs they are designed to measure and among the constructs (importance of Economics, Environmental, Technical, Project Implementation and Management, Social Equity and Culture, Resource Utilisation and Management, and Climate Action Support) (Raju et al., 2002; Wu et al., 2023). Altogether, 75 parameters were estimated, consisting of 24 regression weights, 8 covariances, and 16 variances. Also, the number of measured and latent dimension variables was 34 and 7, respectively, as can be seen in figure 14.

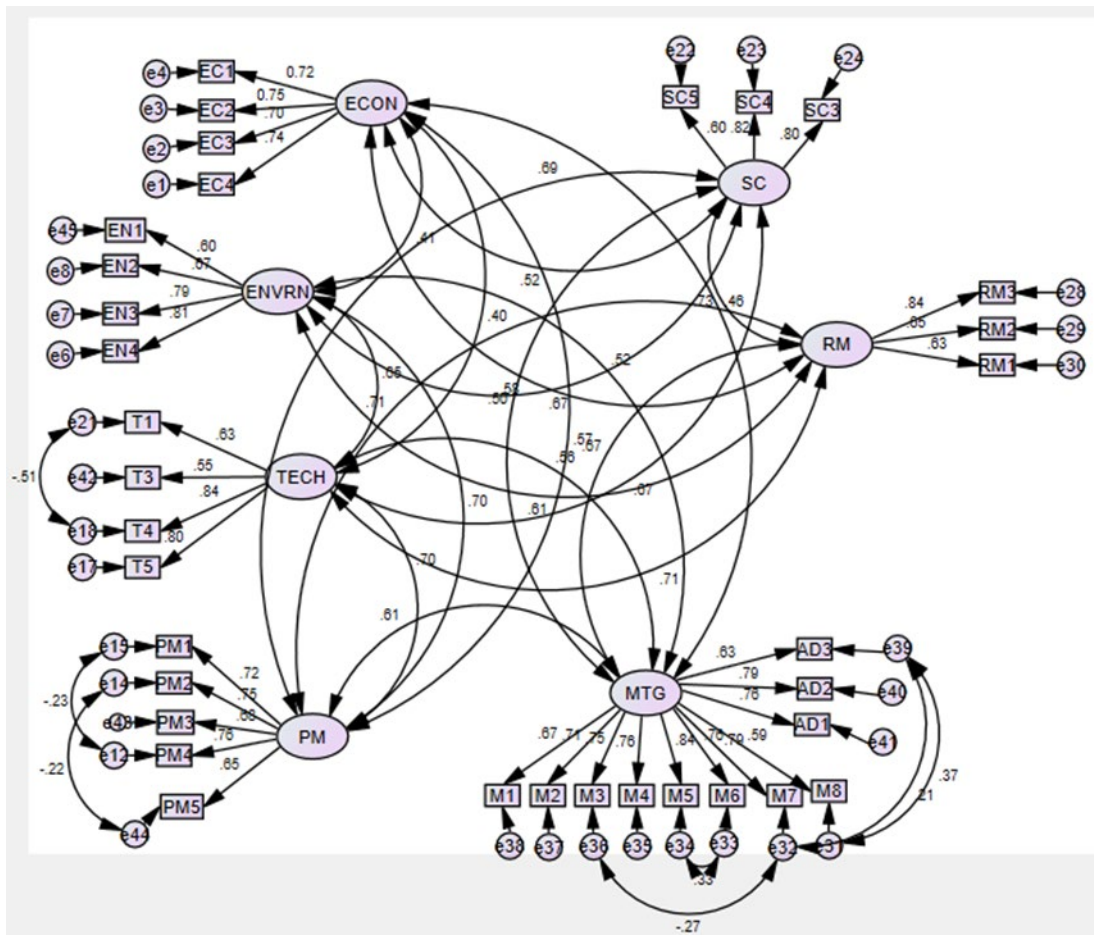


Figure 14: Measurement model.

Notes: ECON=Economic, ENVRN=Environmental, TECH=Technical, PM= Project Implementation and Management, SC=Social Equity and Culture, RM=Resource Utilization and Management, and CAS=Climate Action Support

To be clearer, the modification indices (MI) ≥ 20 values showed that there were high covariances between the error terms of some measured indicators of different latent dimensions. For the purpose of this research, a factor loading of 0.5 was considered the minimum value for the indicator to be retained in the model (Cheung et al., 2024; Nájera et al., 2023). Based on the aforementioned issues, some of the items were removed from the model to improve the overall fit of the model. This environmental dimension, which initially had 5 items, was left with 4 items. Two items were removed from the initial six items in the technical dimension. An item was also removed from both the social equity and culture criteria and the resource utilisation and management criteria.

After the re-specifications, the measurement model obtained in Figure 14 exhibited an acceptable goodness of fit. Cheung et al. (2023) suggested that there should be a minimum of four tests that are acceptable for the model fit. All obtained values except that of the p-value met or exceeded their respective threshold values, indicating good model fit. The p-value is sensitive to sample size; large samples can result in a significant χ^2 even with

minor model deviations, which is a limitation. The model fit indices with the threshold values and the obtained values are presented in the table 13.

Table 13: Model fit indices

Fit index	Obtained Value	Threshold Value	Source
CMIN/DF	1.790	≤ 3.0	(Hair et al., 2014)
CFI	0.963	≥ 0.90	(Hu & Bentler, 1999)
AGFI	0.906	≥ 0.80	(Hooper et al., 2008)
NFI	0.802	≥ 0.80	(Bentler & Bonett, 1980)
RMSEA	0.070	≤ 0.08	(Browne & Cudeck, 1993)
χ^2 (P-value)	0	> 0.05	(Hu & Bentler, 1999)

The loadings of all items on their respective dimensions were statistically significant (p-value <0.001) given C.R. > 1.96 , as shown in Table 14. The convergent and discriminant validity were assessed to check the constructs validity. The model was considered to have no convergent validity issues if the constructs (dimensions) had an average variance extracted (AVE) above 0.5. To the other hand, their AVEs' square root values should be higher than their individual and inter-construct correlation values so that there are no problems with discriminant validity (Baharum et al., 2023; Khine et al., 2015). The reliability of each construct was evaluated through the Cronbach's alpha value and confirmed by the composite reliability, both of which are expected to be above 0.7. The results of convergent validity and reliability are as depicted in Table 14. The Cronbach's alpha values and composite reliability were all found to be above or equal to 0.7, indicating that the constructs are all reliable. Further, the AVEs of the constructs as shown in Table 14 are all above the threshold of 0.5, an indication that the model has no convergent validity problems.

Table 14: Convergent validity assessment

Dimension	Indicator	Factor Loading	CA	CR	AVE
CAS	AD1_Appropriate_network_data_hazard_assessment	0.76			
	AD2_Education_climate_change_adaptation	0.79			

	AD3_Use_natural_vegetation_sustainable_drainage_system	0.631			
	M1_Harness_local_topography	0.669			
	M2_Incorporate_needs_of_vulnerable_people	0.707			
	M3_Implementation_performance_based_award_criteria	0.752	0.927	0.927	0.539
	M4_Incorporate_emissions_criteria_procurement	0.761			
	M5_Construction_methods_social_context	0.838			
	M6_Apply_monitor_climatechange_mitigation_plans_policies	0.757			
	M7_Use_design_software_identify_energysustainable_route	0.786			
	M8_Consider_number_types_wattage_hours_of_lights	0.586			
<i>ECON</i>	EC1_Life_cycle_costs	0.72			
	EC2_Material_costs	0.75			
	EC3_Construction_time	0.7	0.721	0.819	0.531
	EC4_Maintenance_and_operation_costs	0.744			
<i>ENVRN</i>	EN1_Dust_control	0.6			
	EN2_Environmentally_friendly_materials	0.668			
	EN3_Ecological_functions_drainage_corridor	0.788	0.765	0.810	0.519
	EN4_Environmental_monitoring_measures	0.805			
<i>PM</i>	PM1_Comply_environmental_requirements_project_specification	0.718			
	PM2_Sustainable_policy_and_strategy	0.75			
	PM3_Meeting_project_duration	0.68	0.8	0.837	0.507
	PM4_Project_risk_assessment	0.757			
	PM5_Criteria_for_contractor_prequalification	0.649			
<i>RM</i>	RM1_Supply_chains	0.63			
	RM2_Local_materials	0.65	0.7	0.753	0.508
	RM3_Material_quality_control	0.84			
<i>SC</i>	SC3_Traffic_congestion_design_operations	0.804			
	SC4_Traffic_congestion_construction	0.818	0.769	0.790	0.560
	SC5_Public_participation	0.604			
<i>TECH</i>	T1_Durable_materials	0.631			
	T3_Climate_change_resilient_designs	0.552	0.734	0.804	0.513
	T4_Technology_design_construction	0.843			
	T5_Adaptability_flexibility	0.8			

Note(s): CA: Cronbach's Alpha; CR: Composite Reliability; AVE: Average Variance Extracted

Table 14 shows the inter-construct correlation matrix used for assessing the discriminant validity. It was compared to the construct with the highest inter-construct correlation in the correlation matrix (Shirazi et al., 2021). The square root of the AVEs shown in boldface and on the diagonal for each construct was used. The results reveal no concerns with regards to the discriminant validity of the model. This means that the dimensions are

distinct and each of them measure a unique concept and paved the way for the structural model to be developed.

In this structural equation model, correlations between exogenous latent constructs were selectively implemented rather than universally applied. This approach aligns with contemporary SEM best practices that emphasize theory-driven model specification (Hair et al., 2019; Kline, 2018). Multiple discriminant validity tests are recommended to establish that predictor constructs are sufficiently distinct to make unique contributions to the dependent variable. However, as Ab Hamid et al. (2017) note, a single discriminant validity test can be considered acceptable for predictive purposes when properly conducted and validated. This approach recognizes both the ideal standard of multiple tests and the practical acceptance of a single robust test in research contexts. The results of the structural model are presented in the next subsection.

Table 15: Discriminant Validity Assessment

<i>Dimension</i>	<i>MSV</i>	<i>MaxR(H)</i>	<i>PM</i>	<i>ECON</i>	<i>ENVRN</i>	<i>TECH</i>	<i>MTG</i>	<i>RM</i>	<i>SC</i>
<i>PM</i>	0.504	0.841	0.712						
<i>ECON</i>	0.340	0.820	0.566	0.729					
<i>ENVRN</i>	0.504	0.829	0.710	0.407	0.720				
<i>TECH</i>	0.500	0.842	0.702	0.396	0.650	0.717			
<i>MTG</i>	0.449	0.933	0.613	0.462	0.519	0.561	0.734		
<i>RM</i>	0.504	0.791	0.709	0.583	0.613	0.707	0.670	0.713	
<i>SC</i>	0.504	0.816	0.689	0.518	0.673	0.671	0.498	0.710	0.748

4.6.2 Structural models for hypothesis testing

The investigation into the dynamics between highway professionals' assessment of sustainability criteria and their support of climate action is articulated through the analysis of two structural models. The essence of Model 1 is to scrutinize the hypothesis positing that the perceived significance of sustainability criteria among highway professionals exerts a substantial and affirmative influence on their support for climate action. Conversely, Model 2 explores the hypothesis that the professionals' support for climate action significantly and positively influences their perceived importance of sustainability criteria in road and highway infrastructure development.

Model 1 evaluates the directional impact of each sustainability criteria—Economic, Environmental, Technical, Project Implementation and Management, Social Equity and Culture, and Resource Utilization and Management—on the tendency of highway professionals to support climate action initiatives. This model underlines the assumption

that a higher valuation of these criteria correlates directly with increased advocacy for climate-related actions, reflecting an integrated approach to sustainable development and climate resilience in road and highway infrastructure development.

Model 2, in contrast, explores the reciprocal relationship, hypothesising that a pronounced commitment to climate action catalyses a heightened appreciation for the integration of sustainability principles across the various phases of road and highway infrastructure development. This model posits that professionals who are actively engaged in climate action initiatives are more likely to recognise and prioritise sustainability criteria in their projects, thereby fostering an interdependent relationship between climate responsiveness and sustainable development practices.

Both models are instrumental in interpreting the bidirectional influences between sustainability priorities and climate action support within the field of road and highway infrastructure development. By employing structural equation modelling (SEM), these analyses provide empirical insights into the extent to which sustainability criteria and indicators and climate action support mutually reinforce each other, offering an in-depth understanding of the interplay between environmental stewardship and sustainable infrastructure practices among Ghanaian highway professionals.

4.6.2.1 Model 1

The analysis of Model 1, defined in Figure 15 and Table 15, unveils the relationships between various sustainability criteria and their impact on climate action support among highway professionals. The model reveals how economic considerations and resource management practices within road and highway infrastructure development significantly influence the inclination towards climate action support. The significant paths, highlighted in blue in Figure 15, are from the Economic (ECON) and Resource Management (RM) dimensions to Climate Action Support (CAS), with β values of 0.159 ($p=0.016$) and 0.429 ($p=0.02$), respectively, indicating substantial predictive relationships.

- **Economic Dimension Impact**

The analysis confirms that professionals who prioritize economic indicators, including life cycle cost reduction, material cost efficiency, and operational cost savings, exhibit stronger inclinations towards climate action (**Hypotheses H_{1a}** validated). This correlation suggests a perception among professionals that climate action could result in favourable

economic outcomes, such as cost savings and potentially accessing incentives for sustainable practices. This finding resonates with the findings of Gouldson et al. (2015) and Stecula & Merkley (2019) asserting the significant role economic indicators play in fostering support for climate policies, underlining that direct economic benefits enhance climate action support.

- **Resource Utilization and Management Impact**

The model highlights the significant role of efficient resource utilization and management in promoting climate action support (**Hypotheses H_{6a}** validated). Practices such as employing local materials and emphasizing quality control are seen as pivotal in reducing environmental impacts and fostering sustainable construction. This emphasizes the interconnectedness of sustainability practices and climate-friendly actions in the field of road and highway infrastructure development.

- **Non-significant Dimensions**

Contrary to expectations, the Social Equity and Culture (SC), Environmental (ENV), Technical (TECH), and Project Implementation and Management (PM) dimensions did not significantly predict climate action support, leading to the non-validation of Hypotheses **H_{2a}**, **H_{3a}**, **H_{4a}**, and **H_{5a}**. The lack of a significant relationship between these dimensions and climate action support may suggest perceived trade-offs or prioritization conflicts among professionals between these sustainability criteria and climate action initiatives.

- **Surprising Findings and Implications**

The surprising insignificance of the environmental dimension in predicting climate action support contradicts common assumptions that environmental awareness directly enhances climate action advocacy. This may imply an in-depth relationship where environmental concerns do not straightforwardly translate into support for specific climate actions. Also, the fact that technical and project management dimensions didn't have a big effect shows that highway professionals might think there are problems putting climate-resilient practices into action and also managing project efficiency or budgetary limits.

Model 1's insights clarify the complex interplay between sustainability criteria and climate action support within the context of road and highway infrastructure

development. While economic and resource management considerations strongly predict climate action support, the lack of significant influence from other dimensions highlights the multifaceted nature of sustainability considerations among highway professionals. This in-depth understanding is crucial for developing targeted strategies to enhance climate action support, taking into account the varied perspectives and priorities within the sector.

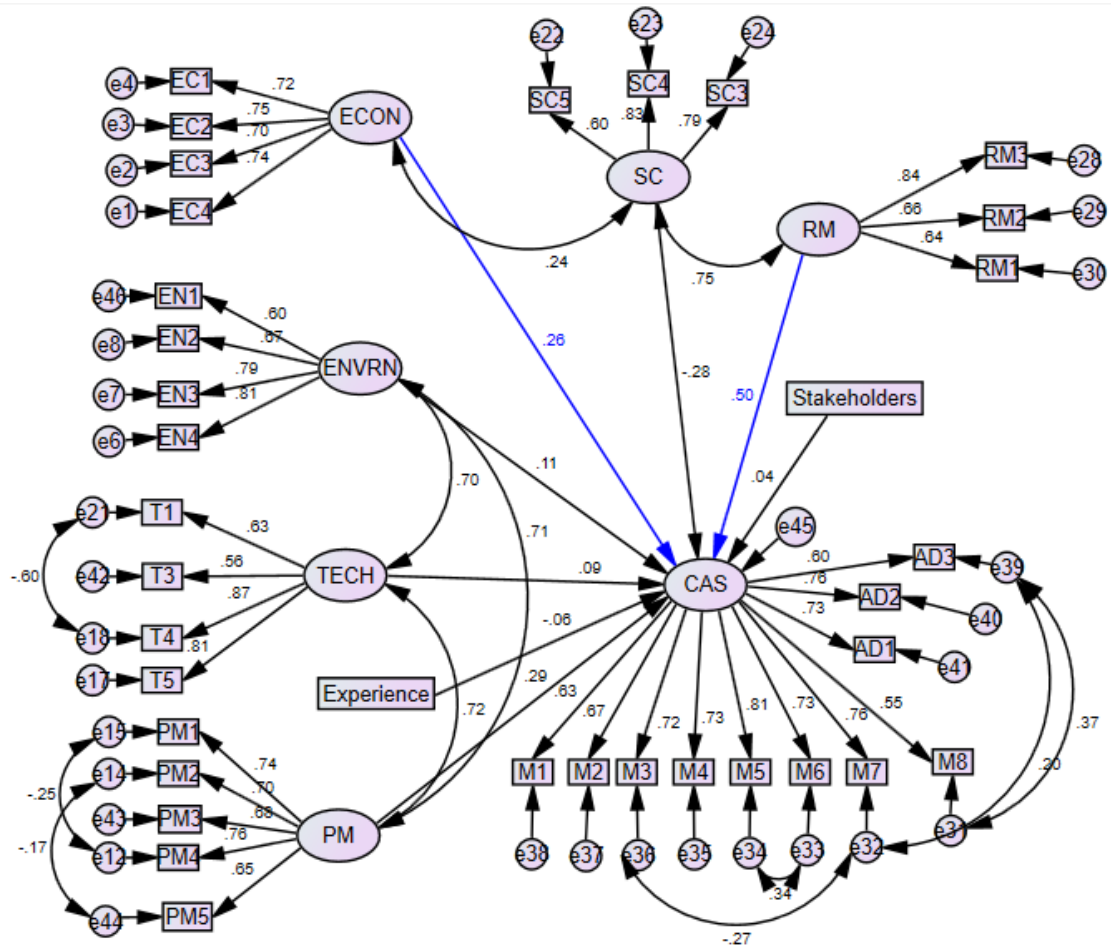


Figure 15: Path diagram of structural model 1.

Table 16: Model output for hypotheses testing (Model 1)

Endogenous variable	Exogenous variable	B	S.E.	C.R.	P	Findings on hypothesis
CAS	SC	-0.238	0.169	-1.408	0.159	H5a: Rejected
CAS	ECON	0.159	0.066	2.403	0.016	H1a: Supported
CAS	TECH	0.055	0.104	0.526	0.599	H3a: Rejected

CAS	<---	PM	0.186	0.153	1.214	0.225	H4a: Rejected
CAS	<---	ENVRN	0.064	0.098	0.657	0.511	H2a: Rejected
CAS	<---	Stakeholders	0.018	0.03	0.587	0.558	n/a
CAS	<---	Experience	-0.026	0.028	-0.911	0.362	n/a
CAS	<---	RM	0.429	0.185	2.32	0.02	H6a: Supported

4.6.2.2 Model 2

The results of Model 2, depicted in Figure 16 and detailed in Table 16, indicate all path coefficients are significant ($p < 0.05$), demonstrating the substantial influence of climate action support (CAS) on various sustainability criteria, including Economics (ECON), Resource Management (RM), Social Equity and Culture (SC), Technical (TECH), Project Implementation and Management (PM), and Environmental (ENVRN) dimensions. This model illustrates that a positive disposition towards climate action correlates significantly with prioritizing these sustainability criteria within road and highway infrastructure development, validating hypotheses **H1b**, **H2b**, **H3b**, **H4b**, **H5b**, and **H6b**.

The association between climate action support and the economic dimension reveals that highway professionals acknowledging the importance of climate action are more inclined to emphasize economic considerations. This insight suggests a recognition among professionals of the synergy between climate initiatives and economic benefits, such as cost reductions and efficient resource allocation, aligning with broader sustainable development objectives. Moreover, the model stresses a significant connection between climate action support and enhanced practices in resource utilization and management. This relationship highlights the professionals' commitment to integrating environmental considerations into material sourcing and management practices. The emphasis on local material usage points to an environmental strategy aimed at reducing transportation emissions and, by extension, the project's overall carbon footprint.

The data also show that climate action supporters are likely to prioritize social equity and culture within road and highway projects, underlining a perceived alignment between climate goals and social benefits. This includes efforts to mitigate congestion and promote worker safety, reflecting a holistic approach to sustainable development that encompasses both environmental and social dimensions.

In essence, Model 2 articulates a comprehensive view of how climate action support influences highway professionals' attitudes towards sustainable development criteria. It illuminates the interconnectedness of climate initiatives with economic, environmental, technical, and social considerations in the context of road and highway infrastructure development. The model's findings advocate for an integrated approach to project management, emphasizing the importance of climate-conscious decision-making in fostering sustainable and resilient infrastructure projects.

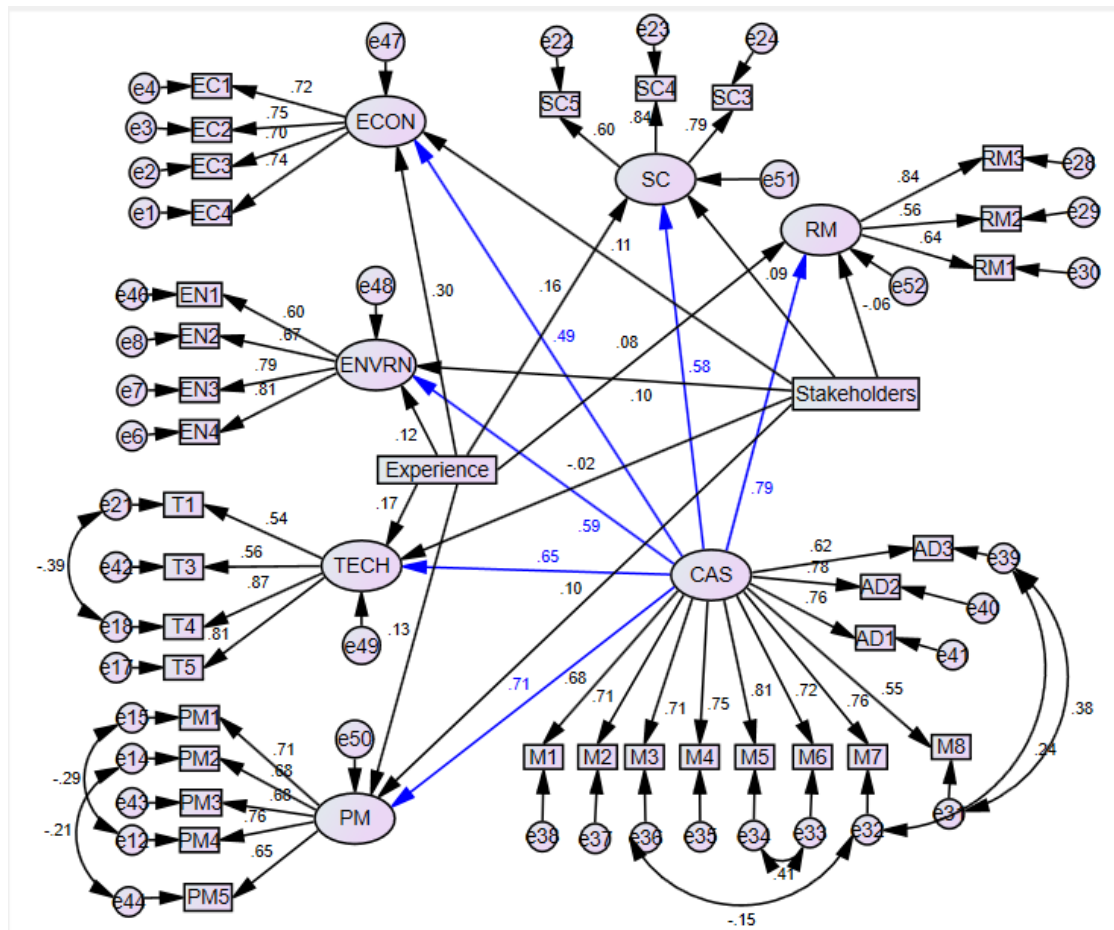


Figure 16: Path diagram of structural model 2.

Table 17: Model output for hypotheses testing (Model 2)

Endogenous variable		Exogenous variable	B	S.E.	C.R.	P	Findings on hypothesis
RM	<---	CAS	1.002	0.157	6.389	***	H1b: Supported
SC	<---	CAS	0.684	0.139	4.928	***	H2b: Supported
ECON	<---	CAS	0.728	0.157	4.648	***	H3b: Supported
ENVRN	<---	CAS	0.936	0.165	5.692	***	H4b: Supported
TECH	<---	CAS	1.017	0.156	6.522	***	H5b: Supported
PM	<---	CAS	0.987	0.16	6.187	***	H6b: Supported
RM	<---	Stakeholders	-0.033	0.043	-0.77	0.441	n/a
SC	<---	Stakeholders	0.05	0.04	1.26	0.208	n/a
ECON	<---	Stakeholders	0.074	0.055	1.34	0.18	n/a
ENVRN	<---	Stakeholders	0.073	0.053	1.372	0.17	n/a
TECH	<---	Stakeholders	-0.016	0.048	-0.343	0.731	n/a
RM	<---	Experience	0.044	0.04	1.093	0.274	n/a
SC	<---	Experience	0.079	0.038	2.108	0.035	n/a
TECH	<---	Experience	0.11	0.045	2.464	0.014	n/a
PM	<---	Experience	0.077	0.039	1.982	0.047	n/a
ENVRN	<---	Experience	0.082	0.05	1.651	0.099	n/a
ECON	<---	Experience	0.188	0.053	3.526	***	n/a
PM	<---	Stakeholders	0.063	0.041	1.524	0.127	n/a

4.7 Main findings of the Questionnaire Survey

The questionnaire survey conducted as part of this study sheds light on the prioritization and consensus among highway professionals regarding sustainability in road and highway infrastructure development. The findings are summarized as follows:

- **Critical Indicators Identified:** Out of the 80 proposed indicators, 31 were identified as critical for enhancing sustainability in road and highway

infrastructure development. These encompass a wide range of indicators including material costs, environmental compliance, disaster resilience, worker safety, and the integration of environmentally friendly materials, among others. This comprehensive list emphasizes the multifaceted approach required to achieve sustainability in infrastructure development.

- **Comprehensive Coverage of Indicators:** The absence of additional indicators suggested by the respondents underlines the thoroughness of the initial list derived from extensive literature review, indicating it effectively captures the key elements necessary for sustainable road and highway infrastructure development.
- **Broad Consensus Among Professional Groups:** There was a notable consensus among different professional groups on the importance of 29 out of the 31 indicators, highlighting a shared understanding and agreement on the key indicators that drive sustainability in road and highway infrastructure development. However, disparities emerged in perceptions regarding "durable and cost-effective highways" and "project control and monitoring guidelines," pointing to areas where further dialogue and consensus-building are needed.
- **Significant Variations in Certain Indicators:** Differences in how environmental agencies and other professional groups value "project control and monitoring guidelines" and "durable and cost-effective highways" suggest an in-depth perspective on these issues, potentially influenced by specific roles and experiences within the industry.
- **Foundation for Decision-Making Guidelines:** The identified critical indicators offer a robust foundation for formulating guidelines to guide sustainable practices in road and highway projects, ensuring a balanced consideration of economic, environmental, technical, social, and managerial aspects.
- **Inclusive of Sustainability Pillars:** The critical indicators span all three pillars of sustainability—economic, environmental, and social—through categorized criteria, reflecting a holistic approach to sustainable development in road and highway infrastructure that is economic value, environmental impact, technical quality, social equity and culture, project implementation and management, resource utilization and management criteria.
- **Economic and Resource Management's Influence on Climate Action:** The survey revealed a significant relationship between economic indicators, resource management practices, and support for climate action, highlighting the integral role these aspects play in fostering sustainable infrastructure development.

- **Unexpected Findings:** Notably, the environmental dimension's influence on climate action support was less pronounced than anticipated, indicating potential areas for deeper investigation, and understanding of the underlying indicators.
- **Impact of Climate Action Support on Sustainability Criteria:** The strong influence of climate action support on various sustainability criteria underlines the interconnectedness of climate initiatives with broader sustainability objectives in infrastructure development.

These findings not only provide empirical insights into the current state of sustainability considerations in the Ghanaian road and highway construction industry but also offer a valuable framework for integrating sustainable practices into future projects, ultimately contributing to more resilient, environmentally responsible, and socially inclusive infrastructure development.

4.8 Summary

This chapter looked at the results of the questionnaire survey and answered the original research questions about what professionals in the field think are the most important sustainability criteria and indicators for road and highway construction. It also looked at how these perceptions relate to their support for climate action initiatives. The survey established 29 indicators deemed critical for the advancement of sustainable road and highway infrastructure development. These indicators span a wide array of considerations, including Material costs, Comply with environmental and project spec requirements, Disaster resilient designs, Workers' health and safety, Construction time, Project risk assessment, Traffic congestion - design/operational phase, Climate change resilient roadway infrastructure, Environmentally friendly materials, Meeting project duration, Durable materials, Adaptability and flexibility for future changes, Material quality control, Flood and surface run-off, Life cycle costs, Environmental monitoring measures, sustainable policy and strategy, Safety risk assessment and mitigation, Use of local materials, Recycled construction materials, Maintenance and operation costs, Dust control, Ecological functions of drainage corridor, Criteria for contractor (e.g., prequalification, Contractor selection, Availability of competent supervisors and labours, etc, Public participation in early project phase, Integration of supply chains, Technology in design and construction.

Notably, the survey did not obtain any suggestions for additional indicators, indicating a comprehensive coverage by the existing set. However, an openness among participants

for further involvement in the research process presents an advantageous opportunity for deeper exploration in subsequent phases.

The importance of understanding these indicators is matched by the need for implementing effective strategies to tackle them. To facilitate this, the indicators were categorized into six distinct groups: ecological performance, economic value, social equity and culture, technical quality, project implementation and management, and resource utilization and management. This categorization enriches the traditional "triple bottom line" approach by integrating additional dimensions of technical and managerial considerations, thereby providing a holistic framework for sustainable infrastructure development.

A preliminary conceptual model was formulated to guide systematic decision-making processes in sustainable road and highway infrastructure development, leveraging the identified categories. This model emphasizes the significant influence of economic and resource management considerations on climate action support. Interestingly, the analysis revealed that, contrary to conventional wisdom, environmental criteria did not directly predict climate action support, indicating a more in-depth relationship between environmental awareness and climate advocacy. Instead, a strong inclination towards climate action was significantly associated with prioritizing a broad spectrum of sustainability criteria in road and highway infrastructure development.

Following the identification of critical indicators, the research progresses to explore methodologies for effectively addressing these indicators. Through qualitative analysis, semi-structured interviews will explore the specifics of each indicator, aiming to craft actionable strategies for enhancing sustainability in road and highway infrastructure. The subsequent chapter will detail the insights and proposed action plans derived from these interviews, thereby enhancing the research's contribution to sustainable infrastructure development.

Chapter 5 : Interviews

5.1 Introduction

This chapter explores the semi-structured interviews conducted with key highway professionals following the foundational questionnaire survey discussed in the preceding chapter. These interviews aimed to validate the research framework and further explore the sustainability indicators identified for road and highway infrastructure development, as illustrated in Figure 17. Fourteen interviews were carried out with experts who have substantial expertise and experience in the area of road and highway infrastructure sustainability. These interviews provided valuable insights and ideas for improving sustainability outcomes.

The chapter outlines the participant selection process, their professional backgrounds, the instruments employed for the interviews, and the analytical methods used to interpret the data. Subsequently, it presents a detailed discussion of the interview findings, highlighting the main insights obtained from the interactions with the participants. The chapter concludes by summarizing the significant outcomes of the interviews, which are instrumental in advancing the research towards developing actionable guidelines for sustainable road and highway infrastructure development.

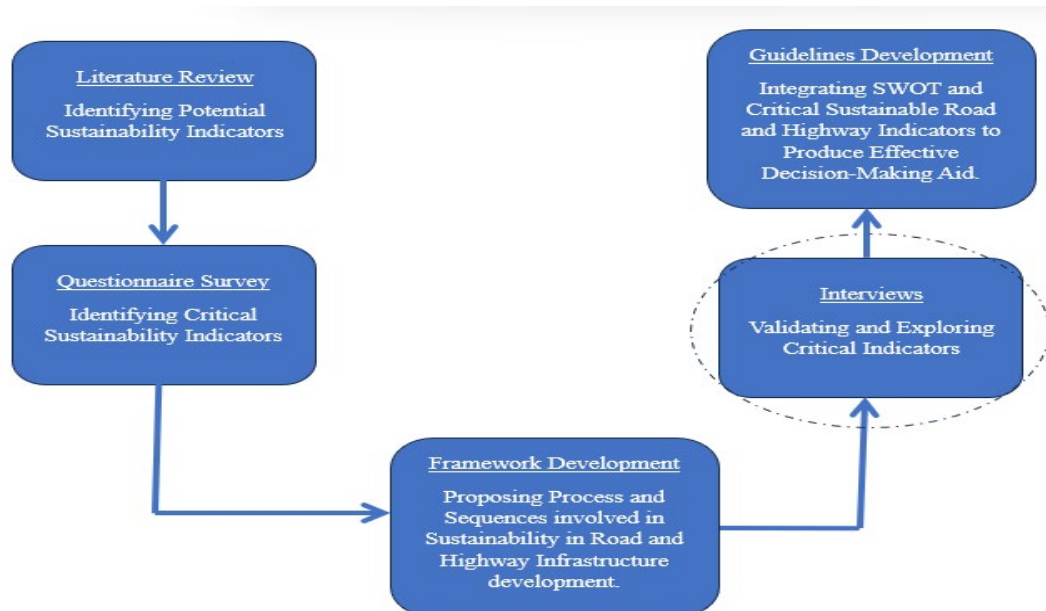


Figure 17: Role of interviews in overall guideline development process.

5.2 Participants' selection and their background

5.2.1 Selection of Interviewees

The interviewee selection process is critical for fulfilling the interview objectives and ensuring comprehensive data collection. For this study, interviewees were chosen based on criteria including their current roles within their organisations, professional expertise, experience relevant to road and highway infrastructure sustainability, and their availability during the predetermined interview period. Potential candidates who indicated a desire to participate in further phases of the study were identified based on their responses to the questionnaire survey. Out of the respondents who participated in the questionnaire survey, 35 provided their contact information, indicating a willingness to continue the research. Consequently, a total of 14 professionals consented to partake in the interviews, scheduled between May 1, 2023, and June 30, 2023, contributing valuable insights into the development of sustainable road and highway infrastructure.

5.2.2 Interviewee Background

The respondents' backgrounds and affiliations were recorded to enhance the analysis and guarantee that the insights gained were based on significant experience and expertise. Table 17 presents the professional capacities and organisational affiliations of the respondents, representing a wide range of individuals involved in the subject of road and highway infrastructure development. The interviewees' selection criteria were based on their qualifications and extensive industry experience, with the goal of utilising their knowledge for this research.

Table 18: Details of interviewee and their organisations

<i>ID</i>	<i>Stakeholder Organisation Type</i>	<i>Interviewee Position</i>	<i>Sector</i>	<i>Experience (years)</i>	<i>Interview Type</i>
<i>P1</i>	Academia / Researcher	Senior Lecturer	Government	10	Face-to-face
<i>P2</i>	Ghana Highway Authority	Survey & Design Manager	Government	18	Face-to-face
<i>P3</i>	Ministry of Road and Highway	Principal Engineer	Government	13	Face-to-face
<i>P4</i>	Department of Urban Roads	Regional Manager	Government	19	Phone
<i>P5</i>	Contractor	Project Manager	Private	21	Face-to-face

<i>P6</i>	Department of Feeder Roads	Deputy Regional Manager	Government	16	Face-to-face
<i>P7</i>	Department of Feeder Roads	Project Engineer	Government	16	Phone
<i>P8</i>	Environmental Agencies	Deputy Director	Government	24	Phone
<i>P9</i>	Ghana Highway Authority	Principal Engineer	Government	12	Face-to-face
<i>P10</i>	Department of Feeder Roads	Regional Manager	Government	20	Face-to-face
<i>P11</i>	Consultant	Project Manager	Private	14	Face-to-face
<i>P12</i>	Ghana Highway Authority	Contract Manager	Government	15	Face-to-face
<i>P13</i>	Consultant	Managing Director	Private	18	Face-to-face
<i>P14</i>	Academia / Researcher	Senior Researcher	Government	15	Face-to-face

The organizations represented by the interviewees are important to the industry, promising a wide range of perspectives on the sustainability indicators under examination. All participants brought to the table over a decade of experience in the field, with many holding senior roles such as Managing Director, Regional Managers, Project Managers, and Contract Managers, Senior Researcher, and Senior Lecturer with extensive years of research in the field of road and highway infrastructure development in Ghana. This level of expertise and leadership positions within their respective organizations ensured that the insights, recommendations, and information provided would significantly contribute to the development of comprehensive and effective decision-making guidelines for sustainable road and highway infrastructure development.

5.3 Interview Instruments

Prior to conducting the interviews, preparations were undertaken to ensure a smooth and productive session. Potential interviewees were contacted via email or telephone to schedule the interview, offering two modes of interaction: telephone or face-to-face meetings. To facilitate informed participation, interviewees were provided with essential preparatory documents, including:

- Interview Participant Information Sheet (see Appendix I [D] for details),

- Consent Form for an AUT Research Project (detailed in Appendix I [E]),
- A set of interview questions, and
- The conceptual framework guiding the study (illustrated in Figure 13).

An invitation letter was dispatched via email, encompassing these documents to clarify the interview's purpose and enable participants to prepare thoroughly. This preparation aimed to enhance the quality of the discussion and the efficiency of the interview process. The face-to-face interviews were primarily conducted within the interviewee's office. Due to geographical limitations, three interviews were conducted over the phone, with the researcher coordinating these sessions from the middle belt of Ghana (Ashanti Region – Kumasi). Interview durations varied, typically lasting about one and a half hours, with the shortest sessions being one hour.

Each interview began with the researcher introducing himself to establish rapport and set a comfortable tone for the conversation. A brief overview of the researcher's background was provided before exploring the objectives of the study. The researcher then confirmed the interviewee's understanding of the pre-shared documents and secured a signed consent form for record-keeping. Where permissible, conversations were recorded using a digital recorder, with most interviewees consenting to this method of documentation. This approach was key in ensuring that the insights gathered were accurately captured and could be effectively analysed to contribute to the research objectives.

5.4 Interview Format and Structure

The semi-structured interviews were crafted, drawing upon the insights gained from the questionnaire survey, specifically focusing on the 29 critical sustainability indicators identified through this research. The objective was to examine each indicator, exploring avenues to enhance sustainability within the context of road and highway infrastructure development. The questions were qualitative, crafted to elicit detailed responses and allow interviewees the latitude to share comprehensive insights, thereby broadening the research's understanding of sustainability practices. Each question was targeted, asking how sustainability could be augmented through the specific lens of each identified indicator. The core questions posed to the interviewees are catalogued in Table 18, serving as a foundation for the in-depth discussions aimed at uncovering in-depth strategies and solutions for sustainable road and highway infrastructure development.

Table 19: Main interview questions

Main Interview Questions
Economic Criteria
<ol style="list-style-type: none"> 1. Can you share your insights on the strategies and practices that can be implemented to effectively manage and optimize material costs in road and highway infrastructure projects? 2. How can incorporating life cycle cost analysis into the planning and development phases of highway infrastructure projects enhance sustainability outcomes? 3. How does the management of construction time impact the sustainability of road and highway infrastructure projects, and what strategies have proven effective in minimizing construction time while ensuring sustainability goals are met? 4. How can the management of maintenance and operation costs be optimized to enhance the long-term sustainability and efficiency of highway projects?
Environmental Criteria
<ol style="list-style-type: none"> 1. What strategies and practices can be implemented to effectively control and minimize dust emissions during the construction and operational phases of highway projects? 2. What strategies can be implemented to ensure the effective selection and utilization of environmentally friendly materials to minimize environmental impact? 3. How can highway infrastructure projects be designed and implemented to protect and enhance these ecological functions while meeting development goals? 4. What strategies and practices can be implemented to effectively minimize flood and surface run-off, thereby contributing to the project's environmental sustainability? 5. How do you envision the implementation of environmental monitoring measures after the completion of highway projects to effectively assess and ensure long-term sustainability and environmental compliance?
Technical Criteria
<ol style="list-style-type: none"> 1. What strategies and considerations should be implemented to ensure the selection and use of durable materials contribute effectively to the sustainability of highway infrastructure projects? 2. Can you elaborate on the strategies and considerations that are pivotal in integrating flood resilience into the design and planning stages of highway infrastructure projects? 3. What innovative approaches and considerations should be incorporated into the design and construction phases to ensure infrastructure is adaptable and resilient to climate change impacts? 4. What are the most effective strategies and technologies that can incorporate technology to advance sustainable practices in highway infrastructure projects? 5. What strategies and practices can be implemented to design and construct highway infrastructure that is resilient and adaptable to evolving environmental, technological, and societal changes?

6. How does ensuring the availability of competent supervisors, labourers, and other essential personnel contribute to the success and sustainability of highway infrastructure projects?

Project Implementation & Management Criteria

1. What strategies can be employed to ensure compliance with environmental requirements, contract documents, and project specifications, thereby facilitating sustainable highway infrastructure development?
2. How can the implementation of sustainable policies and strategies be effectively leveraged to enhance construction efficiency within the context of project management and implementation criteria?
3. What strategies and practices can be implemented to ensure projects are completed on schedule while maintaining high standards of sustainability and quality?
4. How can comprehensive project risk assessment practices be integrated and managed within the project lifecycle to mitigate potential impacts on the sustainability of highway infrastructure projects?
5. What best practices can be adopted to ensure contractor prequalification criteria contribute effectively to sustainable development goals?
6. How can the process of contractor selection be improved to ensure that it contributes to the overall sustainability of highway infrastructure projects?

Social Equity & Culture Criteria

1. What strategies and practices do you recommend for effectively assessing and mitigating safety risks during the construction phase to ensure the well-being and protection of both workers and the surrounding community?
2. What strategies and practices can be implemented to significantly improve worker's health and safety on construction sites?
3. What strategies and practices can be implemented during the design and operational phases of highway projects to effectively reduce traffic congestion and ensure equitable access and mobility for all community members?
4. What strategies and approaches can be implemented to effectively engage and involve the public in the early phases of highway project planning to ensure inclusivity and address community concerns?

Resource Utilization & Management Criteria

1. How can the integration of supply chains be improved to ensure a smooth and efficient flow of materials and resources for highway infrastructure projects, thereby contributing to sustainable development objectives?
2. What strategies can be implemented to effectively integrate local materials into highway construction projects to promote environmental sustainability and economic development?
3. How do you ensure rigorous material quality control and assurance practices are implemented effectively to contribute to the sustainability of highway infrastructure projects?
4. What strategies and practices can be implemented to effectively incorporate recycled materials in highway construction projects, ensuring environmental sustainability and project quality?

The interview format was designed to obtain detailed insights from respondents about their experiences and suggestions for advancing sustainability in road and highway infrastructure development. This included discussions on the strengths, weaknesses, opportunities, and threats (SWOT) associated with each identified critical sustainability indicator. To ensure a comprehensive understanding, the interview protocol allowed for the inclusion of follow-up questions whenever initial responses necessitated further exploration. These supplementary questions were prepared in advance to address potential areas of interest that could emerge from the discussion of the main topics. Table 19 presents a selection of these additional questions, illustrating the flexible and adaptive approach adopted to garner in-depth information and facilitate a rich dialogue on sustainability practices within the road and highway infrastructure development sector.

Table 20: Follow-up questions [Adopted from Srivastava et al. (2005) cited in Yunus (2012)]

Additional Questions
Strengths
<ol style="list-style-type: none"> 1. What are the advantages? 2. What can this factor do well? 3. What are the elements supporting this factor?
Weaknesses
<ol style="list-style-type: none"> 1. What could be improved? 2. What is not being done properly? 3. What should be avoided? 4. What obstacles prevent progress? 5. Which elements need strengthening? 6. Where are the complaints coming from? 7. Are there any real weak links in the chain?
Opportunities
<ol style="list-style-type: none"> 1. Where are the good chances facing the indicator? 2. What are the interesting trends? 3. What benefit may occur? 4. What changes in usual practices and available sustainable technology on both a broad and narrow scale may occur? 5. What changes can be done by authorities to enhance this indicator?
Threats
<ol style="list-style-type: none"> 1. What are the obstacles for this indicator? 2. Are the required support and necessary facilities for this indicator available? 3. Is the changing technology or policy threatening the indicator? 4. Do the stakeholders show their interest and willingness for supporting the indicator?

The interview process was designed to be semi-structured, allowing for flexibility in

exploring each critical sustainability indicator in depth. This format facilitated a dynamic dialogue between the interviewer and the interviewees, enabling the adaptation of questions based on the participants' responses and expertise. The core set of questions served as a foundational guide, but additional inquiries were asked to further explore subjects where interviewees demonstrated substantial knowledge or provided insightful perspectives. This approach ensured a comprehensive exploration of each critical indicator, enriching the research with detailed insights and facilitating an in-depth understanding of sustainability in road and highway infrastructure development. The adaptability of the interview format was instrumental in uncovering valuable information beyond the initial scope, thus contributing significantly to the depth and breadth of the study's findings.

5.5 Data Interpretation and Analysis

The data interpretation and analysis process for this research was systematically undertaken in three primary steps, as outlined in Section 3.6.3.2, to ensure thorough examination and meaningful insights from the semi-structured interviews:

- i. **Data Organization:** Initially, field notes, audio recordings, and any associated visual materials were sorted and organized to facilitate ease of access. This stage involved a comprehensive review of all collected data to guarantee that no critical information was overlooked. All interviews were then transcribed verbatim into text documents to prepare for detailed analysis.
- ii. **Coding and Thematic Analysis:** Utilizing ATLAS.ti software, the transcribed data underwent coding process. This advanced analysis tool significantly streamlined the categorization and interpretation efforts, allowing for the efficient identification of themes and sub-themes. Codes were assigned to segments of the text that represented distinct ideas or concepts, facilitating the organization of data into coherent themes. Additional annotations were incorporated to interpret the context and degrees of these themes, enhancing the clarity and depth of the analysis. This process was depicted in Figure 18, illustrating the systematic categorization of data and the interconnections between various themes.

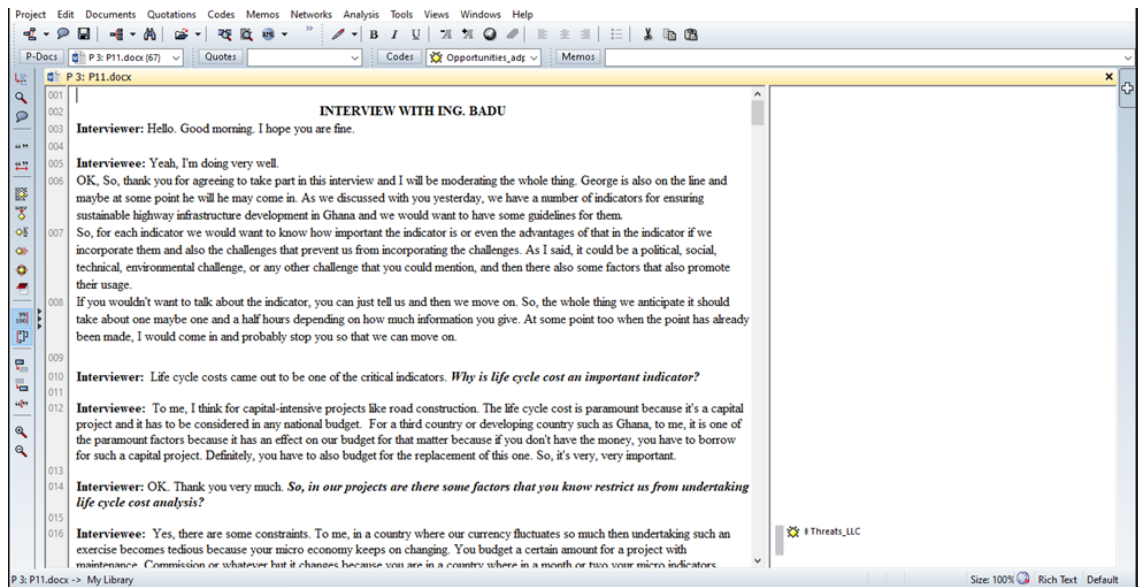


Figure 18: ATLAS.ti Software interface.

- iii. **SWOT Analysis and Framework Development:** In the final step, the coded data were examined to define the strengths, weaknesses, opportunities, and threats associated with the sustainability indicators. This involved a detailed interpretation of the thematic content to construct a comprehensive SWOT analysis, which served as the foundation for developing targeted decision-support guidelines. The interpretative phase was crucial in translating the thematic findings into actionable insights, contributing to the formulation of strategic frameworks that highlighted the potential action plans for enhancing sustainability in road and highway infrastructure development.

Through this structured approach, the research effectively translated raw interview data into strategic insights, laying the groundwork for developing guidelines that address the complexities of sustainable road and highway infrastructure development.

5.6 Interview Analysis and Results

5.6.1 Validation of the Proposed Framework

The primary aim of the semi-structured interviews was to validate the framework proposed for this study, which outlines critical sustainability indicators and defines the process for integrating these into sustainable road and highway infrastructure development (refer to Figure 13). Interviewees were briefed on the formulation of the framework and the method through which the critical indicators were identified. The consensus among the majority of participants was that the framework is robust and comprehensively addresses the key issues of sustainability within road and highway

infrastructure development. This endorsement underlines the framework's potential to serve as a valuable tool for decision-makers, offering a comprehensive assessment model for sustainability and furnishing actionable guidance for the implementation of sustainable practices in road and highway infrastructure development.

5.6.2 Economic Criteria

The semi-structured interviews with key highway professionals provided deep insights into the role and impact of economic indicators on sustainable road and highway infrastructure development. These indicators include material costs, life cycle costs, construction time, and maintenance and operation costs.

5.6.2.1 Material Costs

After conducting interviews with highway professionals, it became clear that reducing material costs is critical for both economic efficiency and sustainability in road and highway projects. Professionals highlighted that effective cost management enables the reallocation of resources to vital aspects of project development, such as environmental conservation and social equity initiatives, thus contributing significantly to the sustainability of road and highway infrastructure. This perspective showcases a deep understanding of the synergy between economic viability and sustainability goals, where reducing material costs is seen as a strategic approach that ensures project affordability while promoting resource efficiency. The interviews revealed that innovation plays a crucial role in achieving cost reductions. The adoption of new materials and construction techniques was identified as a primary avenue for saving costs, which, in turn, advances sustainability goals. This emphasis on innovation highlights the strategic importance of integrating modern, cost-effective solutions without compromising environmental standards.

However, participants also acknowledged the challenges and trade-offs involved in reducing material costs. Concerns were raised about the potential for compromised project quality and the risk of short-term savings leading to higher long-term costs. This highlights the complexity of cost management in sustainable infrastructure development, where the pursuit of cost reductions must be balanced with maintaining high standards of quality and longevity. The importance of collaboration among various stakeholders was featured as critical for effective cost management. Early engagement with suppliers, contractors, and regulatory bodies was suggested as a means to facilitate better cost optimization without sacrificing sustainability or quality. This collaborative approach is

viewed as essential for navigating the complexities of sustainable project development and achieving a consensus on cost management strategies.

Furthermore, interviewees recommended several practices for reducing material costs in a sustainable manner, including the utilization of local materials, recycling and reusing materials from demolished infrastructure, and investing in research on cost-effective yet durable materials. These recommendations reflect a commitment to sustainable development practices that align with environmental conservation and social equity objectives while ensuring economic viability. Some of the important remarks in the interview sessions regarding the material costs indicator are set out in Table 20.

Table 21: Remarks in the interview sessions regarding the material costs indicator

<i>Action Plan</i>	<i>Remarks</i>
<i>Collaboration and Communication</i>	We inform them, we give them the necessary information about the project, we make them own the project, let them understand the benefit of the project.....P1
<i>Sustainable Material Innovation</i>	However, if we blend materials properly and ensure good supervision and compaction during construction, we can achieve a durable road..... P4
<i>Local Sourcing and Community Engagement</i>	We must explore and understand our local materials and how we can modify them to meet specifications and industry trendsP12
	We should explore green alternatives and consider our local context.....P3
	...the community also plays a role because they pay the community in order to wean the material that is the laterite. So, that would be more like a social impact on the cost of materials, so that if we want to way out, we should ensure that we bring the community on board of the project at the early stages.....P1
	... whether they need to be imported or sourced locally P2
<i>Procurement and Contractual Measures</i>	... By sourcing local materials and adopting local approaches, we can address these challenges and optimize material cost P3
	By exploring nearby sources for materials, we can reduce transportation expenses. P7
 Right from day one, when we are given possession of time, within two weeks we need to establish where you are hauling all your materials from P10

Flexibility and Continuous Improvement

.... We have indices that the Ministry publishes to mop up the inflation of material cost but sometimes it doesn't reflect the market cost. P11
Sometimes, we become too rigid and reject materials that don't fall within certain specifications... P4

To reduce material costs, research is crucial.....

P12

Economic Considerations and Budget Management

The government can play a role in reducing costs by providing tax incentives for imported materials and equipment.P12

Planning and budgeting should consider the availability of materials and whether they need to be imported or sourced locally..... P12

5.6.2.2 Construction time

The reduction of construction time in road and highway infrastructure projects in Ghana is a crucial economic indicator that greatly impacts the success and long-term viability of the projects. Insights from interviews with experienced professionals in the field clarify the critical benefits, challenges, and strategies associated with minimizing construction timelines, proposing actionable steps toward more efficient projects. Professionals unanimously acknowledge that reducing construction time is crucial for economic efficiency, directly impacting project costs, including labour, equipment, and administrative expenses. A shorter construction period accelerates the utility of infrastructure, thereby enhancing economic development and societal benefits. This consensus emphasizes the essential link between time efficiency and the broader goals of sustainable infrastructure development.

Challenges in minimizing construction time were extensively discussed, highlighting unpredictable weather conditions, material supply delays, coordination complexities among stakeholders, bureaucratic obstacles in permit acquisition, and the technical challenges posed by innovative construction technologies. These barriers underline the multifaceted nature of construction time reduction, necessitating a comprehensive approach to overcome them.

In response, professionals advocate for a series of strategic measures aimed at expediting construction processes. Emphasizing detailed project planning and efficient scheduling emerges as a foundational strategy to anticipate and mitigate potential delays. Additionally, the adoption of prefabricated components and modular construction

methods, alongside innovative technologies, is recommended to streamline construction activities. The establishment of reliable supply chains and logistics for timely material delivery is identified as critical, with local sourcing of materials suggested to minimize transportation delays. Furthermore, the implementation of integrated project delivery approaches is proposed to enhance stakeholder coordination, including contractors, suppliers, and government agencies.

Advocacy for streamlined governmental approval and permit processes is highlighted as essential for reducing bureaucratic delays. In conjunction with these strategies, actionable recommendations are provided, including training for project managers on advanced management and scheduling tools, engagement with regulatory bodies for process reforms, and encouragement of innovative construction techniques that reduce timelines. Leveraging Public-Private Partnership (PPP) models is also suggested as a means to mobilize additional resources and expertise from the private sector, fostering efficiency and innovation in project execution.

In summarise, reducing construction time in road and highway projects is essential for achieving economic efficiency and delivering timely societal benefits. Despite identified challenges, the insights and strategic recommendations offered by professionals pave a clear pathway towards more sustainable and time-efficient road and highway infrastructure projects in Ghana. Table 21 shows some of the important actions and suggestions that arose in the interview sessions in relation to the construction time indicator.

Table 22: Remarks made in interviews about the construction time indicator

<i>Action Plan</i>	<i>Remarks</i>
<i>Project Management Optimization</i>	Another factor that also may reduce construction time is the use of technology and even appropriate work methods P1 The planning of activities and the level of mobilization should align with the volume of work that needs to be done. P7 It is essential to plan extensively and engage stakeholders P14
<i>Workforce Development and Training</i>	...but sometimes because of lack of ... lack of technical know-how to execute some jobs, P1 Even if the contractor has it, they may have to bring in an expert. And bringing in an expert from outside to come and carry out an operation takes time. P1

Stakeholder Engagement and Relationship Management

Yes, we need to educate and sensitize the community about the importance of the infrastructure and their role in it P3

we are emphasizing the importance of thorough planning and conducting community engagement before the start of any construction project P5

It is important to engage stakeholders early on, during the planning stages and throughout the implementation. P14

Financial Planning and Resource Allocation

We need to ensure adequate funding is available before starting a project.....P3

To address this, we are working on integrating the payment of affected persons into the project cost, ensuring a smoother process that minimizes delays. P3

Currently in Ghana, many projects experience delays due to payment issues...it affects the contractors financially, as they may not be able to continue working...P7

Risk Mitigation and Project Preparedness

It's important to address funding concerns to expedite construction...P3

By identifying potential time overrun factors and addressing them proactively, construction time can be managed effectively. P14

Accurately assessing the qualifications of contractors is crucial, as the qualifications presented on paper may not match their actual resources and capabilities. P12

Regarding right of way, if an inventory is carried out earlier or before the start of the project, identifying electric poles, pipelines, or other permanent or temporary structures.... P8

5.6.2.3 Life cycle Costs

Interviews with experienced highway professionals shed light on the need of minimising life cycle costs in the development of sustainable road and highway infrastructure in Ghana. This holistic approach to cost management, spanning from construction through maintenance to decommissioning, is pivotal for the long-term economic sustainability and environmental stewardship of infrastructure projects. The collective insights from these interviews reveal a consensus on the necessity of life cycle cost reduction as integral to achieving broader sustainability goals. Professionals pointed out that, while the initial focus tends to be on upfront construction costs, true sustainability and economic efficiency are realized when the entire life span of the project is considered. This includes a strategic look at maintenance, operation, and eventual decommissioning costs. However, accurately forecasting these long-term expenses poses a considerable challenge

due to the evolving nature of construction technologies, fluctuating material costs, and changing regulatory environments.

One significant barrier identified is the initial higher investment required for innovative and durable materials and technologies, which are essential for extending the infrastructure's lifespan and thus reducing long-term costs. Despite these barriers, the professionals advocated for a strategic approach to life cycle cost management. This approach entails prioritizing the selection of quality materials and construction techniques that, despite their higher upfront cost, result in significant maintenance and operational savings. Furthermore, employing advanced planning tools and life cycle cost analysis methodologies is crucial for making well-informed decisions that consider the total cost of ownership. Additionally, exploring innovative financing models such as public-private partnerships (PPPs) can distribute life cycle costs and risks among stakeholders, encouraging investments that yield long-term savings.

Drawing from the discussions, actionable steps were proposed to enhance life cycle cost management in road and highway infrastructure projects. These include building the capacity of project managers and decision-makers in applying life cycle cost analysis tools, advocating for policy reforms that incentivize practices contributing to life cycle cost reduction, and fostering collaborative platforms for knowledge sharing among stakeholders. Such collaborative efforts aim to disseminate best practices and innovative solutions in managing life cycle costs.

In summary, the interviews highlighted that reducing life cycle costs is not merely a financial strategy but a foundation of sustainable road and highway infrastructure development. Through strategic planning, investment in quality, and innovative financing, the challenges of managing life cycle costs can be addressed. The insights and strategies shared by the professionals provide a clear pathway toward developing cost-efficient and sustainable road and highway infrastructure, aligning with the overarching goals of economic viability and environmental sustainability in Ghana. Some of the important remarks made by the interviewees regarding the role of the life cycle costs are set out in Table 21.

Table 21: Remarks made in interviews about the Life Cycle Costs Indicator

<i>Action Plan</i>	<i>Remarks</i>
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Capacity Building and Education

So, if they are well trained in the use of these sophisticated tools that will quicken their activities, then they will be able to quickly put together everything and go through their processes accurately....P1

... the lack of the skills and the knowledge to do that...P1

Overall, there is a need to improve technical know-how ... within the industry to enhance life cycle cost analysis.... P12

Technological Advancements and Competence

Additionally, conducting a thorough life cycle cost analysis requires expertise and resources, which may not always be readily available....P6

So, if you don't get the right person to do the assessment, it becomes a problem. This is because if the person is inexperienced, you are likely to have so many issues even undersize some of the structures... P10

On technology, I will not rule it out because you know that day-in day-out, new things come up and there are new ways of getting things done... P10

Project Planning and Risk Mitigation

One other thing that would affect this life cycle cost and maybe any other cost projection is the instability with regards to the country's financial and economic situation that is the increasing rate of the inflation which is going to introduce high variation over time P1

...it might be a matter of having enough time to conduct thorough cost analysis. To conduct a comprehensive life cycle cost analysis, you need to establish maintenance standards, which would be part of the life cycle cost calculation...P14

By carefully analyzing and factoring in all inputs throughout the life cycle, we can identify optimal designs that make efficient use of scarce resources. This, in turn, reduces the total cost of the project...P6

And the second one I know will be also poor planning. We don't really plan our project well probably because of political interference.... P9

To me, in a country where our currency fluctuates so much then undertaking such an exercise becomes tedious because your micro economy keeps on changing.... P11

Data Collection and Transparency

Gathering comprehensive data on factors such as expected lifespan and maintenance costs can be complex..... P6

One major challenge would be the lack of information or data. Without the necessary information, it would be difficult to effectively use or work with life cycle cost analysis..... P8

Stakeholder Collaboration and Advocacy

Well, to me historical data for you to make accurate projection is very necessary, as I said. The way our physical or let's say Monetary fluctuates so much.. P11

In terms of politics, the alignment of objectives between politicians and technocrats is crucial. If politicians prioritize the successful implementation of projects based

on sound analysis, it can facilitate the usage of the indicator.... P6

It is essential to have technocrats involved in the decision-making process to ensure optimal utilization of funds and the consideration of key indicators throughout the life cycle..... P6

It is also important to consider the collaboration between industry stakeholders, including consulting capabilities, training of technical personnel, and collaboration with academia to incorporate their research outputs.... P12

5.6.2.4 Maintenance and Operation Costs

Interviews with experienced highway professionals have provided valuable insights into the importance, difficulties, and strategic approaches to decreasing maintenance and operating costs in road and highway infrastructure development in Ghana. This comprehensive analysis draws upon their insights to highlight the critical role that efficient maintenance and operational cost management plays in enhancing the sustainability and economic viability of infrastructure projects. The consensus among these professionals features the fundamental importance of minimizing maintenance and operation costs—not merely as a fiscal strategy but as an integral component of sustainable infrastructure development. This approach is key to extending the lifespan of infrastructure assets while ensuring they remain functional and safe for public use over time. Moreover, efficient cost management in maintenance and operation phases contributes significantly to the overall reduction of the financial burden on government budgets and public resources, aligning with the broader objectives of sustainable development and fiscal responsibility.

However, the pursuit of reduced maintenance and operation costs is met with several challenges that necessitate a strategic and multifaceted response. Among the notable challenges are the complexities involved in integrating cutting-edge maintenance technologies into existing and future infrastructure frameworks and the inherent unpredictability of long-term maintenance needs and their associated costs. Such unpredictability is often compounded by environmental factors, usage patterns, and the evolving nature of infrastructure technologies. Additionally, a prevalent budgetary focus on upfront construction costs, at the expense of comprehensive long-term maintenance planning, poses a significant barrier to achieving cost efficiency over the lifecycle of infrastructure projects.

To navigate these challenges, the interviewed professionals advocate for a strategic approach centred around comprehensive planning and the adoption of life cycle cost analysis methodologies. Such planning should aim to anticipate future maintenance and operational needs, allowing for the proactive allocation of resources. Emphasizing the selection of durable materials and construction methods—despite their higher initial costs—is recommended as a means to mitigate the frequency and severity of future maintenance requirements. Moreover, leveraging modern technology and data analytics for predictive maintenance purposes can enable timely interventions, thus preventing extensive repairs and prolonging the infrastructure's operational life.

Drawing from the discussions, actionable steps were proposed to optimize the management of maintenance and operation costs. These include enhancing the capacity of infrastructure managers and decision-makers through targeted training in life cycle cost analysis and predictive maintenance technologies. Furthermore, advocating for policy reforms that encourage upfront investment in durability, and exploring innovative financing models such as public-private partnerships, can provide a sustainable funding mechanism for the maintenance and operational phases of infrastructure projects.

In conclusion, the organised insights from highway professionals articulate a compelling case for prioritizing the reduction of maintenance and operation costs as a cornerstone of sustainable and economically viable road and highway infrastructure development in Ghana. By employing a forward-looking and strategic approach to planning, investment, and technology utilization, it is possible to significantly lower life cycle costs, thereby achieving the dual objectives of infrastructure sustainability and fiscal efficiency. This integrated perspective provides a valuable support for guiding future efforts in infrastructure development, ensuring that maintenance and operation costs are minimized through strategic planning and innovative practices. Table 22 presents the key statements made by the interviewees regarding maintenance and operation costs indicator.

Table 23: Key statements made by the interviewees regarding maintenance and operation costs

<i>Action Plan</i>	<i>Remarks</i>
<i>Commitment to Infrastructure Maintenance</i>	I think that it must be incorporated at every stage and in every decision that would have to be undertaken, not only under construction but from the planning and design, construction, and even operation. P1

*Financial Management and
Accountability*

if you incorporate the life cycle cost in your design, you come out with designs that will eventually reduce the total cost of the project..P1

beyond technical challenges, institutional commitment and a holistic approach to the entire life cycle of the project are key factors in successfully implementing life cycle cost analysis..P3

So, regular maintenance is crucial to avoid costly repairs in the long run. P7

So, one problem that you know inhibit the road agencies to carry out maintenance is lack of funds... P1

Sometimes there is misuse of funds, so it will end up like there is no fund... P1

The release of funds for maintenance is subject to approval, and sometimes there are delays or insufficient funds allocated. P5

unfortunately, we as projects managers usually, do not add that to our project preparation and so it creates an isolated cost we have to budget for so in the absence of any funds from central government P9

Monitoring and enforcement

but enforcement of regulations is equally crucial. Weak enforcement leads to challenges such as vehicles exceeding weight limits. Strengthening enforcement efforts is necessary to ensure compliance and reduce excessive maintenance needs. P12

*Stakeholder Engagement, Education and
Technology integration*

When these politicians have special interest in the project, then they may not be patient enough for the road agencies to go through the due process. P1

challenges can arise regarding construction methods and techniques that can affect the sustainability and expected lifespan of the infrastructure. It is crucial to ensure that the chosen methods are capable of self-maintenance and long-term sustainability. P3

Yes, exploring technological solutions is crucial to enhancing maintenance practices. However, it is important to incorporate these solutions early in design and feasibility stages of the project. P13

Quality Control and Standards

that if you want to reduce your maintenance costs, it means that you have to ensure quality of work, quality of materials and quality with regards to workmanship P1

when you set up a performance-based contract which is one of the ways of achieving quality execution of the work and that will reduce

defect in the long run then we'll reduce maintenance cost. P1

Proper construction can reduce maintenance and operation costs. P4

By selecting materials and design options that are more durable and require less maintenance P6

There is often insufficient emphasis on proper supervision and adherence to the necessary standards. P13

5.6.3 Environmental Impact Criteria

In the pursuit of sustainable highway infrastructure development, semi-structured interviews with experts in the field provided rich insights into the environmental impact indicators critical to the industry. These indicators—dust control, use of environmentally friendly materials, preservation or improvement of ecological functions of drainage corridors, environmental monitoring measures after project completion, and minimization of flood and surface run-off—are fundamental to the environmental criteria of sustainable road and highway projects. The results of these interviews are detailed below, providing a comprehensive overview of stakeholder perspectives on these crucial sustainability indicators.

5.6.3.1 Dust control.

When considering the management of dust in the context of road and highway infrastructure development, experts emphasise the importance of this matter as a substantial environmental and health issue. These discussions emphasize the importance of effective dust management strategies for protecting community health, preserving nearby ecological systems, and ensuring the safety and longevity of infrastructure projects. There's a universal recognition among the interviewed professionals that controlling dust is crucial for minimizing its adverse effects on both human health and the environment. This consensus underlines dust control as a fundamental aspect of sustainable infrastructure development practices, beyond a mere technical challenge. Despite acknowledging its importance, professionals encounter substantial challenges in implementing effective dust control measures. These challenges include the variability of construction sites, the financial implications of dust suppression technologies, and complexities in adhering to environmental regulations within the constraints of project timelines. Moreover, a significant gap in awareness and training about dust control

importance and methodologies among construction personnel emerges as a barrier to deploying effective strategies.

Responding to these challenges, the professionals advocate for a comprehensive approach to dust control. This entails adopting advanced dust suppression technologies and materials that offer a balance between efficiency and environmental friendliness, ensuring that dust control measures are integrated early into project planning. Such practices should become foundational to the construction process. Collaboration with environmental agencies is also highlighted as essential for ensuring regulatory compliance and adopting best practices in dust management. Based on professional insights, several actionable recommendations have been identified to enhance dust control in road and highway infrastructure projects. There's a clear need for investing in training for project managers and construction teams on the application of the latest dust control technologies to equip all personnel with the necessary skills for effective implementation. Furthermore, developing policies that mandate the comprehensive integration of dust control measures across all construction phases, supported by adequate funding and resources, is crucial for embedding these practices within the industry. Lastly, encouraging innovation in dust suppression methods through research and development initiatives is recommended to foster the adoption of cost-effective and sustainable solutions.

The collated interviews reveal that effective dust control is a critical indicator of sustainable and responsible road and highway infrastructure development. It is deeply linked to environmental preservation, public health, and the operational integrity of infrastructure projects. By adopting strategic planning, investing in advanced technologies, and promoting a culture of compliance and awareness, the construction industry can address the inherent challenges associated with dust management. These professional insights offer a coherent framework for advancing practices that ensure comprehensive dust control, aligning with the broader goals of sustainability and community well-being in infrastructure development. The key remarks made by the interviewees in relation to dust control are shown in Table 23.

Table 24: Key remarks made by the interviewees in relation to dust control

<i>Action Plan</i>	<i>Remarks</i>
<i>Research and capacity building.</i>	yes, it is something we can look at, but that would call for research because before you use any other material, they have to meet specification. P1

<p><i>Regulatory compliance and enforcement</i></p>	<p>If it is environmental institution, then their capacities will have to be enhanced by giving them vehicles and training them for them to also move around. P1</p> <p>One way to improve contractors' awareness and adherence to dust control measures is through capacity building and training programs. P6</p> <p>After conducting our environmental assessment, we need to support and strengthen institutions like the EPA to effectively monitor and prevent environmental issues.P8</p> <p>the inclusion of clear guidelines and specifications for dust control in project contracts can also help ensure compliance. By explicitly outlining the requirements for dust control measures and their enforcement...P6</p>
<p><i>Financial Management in Construction</i></p>	<p>It's a weak enforcement issue, and it stems from the whole non-payment regime that is causing havoc in the construction industry.P7</p> <p>...if the contractor is not paid on time, then what money is he going to use to control the dust? So, lack of funds is also one factor that affects the control of that on site.P1</p> <p>Yes, the source should be well secured so that you have that kind of cash flow into the project.P8</p>

5.6.3.2 Environmentally Friendly Materials

The investigation of utilising environmentally friendly materials is a vital undertaking in the attempt to achieve sustainable road and highway infrastructure development. Insights collected from interviews with seasoned road and highway professionals shed light on the significance, challenges, and pathways forward in integrating these materials into construction projects. Professionals across the board emphasize the vital role of eco-friendly materials in reducing the environmental impact of construction activities. Such materials are indicated for their potential to lower carbon emissions, reduce the extraction of finite natural resources, and increase the recyclability of construction waste, aligning infrastructure development more closely with principles of environmental conservation and sustainable development. The use of these materials is not just a technical adjustment but a strategic move towards more sustainable construction practices.

However, the journey toward widespread adoption of environmentally friendly materials is fraught with challenges. During the interviews, experts pointed to the higher initial costs of these materials compared to traditional alternatives, their variable availability, and the stringent performance demands of road and highway infrastructure as significant

barriers. Moreover, they mentioned that there exists a knowledge gap among stakeholders, from project managers to construction teams, regarding the selection, benefits, and application of eco-friendly materials, which hampers their broader implementation.

To navigate these obstacles, the interviewed professionals advocate for a comprehensive strategy encompassing rigorous evaluation and certification of eco-friendly materials to ensure their environmental benefits and performance adequacy. They call for strengthened collaboration among material suppliers, construction firms, and regulatory bodies to enhance the accessibility and affordability of sustainable materials. Furthermore, there is a consensus on the need for continuous investment in research and development to discover and refine new materials that meet the dual criteria of environmental sustainability and infrastructural integrity.

Drawing from these discussions, several actionable steps have been identified to promote the use of environmentally friendly materials in infrastructure projects. Enhancing the expertise and awareness of construction industry stakeholders about the advantages and utilization of sustainable materials is deemed essential. This involves targeted training and education efforts aimed at embedding sustainability considerations into the decision-making processes of project planning and execution. Additionally, the formulation of supportive policies and incentives by governmental and regulatory entities can catalyse the adoption of eco-friendly materials by making them more economically viable and attractive compared to conventional materials. Encouraging public-private partnerships and collaborative research efforts dedicated to the development and testing of innovative sustainable materials also emerges as a key recommendation for overcoming current limitations and setting new standards in construction practices.

In conclusion, the need of incorporating environmentally friendly materials in road and highway infrastructure development is a reflection of the industry's commitment to sustainability. Overcoming the challenges associated with their adoption requires a concerted effort from all stakeholders, underpinned by strategic planning, education, policy support, and innovation. The insights provided by infrastructure professionals offer a valuable framework for advancing sustainable construction practices, ensuring that the development of road and highway infrastructure proceeds in harmony with environmental stewardship and sustainability objectives. The key remarks made by the interviewees in relation to the use of environmentally friendly materials are shown in Table 24.

Table 25: Key remarks made by the interviewees in relation to the environmentally friendly materials

Action Plan	Remarks
<i>Promote Environmental Sustainability in Infrastructure Development</i>	<p>it's crucial to enhance the technical capacity and knowledge of contractors regarding environmentally friendly materials. This can be achieved through training programs and workshops specifically focused on raising awarenessP5</p> <p>So, it is an advocacy that should be promoted. P9</p>
<i>Develop and enforce Policy and Regulatory Framework for Sustainable Construction</i>	<p>it's important to strengthen the monitoring and inspection processes. This can be achieved through the involvement of regulatory bodies P5</p> <p>By adopting a system-level approach, we can develop guidelines, standards, and procurement processes that prioritize environmentally friendly materials. P13</p> <p>The specifications and guidelines we have in place often restrict us to certain materials and methods without room for exploration or adaptation P13</p>
<i>Research and Innovation for Sustainable Construction Technologies</i>	<p>Research and collaboration with the industry are crucial to identifying and adopting more sustainable materials and construction practices. By investing in research and working together, we can develop new solutions that are both environmentally friendly and economically viable. . P12</p> <p>Research should be conducted to identify and incorporate environmentally friendly materials into project specifications. P7</p> <p>Yes, we need government to invest into these and also try to have pilot for the already researched ones... We have a lot of coconuts around and there are research where there's been replacements with organic materials like coconut, organic fibres, ashes etc. P9</p>
<i>Community Awareness and Cultural Shift in the Construction Sector</i>	<p>We need to move away from the mindset of always relying on imported materials and be open to exploring what we have available locally.P13</p> <p>Once we settle on a particular approach, we tend to stick with it and resist change.P13</p>

5.6.3.3 Ecological Functions of Drainage Corridors

An agreement was reached among the highway professionals interviewed during the interview phase of the study on sustainable road and highway infrastructure development on the significant significance of preserving or improving the ecological functions of drainage corridors. This recognition features a growing awareness within the sector of the need to integrate environmental sustainability into infrastructure projects, particularly in the context of drainage management. Interviewees highlighted the multifaceted benefits of maintaining healthy drainage corridors, which extend beyond conventional stormwater management to encompass biodiversity conservation, water quality improvement, and enhancement of local ecosystems. The professionals emphasized that well-designed drainage solutions could serve as green infrastructure, contributing to the overall resilience and sustainability of road and highway projects.

A key theme that emerged from the interviews was the necessity of adopting a holistic approach to drainage corridor design—one that considers the ecological, hydrological, and social dimensions of infrastructure development. Participants advocated for the incorporation of naturalistic design elements, such as vegetated swales and constructed wetlands, to mimic natural hydrologic processes and support diverse habitats. Moreover, the interviewees recognized challenges in implementing such ecological considerations, including spatial constraints, regulatory barriers, and the need for interdisciplinary collaboration among engineers, ecologists, and planners. Despite these challenges, there was a strong call for increased education and training on ecological design principles and for policies that encourage or mandate the preservation of ecological functions in drainage planning.

Strategies for overcoming identified barriers included leveraging advances in modelling and monitoring technologies to better predict and mitigate potential environmental impacts, as well as advocating for policy reforms that prioritize ecological considerations in infrastructure development. Additionally, the importance of public engagement and stakeholder involvement was highlighted as crucial for gaining support for environmentally focused drainage solutions.

In summary, the interview findings emphasize the critical role of preserving and enhancing the ecological functions of drainage corridors in sustainable road and highway infrastructure development. They point to a paradigm shift towards more environmentally responsible and sustainable practices in the industry, reflecting a broader societal

recognition of the importance of ecological preservation in the face of ongoing environmental challenges. Table 25 displays the key remarks by the interviewees about the preservation or improvement of ecological functions in drainage corridors.

Table 26: key remarks by the interviewees about ecological functions in drainage corridors

<i>Action Plan</i>	<i>Remarks</i>
<i>Environmental Management and Regulation</i>	<p>So, for some of the projects that are well-planned, we have an environmental management plan. ... But for most you don't have these plans.....P9</p> <p>The ecological aspect is typically part of the requirements imposed by regulatory bodies before granting permits....P13</p> <p>So usually, they require that to some extent but sometimes the implementation phase they may do otherwise.....P1</p>
<i>Ecological Integration in Infrastructure Projects</i>	<p>Unfortunately, the design of our drainage systems does not adequately consider the movement of animals and water flow.....P5</p> <p>The moment they say this road is to be constructed, the focus is mainly on the road. We do not care much about the ecological aspects.....P10</p> <p>Well, one of the challenges as we have mentioned is that sometimes the designers do not have the environment at the back of your mind.P1</p>
<i>Data-Driven Decision-Making</i>	<p>We take the noise, air pollution and if the infrastructure involves construction of drainage, we take the quality of the water at the time you want to start the project. So, these baseline data collected and after the project we monitor P11</p>
<i>Stakeholder Engagement and Bureaucratic Streamlining</i>	<p>There is that coordination existing but it is up to every institution to do what it is supposed to do.....P6</p> <p>The procedure of getting your environmental permit is a problem because sometimes it involves a lot of stakeholders and that frustrates the systemP1</p>

5.6.3.4 Environmental Monitoring Measures After Project Completion

The interviews highlighted the agreement among professionals in the field of road and highway construction in Ghana regarding the critical significance of implementing environmental monitoring procedures after the completion of a project. While acknowledging the challenges, the professionals provided valuable insights into strategies that could enhance the effectiveness of environmental monitoring, ultimately contributing

to the sustainability of road and highway infrastructure development in Ghana. Through a series of semi-structured interviews with experienced practitioners in the field, several key insights have emerged regarding the role, challenges, and strategies associated with post-construction environmental monitoring. Interviewees unanimously recognized the critical importance of post-completion environmental monitoring in assessing the actual versus projected environmental impacts of road and highway projects. This process was deemed essential for the ongoing management and mitigation of any adverse environmental consequences, ensuring compliance with both national and international environmental standards.

Professionals highlighted several challenges in the effective implementation of environmental monitoring measures, including limited financial resources, the need for specialized training and equipment, and the difficulty in sustaining long-term monitoring efforts. Additionally, the lack of a standardized framework for environmental monitoring in Ghana was cited as a significant barrier to consistent application across projects. Strategies suggested by the interviewees for overcoming these challenges included securing dedicated funding for monitoring activities, integrating environmental monitoring into the project's initial budget and planning phases, and establishing partnerships with academic and research institutions to leverage their expertise and resources. The development of a comprehensive national guideline for post-construction environmental monitoring was also advocated to standardize practices and ensure uniformity across projects.

The benefits of effective post-completion environmental monitoring, as articulated by the interviewees, extend beyond regulatory compliance. They encompass enhanced ecological conservation, improved stakeholder relations, and the ability to make data-driven decisions for future infrastructure projects. Effective monitoring was also seen as a means to demonstrate the project's contribution to sustainable development goals, potentially attracting further investment. Table 26 displays the primary statements expressed by the respondents regarding Environmental Monitoring Measures after project completion.

Table 27: Key interview remarks regarding environmental monitoring measures after project completion

<i>Action Plan</i>	<i>Remarks</i>
<i>Enhance Environmental Impact Assessment (EIA) Process</i>	The procedure of getting your environmental permit is a problem because sometimes it involves

*Monitoring and Regulatory
Strengthening*

a lot of stakeholders and that frustrates the system so that is one problem associated with environmental issues.

P1

The government and again the ministry will have to ensure that all the institutions required to perform a certain task are resourced P1

However, one of the challenges is often the lack of funding for such monitoring. It requires resources and manpower to conduct field assessments and gather data, so without adequate funding, it becomes challenging to carry out comprehensive environmental monitoring.

P7

After conducting our environmental assessment, we need to support and strengthen institutions like the EPA to effectively monitor and prevent environmental issues.

P8

there should be monitoring as part of the environmental documentation for the project. It would help ensure that any potential negative impacts are addressed.P13

Policy influence

The government and again the ministry will have to ensure that all the institutions required to perform a certain task are resourced.P1

Advocacy, Policy and Training

So, I think the challenge is rather the architecture of the project whether right from the inception, the agency sees it as important.P11

Well, one of the challenges as we have mentioned is that sometimes the designers do not have the environment as a major focus...And how engineers look at the environment may be different from how environmentalists look at it.P1

5.6.3.5 Flood and Surface Run-off

The issue of mitigating flood and surface run-off arises as a significant environmental concern in the pursuit of sustainable road and highway infrastructure development in Ghana. Insights from a series of semi-structured interviews with experienced highway construction professionals and environmental expert clarify the complexity of this challenge and the comprehensive approach required for its effective management. The unanimous viewpoint among interviewees is the significant adverse impact of unmanaged flood and surface run-off on infrastructure integrity and surrounding ecosystems. Effective water run-off management transcends the protection of road and highway infrastructure, extending to the preservation of water quality, and the prevention of erosion and habitat destruction in adjacent areas. The professionals advocate for a strategic combination of engineering solutions and natural management practices.

Solutions such as permeable pavements, retention basins, rain gardens, and the integration of green infrastructure stand out for their potential to both manage water effectively and enhance biodiversity.

However, realizing these solutions is met with notable challenges. Land use constraints, financial limitations, and the necessity for planning that anticipates climate change impacts are among the key barriers identified. Additionally, a local expertise gap in the design and implementation of advanced sustainable drainage systems poses a significant barrier to progress. Amid these challenges, there's a strong consensus on the need for robust policy frameworks that mandate the inclusion of sustainable water management practices in road and highway infrastructure projects. The critical role of educating a wide-range of stakeholders—from policymakers to local communities—on the methodologies and benefits of effective run-off management is featured. Emphasizing the importance of a collaborative approach, interviewees highlight the necessity of bringing together government agencies, construction firms, environmental organizations, and the academic community. This collaboration is deemed crucial for fostering the development and implementation of innovative solutions aimed at effectively minimizing flood and surface run-off.

These professional insights offer a valuable blueprint for advancing practices that ensure the comprehensive management of flood and surface run-off in road and highway infrastructure development. By adopting a multifaceted approach that combines strategic planning, innovative engineering, and robust policy support, Ghana can address this environmental challenge, paving the way for more sustainable infrastructure projects. The participants in the interviews offered insights on strategies for mitigating flood and surface run-off, which are given in Table 27.

Table 28: Key interview remarks regarding minimize flood and surface run-off

<i>Action Plan</i>	<i>Remarks</i>
<i>Infrastructure and Engineering</i>	Before any design is developed, it's important to gather relevant data. This data helps in making informed decisions during the design process P8
	It's important to review and update existing guidelines and manuals to better address flooding issues and incorporate the necessary measures.13
	First, it's crucial to establish a general framework that guides designs across all agencies and ensures

	<p>the comprehensive management of floods and related issues on highways. P13</p> <p>Additionally, promoting natural water infiltration through the use of permeable surfaces, such as permeable pavements or rain gardens, can help reduce surface runoff. P7</p> <p>To curb flooding, we need to control our settlements and address the issue of uncontrolled development ...P6</p> <p>but if people face consequences for their actions and are held accountable, it can serve as a deterrent. Punishments and penalties can act as a form of education and encourage people to act responsibly...P6</p> <p>To address this problem, planning agencies and local authorities should engage urban planners and engineers to ensure that sufficient space is allocated for future drainage interventions in any layout or development plan. PXX</p> <p>This is something that needs law enforcement when it comes to land use.P10</p>
<p><i>Community Engagement and Education</i></p>	<p>I think it's important to talk not only to test but also to talk to people who live around and involve them in the design process...P8</p> <p>It's important to sensitize the public about the impacts of their activities and provide alternative waste disposal options to prevent such issues...P3</p>
<p><i>Capacity Building and Training</i></p>	<p>To address the challenges we face with drainage systems, it is essential to enhance the capacity and technical expertise of drainage designers and engineers.P12</p> <p>Additionally, investing in capacity building and training for engineers is essential to equip them with the necessary skills and knowledge to effectively address flooding in their designs...P13</p> <p>If there are new technologies or software to help them carry out their design effectively, then that is something that should be looked at because with the sophisticated software they could come out with comprehensive designs.P1</p>

Additionally, budgetary constraints can sometimes lead to compromises in design, such as opting for less expensive culvert options even if they may not be as effective.P6

5.6.4 Technical Criteria

In the field of sustainable road and highway infrastructure development, technical critical indicators play a pivotal role in determining the efficiency, resilience, and longevity of the projects. This section presents an analysis and results derived from semi-structured interviews conducted with industry professionals regarding six technical critical indicators: application of durable materials, disaster (flood) resilient designs, design and construct climate change-resilient roadway infrastructure, incorporate technology in design and construction, allow adaptability and flexibility for future changes, and ensuring the availability of competent supervisors, labourers, etc.

5.6.4.1 Durable materials

This research focuses on investigating the utilisation of long-lasting materials in the construction of road and highway infrastructure. It provides valuable insights into the fundamental principles of sustainability and durability in transportation networks. Through a series of detailed semi-structured interviews with an array of professionals from the fields of road and highway construction and material science, an in-depth understanding has been distilled, emphasizing the strategic importance of material durability in the lifecycle of infrastructure projects. The unanimous perspective among the interviewed professionals is the recognition of durable materials as foundational to constructing road and highway infrastructure that is not only resilient but also economically and environmentally sustainable. Durable materials stand out for their ability to endure environmental stresses, thereby reducing the frequency and intensity of maintenance interventions and significantly extending the usable life of infrastructure assets. This capability translates into considerable economic savings and environmental benefits, positioning durability as a critical criterion far beyond mere technical specifications.

However, the path to widespread adoption of durable materials is fraught with challenges. Higher initial investment costs, the complexity of evaluating long-term performance and sustainability impacts, industry resistance to change, and the absence of comprehensive standards for assessing material durability are identified as principal barriers. These

challenges stress the need for a holistic approach that bridges the gap between the current state of practice and the envisioned future of sustainable infrastructure. Addressing these challenges calls for a concerted effort that encompasses enhanced research and development aimed at both innovating new materials and augmenting the durability of existing ones. The pivotal role of life-cycle assessment tools emerges, offering a means to quantify the long-term benefits and sustainability impacts of durable materials, thereby informing more in-depth decision-making processes. Furthermore, the development of robust standards and certification processes is highlighted as essential for ensuring that materials meet both durability and environmental performance criteria.

In sum, the integration of durable materials into road and highway infrastructure projects is specified as a key indicator of sustainable and resilient development. Overcoming the articulated challenges necessitates a comprehensive strategy that synergizes research, policy support, and education across the construction industry. These professional insights lay a foundation for advancing the use of durable materials, ensuring that infrastructure not only endures but also contributes positively to our collective sustainable future. The insights into methods for the application of durable materials were provided by the participants in the interviews, as presented in Table 28.

Table 29: Participants comments on the application of durable materials

<i>Action Plan</i>	<i>Remarks</i>
<i>Quality Assurance in Construction</i>	Another challenge is the lack of labs within the areas increases the cost when you have to test the materials P1
	Competent materials engineers play a vital role in ensuring the durability of construction materials. They need to have the necessary knowledge and expertise. P7
	So, we have guidelines and expectations for materials, ... We need to ensure the quality of the materials before making decisions on their use. P4
<i>Local Sustainability and Production</i>	Cost and availability can be additional challenges. P6
	So, the availability of gravel material is becoming scarce. P9
<i>Innovation and Research for Cost-Effective Solutions</i>	Sometimes there is a need for the engineer to blend some materials when the material they have obtained is not meeting the specification P1

Specification Compliance and Governance in Construction

So, we are digressing into more alternative materials like crash rock or even if we have a few stabilized or blended improved materials P9

The standards board should have the power to monitor and enforce quality control measures. P6

Contractors may not always be willing to use durable materials, but as supervisors or engineers, we should instruct and guide them. P6

The provisions in contracts can address this issue, but there are individuals who will still choose inferior materials despite having the means to invest in quality P13

5.6.4.2 Disaster (Flood) Resilient Designs

Semi-structured interviews conducted with a wide-ranging of professionals have shed light on the significance of disaster (flood) resilient designs as a crucial indicator in the pursuit of enhancing sustainable and resilient infrastructure in Ghana's road and highway sector. The collective insights reveal a unanimous recognition of the necessity to embed flood-resilient features within infrastructure projects. This consensus emerges against the backdrop of escalating flood events, intensified by climate change and urbanization, placing Ghana in a position of significant flood risk due to its geographic and climatic predispositions. The professionals engaged in the discussion presented various flood-resilient design strategies for consideration or implementation across Ghana. These strategies encompass elevated roadways, sophisticated drainage systems, and the incorporation of green infrastructure elements such as bioswales and retention ponds, all aimed at efficacious stormwater management, runoff reduction, and enhanced absorption capabilities of the landscape.

Despite the clear consensus on the importance of integrating flood-resilient designs, the interviews also unveiled several challenges impeding their widespread adoption. Notable among these challenges are the scarcity of comprehensive flood risk data, financial constraints, a deficiency in technical expertise concerning advanced resilient design techniques, and obstacles in stakeholder coordination.

These interviews highlight a shared recognition among Ghanaian infrastructure professionals of the critical role played by disaster (flood) resilient designs in safeguarding long-term functionality and safety. Moreover, they highlight the complex,

multifaceted approach required to effectively integrate these resilient designs into practice, overcoming technical, financial, and institutional barriers. Such an approach is indispensable for bolstering the resilience and sustainability of Ghana's road and highway infrastructure in the face of mounting flood risks. Table 29 shows some of the important actions and suggestions that arose in the interview sessions in relation to the Disaster (flood) resilient designs.

Table 30: Remarks made in interviews about the Disaster (flood) resilient designs indicator

<i>Action Plan</i>	<i>Remarks</i>
<i>Climate-Responsive Infrastructure Development (Designs)</i>	Climate-resilient design is crucial, and we must consider future developments and potential changes in the environment P2
	The problem is whether we are effectively maintaining what we have provided. Basic maintenance is crucial to prevent flooding. P3
	Yes, lack of proper preparation and inadequate feasibility studies can also contribute to challenges in dealing with flooding P3
<i>Capacity Building and Training for Disaster Response</i>	We need up-to-date data to design disaster-resilient structures.P7
	And to do that, the designers will have to get the skills and knowledge of that. So, training the engineers is important and also training them to use technology and software will help P1
<i>Policy and Standards Enhancement</i>	However, when it comes to incorporating climate change considerations, there is a need for capacity building and adopting new approaches P6
	Then it means there is a need to have a second look at our design manual and incorporate these things in it because as for disasters you may never know when they will come P1
	We need to recognize climate change as a significant issue and incorporate it into our manuals and protocols P6
<i>Financial and Governance Strategies for Resilient Infrastructure</i>	Yes, I haven't come across a specific framework or guideline for floods on highways in our local context.P13
	...planning agencies and local authorities should engage urban planners and engineers to ensure

that sufficient space is allocated for future drainage interventions in any layout or development plan. P13

Additionally, the level of importance placed on these tools by the government and industry plays a role. P13

5.6.4.3 Design and Construct Climate Change Resilient Roadway Infrastructure

The investigation of the development of sustainable road and highway infrastructure in Ghana emphasises a crucial change in focusing on the resilience of road and highway construction and design to climate change. Insights from semi-structured interviews with a various range of industry professionals emphasize the urgent need for integrating climate resilience into road and highway planning and design frameworks. This importance is driven by Ghana's exposure to climate change phenomena such as increased rainfall variability, intensified flooding, and elevated temperatures, which collectively threaten the durability and operational viability of the nation's road networks. Professionals uniformly recognize the importance of embedding climate-resilient features within infrastructure projects. Key design strategies identified for bolstering climate resilience include implementing robust drainage systems to manage augmented stormwater flows, elevating essential infrastructure components to mitigate flood risks, and selecting heat-resistant materials to counteract temperature-induced degradation.

Despite a shared understanding of the critical nature of climate-resilient designs, professionals articulate several barriers to their implementation. Challenges highlighted encompass the scarcity of precise climate projections, financial limitations that curtail the use of advanced materials and technologies, and a universal lack of awareness and expertise in climate-adaptive design practices among key stakeholders.

Moreover, a substantial emphasis is placed on the integration of green infrastructure elements—such as urban green spaces and naturalized drainage features—into roadway designs. These elements are celebrated not only for their ecological benefits but also for their role in offering natural defences against the impacts of climate change. The collective insights from Ghanaian road and highway infrastructure professionals articulate a clear consensus on the necessity of constructing roadways that are resilient to climate change. While acknowledging the exhibit of challenges encountered, the discourse consistently highlights the vital importance of adopting innovative and

integrated strategies. These strategies aim to fortify Ghana's road and highway networks against climate adversities through a blend of technical innovations, supportive policies, and sector-wide collaborative efforts, charting a course towards achieving sustainable, climate-resilient infrastructure development. The ideas that emerged from the interview sessions about the Design and Construct Climate Change Resilient Roadway Infrastructure are presented in Table 30.

Table 31: Key ideas emerging from the interview session about the design and construct climate change resilient roadway infrastructure

<i>Action Plan</i>	<i>Remarks</i>
<i>Capacity Building and Training</i>	Yeah, capacity building is necessary for any organization that wants to become better. Things are changing and every now and then,...P9 It requires statistical modeling and analysis, which very few professionals have the capacity and time to do. P13
<i>Guidelines and Standards Development</i>	Our guidelines need to be reviewed not only in terms of climate change but a whole lot. P9 We have design manuals which is over 30 years old and should be changed like every three years ... there should be reviews to identify current designs.P10
<i>Data Management</i>	there is the need for up-to-date data and the need for a national database so that we store all the necessary data there for designs.P1 Data collection, even for simple things like traffic data to estimate pollution levels, can be a challenge. We need to address these data collection issues to support effective infrastructure design.P12
<i>Advocacy and Funding</i>	I think the stakeholders see the need to ensure that our infrastructure is climate change resilient P1 While there is some level of awareness among industry players, it may not be deep enough.P12 Economic considerations often overshadow the importance of climate change resilience in infrastructure P12

5.6.4.4 Incorporate Technology in Design and Construction

The investigation into the impact of technology on the progress of road and highway infrastructure development in Ghana, conducted through semi-structured interviews with professionals in the field of road and highway construction, has shed light on the crucial significance of incorporating technology to improve project efficiency, sustainability, and

resilience. There's a shared understanding among these stakeholders that harnessing technological innovations is instrumental in elevating the quality and effectiveness of infrastructure projects. The discussions have brought to the fore the substantial benefits offered by specific technologies such as Building Information Modelling (BIM), Geographic Information Systems (GIS), and drone technology. BIM stands out for its capacity to foster enhanced collaboration, precision, and efficiency across all project phases, while GIS and drone technology are lauded for their accuracy in surveying and data collection, facilitating planning and comprehensive environmental impact assessments.

Despite the evident enthusiasm for these technological solutions, interviewees have labelled several obstacles hindering their widespread adoption. The high costs associated with advanced technological tools, a skills gap preventing effective utilization of these technologies, and a prevailing resistance to change within the construction industry were identified as major challenges. Additionally, the inadequacy of digital infrastructure in Ghana emerges as a significant impediment to technology adoption. To surmount these difficulties, participants advocate for a multifaceted strategy. Proposed solutions include government-led initiatives aimed at reducing the financial burden of technology adoption and bolstering digital infrastructure. Augmenting educational and training programmes for construction professionals is emphasized as essential for cultivating the requisite technical expertise. Moreover, there is a pressing call for policy reforms designed to foster or mandate the use of technology in infrastructure development. The suggestion to establish public-private partnerships highlights a strategic avenue for infusing private sector innovation and investment into technological advancement within the sector.

In brief, the integration of advanced technologies into Ghana's road and highway infrastructure development is viewed as a critical step toward realizing a modern, sustainable, and resilient infrastructure framework. Addressing the barriers to technology adoption demands collaborative efforts across all stakeholder groups, highlighted by strategic investments in training, digital infrastructure, and policy innovation. This concerted approach is deemed crucial for harnessing the transformative potential of technology in shaping Ghana's infrastructure future. Table 31 shows some of the important actions and suggestions that arose in the interview sessions in relation to the Incorporate Technology in Design and Construction.

Table 32: Remarks made in interviews about the Incorporate Technology in Design and Construction indicator

<i>Action Plan</i>	<i>Remarks</i>
<i>Technology Integration and Adoption Strategies</i>	<p>So, in as much as we are saying that software are important the user should have the basic understanding or basis or theory behind what he or she is doing.P1</p> <p>One challenge is the need to standardize and follow specific procedures. There are different brands and technical specifications, so we have to be cautious and ensure that we are adhering to our own specifications...P3</p>
<i>Capacity Building and Training</i>	<p>Research and training are necessary to understand and incorporate new technologies into our work...We need to bridge the gap between research and actual practice to benefit from new technologies and ideas. P7</p> <p>but I think we should first understand the basic principle as always to understand the basis. P11</p> <p>It should be mandatory for every agency to have a database system that provides the required information. P11</p>
<i>Change Management for Technological Innovation</i>	<p>Another one is resistant of some people especially the older ones, they usually will resist software and its application.P1</p> <p>Additionally, there may be a learning curve for technicians and engineers to adapt to new tools and softwareP6</p> <p>The system does not encourage the adoption of new technologies. P7</p> <p>Change management plays a crucial role in addressing resistance to technology adoption. It's important to create a culture that encourages flexibility and openness to change.P14</p>
<i>Public-Private Partnerships and Funding for Technology Infrastructure</i>	<p>Now the challenge is the lack of funds to purchase these technologies. There is lack of funds to maintain them.P1</p> <p>The cost of technology, including software subscriptions or renewals, can be a factor. P4</p>

5.6.4.5 Allow Adaptability and Flexibility for Future Changes

The significance of incorporating adaptation and flexibility into infrastructure designs has been examined through a series of semi-structured interviews with industry experts, shedding light on the sustainable development of road and highway infrastructure in Ghana. This design principle is showed as essential for enabling infrastructure to adeptly respond to technological advancements, environmental changes, and shifts in societal needs over time. A common thread among the insights shared is the acknowledgment of

the need for infrastructure designs that are anticipatory of future demands and challenges. Experts highlighted the criticality of planning infrastructure with the capacity for easy modification and expansion. This foresight is crucial for integrating emerging technologies, such as electric vehicle charging stations, and accommodating fluctuations in traffic volumes or altering weather patterns attributed to climate change.

The concept of "built-in flexibility" emerged prominently in discussions, with professionals advocating for modular designs that allow for adjustments or expansions with minimal disruption and cost. Such strategies are viewed as instrumental in prolonging the utility and sustainability of infrastructure assets, significantly enhancing their lifespan. Despite the widespread agreement on the significance of adaptability in infrastructure design, the interviews uncovered several impediments to its realization. Financial constraints are frequently cited, with the initial cost of incorporating adaptable features often deemed prohibitive. A notable absence of regulatory frameworks explicitly promoting or requiring design flexibility further complicates this issue. A skills gap within the professional community, highlighting a scarcity of engineers trained in adaptable infrastructure design, presents an additional challenge. This shortfall, combined with a prevailing construction mindset resistant to change, hinders the adoption of innovative design principles.

In response to these barriers, interviewees outlined a comprehensive strategy focusing on education, policy reform, and enhanced collaboration among stakeholders. There's a pronounced need for targeted training programmes aimed at equipping professionals with the necessary skills to design adaptable infrastructure. Furthermore, the development of policies and guidelines that incentivize flexibility in infrastructure projects is called for. Emphasizing the importance of collaboration, the engagement between the public sector, academia, and the construction industry is identified as vital for creating an innovation-friendly environment. Such partnerships are expected to facilitate knowledge exchange, pilot flexible design concepts, and establish best practices.

The collective insights from Ghanaian road and highway infrastructure professionals highlight the critical role of adaptability and flexibility in future-proofing infrastructure projects. While challenges are acknowledged, the path forward involves actionable steps toward incorporating these principles into infrastructure development, aligning Ghana with global best practices in sustainable and resilient design. The ideas that emerged from

the interview sessions about the allowing Adaptability and Flexibility for Future Changes are presented in Table 32.

Table 33: Remarks made in interviews about the allow adaptability and flexibility for future changes indicator

Action Plan	Remarks
<i>Strategic Planning and Enforcement</i>	<p>So, every city must have strategic land use plan and that plan will have to be strictly followed... So, we should have strategic land use plan which will have to be followed and obeyed. P1</p> <p>The enforcement of road reservation rules and proper land use planning by agencies like town and country planning and metropolitan municipal districts is essential P14</p>
<i>Collaborations and Forecasting</i>	<p>One of the challenges is predicting future changes accurately. It can be difficult to anticipate how traffic patterns, technology, and urban development will evolve over time. P2</p> <p>We cannot ensure adaptability and flexibility if we don't anticipate the changes that are likely to occur. P4</p> <p>Nevertheless, the design processes should be consistent and standardized across agencies to ensure smooth transitions and handovers between projects. P7</p> <p>Collaboration among agencies and ensuring consistency in design manuals would be beneficial in addressing such changes. P8</p>
<i>Stakeholder Engagement and Capacity building</i>	<p>And to do that you will have to bring all the stakeholders on board...P1</p> <p>Some stakeholders may resist certain design changes or environmental requirements due to their own interests or lack of understanding. P5</p> <p>Competent supervision is crucial to ensure that the project is executed according to the design and specifications.P7</p>
<i>Sustainability and Retrofitting</i>	<p>Another challenge is striking a balance between adaptability and initial construction costs. While it's important to design with flexibility in mind, there are budget constraints to consider. P2</p> <p>For instance, using modular construction techniques enables easier modifications and repairs, should they be required. We also integrate smart technology solutions, such as sensor-based monitoring systems, which provide real-time data on road conditions and traffic patterns.P5</p>

5.6.4.6 Ensuring Availability of Competent Supervisors, Laborers, etc.

The investigation into road and highway infrastructure development in Ghana, informed by semi-structured interviews with a broad range of stakeholders, has highlighted the paramount importance of securing a competent workforce. This includes supervisors, labourers, and other critical personnel, a factor deemed essential for elevating construction quality, upholding safety standards, and adhering to project timelines effectively. A common recognition of existing skill gaps within the Ghanaian construction sector was evident among interviewees. They spotlighted a conspicuous shortage of adequately trained and experienced personnel across all project implementation levels. This deficiency is a significant detriment to the overall quality and sustainability of infrastructure projects, with direct consequences such as project delays, escalated construction costs due to rework, and compromised safety standards on construction sites.

The proficiency of the workforce is directly correlated with the successful execution and outcome of infrastructure projects. Challenges highlighted include the limited capacity of existing training institutions to fulfil the industry's demand, scarce opportunities for on-the-job training and professional development, and the migration of local talent in search of better prospects abroad. The enhancement of vocational and technical education, specifically tailored to the construction industry's needs and emphasizing practical skills alongside exposure to contemporary construction practices, was highlighted. There was a notable emphasis on the need for government-led initiatives, in collaboration with private sector entities, to foster workforce development programmes. Suggestions spanned scholarships, apprenticeship programmes, and incentives for companies that invest in employee training.

Policy reforms focusing on the development of a skilled construction workforce were advocated. These reforms include standardizing training curriculums and certification processes to ensure a uniformly high competence level across the sector. Additionally, the significance of Continuous Professional Development (CPD) for existing construction industry professionals was highlighted as crucial for staying updated with emerging technologies, methodologies, and best practices.

The interviews clearly assert that a competent workforce is fundamental to the successful advancement of road and highway infrastructure in Ghana. Tackling the challenges tied to workforce development demands concerted efforts among educational institutions,

industry stakeholders, and government agencies. By prioritizing the improvement of education, training, and professional development opportunities, Ghana can cultivate a more skilled and adept construction workforce. This, in turn, promises to elevate the quality, efficiency, and sustainability of its infrastructure projects, aligning with both national development goals and global best practices. Table 33 presents some of the insights derived from the interview sessions pertaining to the Ensuring Availability of Competent Supervisors, Labourers, etc.

Table 34: Interview highlights on ensuring availability of competent supervisors, Labourers, etc

<i>Action Plan</i>	<i>Remarks</i>
<i>Professional Development and Training</i>	On the government side, we need to continue training our staff and ensuring we have an adequate number of engineers and project managers to oversee projects. P3
<i>Ethical and Transparent Practices</i>	Economic constraints also play a role, as contractors may opt for cheaper labor rather than hiring competent supervisors or engineers.P13 Before anyone is introduced to a project, they should be assessed and evaluated by an experienced professional. This evaluation should consider the competence and qualifications of the individuals involved. P13
<i>Collaboration between Industry and Academia</i>	Secondly, there should be investment in training and skill development programs. This can be done through collaboration between educational institutions, industry associations...P6 Technical skills training should be introduced in our educational system, allowing individuals interested in specific sectors, such as roads, to receive specialized training P13
<i>Strategic Workforce Planning</i>	But there is this knowledge gap because there are some knowledge and skills that you will gain on the field not from school. P1 On-the-job training and apprenticeship programs can also be implemented to bridge the experience gap and ensure a smooth transition from senior supervisors to younger professionals. P6
<i>Political Interference and Governance</i>	Yes, there have been challenges with recruitment, especially with government directives prioritizing employment in other sectors such as health and education P3 Yes, political factors can have an impact. Even if the engineer is competent, if there are political interferences, the contractor may complain to higher authorities and create delays. P4

5.6.5 Social equity and culture Criteria

The semi-structured interviews conducted with experts and practitioners in sustainable road and highway infrastructure development have provided rich insights into the critical indicators related to social equity and culture. These include safety risk assessment and mitigation during construction, improvement of worker's health and safety, reduction of traffic congestion in design and operational phases, and public participation in the early project phase. This analysis explores into the significance, implementation challenges, and strategies associated with these indicators within the context of sustainable highway development.

5.6.5.1 Safety Risk Assessment and Mitigation During Construction

Semi-structured interviews with industry professionals demonstrate an in-depth understanding of safety's significance in construction processes through the incorporation of safety risk assessment and mitigation measures in Ghana's road and highway infrastructure development. These insights reflect a consensus on the essential nature of safety risk assessments and mitigation efforts in safeguarding worker well-being and preventing accidents on construction sites. Professionals shared their current safety practices, including conducting regular safety audits, identifying hazards, and organizing safety training workshops, to cultivate a safety-first culture on construction sites. The adoption of personal protective equipment (PPE) and the implementation of safety signage were highlighted as fundamental measures to enhance safety.

Despite these initiatives, significant challenges in consistently applying comprehensive safety risk assessments and mitigation strategies were reported. Key issues include a widespread lack of awareness and understanding of safety protocols among workers, often due to insufficient training and education. Financial constraints pose another significant barrier, with firms finding it difficult to dedicate adequate resources to safety programmes. The inherently dynamic nature of construction sites and the complexity of projects further complicate the effective implementation of safety measures.

These interviews highlight a persistent recognition of the need for systematic safety risk assessments and the implementation of effective mitigation strategies in Ghana's construction sector. A multifaceted approach that encompasses education, regulation, technology, and collaboration stands out as a comprehensive pathway to improving construction safety outcomes, emphasizing the sector's commitment to ensuring the well-being of its workforce and the successful execution of infrastructure projects. The ideas

that emerged from the interview sessions about the Safety Risk Assessment and Mitigation During Construction are presented in Table 34.

Table 35: Remarks made in interviews about the Safety Risk Assessment and Mitigation During Construction indicator

<i>Action Plan</i>	<i>Remarks</i>
<i>Workplace Safety Improvement</i>	<p>The contractor should never compromise on providing the required PPE. It's their responsibility to ensure that workers have access to and wear the necessary protective gear.P7</p> <p>And there is also the need to enhance their capacity to do that. Not every engineer can do this risk assessment P1</p> <p>There should also be a toolbox talk on the construction site to create the awareness of the risk involved in every activity.P1</p>
<i>Contractor Performance and Evaluation</i>	<p>Yes, regular inspections and monitoring activities are conducted to ensure compliance with safety measures. P6</p>
<i>Proactive Safety Measures</i>	<p>Yes, having a dedicated safety officer is highly recommended. Although not all contractors may have one, it is necessary for ensuring safety standards are upheld.P7</p> <p>I believe it's already a requirement to have a safety officer when applying for the road certificate. However, there should be proper follow-up and monitoring to ensure compliance. P8</p>
<i>Protocol Development and Adherence</i>	<p>The department has a policy where I think during construction and every half of a year, there is safety audit. P11</p> <p>We call safety audit to see where there are needs for safety measures. At the design stage, we take into consideration most of the variables which makes it safer for people to use the road. P9</p> <p>Collaborating with the National Road Safety Authority helps us promote campaigns for attitudinal change and behavioral aspects related to road safety.P3</p> <p>While we conduct assessments, ensuring proper implementation is a challenge. P5</p> <p>There is no availability of funds to conduct or fully implement the schemes and recommendations from the audit.P9</p> <p>Yes, there is a continuous need to update knowledge and build capacity in this area, as risk assessment practices evolve over time.P12</p>

5.6.5.2 Improvement of Worker's Health and Safety

The series of semi-structured interviews conducted with stakeholders from Ghana's construction industry has cast a spotlight on the critical issue of worker health and safety within road and highway infrastructure development. These discussions have offered an in-depth look at the prevailing state of health and safety practices, emphasizing both the progress made and the substantial gaps that persist in safeguarding construction workers. A unanimous theme emerged from the interviews: the paramount importance of health and safety measures in construction projects cannot be overstated. Despite noticeable advancements in recent years, significant deficiencies in the implementation of robust health and safety protocols were identified. Key concerns include the relaxed enforcement of safety regulations, a deficiency in worker training, and a widespread underappreciation of safety's critical role in construction sites.

Interviewees articulated a pressing need for a cultural transformation within the construction industry, advocating for health and safety to be prioritized. This shift calls for more than mere regulatory compliance; it demands a change in attitudes and practices across the industry field. The proposed cultural shift encompasses enhancing worker and employer awareness, embedding safety considerations into the early stages of project planning, and cultivating an environment where safety is intrinsically linked to quality and productivity. The dialogue with industry professionals uncovered several difficulties to elevating health and safety standards, such as financial limitations facing smaller firms, the challenges posed by the informal construction workforce, and the absence of a unified system for accident and safety violation tracking.

These interviews inform a collective acknowledgment among Ghana's road and highway infrastructure sector professionals of the necessity to enhance worker health and safety. Embracing a holistic approach that includes comprehensive training, regulatory reform, and a shift in industry culture, stakeholders are optimistic about achieving substantial progress in ensuring the well-being of construction workers, marking a pivotal step towards safer and more sustainable infrastructure development. The insights obtained from the interview sessions about the enhancement of worker's health and safety are presented in Table 35

Table 36: Interview highlights on Improvement of Worker's Health and Safety

<i>Action Plan</i>	<i>Remarks</i>
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<i>Workplace Safety and Training</i>	And there is also the need to enhance their capacity to do that. Not every engineer can do this risk assessment P1
	Now before any new worker or even a visitor gets to the site, there is the need for safety induction to also create the awareness for such person...P1
	We expect a certain level of compliance, but the reality is that many of the workers come from backgrounds where safety standards were not a priority. It's challenging to change their mindset and make them appreciate the importance of health and safety measures.P13
<i>Employee Well-being and Collaboration</i>	Yes, the contract documents include provisions for these issues. They cover things like ensuring worker safety, providing insurance coverage for workers in case of accidents...P12
<i>Contractor Management and Safety Compliance</i>	Yes, there is a regulatory agency, often referred to as the Ministry of Welfare or a division within the Ministry, that oversees health and safety issues.P11 However, overall enforcement and implementation of safety measures can be improved, especially with stronger involvement from the regulatory agency. P12
	In our contracts, safety measures are specified, including the provision of first aid, personal protective equipment (PPE), and adherence to health and labor laws. Compliance is beneficial for both workers' well-being and project success. P6 That comes to supervision. For us, the bank ensures the engineer bears the consequence of not ensuring health and safety. P11
<i>Advocacy and Policy Development</i>	On construction sites, they usually have what they call toolbox meetings, where they reinforce the need for health and safety measures.P12 ... one of the conditions in the contract is that he is fully responsible for the safety of his staff on site. So, there are those provisions but the implementation of it.P9 This is how AFD do...So, funding is provided as part of the project. There is also charges or monies for the contractor to undertake these health and safety issues for workers.P11 Yeah, I think the continuous awareness. For road construction, your stakeholder is not just the workers but the road users, pedestrians, drivers and so forth. P11

5.6.5.3 Traffic Congestion – Design/Construction/Operational Phases

The issue of tackling traffic congestion during the design, construction, and operational phases of road and highway infrastructure development in Ghana has become a

significant concern in the quest of sustainable development. Insights drawn from semi-structured interviews with a diverse array of highway construction professionals have explained the strategies, obstacles, and recommendations pivotal to congestion reduction efforts. A consensus among interviewees highlights the significance of strategic planning and innovative design as indispensable tools in the congestion mitigation arsenal. The application of traffic simulation models during the design phase emerges as a key strategy, enabling the identification and pre-emptive addressing of potential congestion points. Furthermore, the integration of infrastructure features such as roundabouts, bypasses, and dedicated bus lanes is recognized for its potential to significantly enhance traffic flow. The implementation of Intelligent Transportation Systems (ITS) stands out as a proactive approach to managing congestion, emphasizing the value of technology in contemporary traffic management.

The construction phase, often a source of temporary traffic congestion, necessitates the adoption of effective traffic management strategies. Stakeholders underline the importance of scheduling construction activities during off-peak hours, maintaining clear signage for diversions, and engaging in real-time communication with the public about ongoing construction work. Minimizing the construction footprint on existing roadways to sustain traffic movement is also emphasized as crucial. As projects transition to the operational phase, maintaining optimal traffic flow and preventing future congestion becomes paramount. Continuous monitoring of traffic patterns, the deployment of adaptive traffic control systems, and the encouragement of public transportation and non-motorized transport are advocated as enduring solutions to vehicular congestion on roads. Despite the array of identified strategies to alleviate traffic congestion, stakeholders acknowledge several pervasive challenges, including limited funding for infrastructure initiatives, the slow adoption rate of technology, and the necessity for comprehensive data to inform planning and monitoring efforts. Additionally, the effectiveness of congestion mitigation measures is often compromised by a lack of public awareness and cooperation.

To surmount these obstacles, an increase in investment in transportation infrastructure, with a particular focus on technology-driven solutions like ITS, is recommended. Enhancing collaboration among government entities, the private sector, and the general public is deemed essential for the successful management of congestion. Furthermore, there is a pressing need for capacity building among sector professionals to facilitate the effective implementation of innovative traffic management strategies.

In conclusion, addressing traffic congestion during the design, construction, and operational stages of road and highway projects in Ghana demands a comprehensive and integrated approach. This encompasses advanced planning, innovative design, effective construction management, and dynamic operational tactics. Navigating the challenges ahead will require bolstered investment, improved stakeholder collaboration, and a steadfast commitment to public engagement and education, laying the groundwork for a future of sustainable and congestion-free road infrastructure in Ghana. Table 36 presents the concepts that were derived from the interview sessions pertaining to the Reduction of Traffic Congestion - Design/Construction/Operational Phases.

Table 37: Interview highlights on Reduction of Traffic Congestion – Design / Construction/Operational Phases

<i>Action Plan</i>	<i>Remarks</i>
<i>Traffic Management Plan and Enforcement</i>	Regarding construction-related traffic congestion, it requires having a proper traffic management plan.P12 To reduce traffic congestion, we need to have good planning and efficient traffic management. Proper diversions and alternative routes should be implemented to minimize disruptions.P8 While it's important to have a traffic control plan, enforcing it is another matter. You can have a well-designed plan on paper, but the actual implementation is crucial.P8
<i>Training and Professional Development</i>	In my experience, some flagmen may lack the necessary knowledge and skills to effectively control traffic. If we provide them with proper training, ..., it would greatly help improve their performance.P8
<i>Community Engagement and Communication</i>	Firstly, implementing traffic warnings is essential to alert drivers about construction activities and potential congestion. P7 Now there is the need during construction to train the flag men. They also play a critical role to reduce congestion P1
<i>Integrated Urban Planning and Sustainable Development</i>	You need incorporate all these things in your design decisions and put down measures that would curb people from taking the carriage way or the road way space or the travel lanes.P1 In my opinion, the main cause of traffic congestion is poor land use planning. We haven't properly considered where to place settlements, commercial sectors, and how to efficiently move people around. P12

5.6.5.4 Public Participation in Early Project Phase

The study involved conducting semi-structured interviews with various stakeholders to thoroughly examine the impact of public participation on the early phases of road and highway infrastructure development in Ghana. These interviews provided critical insights into the value, challenges, and strategies of integrating public input from the inception of infrastructure projects. Interviewees unanimously highlighted the crucial role of public participation in enhancing project acceptability, relevance, and sustainability. They noted that early engagement with communities helps to identify and incorporate local needs and preferences, potentially reducing conflicts and resistance later in the project lifecycle. Several professionals also pointed out that public participation aids in identifying environmental and social concerns that might not be apparent without community input, leading to more comprehensive project planning.

Despite the recognized benefits, stakeholders identified several challenges in effectively implementing public participation. Key issues include a lack of awareness and understanding of the participation process among community members, logistical challenges in organizing inclusive and representative engagement activities, and sometimes, a scepticism of the process's genuineness or effectiveness. The institutional capacity for managing participatory processes was also cited as a limitation, with some government and project implementing agencies lacking the resources or expertise to conduct meaningful engagement. To overcome these challenges, interviewees recommended several strategies. Enhanced education and awareness campaigns targeted at both community members and project teams were suggested to improve understanding of the value and processes of public participation. The development of clear guidelines and frameworks for public participation, tailored to the Ghanaian context and endorsed by relevant authorities, was another key recommendation. This would help standardize participation practices and ensure consistency across projects.

Furthermore, stakeholders emphasized the need for capacity building within government agencies and project teams to effectively manage participatory processes. This includes training in community engagement techniques and conflict resolution. Finally, leveraging technology, such as social media platforms and mobile applications, was proposed to broaden outreach and facilitate easier and more cost-effective engagement with a wider audience. The interviews emphasized that while public participation in the early phases of infrastructure development in Ghana faces several challenges, its potential benefits in terms of project success and sustainability are significant. Addressing the identified

challenges through strategic interventions could greatly enhance the effectiveness of public participation, ultimately contributing to more responsive, inclusive, and sustainable infrastructure development in Ghana. The ideas that emerged from the interview sessions about the public participation in early project phase are presented in Table 37.

Table 38: Remarks made in interviews about the Public Participation in Early Project Phase indicator

<i>Action Plan</i>	<i>Remarks</i>
<i>Stakeholder Engagement and Communication</i>	<p>...one challenge with it is that sometimes there is mistrust and also lack of information from the contractors and even the road agencies. And sometimes too another problem could be misinterpretation of information on the part of the public so if you give out an information, they misinterpret it. P1</p> <p>In our budget for road construction, most of them because they are politically motivated and made, there is no proper coordination. P11</p> <p>they are demanding and the moment they see contractors they want to see money and that keeps them from not involving them anymore.P10</p> <p>Financial constraints or other issues might limit the extent of stakeholder consultations,...P12</p> <p>One of the biggest challenges is that at the inception of the project, sometimes we fail to take the needs of the people into consideration P9</p>
<i>Conflict Resolution and Consensus Building</i>	<p>They are concerned about the impact on their businesses and disruptions caused...The Land Valuation Board plays a crucial role in convincing them and addressing their concerns, showing them the benefits they will gain.P3</p> <p>However, dealing with politicians can be challenging, as they may make promises beyond the project's scope and design. It requires careful communication and training to navigate these challenges.P5</p> <p>Ensuring that the right people represent the project and control how they communicate is important. P5</p>
<i>Effective Project Management and Timelines</i>	<p>That can be one of them but as I said there are times when the time given for project preparation is also very short to submit. When you have only two weeks to submit a proposal or feasibility report on a particular road, that is not enough time to engage the public. P9</p> <p>Time is a factor but sometimes....P10</p>

5.6.6 Project implementation and management criteria

The interview analysis on the project implementation and management criteria within sustainable road and highway infrastructure development yielded comprehensive insights into the critical indicators identified: compliance with environmental requirements, sustainable policy and strategy, meeting project duration, project risk assessment, contractor prequalification criteria, and contractor selection. These indicators are pivotal in ensuring that road and highway projects are not only sustainable but also efficiently managed and implemented.

5.6.6.1 Compliance with project requirements, documents, and specifications

Through a series of semi-structured interviews conducted with a range of stakeholders, an examination of the essential components of road and highway infrastructure development in Ghana has revealed the utmost significance of adhering to environmental regulations, contract documents, and project specifications. This indicator is unanimously regarded as essential for the sustainability, legality, and overall quality of infrastructure projects, acting as a foundation for mitigating environmental impacts, adhering to standards, and protecting community interests.

Despite the unanimous agreement on the importance of compliance, stakeholders identified a range of challenges in maintaining stringent adherence. These challenges encompass the complexities of the regulatory landscape, inconsistencies in contract documents, variations in project specifications, and limitations in enforcement mechanisms. A notable concern is the awareness gap among smaller contractors about the intricacies of compliance requirements, highlighting a need for enhanced understanding and capability in this sector.

The role of government and regulatory bodies was emphasized as crucial in promoting compliance, not just through enforcement but also by providing support and resources for capacity building and the clarification of guidelines. The interviews highlighted the significant repercussions of non-compliance, including project delays, escalated costs, legal ramifications, and notably, detrimental environmental impacts. The consensus among participants is that the costs associated with non-compliance significantly surpass those required for maintaining adherence to established standards.

These interviews lighten the critical nature of compliance within Ghana's road and highway infrastructure development, emphasizing a collective call to action for all

involved stakeholders—governmental entities, industry professionals, and the community. The discussions emphasize the necessity for a unified effort to ensure that infrastructure projects not only align with current standards but are also geared towards delivering sustainable and responsible long-term benefits. This collective insight into the importance of compliance stresses the need for strategic interventions, enhanced collaboration, and a steadfast commitment to upholding high standards across the board, ensuring the successful realization of infrastructure projects that stand the test of time and contribute positively to Ghana's developmental aspirations. The insights obtained from the interview sessions about the compliance with environmental requirements, contract documents, and project specification are presented in Table 38.

Table 39: Interview highlights on Compliance with Environmental Requirements, Contract Documents, and Project Specification

Action Plan	Remarks
<i>Cost Estimation and Budget Management</i>	they emphasized training and upgrading personnel, as well as adapting to new technologies. However, the issue of cost poses a challenge in adhering to these policies. P13
<i>Project Management and Stakeholder Collaboration</i>	<p>...one of the main factors is cost. If there is a design, the contractor thinks doing another could save cost,.... P11</p> <p>Implementing a more robust monitoring system that involves regular inspections, audits, and the involvement of regulatory bodies would greatly enhance compliance P6</p> <p>One common reason is the lack of proper understanding or interpretation of the documents. P7</p> <p>Thus, there is a need for stronger collaboration and commitment between all parties involved in the project. P12</p>
<i>Environmental Management and Sustainability</i>	<p>There's no strong enforcement on the management plans that we have.P9</p> <p>One of the challenges is the enforcement of standards, which requires training and capacity building for supervisors and other stakeholders involved. P9</p>
<i>Regulatory Compliance and Legal Aspects</i>	<p>The plans are outlined in the EPA (Environmental Protection Agency) laws, and we have incorporated them into our environmental management plans P3</p> <p>Currently, we don't have specific legal provisions or contractual clauses that impose fines or penalties for non-compliance with contract documents and environmental requirements P6</p>

5.6.6.2 Sustainable Policy and Strategy to improve Construction Efficiency

Semi-structured interviews were performed with major stakeholders in the construction sector, such as policymakers, contractors, engineers, and environmental consultants, to improve road and highway infrastructure development in Ghana. The focal point of these discussions was the accomplishment of sustainable policy and strategy to improve construction efficiency, identified as a pivotal indicator for the sector's advancement. Interviewees universally acknowledged the critical need for sustainable policies and strategic frameworks aimed at improving construction efficiency in Ghana's infrastructure projects. They emphasized that such policies and strategies are fundamental in addressing the triple bottom line of sustainability: environmental, social, and economic dimensions.

Despite the consensus on the importance, stakeholders highlighted several challenges impeding the effective implementation of sustainable policies and strategies. Key issues included a lack of coordination among government agencies, insufficient funding for sustainability initiatives, and a prevailing gap in awareness and capacity among industry professionals regarding sustainable construction practices. Participants discussed various strategic approaches to enhance construction efficiency. This included the adoption of Building Information Modelling (BIM) for improved project planning and execution, the integration of advanced materials and construction techniques to reduce waste and enhance durability, and the application of life cycle assessment (LCA) methods to evaluate and mitigate environmental impacts.

A strong call for robust policy development and enforcement emerged from the interviews. Stakeholders advocated for the establishment of clear, actionable policies that mandate sustainable construction practices, alongside incentives for projects that demonstrate high levels of efficiency and sustainability. The need for policies that foster public-private partnerships (PPPs) was also emphasized, highlighting the potential of PPPs in leveraging private sector innovation and investment in sustainable infrastructure development. Addressing the capacity gap within the industry was identified as a crucial step toward achieving sustainability goals. Interviewees recommended the expansion of education and training programmes focused on sustainable construction practices, targeted at both emerging professionals and established industry players. Furthermore, the development of a professional certification programme in sustainable construction was suggested as a means to standardize qualifications and promote best practices.

The importance of engaging a broad spectrum of stakeholders, including local communities, in the policy development and project planning processes was highlighted. This engagement is seen as essential for ensuring the relevance and acceptability of infrastructure projects, as well as for fostering a culture of sustainability within the construction industry. The interviews revealed a comprehensive understanding among Ghanaian construction industry stakeholders of the critical role that sustainable policy and strategy play in improving construction efficiency. Overcoming existing challenges and harnessing strategic, policy, and educational tools were identified as key pathways toward achieving sustainability objectives in road and highway infrastructure development. Table 39 displays the perspectives derived from the interview sessions pertaining to the accomplish sustainable policy and strategy to improve construction efficiency.

Table 40: Interview highlights on Accomplish Sustainable Policy and Strategy to Improve Construction Efficiency

<i>Action Plan</i>	<i>Remarks</i>
<i>Sustainable Infrastructure Development</i>	<p>There should be clear policy on the part of the highway industry.... If there should be a legal backing of the policy then that should be done P1</p> <p>To enforce the policies effectively, there needs to be sufficient resources and the willpower to follow through on implementation. P7</p> <p>It is essential to have well-defined and integrated sustainable policies and strategies that guide our infrastructure development and environmental initiatives. P12</p>
<i>Interagency Collaboration and Coordination</i>	<p>We need one but as I said it should be a harmonize one for all the agencies to use P11</p>
<i>Capacity Building and Professional Development</i>	<p>We have the policy, and we continuously train our technical staff to stay updated. However, sometimes the results don't align with the intended objectives, and political factors can hinder effective implementation. P5</p>

5.6.6.3 Project Duration

In order to investigate the various factors that impact the duration of road and highway infrastructure projects in Ghana, a series of semi-structured interviews were conducted with a range of industry stakeholders. These interviews provided valuable insights into the complex challenges, strategies, and perceptions that shape project timelines within the specific context of Ghana. A pattern of challenges contributing to project delays

emerged from the discussions. Foremost among these are funding issues, where delays in financial disbursements critically impede project momentum. Logistical difficulties and supplier unreliability, leading to material supply delays, were highlighted as significant barriers to timely project execution. Additionally, the procedural complexities associated with securing necessary permits and approvals from various governmental bodies frequently introduce unexpected delays. The details of conducting environmental and social impact assessments were recognized as vital yet potentially time-extending activities if not adeptly managed.

In response to these challenges, stakeholders underlined the critical importance of project planning and comprehensive risk management. Strategies such as effective scheduling that incorporates buffers for potential delays, and the leverage of modern project management tools like Building Information Modelling (BIM), were proposed to enhance coordination and project efficiency. Furthermore, the early and sustained engagement with suppliers and government agencies was identified as pivotal for smoothing the material supply chain and fast-tracking regulatory approvals.

The essence of stakeholder collaboration was consistently highlighted as a cornerstone for success. Transparent and continuous communication among all parties involved—from project inception to completion—was deemed indispensable. Proactive community and stakeholder engagement was also emphasized as a key strategy for pre-empting and resolving issues that could lead to project delays. Building local capacity and expertise emerged as a crucial element in meeting project durations. Stakeholders advocated for targeted training programmes aimed at equipping project managers and construction workers with advanced project management skills and familiarity with cutting-edge technologies. This skill enhancement is vital for navigating the complexities of large-scale infrastructure projects efficiently.

Policy and regulatory framework reviews were called for, with stakeholders recommending the simplification of permit and approval processes and ensuring the prompt release of project funds as measures to alleviate delays.

In summary, achieving the desired project duration for road and highway infrastructure projects in Ghana necessitates a comprehensive approach. This approach encompasses addressing financial, logistical, and regulatory challenges while emphasizing enhanced planning, stakeholder collaboration, capacity building, and supportive policy frameworks. These insights emphasize the need for a concerted effort among construction

industry stakeholders to refine project delivery timelines in Ghana, highlighting a pathway towards more efficient and effective infrastructure development. Some of the insights obtained from the interview sessions about the meeting project duration are presented in Table 40.

Table 41: Interview highlights on Meeting Project Duration

<i>Action Plan</i>	<i>Remarks</i>
<i>Project Management and Planning</i>	One major factor that affects construction time is poor planning. If the project isn't planned well, the contractor may mobilize to the site but not be adequately prepared for specific activities. P7 If we do proper planning, we know how much it would take from feasibility and knowing the scope of what we already want to do we go into implementation of the project. P9
<i>Team Collaboration and Motivation</i>	But again, every stakeholder must be brought on board as early as possible including early public participation P1 All the stakeholders need to be brought on board to let them know what it is involved that is when you have enough time, you can do all this. P10
<i>Risk Mitigation and Contingency Planning</i>	It's essential to identify and address the risks that can cause delays and hinder progress. This includes factors such as financial risks, construction-related challenges, and even external factors beyond our control P3
<i>Financial Management and Funding Strategies</i>	Before a project starts or when you secure financing, the source should be well secured so that you have a consistent cash flow into the project. P8 I believe we need to be resourced. Because to get all these things done, if there are no funds it looks difficult and that is for the agency part that is right from planning and then when we are resourced and we give adequate timelines. P10

5.6.6.4 Project Risk Assessment

Semi-structured interviews with various industry stakeholders have enhanced the investigation of the function of project risk assessment in road and highway infrastructure development in Ghana. These interviews have collectively emphasized the indispensable role of project risk assessment in the successful and sustainable execution of infrastructure projects within the region. A common agreement among interviewees highlighted the significance of project risk assessment as a pivotal component of project management. It is recognized for its capacity to identify potential hazards, uncertainties,

and challenges that could adversely affect project timelines, costs, and overall quality. This consensus establishes risk assessment as an essential tool for proactive management, facilitating the anticipation and mitigation of potential risks.

Despite the recognized value of project risk assessment, stakeholders identified several impediments to its effective execution. A prevalent concern is the limited capacity and expertise among project teams, especially in applying advanced quantitative risk assessment methods. Additionally, the inherently dynamic nature of construction projects in Ghana—marked by variable market conditions, regulatory shifts, and environmental considerations—presents significant challenges to precise risk forecasting and management. The discussions also brought to light the inadequacies in the institutional and regulatory frameworks that oversee risk management within Ghana's construction industry. There is an expressed need for more defined guidelines and standards tailored to infrastructure risk assessment and management, aiming to foster uniformity across projects.

These interviews have clarified the complex landscape of project risk assessment in Ghana's road and highway infrastructure sector, emphasizing both its undeniable importance and the challenges to its comprehensive implementation. Advancing risk management practices necessitates a concerted effort towards capacity building, refining regulatory frameworks, embracing technological advancements, and fostering deeper stakeholder engagement. This strategic approach is pivotal for enhancing the effectiveness of risk management in infrastructure projects, ultimately contributing to their successful and sustainable completion. Table 41 displays the perspectives derived from the interview sessions pertaining to project risk assessment.

Table 42: Interview highlights on Project Risk Assessment

<i>Action Plan</i>	<i>Remarks</i>
<i>Integrated Risk Management</i>	<p>It's essential to have comprehensive risk management plans in place that address various aspects of project implementation.P3</p> <p>there should be a more systematic approach to risk assessment and management, considering all project risks, including social, economic, and environmental factors P6</p> <p>However, there can be a gap between the assessment and its implementation, which can negatively impact project outcomes.P5</p>

Capacity Building and Training

And there is also the need to enhance their capacity to do that. Not every engineer can do this risk assessment. P1

I believe it would be beneficial for contractors to receive training in risk assessment. P8

Knowledge Sharing and Standardization

Indeed, managing risks is a shared responsibility between the contractor and the client. Both parties have obligations and rights, and it's essential to have effective communication and coordination to address and manage risks. P3

Resource Allocation and Financial Sustainability

But if the project is politically motivated, they may not do these things and we have a lot of these projects ... Secondly, even if they would want to do it they don't have enough time to put together the proposal. P1

Ideally, risk assessments should be conducted for every project. However, in reality, resource constraints may limit their execution. P7

5.6.6.5 Approach/Criteria for Contractor (e.g., Prequalification)

Semi-structured interviews with key industry stakeholders have shed light on the crucial role of the contractor selection approach and criteria, such as prequalification processes, in ensuring the success and sustainability of road and highway infrastructure development in Ghana. Stakeholders from various sectors universally recognized the critical importance of stringent contractor selection criteria in positively influencing project outcomes. A comprehensive prequalification process was identified as essential for evaluating contractors' financial stability, technical expertise, and track record on previous projects. This rigorous vetting ensures that only the most capable and dependable contractors are tasked with infrastructure projects. Stakeholders outlined several key criteria for contractor selection, such as technical competence, financial capacity, experience in similar projects, commitment to safety and environmental standards, and the ability to adhere to project timelines. These factors are considered crucial in minimizing project risks and guaranteeing quality delivery.

Despite widespread acknowledgment of its significance, stakeholders outlined several challenges in executing effective contractor selection processes. These include the subjectivity in assessing criteria, potential biases, and the administrative complexities tied to in-depth prequalification processes. To scale these problems, interviewees proposed the adoption of standardized prequalification frameworks that establish clear, objective, and transparent criteria. The incorporation of technology, like Building Information Modelling (BIM) and digital tendering platforms, was recommended to streamline the

selection process and bolster transparency. There was also a strong emphasis on the need for solid regulatory frameworks and policy backing to enforce best practices in contractor selection, suggesting policies that mandate the utilization of standardized selection criteria to promote fairness and efficiency.

Building the capacity of project owners, especially within the public sector, to effectively implement selection criteria and manage the prequalification process emerged as a crucial need. The involvement of industry associations in the development and refinement of contractor selection criteria was also encouraged, ensuring these criteria are comprehensive and reflective of industry standards. The collective insights from these interviews emphasize a consensus on the critical need for well-defined and rigorously applied criteria for contractor selection in Ghana's road and highway infrastructure projects. Tackling the identified challenges through the development of standardized frameworks, embracing technological advancements, reinforcing regulatory support, and fostering stakeholder collaboration is deemed essential for boosting construction efficiency and ensuring the success of infrastructure projects. Some of the insights obtained from the interview sessions about the approach / criteria for contractor (e.g., prequalification) are presented in Table 42.

Table 43: Interview highlights on Approach / Criteria for contractor (e.g., prequalification)

<i>Action Plan</i>	<i>Remarks</i>
<i>Process Improvement and Evaluation</i>	Sometimes the process may take a long time. P1 The evaluation and opening of bids can be done within the specified time. However, interferences often hinder the process from proceeding smoothly. P7
<i>Compliance and Monitoring System</i>	The guidelines are supposed to be adhered to so that interference will have to stop. P1 While we have requirements and regulations in place, political influence sometimes creates situations that are not beneficial. P3
<i>Transparency and Standardization</i>	You know sometimes the selection of contractors is influenced politically. P1 We should focus on transparent and open tendering processes. P3 We evaluate the method statement provided by the contractor, which outlines how they plan to execute the work. P6

5.6.6.6 Contractor Selection

Through the utilisation of semi-structured interviews with a range of stakeholders, this study explores into the contractor selection process for road and highway infrastructure development in Ghana. The findings of this research provide valuable insights into the existing practices, encountered challenges, and potential opportunities for improvement. The interviewees collectively stress the paramount importance of a contractor selection process, highlighting its fundamental role in ensuring project success across quality, timeliness, and adherence to budget. Key criteria identified for contractor selection encompass financial stability, technical proficiency, prior experience in similar projects, and a commendable history of safety and environmental compliance. Stakeholders note the importance of employing a mix of qualitative methods, such as interviews and reference checks, alongside quantitative assessments, like financial analyses, to facilitate well-rounded decision-making.

Despite broad agreement on the critical nature of selection process, respondents articulate several enduring challenges. Among these, the subjective nature of certain selection criteria stands out, potentially leading to bias and unfair practices. Furthermore, the absence of a standardized, transparent framework for contractor selection across various projects and sectors emerges as a notable obstacle, impeding consistency and fairness in the selection process. Additionally, smaller local contractors often face difficulties competing against larger, more established entities due to the stringent requirements that disproportionately favour well-resourced firms.

Derived from these discussions, the details of contractor selection in Ghana's road and highway infrastructure sector are emphasized, revealing both strides made and areas requiring further attention. Stakeholders call for a more standardized, transparent, and inclusive approach to the contractor selection process. Such improvements necessitate regulatory and procedural reforms alongside a cultural shift toward increased openness and collaboration within the construction industry, aiming to elevate both the efficiency and fairness of the contractor selection process. These collective insights emphasize the need for an integrated effort to refine and enhance the contractor selection framework, thereby contributing to the successful realization of infrastructure projects that meet the highest standards of quality, efficiency, and sustainability. Table 43 displays some of the perspectives derived from the interview sessions pertaining to Contractor Selection.

Table 44: Interview highlights on Contractor Selection

<i>Action Plan</i>	<i>Remarks</i>
<i>Compliance and Rule Enforcement</i>	The government agencies should be committed to following the criteria and preventing misuse of the system. P13 It requires strict adherence to the laws and regulations governing procurement. The technical people involved need to follow the right processes and not engage in actions that serve personal interests.14
<i>Efficiency and Optimization</i>	One challenge is the lack of a comprehensive database for contractors. Having a proper database with detailed information about their strengths, weaknesses, and resources would be beneficial. P12 Regarding the contractor selection process, the first step is to create a database of contractors through advertisements and local registrations. P14
<i>Integrity and Political Neutrality</i>	While you may have your own classification, I believe there should be another authority responsible for checking and following up on these contractor categories after the procurement process. P8 So, as I said, the guidelines are there but the political influence tends to take upper hand and some of these criteria are cut short. P11

5.6.7 Resource utilization and management Criteria

The semi-structured interviews with key stakeholders in sustainable road and highway infrastructure development offered profound insights into the critical indicators of resource utilization and management, namely, the integration of supply chains for a smooth flow of materials and resources, material quality control and assurance, and the use of recycled construction materials. This section synthesizes the discussions, highlighting the significance, implementation challenges, and recommended practices associated with these indicators.

5.6.7.1 Supply Chains

Through the utilisation of semi-structured interviews with various industry stakeholders, an examination of the incorporation of supply chains in road and highway infrastructure projects in Ghana has shed light on the crucial significance of effective supply chain management in the achievement of the sector. The insights gathered reveal a consensus on the importance of unified supply chain integration as a basis for timely and cost-effective project completion, emphasizing that an efficient flow of materials is crucial to

preventing delays and reducing construction costs. Despite the general agreement on its significance, stakeholders reported varied success levels in achieving effective supply chain integration across projects. While some demonstrated exemplary coordination, ensuring a smooth material flow, others faced considerable obstacles that hampered this efficiency.

Key challenges to achieving a fully integrated supply chain identified include poor road infrastructure and unreliable transportation services, significantly impeding the timely delivery of materials. Furthermore, inconsistencies in supplier performance, such as material delivery delays and quality variability, emerged as critical issues. The lack of effective coordination among different supply chain actors, including contractors, suppliers, and project owners, was highlighted as a source of inefficiency, leading to blockages and disorders. Additionally, the underutilization of supply chain management technologies was recognized as a gap, limiting the potential for higher integration levels and supply chain visibility. The findings emphasize a shared recognition of the need for enhanced supply chain integration in road and highway infrastructure projects in Ghana. Addressing the challenges identified requires a comprehensive approach focusing on several strategic interventions:

Improving logistical infrastructure and transportation services is essential for ensuring the reliable and timely delivery of materials. Strengthening relationships with suppliers and fostering consistent performance can mitigate risks associated with material delays and quality issues. Enhancing collaboration and coordination among all parties within the supply chain is crucial for eliminating inefficiencies and ensuring a cohesive project execution strategy. Finally, leveraging advanced supply chain management technologies can provide the necessary visibility and integration to streamline the flow of materials and resources.

In summary, the path to successful road and highway infrastructure development in Ghana lies in overcoming the current challenges to supply chain integration. By focusing on logistical improvements, supplier engagement, collaborative practices, and technological adoption, the sector can move towards more efficient, timely, and cost-effective project completions. These mutual efforts among all construction industry stakeholders are essential for achieving the seamless integration of supply chains, ultimately contributing to the sector's overall success and sustainability. Some of the

insights obtained from the interview sessions about the integration of supply chains - smooth flow of highway materials and other resources are presented in Table 44.

Table 45: Interview highlights on Integration of Supply Chains - Smooth Flow of Highway Materials and Other Resources

<i>Action Plan</i>	<i>Remarks</i>
<i>Supply Chain Optimization</i>	<p>But it's also important to ensure competition and that will help you get the right materials in terms of cost and quality. so you need to at least contact a number of suppliers and you select the right one or the best option. P1</p> <p>Having a proper plan and schedule of work is crucial. It allows us to know the sequence of tasks and when materials will be needed on-site. P8</p> <p>Proper planning and timely procurement of materials are crucial to avoid last-minute changes and storage issues..P12</p>
<i>Cost Efficiency and Analysis</i>	<p>If government wants to help reduce the cost especially on the importation of materials, there is a tax waiver when you are bringing in construction equipment. P1</p> <p>Firstly, we should consider exploring local alternatives for materials that are usually imported.P4</p>
<i>Quality Assurance and Collaboration</i>	<p>But contacting the supplier means you need to check the capacity of the supplier so you need to audit the capacity of the supplier.P1</p> <p>Proactive measures, such as conducting early quality testing of materials and personally visiting suppliers to ensure their reliability, can help prevent delays and ensure the materials are suitable for the project.P4</p>

5.6.7.2 Local materials

By conducting semi-structured interviews with a wide range of stakeholders, valuable insights can be obtained regarding the use of local materials in road and highway infrastructure development in Ghana. These interviews highlight the crucial role that local materials play in promoting sustainable infrastructure projects. The consensus among these professionals highlights local materials' critical contribution to not only reducing project costs and supporting the local economy but also in enhancing the environmental sustainability of construction practices. The stakeholders universally acknowledged the advantages of using local materials, emphasizing their potential to lower transportation costs, reduce carbon emissions associated with long-distance material transport, and foster local industries. The integration of such materials into construction projects is seen as aligning with global sustainability goals and local development objectives, promoting a more circular economy within the construction sector.

Despite the recognized benefits, the interviews revealed several challenges in maximizing the use of local materials in infrastructure projects. One significant concern raised was the variability in the quality and availability of local materials, which can pose risks to project timelines and outcomes. Stakeholders also pointed to a general lack of standardized testing and certification processes for local materials, which complicates their broader acceptance and use in formal construction projects. Additionally, there exists a perceptual barrier among some industry professionals who remain sceptical of the performance and durability of local materials compared to imported alternatives.

The insights from the interview on the use of local materials in Ghana's road and highway infrastructure projects reveal a clear path forward, addressing the challenges that currently hinder their broader adoption. These strategies, conceived through the collective wisdom of engineers, project managers, suppliers, and policy advisors, chart a course for integrating local materials into construction projects more effectively and sustainably. Firstly, the development of rigorous standards and certification processes stands out as a foundational step. Establishing clear guidelines ensures that local materials meet quality and reliability benchmarks, facilitating their acceptance within the construction industry. This move towards standardization promises to elevate the profile of local materials, making them viable contenders alongside imported alternatives.

Investment in research and development emerges as another pivotal strategy. By focusing on enhancing the quality and expanding the application range of local materials, there's potential to not only match but possibly exceed the performance characteristics of imported materials. Such efforts can lead to innovative uses and treatments that improve durability and performance, making local materials more attractive for use in infrastructure projects. The role of education and awareness cannot be understated. Changing the industry's perception of local materials requires targeted education and training programmes that highlight their benefits and potential. By shifting perspectives and building knowledge, stakeholders can encourage a broader adoption of local materials, recognizing their value in constructing durable, cost-effective, and sustainable infrastructure. Finally, strengthening the supply chains for local materials is identified as crucial for ensuring their consistent availability and cost-effectiveness. Supporting local suppliers through policy incentives and capacity-building efforts is essential for building robust supply networks that can meet the demands of large-scale infrastructure projects.

The insights from these interviews paint a picture of a sector that recognizes the untapped potential of local materials in contributing to more sustainable and economically beneficial infrastructure development in Ghana. Addressing the identified challenges through strategic interventions could significantly enhance the utilization of local materials, paving the way for infrastructure projects that are not only more sustainable and cost-effective but also supportive of local economies and aligned with environmental conservation efforts. The discussions reflect a consensus on the necessity of concerted efforts across the industry to elevate the role of local materials in Ghana's road and highway infrastructure projects. The key remarks made by the interviewees in relation to the use of local materials are shown in Table 45.

Table 46: Key remarks made by the interviewees in relation to the use of local materials

<i>Action Plan</i>	<i>Remarks</i>
<i>Regional Development and Collaboration</i>	<p>The agencies and contractors are supposed to collaborate with research institutions to conduct this research P1</p> <p>Currently, we tend to be conservative and strictly adhere to specifications, sometimes rejecting materials that could have been modified to meet our needs. Updating specifications to accommodate the use of more local materials would be beneficial.....P12</p>
<i>Promotion of Local Materials</i>	<p>...there is a need for the government or the ministry to advocate for the use of local materials. P1</p> <p>Flexibility in design expectations can help ensure the use of local materials while maintaining project goals. P4</p>
<i>Capacity Building and Training</i>	<p>Our taste for foreign products is also killing us because locally made materials are not mostly of interest. P10</p> <p>However, it's crucial to focus on building local capacity to decrease dependency on imports. P12</p> <p>you need to set up labs to conduct your test, so we also need money to build the labs and support the research P1</p> <p>Therefore, staying updated with testing equipment and procedures is vital, especially when working with local materials. P12</p>
<i>Policy Advocacy and Research Enhancement</i>	<p>And the need to conduct research to ensure that the local materials proposed will meet specifications to understand how it improves performance, so research is very important. P1</p> <p>We should explore and research the materials available in our surroundings. P8</p> <p>The focus should be on understanding their production processes and ensuring they meet the required</p>

specifications. Having a conscious policy in place would be helpful as well. P6

The willingness to use them depends on factors such as availability and cost-effectiveness, which can be influenced by government policies and project specifications. P6

Yeah, there is a need. There's a huge gap for research. P9

5.6.7.3 Material Quality Control and Assurance

Interviews with highway industry stakeholders shed light on the consensus about the crucial significance of integrating material quality control and assurance in Ghana's road and highway infrastructure development. This unified stance highlights the role of material quality standards in ensuring the longevity, safety, and overall project success, highlighting standardized testing of asphalt, concrete, and aggregates as pivotal practices. Despite the universal acknowledgment of these practices' necessity, the interviews reveal persistent challenges in achieving consistent material quality. Variability in the quality of locally sourced materials, difficulties in ensuring supplier compliance, and limitations in current testing infrastructure significantly impede the attainment of desired quality levels. The challenges extend to subjective evaluation criteria and the logistical problems of navigating the regulatory landscape, further complicating the assurance of material standards.

Addressing these complexities, stakeholders propose a comprehensive strategy focused on enhancing the current state of material quality control and assurance. Key to this approach is the modernization of testing infrastructure, requiring significant investment in advanced equipment and technologies to improve the scope and accuracy of material assessments. Moreover, fostering robust partnerships between project stakeholders is identified as crucial for a shared commitment to quality standards. The enhancement of professional development stands out as a critical need, emphasizing continuous education on the latest material quality standards and testing techniques. This focus on building internal capacity aims to elevate the sector's overall quality assurance practices. Additionally, the potential of technology, particularly Building Information Modelling (BIM) and digital tools, is recognized for its ability to revolutionize material tracking, documentation, and quality assurance processes, suggesting a pivotal role for technology in advancing more efficient and transparent control measures.

The collective insights from these interviews highlight a consensus on the indispensable role of material quality control and assurance in the construction of durable, safe, and successful infrastructure projects in Ghana. While challenges remain, particularly in standardizing quality assessment and ensuring supplier compliance, the articulated strategies emphasize the sector's need for infrastructural investments, stakeholder collaboration, and a commitment to professional development. Overcoming these challenges through a strategic, multi-faceted approach is essential for enhancing construction efficiency and ensuring the successful delivery of high-quality infrastructure projects. Table 46 displays some of the perspectives derived from the interview sessions pertaining to material quality control and assurance.

Table 47: Interview highlights on Material Quality Control and Assurance

<i>Action Plan</i>	<i>Remarks</i>
<i>Regulatory bodies and protocols</i>	<p>Additionally, there are governing bodies and institutions that oversee quality standards and can provide guidance and supervision to ensure compliance. P4</p> <p>The guidelines and documents guiding these processes should be comprehensive and reflective of quality standards. P13</p>
<i>Strategic Resource Management</i>	<p>Additionally, dedicating sufficient time and resources for quality control can be challenging, especially when faced with tight project schedules.</p> <p>That has to do with lack of expertise and resources to undertake the labs. P9</p> <p>Plans are underway to establish three central labs in Ghana; Accra, Kumasi and Tamale to ensure that accessibility of testing of materials. P10</p>
<i>Ethical and Unbiased Practices</i>	<p>Sometimes if the work is politically motivated, some tests could be skipped because the politicians want the work to move so even if it is failing, they don't allow the engineer to do his/her work. P1</p> <p>We also follow up with supervision to ensure compliance with specifications and contractual requirements. Timely and appropriate testing of materials is essential, and if any issues arise, we use clauses in the contract to address and remedy the situation P3</p>
<i>Organizational Culture of Quality</i>	<p>It starts from the contracting stage, where we ensure the best quality in the preparation and specification drawings. P3</p> <p>Additionally, there is a lack of motivation among staff to carry out quality assurance work. P3</p> <p>One of the challenges we encounter is the dissatisfaction of some contractors and politicians</p>

who may not appreciate the importance of quality control. This can create conflicts and disagreements. P5

Yes, effective communication between the contractor and the construction management team is essential to address these challenges. Both parties need to understand the importance of quality control and work together to find practical solutions. P14

5.6.7.4 Recycled Construction Materials

An examination of the utilisation of recycled construction materials in Ghana's road and highway infrastructure sector yielded valuable information through semi-structured interviews with a wide range of stakeholders. The collective viewpoint underlines the significant potential benefits of incorporating recycled materials, such as environmental sustainability, cost efficiency, and resource conservation. This approach resonates with both global sustainability trends and Ghana's specific environmental goals. Despite widespread acknowledgment of these advantages, the transition towards using recycled materials faces considerable challenges. Concerns over the quality and performance of these materials loom large, raising fears about their impact on the structural integrity and longevity of infrastructure projects. Additionally, the lack of clear regulatory guidelines and established standards for recycled materials usage poses a substantial barrier to their broader adoption. Compounding these issues are the limited availability of recycled materials and the emerging state of their supply chains, alongside a general lack of awareness and understanding of their benefits and applications among industry professionals.

In response to these difficulties, stakeholders suggest a comprehensive strategy aimed at overcoming the impediments to the use of recycled materials in construction. Key recommendations include the formulation of explicit standards and regulations to ensure the quality and performance of recycled materials, alongside increased investment in research and development to validate their efficacy and explore new applications. Strengthening the supply chains for these materials is also highlighted as essential for enhancing their accessibility and cost-effectiveness. Furthermore, there is a call for heightened education and training programmes to bolster industry professionals' understanding of the advantages and technical considerations of using recycled materials.

This in-depth interview reveals a consensus on the potential of recycled construction materials to contribute to more sustainable and efficient road and highway infrastructure development in Ghana. However, this potential is currently tempered by realistic apprehensions related to material quality, regulatory support, and market readiness. Addressing these concerns through targeted interventions could pave the way for the wider acceptance and utilization of recycled materials, marking a significant step towards achieving sustainable infrastructure development in Ghana. The findings highlight the complexity of integrating recycled construction materials into the sector and stress the need for collective efforts to navigate the identified barriers successfully. The insights obtained from the interview sessions about use of recycled construction materials are presented in Table 47.

Table 48: Interview highlights on Use of Recycled Construction Materials

<i>Action Plan</i>	<i>Remarks</i>
<i>Dedicated Research</i>	<p>So, it calls for research but when the research is done there is a need to pilot and the piloting process, I think sometimes becomes an issue. P1</p> <p>So, there is the need for the agencies to collaborate with the research institutions and ensure that some works that have been done breakthroughs will be piloted. P1</p> <p>Conducting thorough research will help us determine the best ways to recycle these materials, reduce costs, and promote sustainability. P6</p> <p>It's essential to have trial sections or experimental projects to test new ideas and assess their performance. This allows for continuous improvement and innovation in the field. P13</p>
<i>Provision of Resources</i>	<p>It's important to allocate enough time for these assessments to identify opportunities for reusing materials and filling specific needs within the project. P12</p> <p>Another challenge is the availability of resources and infrastructure to support the implementation of innovative techniques. P13</p> <p>The lack of plan on the part of the contractors and the technology to be able to undertake the recycling. P9</p> <p>Additionally, there may be constraints in terms of funding and budgeting for research and development of new approaches. P13</p>
<i>Development of standards, regulations and protocols</i>	<p>Well, I think we have not done that so far because we don't have adequate guidelines in using recycling material for now. P11</p> <p>Furthermore, the regulatory framework and approval processes may not always accommodate</p>

<i>Training and awareness creation</i>	<p>or facilitate the introduction of innovative techniques. P13</p> <p>Promoting the availability and utilization of recycled materials in the market can foster sustainable construction practices. P4</p> <p>Currently, our industry pays little attention to this aspect. We primarily focus on using new materials...P12</p> <p>One common barrier is the resistance to change. Some people may prefer to stick with what they already know and are familiar with, rather than embracing new ideas. P12</p> <p>Providing training programs, workshops, and sharing success stories can help build knowledge and confidence among professionals in the industry. P13</p>
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5.7 Main findings of the interviews

The semi-structured interviews conducted as part of this research have yielded valuable insights and perspectives from key stakeholders, which are instrumental in developing effective decision-making guidelines for sustainable road and highway infrastructure development. The process of data reduction and transformation facilitated the distillation of complex information into accessible, coherent themes and patterns, as advocated by Green et al. (2007) and Lune & Berg (2017). This methodological approach ensured the extraction of actionable intelligence from the respondents' feedback on each critical sustainability indicator. The collected remarks were systematically analysed and categorised, leading to the formulation of targeted action plans aimed at enhancing sustainability practices within road and highway infrastructure projects. These plans are grounded in the empirical data derived from the interviews and are structured to address the specific sustainability challenges identified by the respondents.

To ensure the validity of these findings, the research methodology included verification process. This involved retracing the analytic steps to confirm that the conclusions drawn were faithfully representative of the data collected. Table 48 in the thesis presents a concise summary of the main findings from the interviews, highlighting the proposed action plans derived from the stakeholders' input.

Table 49: Major findings of the interview study

<i>S/N</i>	<i>Sustainability Indicators</i>	<i>Action Plans</i>
1	Material Costs	Collaboration and Communication Sustainable Material Innovation Local Sourcing and Community Engagement

		Procurement and Contractual Measures Flexibility and Continuous Improvement Economic Considerations and Budget Management
2	Construction time	Project Management Optimization Workforce Development and Training Stakeholder Engagement and Relationship Management Financial Planning and Resource Allocation
3	Life cycle Costs	Risk Mitigation and Project Preparedness Capacity Building and Education Technological Advancements and Competence Project Planning and Risk Mitigation
4	Maintenance and Operation Costs	Data Collection and Transparency Stakeholder Collaboration and Advocacy Commitment to Infrastructure Maintenance Financial Management and Accountability Monitoring and enforcement Stakeholder Engagement, Education and Technology integration
5	Dust Control	Quality Control and Standards Research and capacity building. Regulatory compliance and enforcement
6	Use of Environmentally Friendly Materials	Financial Management in Construction Promote Environmental Sustainability in Infrastructure Development Develop and enforce Policy and Regulatory Framework for Sustainable Construction Research and Innovation for Sustainable Construction Technologies Community Awareness and Cultural Shift in the Construction Sector
7	Ecological Functions of Drainage Corridors	Environmental Management and Regulation Ecological Integration in Infrastructure Projects Data-Driven Decision-Making Stakeholder Engagement and Bureaucratic Streamlining
8	Environmental Monitoring Measures After Project Completion	Enhance Environmental Impact Assessment (EIA) Process Monitoring and Regulatory Strengthening Policy influence Advocacy, Policy and Training
9	Flood and Surface Run-off	Infrastructure and Engineering Policy and Regulation Community Engagement and Education Capacity Building and Training
10	Durable Materials	Financial Planning and Budget Allocation Quality Assurance in Construction Local Sustainability and Production Innovation and Research for Cost-Effective Solutions Specification Compliance and Governance in Construction
11	Disaster (Flood) Resilient Designs	Climate-Responsive Infrastructure Development (Designs) Capacity Building and Training for Disaster Response Policy and Standards Enhancement Financial and Governance Strategies for Resilient Infrastructure
12	Design and construct climate change resilient highway infrastructure.	Capacity Building and Training Guidelines and Standards Development Data Management Advocacy and Funding

13	Incorporate Technology in Design and Construction	Technology Integration and Adoption Strategies Capacity Building and Training Change Management for Technological Innovation Public-Private Partnerships and Funding for Technology Infrastructure
14	Adaptability and flexibility for future changes	Strategic Planning and Enforcement Collaborations and Forecasting Stakeholder Engagement and Capacity building Sustainability and Retrofitting
15	Availability of competent supervisors, Labourers, etc	Professional Development and Training Ethical and Transparent Practices Collaboration between Industry and Academia Strategic Workforce Planning Political Interference and Governance
16	Safety Risk Assessment and Mitigation during Construction	Workplace Safety Improvement Contractor Performance and Evaluation Proactive Safety Measures Protocol Development and Adherence
17	Worker's Health and Safety	Workplace Safety and Training Employee Well-being and Collaboration Contractor Management and Safety Compliance Advocacy and Policy Development
18	Traffic Congestion – Design / Construction / Operational Phases	Traffic Management Plan and Enforcement Training and Professional Development Community Engagement and Communication Integrated Urban Planning and Sustainable Development
19	Public Participation in Early Project Phase	Stakeholder Engagement and Communication Conflict Resolution and Consensus Building Effective Project Management and Timelines
20	Compliance with Environmental Requirements, Contract Documents, and Project Specification	Cost Estimation and Budget Management Project Management and Stakeholder Collaboration Environmental Management and Sustainability Regulatory Compliance and Legal Aspects
21	Sustainable Policy and Strategy to Improve Construction Efficiency	Sustainable Infrastructure Development Interagency Collaboration and Coordination Capacity Building and Professional Development
22	Meeting Project Duration	Project Management and Planning Team Collaboration and Motivation Risk Mitigation and Contingency Planning Financial Management and Funding Strategies
23	Project Risk Assessment	Integrated Risk Management Capacity Building and Training Knowledge Sharing and Standardization Resource Allocation and Financial Sustainability
24	Criteria for contractor (e.g., prequalification).	Process Improvement and Evaluation Compliance and Monitoring System Transparency and Standardization
25	Contractor Selection	Compliance and Rule Enforcement Efficiency and Optimization Integrity and Political Neutrality
26	Integration of Supply Chains	Supply Chain Optimization Cost Efficiency and Analysis Quality Assurance and Collaboration
27	Use of local materials	Regional Development and Collaboration Promotion of Local Materials Capacity Building and Training Policy Advocacy and Research Enhancement
28	Material Quality Control and Assurance	Regulatory bodies and protocols Strategic Resource Management

29	Use of Recycled Construction Materials	Ethical and Unbiased Practices Organizational Culture of Quality Dedicated Research Provision of Resources Development of standards, regulations and protocols Training and awareness creation
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This process of engaging directly with experienced professionals has not only enriched the research with practical insights but also reinforced the relevance of the proposed sustainability framework. The integration of stakeholder feedback into the development of decision-making guidelines highlights the collaborative approach taken in this study, aligning with best practices in participatory research.

5.8 Summary

This chapter provides an in-depth analysis of the results obtained from semi-structured interviews, presenting a comprehensive examination of the key indicators deemed critical to the sustainable development of road and highway infrastructure. By analysing responses from seasoned professionals, the study provides an in-depth understanding of the factors guiding highway construction professionals towards sustainable and climate-resilient practices. The investigation addresses the third research question: What would guide the decisions of highway construction professionals for sustainable climate resilient highway construction?

Validation and verification of the critical indicators and the preliminary framework by industry representatives were crucial initial steps. This ensured that the identified indicators and the developed framework accurately reflect the key aspects vital for enhancing sustainability in road and highway infrastructure projects. Such validation underlines the relevance and applicability of the research findings to real-world scenarios.

Feedback from participants highlighted a growing recognition within the industry of sustainability development efforts as not only beneficial for enhancing the construction sector's image but also for promoting general awareness. This awareness pertains to the sustainability potential inherent in road and highway projects, suggesting opportunities for improving construction practices and outcomes.

By evaluating both the positive and negative aspects associated with each critical indicator, the study offered comprehensive insights into the sustainability considerations in road and highway construction. The subsequent SWOT analysis and recommendations

aimed at improving sustainable deliverables were formulated based on these insights. This analytical approach facilitated the development of guidelines designed to assist designers (project managers) in evaluating sustainability issues. It also aids in the selection of criteria that optimize the value of road and highway projects within the decision-making process, thereby contributing to the overarching goal of achieving sustainable and resilient infrastructure development.

Chapter 6 : Discussion and Findings

6.1 Introduction

This chapter expands on the analysis from Chapters 4 and 5, synthesizing questionnaire and interview findings into final recommendations for sustainable road and highway infrastructure development. It integrates data analysis with literature insights, discussing the synthesis of methodologies used and presenting guidelines based on critical indicators identified. This approach aims to offer a clear pathway for embedding sustainability in infrastructure projects, contributing actionable strategies for the field.

6.2 Discussion of questionnaire survey

Drawing upon the research design outlined in Chapter 3, the present study utilised a mixed-methods methodology, integrating quantitative and qualitative analysis techniques. This was achieved through the administration of a questionnaire survey and the conduct of semi-structured interviews. An extensive review of relevant literature provided the groundwork for developing these data collection instruments. This section explores the key findings derived from the questionnaire survey, offering insights that contribute to addressing the research questions and achieving the study's objectives. The following section will explore the outcomes of the semi-structured interviews, offering a comprehensive analysis of the gathered data.

6.2.1 Sustainability Pillars in sustainable highway infrastructure development

The identification of key sustainability indicators is of utmost importance in the context of sustainable road and highway infrastructure development. This study identifies six criteria foundational to understanding and enhancing sustainability within this sector: ecological performance, economic value, social equity and culture, technical quality, project implementation and management, and resource utilization and management. These categories broaden the conventional "triple bottom line" approach—traditionally encompassing economic, social, and environmental dimensions—by integrating institutional and managerial dimensions, thereby forming a comprehensive sustainability framework often referred to as “the sustainability prism” (Del Rosario & Traverso, 2023).

To guide decision-making in sustainable road and highway infrastructure projects, a conceptual model was devised, acting as a roadmap for incorporating sustainability into

project planning and execution (Figure 19). This model emphasizes the integration of human aspirations with core values such as social equity, environmental stewardship, and economic feasibility. Achieving a balance among these values is deemed essential for devising effective business strategies and setting visionary goals towards creating sustainable and smart built environments (du Plessis, 2012). By leveraging these indicators, the model aims to provide a comprehensive framework that supports the achievement of sustainability objectives in the development of road and highway infrastructure.

6.2.1.1 Economic Value

The economic value criterion plays a pivotal role in the development of road and highway infrastructure in Ghana, underpinning decisions that affect both the immediate and long-term financial sustainability of projects. There are four indicators in the 'economic value' category, namely: 'Material Costs', 'Life Cycle Costs', 'Construction Time', and 'Maintenance and Operation Costs'.

6.2.1.1.1 Material Costs

Quantitatively, professionals ranked "material cost reduction" highly, with an average score of 4.32, emphasizing its critical role in the economic and sustainable performance of infrastructure projects. This consensus aligns with Blismas & Wakefield's (2009) discussion on the importance of cost efficiency in selecting construction materials, emphasizing the necessity to balance economic constraints without sacrificing project quality.

Qualitative findings further clarify this theme, revealing a deep understanding among professionals that effective cost management not only enhances economic efficiency but also fosters sustainability. The strategic reduction of material costs enables the allocation of resources towards essential sustainability aspects such as environmental conservation and social equity initiatives. This perspective reveals the intricate link between economic viability and sustainability goals, suggesting that innovation in materials and construction techniques serves as a key avenue for cost savings and sustainability enhancements. However, the qualitative insights also highlight the inherent challenges and trade-offs in reducing material costs, including potential risks to project quality and the dilemma of achieving short-term savings at the expense of long-term costs. The emphasis on collaboration among stakeholders underlines the complexity of sustainable infrastructure

development, advocating for early engagement with suppliers, contractors, and regulatory bodies to optimize costs without compromising sustainability or quality.

Recommendations from the interviews for sustainable material cost reduction—such as utilizing local materials, recycling, and investing in research on cost-effective yet durable materials—reflect a commitment to sustainable development practices. These practices align with environmental and social equity objectives while ensuring economic viability. The findings resonate with existing literature, such as Lee et al. (2013) and Koushki & Kartam (2004), highlighting the significance of material cost optimization in maintaining financial sustainability and quality standards in infrastructure projects. The fluctuation in material prices (Koushki & Kartam, 2004) emphasizes the need for efficient material management practices to mitigate cost variability and overruns, echoing Phani & Mathew's (2019) advocacy for an integrated approach to material management.

This discussion brings to light the critical balance required between optimizing material costs and adhering to quality and environmental standards in sustainable road and highway infrastructure development. It showcases the necessity for a multifaceted strategy that embraces innovation, stakeholder collaboration, and sustainable practices to achieve economic efficiency without compromising the long-term viability and sustainability of infrastructure projects.

6.2.1.1.2 Construction Time

The discussion synthesizes findings from both quantitative and qualitative research phases, firmly establishing the reduction of construction time as a critical lever for enhancing the economic efficiency and sustainability of infrastructure projects. The assignment of an average importance score of 4.2 to "Construction Time" by highway professionals underlines a collective acknowledgment of the urgent need for timely project completions. This sentiment is supported by Mahamid et al. (2012), who note that delays worsen material and logistical costs, leading to inflated overall project expenditures. This consensus highlights the indispensable role of efficient construction timelines in preserving the economic integrity of infrastructure initiatives.

Examining into qualitative insights reveals the in-depth economic and sustainable outcomes of minimizing construction time. Through discussions with seasoned professionals, a direct link between time efficiency and project cost—spanning labour, equipment, and administrative expenses—emerges. The acceleration of infrastructure utilization brought about by shorter construction periods is highlighted as a catalyst for

economic development and societal benefits, illustrating the deep-seated relationship between time efficiency and the broader objectives of sustainable infrastructure development. Challenges to curtailing construction time are extensively explored, ranging from unpredictable weather and material supply delays to coordination barriers, bureaucratic barriers, and the technical demands of adopting innovative construction methods. These varied challenges call for a holistic strategy aimed at reducing construction time. In response, professionals advocate for a range of strategic interventions to navigate these obstacles, emphasizing the importance of project planning, the use of prefabricated components and modular construction techniques, and the creation of reliable supply chains. Additionally, calls for streamlined governmental procedures and the application of integrated project delivery models stress the necessity for improved stakeholder collaboration and the reduction of bureaucratic delays.

This discussion concludes in the assertion that reducing construction time is paramount for realizing economic efficiency and ensuring the timely delivery of infrastructure projects' societal benefits. Despite identifiable challenges, the strategies recommended by industry professionals chart a definitive course towards more sustainable and time-efficient road and highway infrastructure projects in Ghana. The comprehensive nature of this approach is in harmony with calls within the literature for empirical research to evaluate these strategies' effectiveness within the Ghanaian setting Akinradewo et al. (2019) and Rivera et al. (2020), highlighting the essential need for a unified effort to refine construction timelines while focusing on sustainability and quality standards.

6.2.1.1.3 Life cycle Costs

Both the quantitative and qualitative phases of this research indicate that Life Cycle Cost (LCC) analysis plays a crucial role in the sustainable development of road and highway infrastructure in Ghana. By evaluating "life cycle cost" as an essential economic indicator with an average score of 4.15, professionals underline the necessity for an approach that, while possibly entailing higher initial investments, ensures reduced operational and maintenance costs over time. This perspective is well-aligned with sustainable development theory, which advocates for holistic, long-term considerations in project planning and execution to balance financial, social, and environmental impacts. The quantitative findings resonate with Juni et al.'s (2008) emphasis on comprehensive cost assessments, advocating for a holistic approach that integrates financial, social, and environmental considerations across a project's lifespan. This approach aligns with the principles of sustainable development by promoting economic efficiency and

environmental stewardship, ensuring that projects are not only financially viable but also contribute positively to society and the environment.

Qualitatively, experienced professionals highlight the significance of minimizing life cycle costs as a foundation for sustainable infrastructure development. The emphasis on considering the entire lifespan of a project—from construction through maintenance to decommissioning—reflects a deep understanding of sustainability's core principles. True sustainability and economic efficiency, as noted, are achieved by extending the project's focus beyond upfront costs to encompass strategic planning for long-term expenses, a challenge compounded by the evolving nature of construction technologies and fluctuating material costs. The highlighted challenges, including the higher initial investment for durable materials and the complexity of forecasting long-term expenses, underline the need for a strategic approach to life cycle cost management. Advocating for quality material selection and the employment of advanced planning and analysis tools exemplifies a commitment to sustainable practices. Furthermore, the exploration of innovative financing models, such as public-private partnerships (PPPs), suggests a pathway to distribute life cycle costs and risks, encouraging long-term sustainability investments. Actionable steps proposed to enhance life cycle cost management include capacity building in life cycle cost analysis, policy reforms to incentivize sustainable practices, and collaborative platforms for knowledge sharing. These recommendations align with sustainable development theory, which emphasizes integrated approaches, stakeholder engagement, and policy support as key drivers of sustainable outcomes. The insights from the interviews and the strategies shared by professionals offer a practical roadmap for implementing LCC in road and highway infrastructure projects, reflecting sustainable development's triple bottom line considerations.

Integrating life cycle cost analysis from the early stages of project planning, as highlighted by Babashamsi et al. (2016b) and supported by recent advancements (Del Rosario & Traverso, 2023; Valdivia et al., 2021), is critical for achieving sustainable road and highway infrastructure development. Despite the identified challenges, the strategic application of LCC, with a focus on comprehensive cost considerations and the inclusion of environmental externalities, enables more informed, sustainable investment decisions. This approach is essential for advancing sustainable development in Ghana's road and highway infrastructure sector, ensuring that projects are economically viable, environmentally responsible, and socially beneficial.

6.2.1.1.4 Maintenance and Operation Costs

The examination of a reduction in maintenance and operational costs in the context of sustainable development of road and highway infrastructure in Ghana, as evidenced by quantitative and qualitative research findings, highlights the crucial importance of this emphasis from both economic and sustainable development perspectives. Quantitatively, the indicator "maintenance and operation costs" received an average score of 4.13, underscoring the strategic emphasis placed by professionals on quality construction, the use of durable materials, and efficient designs as means to curb future expenditures. This finding resonates with the sustainable development principle that advocates for a life-cycle approach to project management, emphasizing the importance of considering the full spectrum of costs associated with infrastructure throughout its lifespan (Fallah-Fini et al., 2015).

Qualitative insights assemble from interviews with experienced highway professionals further clarify the multifaceted approach necessary to minimize maintenance and operation costs effectively. This approach, aligning with the broader sustainability goals, is fundamental in extending the lifespan of infrastructure assets, ensuring functionality, safety, and reducing the financial burden on public resources. Professionals articulate the complexity of forecasting long-term maintenance needs and associated costs due to evolving technologies, environmental factors, and usage patterns, emphasizing the need for strategic and comprehensive planning. The pursuit of reduced maintenance and operation costs confronts several challenges, including the higher initial investment required for adopting innovative materials and technologies that promise longevity. Despite these obstacles, professionals advocate for a strategic approach centred on life-cycle cost analysis, emphasizing quality material selection and advanced planning tools as essential for achieving sustainability and economic efficiency.

Proposed actionable steps include enhancing the capacity for life-cycle cost analysis among project managers, advocating for policy reforms to incentivize sustainable practices, and fostering collaborative platforms for knowledge sharing. These recommendations are deeply rooted in sustainable development theory, which prioritizes integrated approaches, stakeholder engagement, and policy support as key to achieving sustainable outcomes. The emphasis on reducing maintenance and operation costs aligns with sustainable development theory, which advocates for a holistic evaluation of projects that encompasses economic, environmental, and social dimensions. The strategic focus on durability and maintenance optimization from the project's inception reflects a

commitment to the principles of sustainability, ensuring economic viability while minimizing environmental impacts. The literature corroborates the practical significance of minimizing maintenance and operation costs as crucial for the sustainability and financial efficiency of infrastructure projects (Babashamsi et al., 2016a; Plati, 2019). Adopting durable materials and proactive maintenance strategies, as recommended by Abed et al. (2024) and Giustozzi et al. (2012), exemplifies the application of sustainable development principles in practice, balancing upfront costs against the broader benefits of long-term cost savings and environmental stewardship.

The unified insights from quantitative and qualitative findings clarify a compelling narrative for integrating maintenance and operation cost reduction into the fabric of sustainable road and highway infrastructure development in Ghana. This narrative, supported by sustainable development theory, calls for an integrated, forward-looking approach that not only addresses immediate project needs but also anticipates future challenges, ensuring the sustainability and economic efficiency of infrastructure projects through strategic planning, innovation, and policy support.

6.2.1.2 Environmental Impact

The environmental impact criterion assumes a crucial role in promoting sustainable development practices within the context of road and highway infrastructure development in Ghana. There are five indicators—dust control, use of environmentally friendly materials, preservation or improvement of ecological functions of drainage corridors, environmental monitoring measures after project completion, and minimization of flood and surface run-off—are fundamental to the environmental criteria of sustainable road and highway projects.

6.2.1.2.1 Dust control.

The study highlights the importance of dust control as a critical indicator of environmental sustainability in the context of road and highway infrastructure development in Ghana, by including both quantitative and qualitative research findings. The quantitative aspect of the research, which assigns an average importance score of 4.13 to "dust control," corroborates the critical need to address dust pollution proactively. This aligns with the observations of Xing et al. (2018), who emphasize the detrimental effects of dust on both environmental quality and public health. The quantifiable recognition of dust control reflects a broader industry acknowledgment of its necessity in the sustainable planning and execution of infrastructure projects. Qualitative interviews with experts further

clarify the complexities of managing dust in infrastructure projects, emphasizing it as both an environmental and health imperative. The universal recognition of dust control's importance, beyond a technical challenge, signifies its integration into sustainable development practices. Despite its acknowledged necessity, professionals outline several implementation challenges, including site variability, cost considerations, regulatory compliance, and a lack of awareness among construction personnel. Addressing these challenges necessitates a multifaceted approach, emphasizing the early integration of dust control measures, the adoption of advanced suppression technologies, and collaboration with environmental agencies for regulatory compliance. Recommendations derived from professional insights advocate for comprehensive training on dust control technologies, policy development mandating dust control integration, and the encouragement of innovative suppression methods.

The synthesis of quantitative findings and qualitative insights presents a coherent narrative on the centrality of dust control in achieving sustainable road and highway infrastructure development. This narrative is supported by literature, including Spillane et al. (2013) and Dahalan et al. (2023), which advocate for the early integration of dust control measures as a means to enhance project sustainability and success. Research by Roy et al. (2022) and Almaskati et al. (2024) further corroborates the environmental and health provisions of dust control, highlighting its role in air quality management and respiratory health protection. The convergence of findings from both research phases with existing literature highlights the urgency of implementing comprehensive dust management practices. Such practices, as noted by Gonzalez et al. (2019) and Sanders et al. (1997), are pivotal to sustainable construction efforts, though they must be navigated with consideration for cost, environmental impacts, and site-specific conditions (Cui, 2023; Giunta, 2023). In summary, the study's findings, enriched by the sequential explanatory methodology, articulate the criticality of dust control within the spectrum of sustainable road and highway infrastructure development in Ghana. By aligning strategic planning, technological investments, and collaborative efforts, the construction industry can effectively address the challenges associated with dust management. This alignment, as evidenced through the lens of sustainable development theory, offers a comprehensive framework for minimizing the environmental and health impacts of dust, contributing to the broader goals of sustainability and community well-being in infrastructure projects.

6.2.1.2.2 Environmentally friendly materials

The understanding of the importance of using environmentally sustainable materials in road and highway infrastructure projects in Ghana is obtained by combining data from both quantitative and qualitative research phases. The quantitative phase, which assigns an average importance score of 4.17 to the use of eco-friendly materials, reflects a collective industry commitment to sustainable construction practices. This score stresses the recognition among highway professionals of the critical role such materials play in minimizing environmental impact while enhancing the durability and sustainability of infrastructure projects. This perspective aligns with the work of Jiang et al. (2018), who emphasize the significance of eco-friendly materials in improving the environmental sustainability of road pavements. Qualitative insights from interviews with seasoned professionals further explain the challenges and strategic pathways forward in integrating environmentally friendly materials into construction projects. Professionals emphasize the potential of such materials to lower carbon emissions, reduce the depletion of finite natural resources, and increase the recyclability of construction waste. This approach is not merely a technical adjustment but a strategic shift toward sustainable construction practices that align with broader environmental conservation and sustainable development principles.

The journey towards the widespread adoption of eco-friendly materials, however, is met with challenges such as higher initial costs, variable availability, stringent performance demands, and a knowledge gap among industry stakeholders. These challenges necessitate a comprehensive strategy for the rigorous evaluation and certification of eco-friendly materials to ensure their environmental benefits and performance adequacy. Collaboration among material suppliers, construction firms, and regulatory bodies is called for to improve the accessibility and affordability of sustainable materials. Actionable steps identified to promote the use of eco-friendly materials include enhancing stakeholder expertise and awareness about the benefits and application of sustainable materials through targeted training and education. Furthermore, supportive policies and incentives formulated by governmental and regulatory entities can facilitate the adoption of eco-friendly materials, making them more economically viable.

The synthesis of findings from the quantitative and qualitative phases, supplemented by academic literature, emphasizes the importance of employing environmentally friendly materials in achieving sustainable road and highway infrastructure development. Research supports the professionals' views, suggesting that the challenges of adopting

green materials can be addressed through government incentives, research partnerships, and educational programs (Sharma, 2020; Yaro et al., 2023). The literature further highlights the economic efficiencies derived from the durability and reduced maintenance requirements of eco-friendly materials (Bilgen & Altuntas, 2023; Jamshidi & White, 2019; Jiang et al., 2018). In conclusion, the successful integration of environmentally friendly materials into road and highway infrastructure development in Ghana requires a collaborative effort from all stakeholders, underlined by strategic planning, education, policy support, and innovation. The combined insights from both research phases provide a robust framework for advancing sustainable construction practices, ensuring the development of infrastructure that aligns with environmental conservation and sustainability objectives.

6.2.1.2.3 Ecological functions

The incorporation of ecological considerations into the design and construction of road and highway infrastructure, with a specific focus on the roles of drainage corridors, has become an essential aspect of sustainable construction practices. This trend is reflected in the findings from both quantitative and qualitative research phases, highlighting a consensus among highway professionals on the importance of ecological, hydrological, and social dimensions in road and highway development. The quantitative analysis reveals that professionals place significant importance on the ecological functions of drainage corridors, assigning an average score of 4.13. This score signifies a collective commitment to embedding environmental sustainability within infrastructure projects, particularly in the scope of drainage management. Qualitative insights from interviews with highway professionals echo this sentiment, highlighting a shared recognition of the multifaceted benefits associated with maintaining healthy drainage corridors. These benefits extend beyond traditional stormwater management to include biodiversity conservation, water quality improvement, and the enhancement of local ecosystems. Professionals advocate for drainage solutions that embody green infrastructure principles, contributing to the resilience and sustainability of road and highway projects.

A recurrent theme in the interviews is the necessity for a holistic approach to drainage corridor design that incorporates ecological, hydrological, and social considerations. The incorporation of naturalistic design elements, such as vegetated swales and constructed wetlands, is emphasized as a means to align with natural hydrologic processes and support mixed habitats. Yet, professionals acknowledge challenges in integrating these ecological considerations, citing spatial constraints, regulatory barriers, and the imperative for

interdisciplinary collaboration among engineers, ecologists, and urban planners. To overcome these barriers, professionals suggest leveraging advanced modeling and monitoring technologies, advocating for policy reforms prioritizing ecological considerations, and emphasizing public engagement. These strategies align with the principles of Low Impact Development (LID) and Sustainable Urban Drainage Systems (SUDS), which advocate for practices that mimic natural hydrological processes to mitigate environmental impacts.

The literature supports these findings, highlighting the effectiveness of green infrastructure in reducing runoff impacts and enhancing biodiversity within road and highway projects (Shafique & Kim, 2017; Tang et al., 2023). Further, studies feature the benefits of using natural materials and vegetation to improve water filtration and reduce erosion, aligning with efforts toward ecological stability (Rey et al., 2019; Verdonshot & Verdonshot, 2023).

In conclusion, the consensus on the critical role of preserving and enhancing the ecological functions of drainage corridors signifies a paradigm shift towards more environmentally responsible practices in road and highway infrastructure development. This shift reflects a broader societal acknowledgment of the importance of ecological preservation amid ongoing environmental challenges. By employing strategic planning, policy support, and interdisciplinary efforts, the challenges of integrating ecological considerations can be addressed, paving the way for sustainable and environmentally friendly road and highway infrastructure projects.

6.2.1.2.4 Environmental monitoring

The significance of using "post-project environmental monitoring measures" in the establishment of sustainable road and highway infrastructure is emphasised by study findings of both quantitative and qualitative form. Quantitatively, professionals have attributed an average score of 4.15 to this aspect, highlighting the sector's consensus on the need for ongoing environmental oversight. This reflects a commitment to a continuous evaluation of the environmental impacts of road and highway projects throughout their operational life, a stance that is echoed in the literature by Saud et al. (2020), who emphasize the crucial role of post-construction environmental monitoring in sustainable infrastructure development. Qualitative insights from interviews with experienced highway construction professionals in Ghana reinforce the collective understanding of the critical significance of post-completion environmental monitoring. This unanimity

extends to acknowledging the challenges faced in implementing effective monitoring measures and presenting strategies to enhance monitoring efficacy. The fundamental importance of assessing the actual versus projected environmental impacts of road and highway projects post-completion is identified as essential for the management and mitigation of any adverse environmental consequences, thereby ensuring compliance with environmental standards.

Professionals highlight several impediments to effective environmental monitoring, including financial constraints, the necessity for specialized training and equipment, and challenges in sustaining long-term monitoring efforts. The absence of a standardized environmental monitoring framework in Ghana is also noted as a significant barrier. To surmount these challenges, recommendations include securing dedicated funding for monitoring activities, incorporating environmental monitoring into the project's initial budget and planning phases, and fostering partnerships with academic and research institutions. The development of a comprehensive national guideline for post-construction environmental monitoring is advocated, aiming to standardize practices and ensure uniformity across projects. The benefits of effective environmental monitoring extend beyond mere regulatory compliance, encompassing ecological conservation, enhanced stakeholder relations, and the facilitation of data-driven decisions for future projects. Such measures are posited as instrumental in demonstrating the project's adherence to sustainable development goals, potentially attracting further investment.

The application of advanced technologies such as remote sensing, GIS, and IoT-based sensors for environmental monitoring is highlighted, offering opportunities for continuous and real-time environmental data collection. These technological approaches facilitate a more in-depth understanding of environmental dynamics post-construction and support the improvement of ecological conservation and decision-making processes for subsequent projects, as evidenced by Jin et al. (2020). Despite the challenges outlined, the suggested strategies and the integration of innovative technologies provide avenues for overcoming obstacles and enhancing the sustainability of road and highway infrastructure projects. Successful case studies, such as those referenced by Amon et al. (2022) and Flemming et al. (2023), exemplify the potential benefits of comprehensive environmental monitoring, including enhanced ecological restoration efforts and the promotion of adaptive management practices.

6.2.1.2.5 Flood and surface run-off.

The dual analysis through quantitative and qualitative methodologies highlights the critical importance of minimizing flood and surface runoff in the sustainable development of road and highway infrastructure in Ghana. The quantitative phase revealed that professionals ranked this indicator highly, with an average score of 4.16, signifying a broad consensus on prioritizing designs and construction methods that effectively manage flood risks and stormwater runoff. This approach is recognized for its potential to bolster both the environmental integrity and social sustainability of road and highway projects, resonating with the perspectives shared by Imran et al. (2013) and Kaur & Gupta (2022), who emphasize the role of innovative design and construction methodologies in enhancing water management. Qualitative insights from interviews with experienced highway construction professionals and environmental experts further clarify the complexity of effectively managing flood and surface runoff. There is unanimous agreement on the detrimental impacts of unmanaged runoff on infrastructure integrity and adjacent ecosystems. Interviewees advocate for a blend of engineering solutions and natural management practices, such as permeable pavements and green infrastructure, to mitigate these impacts while also enhancing biodiversity—a viewpoint that aligns with findings by Seitzhan et al. (2023) and Shafique & Kim (2017) regarding the effectiveness of such measures.

Challenges to implementing these solutions include land use constraints, financial limitations, the need for climate change-adaptive planning, and a local expertise gap in designing sustainable drainage systems. These obstacles underline the need for comprehensive and anticipatory planning strategies that can accommodate changing environmental conditions, as highlighted by Ocansey (2023) and Owusu et al. (2024). A strong consensus emerged on the necessity for robust policy frameworks that mandate the inclusion of sustainable water management practices in road and highway projects. This is complemented by the critical need for stakeholder education and a collaborative approach involving government agencies, construction firms, environmental organizations, and the academic community to foster the development and implementation of innovative solutions for managing flood and surface runoff effectively.

The insights and recommendations derived from the professional interviews provide a coherent blueprint for advancing practices that ensure the comprehensive management of flood and surface runoff in road and highway infrastructure development. By embracing a multifaceted approach that combines strategic planning, innovative engineering

solutions, and robust policy support, Ghana can effectively address this significant environmental challenge, thereby paving the way for more sustainable and resilient infrastructure projects.

6.2.1.3 Technical quality

The assessment of "technical quality" in road and highway infrastructure development in Ghana is a multifaceted issue that encompasses a range of considerations, from material selection and design standards to construction practices and project management methodologies. The emphasis on technical quality not only aims to ensure the longevity and durability of infrastructure projects but also to meet safety standards and adapt to the evolving technological landscape. There are six indicators in the technical quality category, namely, application of durable materials, disaster (flood) resilient designs, design and construct climate change-resilient roadway infrastructure, incorporate technology in design and construction, allow adaptability and flexibility for future changes, and ensure the availability of competent supervisors, labourers, etc.

6.2.1.3.1 Durable materials

The incorporation of durable materials in the development of road and highway infrastructure in Ghana is identified as an important indicator in guaranteeing the long-term viability and durability of these essential resources. Quantitative data analysis revealed that professionals in the field prioritize the use of durable materials, as indicated by an average importance score of 4.17. This consensus underlines the recognition within the industry that the selection of materials significantly influences the durability and maintenance frequency of road and highway infrastructure, directly impacting its economic and environmental sustainability (Agyekum et al., 2020; Johnson et al., 2019). Qualitative insights gathered from interviews with professionals across highway construction professionals affirm the strategic importance of selecting materials that can withstand environmental stressors, thereby extending the infrastructure's operational life and reducing maintenance needs. This unanimous viewpoint highlights the role of durable materials not only from a technical perspective but also as a foundational element for achieving broader sustainability goals within the infrastructure sector (Ngezahayo et al., 2023; Schmidt et al., 2021).

However, the adoption of durable materials is not without challenges. Professionals identified several barriers, including the higher initial costs associated with these materials, the complexity of evaluating their long-term performance and sustainability

impacts, and the industry's resistance to change. Additionally, the lack of comprehensive standards for assessing material durability complicates the decision-making process (Ghasemi et al., 2024). To overcome these challenges, the interviewed professionals advocate for a multi-pronged approach that includes enhancing research and development efforts, investing in life-cycle assessment tools, and developing robust standards and certification processes. This comprehensive strategy emphasizes the need for industry-wide collaboration, policy support, and education to advance the use of durable materials in Ghana's road and highway projects (Mao et al., 2015).

In summary, the integration of durable materials into road and highway infrastructure development in Ghana is recognized by professionals as crucial for achieving sustainability and resilience. Addressing the challenges associated with their adoption requires a concerted effort from all stakeholders, underpinned by strategic planning, policy initiatives, and education. This approach aligns with sustainable development goals, ensuring that infrastructure projects are economically viable, environmentally responsible, and socially beneficial.

6.2.1.3.2 Disaster (flood) resilient designs

It is essential to incorporate disaster resilience, specifically in relation to floods, into the planning and design of road and highway infrastructure in Ghana. This is necessary to guarantee the long-term viability and ability of these vital assets to withstand and recover from disasters. The quantitative phase of the research underlines this importance, with disaster (flood) resilient design receiving the highest importance score of 4.23 from professionals. This finding aligns with the broader consensus within the industry on the necessity of adopting comprehensive planning, engineering solutions, and community engagement strategies to mitigate the adverse effects of flooding (Ertan & Çelik, 2021; Qiao et al., 2023). Qualitative insights from interviews with a range of professionals further elaborate on the critical role of flood-resilient designs in the context of Ghana's road and highway sectors. The unanimous agreement on the necessity of incorporating such features into infrastructure projects reflects an understanding of Ghana's heightened flood risk, exacerbated by climate change and urbanisation. Strategies discussed for enhancing flood resilience include elevated roadways, advanced drainage systems, and green infrastructure elements, all aimed at effective stormwater management and landscape absorption (Brunner et al., 2021; Cease et al., 2019).

Despite the clear consensus on their importance, several challenges to the widespread adoption of flood-resilient designs were identified, including a lack of comprehensive flood risk data, financial constraints, and gaps in technical expertise. These challenges highlight the need for a multifaceted approach to effectively integrate resilient designs into practice, overcoming the identified barriers (Fields et al., 2021; Wenger, 2013). The integration of green infrastructure and nature-based solutions, highlighted for their cost-effectiveness and environmental benefits, represents an innovative approach to enhancing infrastructure resilience. These strategies not only address flood resilience directly but also contribute to broader ecological and societal benefits, highlighting the value of sustainable infrastructure practices (Blackwood et al., 2022; Liu et al., 2021).

This synthesis of quantitative and qualitative findings, supported by an extensive review of scholarly literature, presents a comprehensive view of the importance of integrating disaster (flood) resilient designs in Ghana's road and highway infrastructure. The collective insights emphasize the necessity of strategic investments in research, data collection, capacity building, and the mobilization of climate finance mechanisms to support the development and implementation of flood-resilient infrastructure designs. Addressing the challenges through collaborative efforts among government, academia, industry, and international partners is crucial for advancing the resilience and sustainability of Ghana's infrastructure sector.

6.2.1.3.3 Design and construct climate change resilient.

In Ghana, it is widely acknowledged that including climate change resilience into the planning and construction of transportation infrastructure is an essential endeavour for achieving sustainable development. Quantitative findings emphasize this significance, with the indicator "Design and construct climate change-resilient highway infrastructure" achieving an average score of 4.18. This consensus among professionals reflects an acute awareness of the detrimental impacts of climate change, such as extreme weather events and rising temperatures, on infrastructure (de Abreu et al., 2022; Regmi & Hanaoka, 2011).

Qualitative insights from interviews with industry professionals reveal an urgent need to embed climate resilience into road and highway infrastructure frameworks. Professionals identify key strategies for enhancing climate resilience, including robust drainage systems, elevation of critical infrastructure, and the use of heat-resistant materials, amidst

Ghana's vulnerability to increased rainfall variability and flooding (Ametepey et al., 2023a; Lueong & Tume, 2024).

Despite the consensus on the importance of climate-resilient designs, professionals outline several implementation barriers, including limited access to precise climate data, financial constraints, and a general lack of expertise in climate-adaptive practices. The integration of green infrastructure elements into road and highway designs is emphasized for their dual role in ecological conservation and climate adaptation (Opoku, 2019; Pontee et al., 2016).

This collective insight from professionals and alignment with academic research points to a clear recognition of the necessity for Ghana's road and highway infrastructure to be resilient to climate change. Addressing the challenges through collaborative efforts, policy reforms, and capacity-building initiatives is crucial for advancing sustainable, climate-resilient infrastructure development.

6.2.1.3.4 Technology in design and construction

The integration of technology into the design and construction workflows of road and highway infrastructure projects in Ghana represents a significant advancement in improving efficiency, sustainability, and resilience within the industry. The quantitative findings reflect this with a notable average score of 4.12, indicating the collective importance professionals place on technological integration as a strategy for advancing sustainable infrastructure development. This perspective is further clarified through qualitative insights, which highlight the potential of technologies like Building Information Modeling (BIM), Geographic Information Systems (GIS), and drone technology to significantly improve project outcomes (Agbelengor & Ayanore, 2024; Quamar et al., 2023).

Despite the acknowledged benefits, the widespread adoption of these technological solutions faces substantial barriers, including high costs, a skills gap, industry resistance to change, and inadequate digital infrastructure. These challenges necessitate a multifaceted approach, highlighted by government initiatives, enhanced educational programs, policy reforms, and public-private partnerships, to foster technological advancement within the construction industry (Eriqat et al., 2024; Oke et al., 2024).

The literature corroborates the insights from industry professionals, emphasizing the need for concerted efforts to integrate advanced technologies into Ghana's infrastructure

projects. Studies advocate for collaborative strategies that involve government support, academic input, and industry participation to address the barriers to technology adoption and to cultivate a conducive environment for innovation (Amankwah-Amoah, 2019; Babon-Ayeng et al., 2022; Seidu et al., 2023).

6.2.1.3.5 Adaptability and flexibility for future changes

This study emphasises the significance of adaptation and flexibility in the context of road and highway infrastructure development in Ghana. The findings, both quantitative and qualitative, feature the forward-thinking strategy advocated by experts in the field. With an average importance score of 4.16, the emphasis on adaptable designs reflects a collective vision for infrastructure that remains resilient in the face of technological advancements, environmental shifts, and evolving societal demands. This perspective aligns with the broader objectives of sustainable and resilient infrastructure development, highlighting the necessity to anticipate and prepare for future changes through thoughtful design and construction practices.

The quantitative analysis underlines a strong consensus among highway professionals on the need for infrastructure designs that accommodate future expansions, integrate new technologies, and adapt to changing traffic patterns and environmental conditions. This finding is consistent with the literature, which suggests that designing for adaptability not only enhances the long-term sustainability of infrastructure projects but also ensures their continued relevance and utility (Asante-Yeboah et al., 2024; Foster & Pushak, 2011). Qualitative insights from semi-structured interviews with industry experts reinforce the quantitative findings, revealing a unanimous acknowledgment of the critical role that adaptability and flexibility play in infrastructure design. The concept of "built-in flexibility" emerges as a key theme, with professionals advocating for modular designs that allow for future modifications and expansions with minimal disruption and cost. This approach is viewed as crucial for extending the lifespan and enhancing the sustainability of infrastructure assets.

Despite the widespread recognition of the importance of adaptability, the interviews also highlighted several significant challenges to its realization, including financial constraints, the absence of regulatory frameworks promoting design flexibility, and a skills gap among professionals. These obstacles echo the concerns identified in the literature, pointing to financial limitations, the complexity of forecasting future requirements, and prevailing institutional inertia as major barriers to integrating adaptable

features in infrastructure projects (Adu-Gyamfi et al., 2023; Afzal & Tumpa, 2024). In response to these challenges, interviewees outlined a multifaceted strategy centered on education, policy reform, and enhanced collaboration among stakeholders. This involves targeted training programmes to equip professionals with the necessary skills for designing adaptable infrastructure, the development of policies and guidelines that incentivize flexibility in projects, and fostering collaboration between the public sector, academia, and the construction industry. Such collaborative efforts are anticipated to facilitate knowledge exchange, pilot flexible design concepts, and establish best practices, aligning with suggestions from the literature for bridging the gap between current practices and the future vision of resilient infrastructure development (Gyimah et al., 2024).

The synthesis of quantitative and qualitative findings from this study, supported by existing literature, highlights the pivotal role of adaptability and flexibility in the sustainable development of road and highway infrastructure in Ghana. Addressing the identified challenges through a comprehensive strategy that includes educational initiatives, policy support, and industry collaboration emerges as essential for fostering an environment conducive to innovation and sustainable development. This integrated approach is critical for future-proofing Ghana's infrastructure projects, ensuring their resilience, sustainability, and alignment with global best practices in infrastructure design and construction.

6.2.1.3.6 Competent Workforce

The study highlights the importance of a skilled workforce, including supervisors, labourers, and other key persons, in the context of road and highway infrastructure development in Ghana. This is supported by both quantitative and qualitative findings. With an average significance score of 4.09, the emphasis on workforce competency outlines a clear recognition among professionals of its direct impact on construction quality, safety standards adherence, and the punctual execution of projects. This acknowledgment is profoundly supported by the literature, which illustrates the correlation between workforce proficiency and project success, thereby affirming the essentiality of skilled human resources in construction endeavours (Deku, 2015; Meng et al., 2015; Moshood et al., 2020). The quantitative analysis, spotlighting workforce competency as a significant indicator, reflects a holistic perspective within the professional community. This perspective emphasizes the crucial role of adequately

trained and experienced personnel in surmounting project challenges, enhancing efficiency, and ensuring the sustainability of infrastructure developments.

Semi-structured interviews with a broad spectrum of stakeholders further clarify the criticality of a competent workforce. Interviewees collectively identify a prevailing skill gap within the Ghanaian construction sector, attributing it to the insufficient capacity of training institutions and the emigration of skilled labour. This deficiency is linked to detrimental outcomes, including project delays, escalated costs, and compromised safety standards—issues that significantly impair the quality and sustainability of infrastructure projects. The call for enhanced vocational and technical education tailored to the construction industry's requirements is echoed across discussions. Stakeholders emphasize the necessity of government-led initiatives, in partnership with the private sector, to cultivate workforce development programmes that include scholarships, apprenticeship programmes, and incentives for employee training investments.

Interview findings and literature reviews converge on strategic recommendations aimed at bridging the workforce competency gap. These encompass the enhancement of educational infrastructure to meet industry demands, the implementation of policy reforms to standardize training curriculums, and the promotion of Continuous Professional Development (CPD) for ongoing skill enhancement. Such comprehensive strategies are pivotal for fostering a skilled construction workforce capable of driving the successful advancement of road and highway infrastructure in Ghana. This study's findings underline the necessity of an integrated approach to workforce development, emphasizing the importance of collaboration among all stakeholders to ensure the successful delivery of sustainable and efficient infrastructure projects in Ghana.

6.2.1.4 Social equity and culture

Within the conversation surrounding the construction of sustainable road and highway infrastructure, the importance of "Social equity and culture" becomes evident. This highlights the need to take into account the wider societal effects and cultural sensitivity while planning and carrying out projects. Safety risk assessment and mitigation during construction, improvement of worker's health and safety, reduction of traffic congestion in design and operational phases, and public participation in the early project phase are the indicators.

6.2.1.4.1 Safety risk assessment and mitigation

The quantitative findings of this research emphasize the critical importance of safety risk assessment and mitigation during construction, receiving an average importance score of 4.14 among professionals. This consensus underlines a collective recognition of safety as a foundational component of sustainable road and highway infrastructure development, resonating with the findings of Nawaz et al. (2019), who highlight the integral role of safety practices in enhancing construction project outcomes. Further qualitative insights obtained from semi-structured interviews with industry professionals explain a comprehensive understanding of safety risk assessments and mitigation efforts' pivotal role. The current safety practices, including regular safety audits and safety training workshops, echo the strategies documented in existing literature, advocating for a proactive safety culture in construction sites (Aboutorab et al., 2021; Rivera Domínguez et al., 2023).

Despite the recognized significance of these safety measures, challenges such as a lack of awareness among workers, financial constraints, and the inherently dynamic nature of construction sites emerge as significant barriers. These findings align with the literature that points to similar obstacles in implementing effective safety measures within the construction industry (Asumeng et al., 2015; Donkor et al., 2023). To navigate these challenges, the literature suggests a multifaceted approach encompassing enhanced training, stakeholder engagement, and technological innovations (Ebekozi et al., 2023; Williams et al., 2020). Specifically, the adoption of Safety Management Systems (SMS) and technological solutions like wearable safety devices are highlighted as promising strategies for advancing construction site safety (Aidoo et al., 2023; Boakye Danquah et al., 2022).

Integrating the insights from this research with existing scholarly work, it becomes evident that while there is a strong foundation of safety practices within Ghana's road and highway infrastructure sector, further efforts are required to address the persistent challenges. The recommendations derived from both the qualitative findings and the literature point out the necessity of a holistic and integrated strategy. This strategy should focus on enhancing safety education, fostering collaborative enforcement of safety standards, and leveraging technology to ensure the wellbeing of the workforce and the successful execution of infrastructure projects.

6.2.1.4.2 Worker's health and safety

Based on the results obtained from both quantitative and qualitative assessments pertaining to the enhancement of workers' health and safety in road and highway infrastructure projects in Ghana, it is apparent that there exists a robust consensus throughout the sector on the prioritisation of safety activities. This consensus aligns with the broader context of sustainable development, where worker well-being is a key component. The quantitative results, indicating an average importance score of 4.20 for improving workers' health and safety, feature the industry's commitment to creating safer work environments. This commitment is echoed in literature, emphasizing the need for comprehensive safety protocols (Boadu et al., 2020; Eyiah et al., 2019).

The qualitative phase deepens this understanding by revealing both progress and existing gaps in health and safety practices. Despite advancements, challenges such as insufficient enforcement of safety regulations, lack of training, and a general undervaluation of safety measures were highlighted by industry professionals. This finding calls for a cultural shift within the construction sector, aiming for a greater integration of safety into project lifecycle and management practices, which is supported by recent studies advocating for safety to be considered at every project phase (Aidoo et al., 2023; Kineber et al., 2023). Furthermore, the potential of technology, including wearable devices and drones for enhancing safety protocols, represents a modern approach to augmenting traditional safety measures. This aligns with research by AL-Sahar et al. (2021) and Rane et al. (2023), who suggest that such technologies can offer real-time hazard detection and improve safety outcomes. The call for robust policy reforms and enhanced stakeholder engagement is identified as essential for instilling a safety-centric culture within the construction industry, a stance similarly advocated in the literature (Amponsah-Tawiah & Dartey-Baah, 2011; Boadu et al., 2021).

The consensus across both empirical findings and literature highlights a critical need for a multifaceted approach to enhancing worker health and safety in Ghana's road and highway infrastructure sector. This approach should combine traditional safety practices with innovative technological solutions and be underpinned by strong policy support and a cultural shift towards prioritizing safety at all project stages. Such a comprehensive strategy is essential for ensuring the long-term sustainability of infrastructure projects, aligning with global best practices in construction safety and sustainable development.

6.2.1.4.3 Traffic congestion

Industry professionals recognise the importance of addressing traffic congestion during the design, construction, and operational phases of road and highway projects in Ghana. This is seen as essential for improving sustainable infrastructure development. This stance is quantitatively supported by an average importance score of 4.19, reflecting the industry's cognizance of congestion's broader economic implications, including increased fuel consumption and reduced productivity. The insights drawn from semi-structured interviews with highway construction professionals reinforce the quantitative findings, shedding light on the multifaceted approach required to effectively mitigate traffic congestion. This dual analysis highlights the importance of strategic planning, innovative design, and the adoption of Intelligent Transportation Systems (ITS) as key measures in addressing congestion issues.

Literature on the subject corroborates these findings, highlighting traffic congestion's adverse impacts on travel time, pollution, and economic efficiency (Agyapong & Ojo, 2018; Armah et al., 2010). Innovative design strategies, such as the deployment of ITS and the construction of roundabouts, are recognized for their efficacy in pre-emptively addressing potential congestion points during the design phase (Debrah, 2019; Ukam et al., 2023). Moreover, the construction phase necessitates strategic scheduling and the implementation of temporary traffic control measures to alleviate congestion-related challenges (Makhdomi & Gillani, 2024; Mesic, 2023). Operational strategies aimed at maintaining smooth traffic conditions post-construction include adaptive signal control and the promotion of alternative transportation modes (Abane, 1993; Barajei et al., 2023).

However, the realization of effective congestion mitigation strategies faces several notable challenges, including limited funding, slow technological adoption rates, and the need for comprehensive data to inform both planning and monitoring efforts (Armah et al., 2010; Barajei et al., 2023). These barriers underline the necessity for a concerted effort involving increased infrastructure investment, enhanced capacity building for management agencies, and the fostering of public-private partnerships to facilitate the successful implementation of congestion reduction measures.

The alignment of empirical findings from both qualitative and quantitative analyses with existing literature forms a robust basis for advocating a comprehensive and integrated approach to traffic congestion management in Ghana's road and highway projects. This approach, capturing advanced planning, innovative design, effective construction

management, and dynamic operational strategies, is crucial for overcoming the identified challenges. It requires bolstered investment, improved stakeholder collaboration, and a steadfast commitment to public engagement and education. Ultimately, these concerted efforts lay the foundation for a sustainable and congestion-free road infrastructure future in Ghana, in line with the broader goals of economic efficiency and environmental sustainability.

6.2.1.4.4 Public participation

The recognition of public participation in the early stages of infrastructure development projects as a vital component for sustainable development in Ghana is affirmed by both quantitative and qualitative analyses, scoring an average importance rating of 4.12. This acknowledgment aligns with scholarly discussions emphasizing the significance of stakeholder engagement for ensuring the alignment of projects with community needs and expectations, thus fostering greater project acceptability and sustainability (Ogryzek et al., 2021; Suprayoga, Witte, et al., 2020).

Interviews conducted with a wide range of stakeholders spell out the profound value of public participation. Early engagement is identified as instrumental in discerning and incorporating local needs and preferences, which can mitigate conflicts and enhance project sustainability. Such involvement also facilitates the identification of environmental and social issues that may otherwise remain unaddressed, highlighting the integral role of community input in holistic project planning.

Despite the consensus on its importance, the implementation of effective public participation encounters numerous challenges. Stakeholders report a lack of awareness and understanding among community members, logistical difficulties in organizing inclusive engagement activities, and scepticism regarding the authenticity of participatory processes. Furthermore, the capacity of governmental and project-implementing agencies to manage these processes is often inadequate, attributed to a scarcity of resources or expertise. To surmount these obstacles, stakeholders advocate for enhanced education and awareness campaigns, the development of clear public participation guidelines, capacity building within government agencies and project teams, and the adoption of technology to facilitate broader and more efficient engagement.

Literature corroborates these interview insights, highlighting both the benefits and challenges of public participation. Studies indicate that engaging the public from the project's inception can lead to more acceptable, relevant, and sustainable outcomes

(Arkorful et al., 2021; Masrom et al., 2024). Yet, effective participation is hindered by similar challenges noted in interviews, including limited public awareness, logistical and institutional barriers, and the need for a genuine engagement process (Abas et al., 2023; Adjei Mensah et al., 2017). The literature also supports the implementation of inclusive and adaptable engagement strategies, emphasizing the use of various communication channels for broader stakeholder involvement (Anaafo & Appiah Takyi, 2021; Zakaria et al., 2023).

In conclusion, both empirical findings and academic literature stress the critical role of public participation in the early stages of road and highway infrastructure development in Ghana. Addressing the identified challenges through targeted strategies promises to enhance the effectiveness of public participation, thereby contributing to more inclusive and sustainable infrastructure projects. This alignment between practical insights and scholarly research underlines the necessity of an integrated, stakeholder-centric approach to infrastructure development, reflecting a collective move towards more sustainable and inclusive practices in the sector.

6.2.1.5 Project implementation and management

The successful implementation and management of road and highway infrastructure projects in Ghana are essential in achieving sustainable development and economic growth. There are six indicators in the technical quality category, namely, comply with environmental requirements, contract documents and project specification; Accomplish sustainable policy and strategy to improve construction efficiency; Meeting project duration (completing the project on schedule); Project risk assessment; Approach / Criteria for contractor (e.g., prequalification); and Contractor selection.

6.2.1.5.1 Project compliance

The integration of compliance with environmental requirements, contract documents, and project specifications as a top-rated indicator, with an average score of 4.25, underlines the paramount importance highway professionals place on executing projects responsibly. This aligns with Elsayegh et al. (2020), who emphasize responsible project management's critical role in ensuring transparency, accountability, and adherence to environmental and contractual guidelines. Semi-structured interviews reinforce the universal recognition among Ghana's road and highway infrastructure development stakeholders of compliance as foundational for sustainability, legality, and project quality. This consensus echoes broader discussions in the literature about the necessity of compliance for mitigating

environmental impacts, adhering to standards, and protecting community interests (Mwelu et al., 2020; Willar et al., 2020). The identified challenges, including regulatory complexities and the knowledge gap among smaller contractors, suggest a pressing need for strategic interventions to enhance understanding and capability within the sector.

The advocacy for a multifaceted approach—comprising clearer regulations, comprehensive training programmes, and the integration of technology like Building Information Modeling (BIM) and environmental monitoring tools—proposes actionable solutions to these challenges. This approach is supported by literature that highlights the significance of enhancing regulatory frameworks and enforcement capacity as critical to improving compliance (Amoah & Eweje, 2022; Asah-Kissiedu et al., 2021). Additionally, the literature suggests education, training, and technology as essential tools in deepening the construction industry's understanding of compliance complexities (Asim et al., 2024; Hashim Mohammed et al., 2022; Kheni & Afatsawu, 2022).

This discussion demonstrates a clear alignment between the insights from semi-structured interviews with industry professionals and the existing literature. Both sources advocate for comprehensive strategies that include regulatory reforms, enhanced educational programmes, and technological integration to address the barriers to compliance. These strategies are not only vital for ensuring that projects adhere to environmental and contractual standards but also for fostering sustainable, responsible, and successful infrastructure development in Ghana. The synthesis of professional insights and academic research presents a coherent narrative that emphasizes the critical role of compliance in achieving the broader goals of sustainability and development within the construction sector.

6.2.1.5.2 Sustainable policy and strategy

The emphasis on sustainable policy and strategy formulation, as indicated by an average score of 4.15 from highway professionals, highlights a growing recognition within Ghana's construction sector of the need for comprehensive policies and strategies. This mirrors Ruiz & Guevara (2020), who support the notion that strategic policymaking is essential for guiding decision-making and operational practices across the lifecycle of road and highway projects, ensuring the alignment with sustainability goals. Semi-structured interviews with a broad range of construction sector stakeholders further reinforce this point. There is a unanimous agreement on the necessity of sustainable policies and strategies to address the environmental, social, and economic dimensions of

sustainability, highlighting a keen awareness of the triple bottom line approach within the industry. This consensus, however, is met with challenges such as inter-agency coordination, funding limitations, and a skills gap in sustainable construction practices, suggesting systemic barriers to implementing these policies and strategies effectively.

Strategic solutions such as BIM, advanced materials, and LCA are identified for their potential to enhance construction efficiency and sustainability. The call for policy development and enforcement to mandate sustainable construction practices and encourage public-private partnerships (PPPs) indicates a strategic pathway for leveraging private sector innovation in sustainable infrastructure development.

These findings resonate with literature emphasizing the importance of embedding comprehensive sustainability considerations into construction policies and frameworks (Agyekum et al., 2022; Ekung & Opoku, 2023). The literature also highlights similar challenges, including gaps in regulatory enforcement and a lack of awareness about sustainability practices among stakeholders (Arku et al., 2016; Armah et al., 2011). Addressing these challenges requires a concerted effort to enhance regulatory frameworks, improve enforcement capacities, and invest in education and technology (Bondinuba et al., 2017; Mwelu et al., 2018). Thus, the synthesis of semi-structured interviews and academic literature presents a cohesive narrative on the critical role of sustainable policy and strategy in advancing Ghana's road and highway infrastructure development. It emphasizes the need for innovative solutions, comprehensive policy reform, and collaborative stakeholder engagement as essential steps towards realizing sustainability objectives. This integrated approach aligns with global best practices in sustainable development, pointing to a future where Ghana's infrastructure projects are not only efficient and sustainable but also resilient and responsive to the evolving demands of society and the environment.

6.2.1.5.3 Project duration

The significance of meeting project duration as highlighted by an average score of 4.17 among highway professionals stresses the critical role of timely project delivery in managing construction costs effectively. This consensus reflects an acute awareness within the Ghanaian construction sector of how delays not only inflate project costs through prolonged labour, equipment rental, and other accruing expenses but also jeopardize overall project viability. This recognition is in harmony with the literature that prioritizes timely project delivery as a cornerstone of effective budget management

(Antoniou, 2021; Rivera et al., 2020). Semi-structured interviews with industry stakeholders reveal a complex landscape of challenges that contribute to project delays, including funding issues, material supply disruptions, and bureaucratic barriers in securing necessary permits and approvals. These challenges, echoed by the literature, highlight the multifaceted nature of project implementation in Ghana (Owusu-Manu et al., 2023; Zakaria et al., 2023). The discussions also bring to light the importance of environmental and social impact assessments, vital for sustainable development, yet noted for their capacity to extend project durations if not adeptly managed.

In response, stakeholders emphasize the need for project planning and risk management, incorporating strategies like effective scheduling and the use of modern project management tools such as Building Information Modeling (BIM) to enhance coordination and efficiency. These strategies align with academic perspectives advocating for the application of technology to optimize project timelines (Darko et al., 2017). Moreover, the role of stakeholder collaboration emerges as a critical theme, with the literature supporting the inclusion of all relevant stakeholders, especially local communities, in project planning and execution as crucial for pre-empting and resolving potential delays (Aigbavboa et al., 2024). The call for targeted training programmes for project management personnel to equip them with necessary skills further underlines the importance of building local capacity and expertise in managing complex infrastructure projects efficiently (Fugar & Agyakwah-Baah, 2010). Additionally, policy reforms aimed at simplifying regulatory processes are highlighted as essential steps toward reducing bureaucratic obstacles to timely project completion (Ahinsah-Wobil, 2021).

This synthesis of semi-structured interviews and academic research presents a clear pathway toward addressing the challenges associated with meeting project durations in Ghana. By emphasizing strategic planning, stakeholder collaboration, capacity building, and regulatory reform, the construction industry can navigate the complexities of infrastructure development, ensuring projects are completed on time and within budget. The alignment of these findings with existing literature not only validates the concerns raised by professionals but also offers actionable insights for enhancing the efficiency and effectiveness of road and highway projects in Ghana, contributing to the broader goals of sustainable infrastructure development.

6.2.1.5.4 Project risk assessment

The emphasis on project risk assessment, evidenced by an average score of 4.20, underlines its perceived critical role in ensuring the successful and sustainable execution of road and highway infrastructure projects in Ghana. This consensus among professionals aligns with the findings of El-Sayegh & Mansour (2015), who stressed the importance of comprehensive risk evaluations in the UAE's highway construction projects, highlighting the universal relevance of risk assessment in infrastructure development across different geographic and economic contexts. Semi-structured interviews with industry stakeholders in Ghana reaffirmed the indispensable role of project risk assessment as a fundamental component of proactive project management. Stakeholders highlighted its utility in identifying potential hazards and uncertainties that could impact project outcomes, emphasizing risk assessment as essential for mitigating potential impediments to project success. This perspective resonates with the broader project management literature, which recognizes risk assessment as a critical tool for anticipating and managing project risks, thereby facilitating smoother project execution (Boateng et al., 2022).

However, the implementation of effective project risk assessment in Ghana faces notable challenges, including limited capacity and expertise in applying sophisticated risk assessment methodologies and the dynamic nature of construction projects influenced by fluctuating market conditions and regulatory environments. These challenges mirror those identified in the literature, which cites the absence of a customized risk assessment framework and a skills deficit among professionals as significant barriers to effective risk management (Chileshe & Boadua Yirenkyi-Fianko, 2012; Kong et al., 2018). To address these impediments, the literature and industry insights converge on the necessity for capacity building, regulatory refinement, technological adoption, and comprehensive stakeholder engagement. Developing context-specific risk assessment frameworks and fostering inclusive stakeholder participation are advocated as strategies to achieve a holistic understanding of project risks and develop resilient project outcomes (Akomea-Frimpong et al., 2023; Tengan & Aigbavboa, 2017).

This synthesis of quantitative findings, qualitative insights, and literature review illustrates a clear recognition of the critical role of project risk assessment in the sustainable development of road and highway infrastructure in Ghana. Overcoming the identified challenges through a multifaceted approach that includes strategic planning, regulatory enhancements, and stakeholder collaboration is crucial for advancing risk

management practices. Such efforts are imperative for ensuring the successful and sustainable completion of infrastructure projects, aligning with global best practices in project risk assessment and management.

6.2.1.5.5 Prequalification of Contractor

The prioritization of sustainable and proficient contractor selection processes, as evidenced by an average score of 4.13, highlights the growing emphasis among highway professionals on thorough and transparent prequalification criteria. This focus mirrors a broader industry trend towards enhancing project outcomes through contractor vetting, emphasizing sustainability and technical excellence. This quantitative finding resonates with existing literature, suggesting a sector-wide shift towards more strategic, inclusive, and technology-driven selection methods (Acheamfour et al., 2023; Osman & Liu, 2023). Semi-structured interviews reveal a unanimous agreement among industry stakeholders on the paramount importance of stringent contractor selection criteria. The comprehensive prequalification process is deemed essential for evaluating contractors' capabilities, thus ensuring that only those with proven financial stability, technical proficiency, and a solid project track record are engaged. This approach is aligned with the objectives of minimizing project risks and enhancing quality assurance, reflecting a strategic move towards securing project success and sustainability.

Despite the consensus on the value of rigorous contractor selection, stakeholders identify several challenges, including the subjectivity of evaluation criteria, potential biases, and the complexities associated with detailed prequalification procedures. To overcome these difficulties, there's a strong advocacy for standardized prequalification frameworks, the use of technology for transparency, and solid regulatory frameworks to enforce best practices. The engagement of industry associations in developing contractor selection criteria further emphasizes the need for a unified approach to ensure industry-wide adherence to high standards (Ampratwum et al., 2023; Boadu, 2022).

The literature supports these insights, highlighting similar challenges and proposing solutions that echo the recommendations from the interviews. The call for more inclusive and transparent selection processes, enhanced by digital platforms and decision-support systems, reflects a collective drive towards improving the prequalification process's efficiency. This suggests a convergence between professional insights and scholarly recommendations on the necessity of evolving contractor selection practices to

accommodate the dynamic demands of infrastructure development (Acheamfour et al., 2023; Osman & Liu, 2023).

The findings from both the quantitative analysis and qualitative interviews, reinforced by the literature review, underline a clear understanding of the critical role that contractor selection plays in the success and sustainability of road and highway projects. Addressing the identified challenges through strategic, technology-enhanced, and regulatory-supported approaches is crucial for advancing contractor selection practices. This collective effort is essential for fostering construction efficiency, project success, and sustainability in Ghana's road and highway infrastructure sector, aligning with global best practices and addressing the evolving needs of the construction industry.

6.2.1.5.6 Contractor selection

The prioritization of comprehensive contractor selection procedures, as evidenced by an average score of 4.13, reflects an industry-wide recognition of the need for a thorough approach in ensuring that contractors adhere to high standards of sustainability and technical proficiency. This quantitative finding underlines the sector's commitment to fostering transparency, fairness, and efficiency in the contractor selection process, a perspective that aligns with current research highlighting the necessity for advanced evaluation methodologies. The qualitative insights gained from semi-structured interviews clarify the critical importance stakeholders place on the contractor selection process. The emphasis on employing a mix of qualitative and quantitative assessment techniques mirrors strategies like the Balanced Scorecard and Multi-Criteria Decision Making (MCDM), particularly the Analytic Hierarchy Process (AHP). These methodologies facilitate a comprehensive evaluation of contractors' capabilities, incorporating both financial stability and qualitative attributes such as safety and environmental compliance records (Kusi-Sarpong et al., 2016; Simpson & Aboagye-Otchere, 2014).

Despite the consensus on the value of stringent selection criteria, the discussions also unveil significant barriers, including subjective assessment criteria, the lack of a unified selection framework, and challenges faced by smaller contractors in competing against larger entities. These findings echo with literature identifying transparency issues, biases, and the complexities of adapting selection processes to dynamic construction markets as ongoing challenges (Afolayan et al., 2020; Ayettey & Danso, 2018). To address these challenges, the interviews and literature suggest a multifaceted strategy encompassing

regulatory reforms, procedural standardization, and the adoption of innovative evaluation methodologies. The call for a more inclusive and transparent selection process highlights the necessity of integrating decision-support tools and technologies to enhance the fairness and efficiency of the contractor selection process.

This convergence of professional insights and academic literature on the need for reform in the contractor selection process signifies a critical step towards improving project outcomes. By advocating for the application of sophisticated evaluation methodologies and emphasizing the importance of regulatory and cultural shifts within the industry, the findings offer a clear pathway towards enhancing the quality, efficiency, and sustainability of infrastructure projects in Ghana. This integrated effort to refine the contractor selection framework aligns with global best practices and addresses the evolving demands of the construction industry, ensuring that infrastructure development is carried out by contractors who meet the highest standards of performance and responsibility.

6.2.1.6 Resource utilization and management

Resource utilization and management is a pivotal criterion in the sustainable development of road and highway infrastructure, particularly in developing countries like Ghana. Efficient resource management not only ensures the economic viability of infrastructure projects but also contributes to environmental sustainability and social welfare. There are four indicators in the resource utilization and management category, namely, supply chains, local materials, material quality control and assurance, recycled construction materials.

6.2.1.6.1 Supply chain.

The critical importance of integrating supply chain management (SCM) in the development of road and highway infrastructure in Ghana is highlighted by both quantitative scores and qualitative insights from industry stakeholders. The average rating of 4.12 highlights the collective acknowledgment among professionals of SCM's role in enhancing project efficiency, reducing costs, and ensuring timely project completions. This sentiment is in line with Prakash & Mohanty (2015), who advocate for the significance of SCM in reducing transportation costs and optimizing project timelines, thereby contributing to the sustainability and efficiency of infrastructure development. Semi-structured interviews reveal a consensus on the necessity of a unified supply chain as foundational to achieving timely and cost-efficient project outcomes. Effective

material flow is identified as vital for avoiding project delays and reducing construction costs. Yet, stakeholders report varying success levels in SCM integration across projects, with some facing significant challenges that detract from supply chain efficiency.

These challenges, including poor road infrastructure, unreliable transportation services, inconsistent supplier performance, and the underutilization of SCM technologies, mirror the issues identified in the literature. Orgen et al. (2011) and Osunsanmi et al. (2022) emphasize the importance of SCM in construction efficiency, noting similar obstacles such as coordination difficulties and a lack of advanced SCM technologies. The literature suggests that overcoming these barriers requires an IT integration, strategic partnerships, and the adoption of SCM practices tailored to the construction sector. The proposed solutions from interviews, focusing on logistical improvements, enhancing supplier relations, fostering collaboration among supply chain actors, and leveraging SCM technologies, align with strategies identified in academic research. Agyabeng-Mensah et al. (2020) and (Hussein et al., 2021) advocate for a comprehensive approach to address SCM challenges, highlighting the need for technological adoption, improved collaboration, and policy support to facilitate efficient and sustainable project execution.

This synthesis of professional insights and literature underlines the critical path towards achieving efficiency and sustainability in Ghana's road and highway projects through innovative solutions, policy reform, and collaborative stakeholder engagement. The acknowledgment of SCM's significance, coupled with the strategic recommendations outlined, provides a coherent framework for addressing the identified challenges and harnessing the full potential of SCM in improving the construction sector's overall success and sustainability.

6.2.1.6.2 Local materials

The emphasis on using local materials in the construction of road and highway infrastructure in Ghana, as revealed through both quantitative scores and qualitative insights, highlights a significant stride towards sustainable development. An average score of 4.14 reflects a growing acknowledgment among professionals of the benefits associated with local material usage, including economic development, job creation, and environmental sustainability. Semi-structured interviews with industry stakeholders clarify the advantages of incorporating local materials into construction projects, such as reduced transportation costs, lower carbon emissions, and the bolstering of local industries. This approach aligns with global sustainability goals and advocates for a

circular economy within the construction sector. However, challenges like variability in material quality, lack of standardized testing, and scepticism towards the durability of local materials compared to imported ones are highlighted as obstacles to broader adoption. These findings resonate with existing literature, which emphasizes the dual benefits of using local materials in terms of economic and environmental sustainability. Studies have shown that local materials can significantly reduce the overall carbon footprint of construction projects by minimizing the distance materials need to be transported (Lokko et al., 2024). Moreover, supporting local industries can lead to economic growth and job creation within the community (Mensah & Laryea, 2023).

Addressing the challenges identified requires a multi-faceted strategy, including the development of rigorous standards and certification processes for local materials. This ensures quality and reliability, making these materials more competitive. Investment in research and development to enhance the quality and applicability of local materials is crucial, potentially leading to innovation that surpasses imported alternatives (Dansoh et al., 2017). Education and awareness programmes are essential to shift industry perceptions and highlight the benefits of using local materials, fostering broader adoption (Tunji-Olayeni et al., 2023). Moreover, strengthening local material supply chains through policy incentives and capacity-building efforts is critical for ensuring their availability and cost-effectiveness. Such measures can build robust networks capable of supporting large-scale projects (Kusi-Sarpong et al., 2016).

In conclusion, the integration of local materials in Ghana's road and highway infrastructure projects is recognized as an essential component of sustainable and economic development. Overcoming the challenges to their broader adoption involves standardizing quality assurance processes, enhancing research and development, educating industry professionals, and strengthening local supply chains. This comprehensive approach can pave the way for infrastructure projects that are sustainable, cost-effective, and supportive of local economies, thereby aligning with the principles of environmental conservation and sustainable development (Dansoh et al., 2017; Kusi-Sarpong et al., 2016; Lokko et al., 2024; Mensah & Laryea, 2023; Tunji-Olayeni et al., 2023).

6.2.1.6.3 *Material quality control and assurance*

The prioritization of material quality control and assurance in road and highway infrastructure development, as highlighted by an average score of 4.16 from industry

professionals, underlines its essential role in ensuring the sustainability, longevity, and safety of projects. This emphasis on rigorous material testing and adherence to standards resonates with the broader discourse within the field, indicating a universal understanding of the critical importance of maintaining high-quality materials throughout the project lifecycle. The consensus reached through interviews with industry stakeholders reinforces the significance of implementing standardized testing practices for key construction materials like asphalt, concrete, and aggregates. These practices are instrumental in achieving compliance with both national and international construction standards, thereby ensuring the structural integrity and durability of infrastructure projects. However, challenges such as variability in material quality, compliance issues with suppliers, and limitations in current testing infrastructure are identified as significant barriers to achieving desired quality levels. These challenges align with the literature, which also identifies variability in local material quality and limitations in testing capabilities as common obstacles to maintaining consistent material quality (Bentum Mensah et al., 2023; Willar et al., 2023).

To overcome these obstacles, stakeholders advocate for a multifaceted approach that includes enhancing testing infrastructure through investment in advanced technologies, fostering robust partnerships among project stakeholders, and emphasizing the need for regulatory oversight to enforce quality standards. This approach is supported by the literature, which underlines the necessity of improving testing infrastructure and the benefits of technological adoption, such as Building Information Modeling (BIM), in enhancing material tracking and quality assurance processes (Simeon et al., 2024; Yuan et al., 2024). Moreover, the importance of continuous education and professional development is highlighted as essential for ensuring that industry professionals remain informed about the latest material quality standards and testing techniques. This emphasis on education and training is critical for elevating the sector's overall quality assurance practices and aligns with the literature's advocacy for ongoing professional development (Bekele et al., 2024).

In conclusion, both the quantitative findings and qualitative insights from interviews, along with the supporting literature, articulate a clear consensus on the necessity of stringent material quality control and assurance measures in the construction of road and highway infrastructure. The challenges identified necessitate strategic interventions, including infrastructural investments, stakeholder collaboration, regulatory reforms, and a commitment to professional development. By addressing these challenges through a

comprehensive strategy, the construction industry in Ghana can enhance its efficiency and successfully deliver high-quality infrastructure projects that meet sustainable development goals. This integrated approach aligns with existing literature and presents a coherent framework for advancing construction practices that prioritize material quality control and assurance.

6.2.1.6.4 Recycle construction materials.

The quantitative finding that the "use of recycled construction materials" received an average score of 4.14 from highway professionals reflects a burgeoning commitment to environmental sustainability within the sector. This acknowledgment aligns with a broader industry trend towards resource conservation, waste reduction, and environmental protection, echoing the sustainable construction goals emphasized by researchers like Segui et al. (2023). The qualitative insights gained from semi-structured interviews corroborate this quantitative data, revealing a consensus among stakeholders on the significant potential benefits of incorporating recycled materials in road and highway infrastructure projects in Ghana. Despite the recognized advantages, the qualitative findings highlight several substantial challenges to the broader adoption of recycled materials, including concerns over material quality and performance, the absence of regulatory guidelines, limited availability, and a lack of industry-wide awareness and understanding. These concerns mirror the obstacles identified in the literature, with Abdulai et al. (2024) and Agyekum & Amudjie (2024) underlining the critical need for clear regulatory frameworks and standards, alongside enhanced awareness and education within the construction industry, to facilitate the integration of recycled materials into construction practices.

To overcome these barriers, stakeholders suggest a multi-faceted strategy that includes the development of explicit standards and regulations, investment in research and development, strengthening of supply chains, and the implementation of targeted education and training programs. These recommendations are in line with the strategies proposed by Darko & Chan (2018) and Tecchio et al. (2017), who advocate for comprehensive approaches to improve the quality, regulatory support, and market readiness for recycled materials. By addressing these challenges through targeted interventions, the construction industry in Ghana can move towards more sustainable practices that not only contribute to environmental conservation but also enhance the efficiency and cost-effectiveness of infrastructure projects.

The consensus on the potential benefits of recycled construction materials, tempered by realistic concerns regarding their implementation, highlights the complexity of integrating these materials into Ghana's road and highway infrastructure sector. The collective insights from both quantitative and qualitative findings, supported by existing literature, highlight the need for strategic, coordinated efforts to address the identified challenges. This integrated approach, focusing on standardization, research, education, and collaboration, is pivotal for advancing sustainable construction practices in Ghana. By navigating these challenges successfully, the sector can leverage recycled materials to achieve a balance between environmental sustainability and economic efficiency, aligning with global best practices and contributing to the broader goals of sustainable development.

6.3 Conceptual Model of Sustainability Indicators

The extensive survey conducted within this research underlines a strong consensus among participants on the importance of various sustainability indicators, distributed across six distinct criteria, for advancing sustainable practices in road and highway infrastructure development. This acknowledgment emphasizes the necessity of incorporating these indicators comprehensively into the decision-making framework to foster sustainability in infrastructure projects.

The exploration and analysis of these 29 critical sustainability indicators reveal their individual and collective contributions toward achieving a more sustainable infrastructure framework. Each factor, ranging from environmental conservation efforts to community engagement and economic viability, plays a unique role in the broader context of sustainability. This in-depth understanding facilitates the crafting of targeted, effective strategies that cater to the multifaceted nature of sustainability within infrastructure development.

To interpret the interconnectedness and significance of these indicators, a conceptual model was developed. This model, depicted in Figure 19, serves as a visual representation of how each sustainability indicator contributes to the overarching goal of sustainable development. It highlights the logical relationships between the factors and the foundational sustainability pillars—environmental protection, social equity, economic growth, institutional, and managerial—thereby offering a comprehensive roadmap for integrating sustainability into road and highway infrastructure projects.

The model aims to guide stakeholders, from policymakers to engineers and contractors, in identifying and prioritizing sustainability initiatives. By outlining the pathways through which each indicator impacts sustainability, the model facilitates a more structured approach to sustainable infrastructure development, ensuring that all dimensions of sustainability are addressed. This holistic perspective is critical for the successful implementation of sustainable road and highway projects that not only meet current needs but are also resilient and adaptable to future challenges.

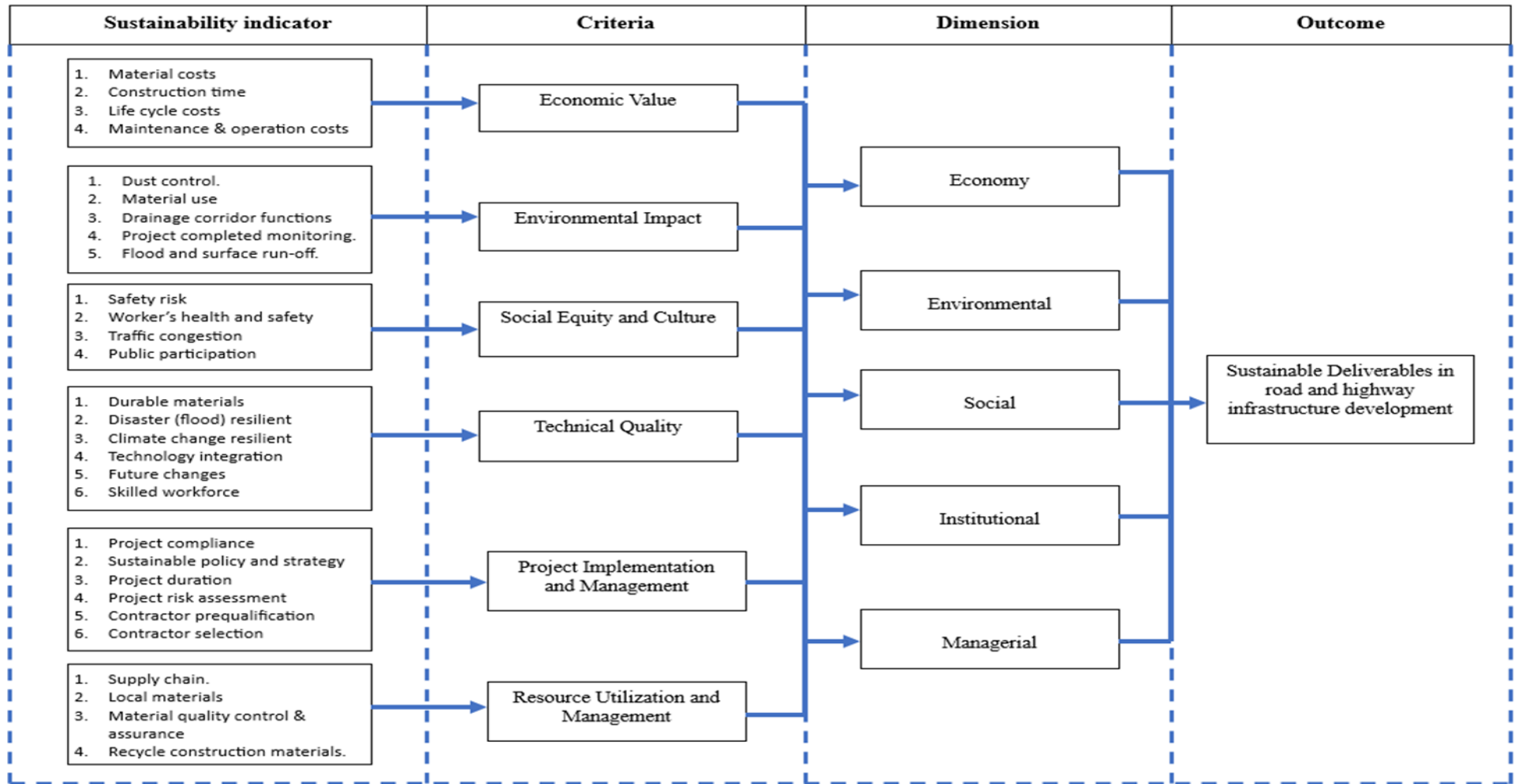


Figure 19: Conceptual model for decision-making.

6.4 Recommended roadmap for translating results into industry practice

The successful implementation of the sustainability framework for road and highway infrastructure development in Ghana requires a structured three-phase approach as depicted in figure 20:

Phase 1: Foundation Building (0-12 months)

1. Policy Development
 - Establish regulatory frameworks aligned with research findings
 - Create implementation guidelines based on the 29 sustainability indicators
 - Define stakeholder roles and responsibilities
2. Industry Awareness
 - Launch targeted awareness programs
 - Organize stakeholder workshops
 - Demonstrate cost-benefit analyses of sustainable practices
3. Capacity Building
 - Develop training modules based on identified action plans
 - Establish partnerships with educational institutions
 - Create technical guidance documents

Phase 2: Implementation (12-24 months)

1. Project Integration
 - Incorporate sustainability indicators into bidding documents
 - Develop assessment checklists and performance metrics
 - Establish monitoring protocols
2. Tool Development
 - Create practical assessment tools
 - Develop digital platforms for sustainability tracking
3. Training Programs
 - Implement professional development programs
 - Establish sustainability certification
 - Create specialized stakeholder training

Phase 3: Institutionalization (24-36 months)

1. Performance Monitoring
 - Establish KPIs and evaluation frameworks
 - Implement regular auditing processes
 - Create feedback mechanisms
2. Industry-wide Adoption
 - Develop incentive programs
 - Establish sustainability benchmarks
 - Create recognition programs

Key Constraints and Mitigation Strategies:

1. Constraints
 - Limited regulatory support
 - Resource constraints
 - Technical knowledge gaps
 - Cost implications
 - Resistance to change
2. Mitigation Measures
 - Public-private partnerships
 - Phased implementation approach
 - Industry-academia collaboration
 - Pilot project demonstrations
 - Regular audits and assessments

This roadmap provides a strategic pathway for translating theoretical findings into practical industry application while addressing potential implementation challenges.

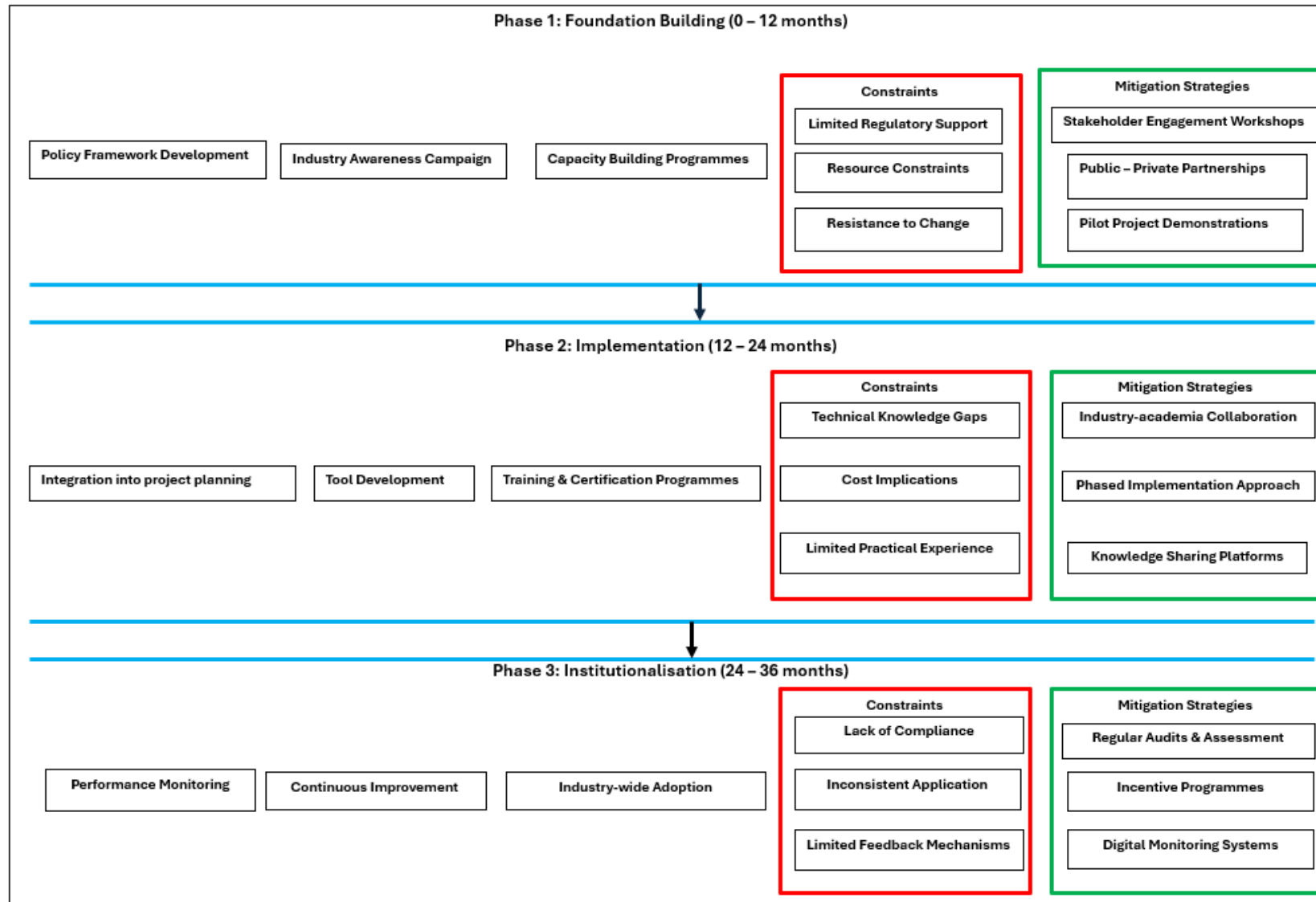


Figure 20: Recommended Roadmap for translating results into industry practice

6.5 SWOT Analysis

In the field of road and highway infrastructure development, the use of SWOT analysis offers a strategic methodology for comprehending and improving the outcomes of projects. Originating from the field of business management, SWOT analysis offers a robust framework for dissecting the internal and external factors influencing a project's success (Cheng et al., 2023; Hosseini Dehshiri et al., 2024). This methodology highlights the necessity of identifying a project's strengths, weaknesses, opportunities, and threats, facilitating informed decision-making from the outset. Within the strategic management process, SWOT analysis serves as a cornerstone, enabling decision-makers to uncover critical facts influenced by both positive and negative perceptions of a project.

The analysis of internal factors aims to emphasize a project's strengths and weaknesses, while external factors assist in recognising potential opportunities and threats (Kamran et al., 2020). Achieving consensus among stakeholders with varied expertise and interests is crucial for enhancing sustainable outcomes in infrastructure projects. Numerous scientific studies have demonstrated the versatility of SWOT analysis by applying it to address distinct research problems. Behzadifar et al. (2023) highlight its utility in the development of health technology assessment and the development of national innovation systems, particularly in emerging economies. Similarly, SWOT analysis has been instrumental in evaluating innovation systems (Awuzie et al., 2021), developing strategic usage of BIM technology in construction (Zima et al., 2020), and understanding the conduct of strategic planning in the construction industry (Lu, 2010).

This research conducted a thorough SWOT analysis for each identified sustainability indicator in road and highway infrastructure development. Through semi-structured interviews, stakeholders provided deep insights, allowing for a comprehensive evaluation of each indicator's internal and external dimensions. The analysis not only identifies strengths, weaknesses, opportunities, and threats but also formulates action plans to leverage these insights for sustainability enhancement. This strategic framework reveals the internal and external conditions impacting each critical sustainability indicator, offering a decision-making blueprint that includes action plans for sustainability improvement. Such a framework becomes an integral part of project briefing documents, guiding project managers and contractors in optimising road and highway infrastructure projects for sustainability while also considering the broader stakeholder landscape.

The findings from SWOT analysis, explaining strengths, weaknesses, opportunities, and threats, facilitate an in-depth understanding of factors influencing sustainability in infrastructure development. To utilise the strengths and address weaknesses by assessing internal indicators, strategies were devised effectively. Simultaneously, external indicators enable the formulation of strategies to seize opportunities and mitigate threats, ultimately fostering a more sustainable approach to road and highway infrastructure development.

In essence, SWOT analysis emerges as a vital tool in this research, equipping project managers with the insights needed to navigate the complexities of sustainability in infrastructure projects. Comprehensive analysis of internal and external factors enables the development of actionable strategies to enhance sustainability, demonstrating a commitment to informed and strategic decision-making in the development of road and highway infrastructure.

6.5.1 Sustainability potential in highway infrastructure development

In this study, it was unanimously agreed among the interview participants that the identified sustainability indicators from the quantitative phase are crucial for enhancing sustainability in the development of road and highway infrastructure. Moreover, they validated the interrelationships and distribution among these critical indicators as being effective in facilitating the integration of sustainability into the decision-making process.

Participants highlighted the importance of managing sustainability potentials to capitalize on opportunities within road and highway infrastructure projects. They argued that with careful consideration and strategic selection, the application of sustainable practices could significantly improve construction efficiency and contribute to the overarching sustainability goals encompassing economic, environmental, social, institutional, and managerial pillars. The guidelines proposed in this study were well-received by participants in the semi-structured interviews, indicating their effectiveness and practical applicability. An in-depth exploration of sustainability potential revealed additional benefits for all stakeholders involved in road and highway projects, including project managers, consultants, government authorities, contractors, and other stakeholders. This approach is poised to transform perceptions of sustainability in infrastructure development, addressing the current gap in project-level sustainability implementation and highlighting the need for increased awareness of its advantages.

Although the critical importance of sustainability is widely acknowledged among key stakeholders in infrastructure development, there exists a hesitancy to fully integrate sustainable practices, often due to concerns over potential additional costs. This study puts forth recommendations aimed at shifting stakeholder behaviour and enhancing their willingness to pursue sustainability through the use of economic incentives, highlighting the tangible and intangible benefits of sustainability as critical indicators in selecting construction methodologies. The guidelines developed through this research assist project managers in focusing on critical sustainability elements within both the physical and social spheres of infrastructure projects, facilitating the selection of suitable materials and components, and enabling the creation of economically viable design solutions. This study stresses the capacity to incorporate sustainability principles into the structure of road and highway infrastructure development, demonstrating a viable pathway for embedding these principles across the project lifecycle.

6.5.2 Decision Guidelines for road and highway infrastructure development

This document presents a comprehensive strategic framework for integrating sustainability principles into the various stages of road and highway infrastructure projects, including planning, design, and implementation. Central to this framework are guidelines developed from a synthesis of empirical research findings, including a detailed SWOT analysis of 29 identified critical sustainability factors. This analytical foundation informs a series of recommendations and actionable strategies aimed at embedding sustainability throughout the infrastructure development lifecycle.

The essence of these guidelines is to offer a structured decision-making tool for industry stakeholders, enabling them to navigate the complexities of sustainable infrastructure development effectively. It highlights the importance of leveraging sustainability potentials to optimize the environmental, social, economic, institutional and managerial benefits of road and highway projects. Key to this process is the active involvement and collaboration of all stakeholders, whose insights and expertise enrich the SWOT analysis and ensure the guidelines are tailored to meet specific project needs. A distinctive feature of this approach is its emphasis on the balanced consideration of internal and external factors influencing sustainability. By examining both the strengths and weaknesses (internal factors) and the opportunities and threats (external factors) associated with sustainability, stakeholders can develop a holistic understanding of the project landscape. This comprehensive perspective facilitates informed decision-making, allowing project teams to prioritize sustainability while addressing potential challenges effectively.

Feedback from a broad spectrum of stakeholders, obtained through questionnaires and interviews, has been instrumental in refining these guidelines. This iterative process of validation and integration of stakeholder feedback ensures that the guidelines are not only grounded in research but also resonate with industry practices and expectations. Presented systematically, the guidelines articulate a path forward for embedding sustainability in road and highway infrastructure projects. They provide a blueprint for managing sustainability potentials, analyzing sustainability impacts, and maximizing the strategic benefits of sustainable practices. By fostering a shared commitment among stakeholders to sustainability principles, this guideline aims to enhance the quality, efficiency, and resilience of infrastructure development, contributing to a sustainable and prosperous future. The guidelines follow.

Table 50: SWOT Framework: Material Cost

Internal		External
Positive (+)	<p>Strengths</p> <p>Indicates long-term value for money. Informs material selection during planning and design.</p>	<p>Opportunities</p> <p>Design principle seeks to balance material cost with functionality. Every contractor considers material costs when undertaking a project.</p>
Negative (-)	<p>Weaknesses</p> <p>Lack of local materials in close proximity. Contractors may prioritize profit over proximity, leading to higher costs. Overly rigid adherence to specifications leads to rejection of improvable materials. Lack of consideration for material availability and suitability in planning. Lack of alternative materials</p>	<p>Threats</p> <p>Inflation poses a threat to material costs. Local community or landowner involvement can influence costs. Transportation costs and importing materials add to overall costs.</p>
<p>Recommendations: actions towards sustainability</p> <ul style="list-style-type: none"> i. Collaboration and Communication ii. Sustainable Material Innovation iii. Local Sourcing and Community Engagement iv. Procurement and Contractual Measures v. Flexibility and Continuous Improvement vi. Economic Considerations and Budget Management 		

Context

The assessment of material costs holds significant importance in the context of sustainable development of road and highway infrastructure due to many different reasons. Managing material costs in sustainable road and highway infrastructure projects presents challenges, but it also offers opportunities for innovation and long-term savings. A comprehensive approach, considering the full lifecycle of the infrastructure and leveraging policy support, can enhance the economic, environmental, and social sustainability of these critical projects.

Actions and Deliverables

1. Collaboration and Communication:
 - Strengthening partnerships between designers, material experts, contractors, and suppliers.
 - Encouraging effective communication channels throughout the construction process.
2. Sustainable Material Innovation:
 - Promoting the adoption of innovative and sustainable materials.
 - Encouraging designers to balance functionality with cost-effectiveness in material choices.
3. Local Sourcing and Community Engagement:
 - Investigating and utilizing local materials to reduce environmental impact.
 - Engaging with local communities and industries for sustainable sourcing.
4. Procurement and Contractual Measures:
 - Developing procurement guidelines prioritizing local materials.
 - Incorporating penalties in contracts to discourage non-compliance.
 - Considering long-term contracts or partnerships to mitigate inflation effects.
5. Flexibility and Continuous Improvement:
 - Reviewing and updating material specifications for flexibility and innovation.
 - Establishing a continuous improvement process based on feedback from experts and contractors.
6. Economic Considerations and Budget Management:
 - Factoring potential inflation into project contracts and budgets.
 - Monitoring economic indicators regularly and adjusting project budgets accordingly.

Table 51: SWOT Framework: Construction time

Internal		External
Positive (+)	<p>Strengths</p> <p>Timely completion controls costs Timely delivery satisfies the needs of the people.</p>	<p>Opportunities</p> <p>Improved project planning enhances construction time efficiency.</p>
Negative (-)	<p>Weaknesses</p> <p>Lack of equipment and technical know-how lead to project stoppages. Inadequate personnel on the contractor's side. Challenges with unclear project designs. Issues with contractor qualifications and on-site efficiency. Poor planning as a major factor affecting construction time.</p>	<p>Threats</p> <p>Political influences can affect construction timelines. Lack of government interest can lead to project delays. Adverse weather conditions can limit construction activities. Community resistance, especially regarding relocations. Cash flow disruptions and difficulties accessing bank support. Encroachment and compensation issues. Delayed release of funds for project payments by government. Limited availability of materials. Variations or changes introduced by stakeholders causing delays.</p>
<p>Recommendations: actions towards sustainability</p> <ol style="list-style-type: none"> i. Project Management Optimization ii. Workforce Development and Training iii. Stakeholder Engagement and Relationship Management iv. Financial Planning and Resource Allocation v. Risk Mitigation and Project Preparedness 		

Context

Effective time management is a fundamental aspect in the development of sustainable road and highway infrastructure. It demands a holistic approach that encompasses careful planning, technological innovation, and collaborative practices. By prioritizing efficient construction time management, project stakeholders can significantly contribute to the economic, environmental, and social sustainability of infrastructure projects, ultimately fostering a balance between development needs and sustainability objectives.

Actions and Deliverables

1. Project Management Optimization:
 - Strengthening project management practices.

- Implementing advanced planning tools and technologies.
 - Establishing a robust project management framework.
2. Workforce Development and Training:
 - Providing training programs for construction teams.
 - Developing recruitment and retention strategies.
 - Collaborating with educational institutions to address skills gaps.
 3. Stakeholder Engagement and Relationship Management:
 - Minimizing political interference by engaging with authorities.
 - Undertaking thorough community engagement.
 - Ensuring transparent communication between government, road agencies, and contractors.
 4. Financial Planning and Resource Allocation:
 - Securing necessary funds before project commencement.
 - Advocating for streamlined fund release processes.
 - Monitoring material supply chains for potential delays.
 5. Risk Mitigation and Project Preparedness:
 - Undertaking comprehensive feasibility studies.
 - Ensuring contractors have appropriate tools and equipment.
 - Clearly defining right of way acquisition and compensation processes.

Table 52: SWOT Framework: Life cycle costs

	Internal	External
Positive (+)	<p>Strengths</p> <p>Provides value for money. Ensures economic sustainability. Reduces total project cost. Long-term benefits</p>	<p>Opportunities</p> <p>Advocacy for life cycle cost analysis of projects exists.</p>
Negative (-)	<p>Weaknesses</p> <p>Lack of skills and knowledge in life cycle cost analysis Lack of commitment to the maintenance and operational stages of the project Lack of technological competence Focus of highway professionals is mostly on implementation phase. Lack of up-to-date data for analysis</p>	<p>Threats</p> <p>Professionals do not get enough time for thorough project preparations. Economic instability (Inflation) Lack of stakeholder /community acceptance Political influences Budgetary constraints</p>

Recommendations: actions towards sustainability

- i. Capacity Building and Education
- ii. Stakeholder Collaboration and Advocacy
- iii. Technological Advancements and Competence
- iv. Project Planning and Risk Mitigation
- v. Data Collection and Transparency

Context

Life cycle costs (LCC) are a crucial measure in the construction of sustainable road and highway infrastructure. They offer a thorough evaluation of the whole expenses related to a project from its inception to its completion. This approach not only captures initial construction expenses but also factors in maintenance, operation, rehabilitation, and eventual dismantlement costs, offering a holistic view of economic sustainability.

Actions and Deliverables

1. Capacity Building and Education:
 - Developing educational materials and programs.
 - Comprehensive training programs for professionals.
 - Integration of life cycle cost analysis in educational curricula.
2. Stakeholder Collaboration and Advocacy:
 - Collaborating with transport-economic experts.
 - Engaging government authorities, industry associations, and educational institutions.
 - Leveraging existing advocacy initiatives.
 - Public engagement strategies to educate and involve stakeholders.
3. Technological Advancements and Competence:
 - Investing in technological/software upgrades.
 - Collaboration with technology providers.
 - Hands-on training for professionals.
 - Integration of user-friendly tools into project management systems.
4. Project Planning and Risk Mitigation:
 - Advocating for realistic project timelines.
 - Developing strategies to mitigate risks.
 - Incorporating flexibility in project budgets.
5. Data Collection and Transparency:

- Establishing protocols and systems for data collection.
- Collaborating with relevant agencies for a centralized database.
- Ensuring transparency in decision-making processes.

Table 53: SWOT Framework: Maintenance and operation costs

Internal		External
Positive (+)	<p>Strengths</p> <p>Maintenance ensures terminal year attainment. Contributes to the design life of the project. Reduces vehicle operating cost. Reduces life cycle cost.</p>	<p>Opportunities</p> <p>Road fund concept for maintenance Improvement in road fund administration</p>
Negative (-)	<p>Weaknesses</p> <p>Weak enforcement of vehicle weight regulations Lack of emphasis on maintenance Insufficient quality control Lack of technical equipment and expertise Inadequate database of infrastructure Lack of assessment of life cycle costs Deferring maintenance activities Lack of proper supervision and adherence to standards</p>	<p>Threats</p> <p>Misuse of road funds by authorities Limited funds for maintenance Absence of dedicated working road fund for maintenance Governments much interested in road construction but not their maintenance.</p>
<p>Recommendations: actions towards sustainability</p> <p>i. Infrastructure Maintenance and Sustainability</p> <p>ii. Financial Management and Accountability</p> <p>iii. Stakeholder Engagement, Education and Technology integration</p> <p>iv. Quality Control and Standards</p> <p>v. Economic and Social Impact of Maintenance</p>		

Context

The management of maintenance and operation costs plays a crucial role in determining the long-term sustainability, environmental effect, and social acceptability of road and highway infrastructure projects. Their careful consideration and management ensure that projects are economically viable, environmentally responsible, and socially beneficial over their entire lifecycle, supporting the overarching objectives of sustainability.

Actions and Deliverables

1. Infrastructure Maintenance and Sustainability:
 - Proactive maintenance programs.
 - Life cycle cost analysis.

- Funding models and special maintenance funds.
2. Financial Management and Accountability:
 - Advocating for a road maintenance fund.
 - Transparency in fund administration.
 - Accountability measures and audits.
 3. Stakeholder Engagement, Education and Technology integration:
 - Engaging stakeholders and policymakers.
 - Raising awareness on the benefits of maintenance.
 - Collaborating with educational institutions for maintenance education.
 - Predictive maintenance technologies.
 - Technologically advanced tools for fund tracking.
 - Modern maintenance equipment and training programs.
 4. Quality Control and Standards:
 - Training programs for quality control personnel.
 - Rigorous assessment and testing protocols.
 - Strict maintenance schedules and adherence to standards.
 5. Economic and Social Impact of Maintenance:
 - Incorporating life cycle cost assessments into decision-making.
 - Presenting evidence-based cases on long-term benefits.
 - Collaborating with government institutions for prioritizing funding.

Table 54: SWOT Framework: Dust control

		Internal	External
Positive (+)		Strengths Reduces health impacts of construction related dust on communities. Creates sustainable environment. Construction periods are usually exceeded.	Opportunities Dust control is specified in contract documents. There exist regulatory bodies for monitoring the environment. Contractors are paid to control dust. There have been exploration of advancements and technologies for dust control.
Negative (-)		Weaknesses Contractors having limited funds. Unwillingness to comply and neglect by contractors.	Threats Lack of monitoring organizations for on-site hazards Irregular payment affecting work progress and dust control.

	Monitoring institutions lacking the necessary resources. Need for research on materials reducing dust emissions. Abandonment of sites due to non-payment and incomplete roads Weak enforcement by supervisors Contractors' knowledge gap and lack of appreciation Water unavailability	Lack of stipulated consequences and penalties for non-compliance in the regulations
Recommendations: actions towards sustainability		
i. Research and capacity building. ii. Regulatory Compliance and Enforcement iii. Financial Management in Construction		

Context

Dust control is a crucial indicator in the sustainability of road and highway infrastructure development. It encompasses strategies aimed at minimizing the dispersion of dust particles during construction and operational phases, which is essential for environmental protection, public health, and the longevity of the infrastructure. It addresses key environmental and health concerns, ensures regulatory compliance, and contributes to the social acceptability and longevity of infrastructure projects. Effective dust management is thus integral to achieving the broader goals of sustainable development in infrastructure projects.

Actions and Deliverables

1. Research and capacity building:
 - Research initiatives on dust control materials.
 - Incentives for eco-friendly practices.
 - Performance metrics for evaluating sustainability.
 - Training and workshop to build supervisors to act.
2. Regulatory Compliance and Enforcement:
 - Clauses enforcing penalties for neglect in construction projects.
 - Strict penalties for non-compliance with dust control regulations.
 - Regular checks and balances for effective implementation.
 - Resource allocation to monitoring authorities.
 - Government-backed initiatives supporting legal enforcement.

3. Financial Management in Construction:

- Standardized payment schedule for contractors.
- Mitigation of site abandonment risk through contractual safeguards.
- Transparent communication to address payment issues.

Table 55: SWOT Framework: Environmentally friendly materials

Internal		External
Positive (+)	Strengths Minimum impact to the environment Minimizes disturbance to ecosystems. Promotes good health among communities.	Opportunities Existing policies provide a foundation for implementation. Existing institutions to monitor infrastructure development. Ongoing research on improved, eco-friendly materials
Negative (-)	Weaknesses Late involvement of stakeholders in project development Institutional challenges: lack of resources for monitoring Resistance to change and lack of innovation in the construction sector. Limitations to certain materials and methods due to rigid specifications	Threats Limited real-world testing for environmentally friendly materials Lack of enforcement in ensuring compliance with environmental standards New ideas not applicable in the local context Limited availability of environmentally friendly materials in Ghana
Recommendations: actions towards sustainability		
i. Promote Environmental Sustainability in Infrastructure Development ii. Develop and enforce Policy and Regulatory Framework for Sustainable Construction iii. Research and Innovation for Sustainable Construction Technologies iv. Community Awareness and Cultural Shift in the Construction Sector		

Context

The utilisation of environmentally friendly materials serves as a crucial indicator in the sustainable development of road and highway infrastructure. This approach involves selecting construction materials that minimize environmental impact, support circular economy principles, and ensure the long-term sustainability and durability of infrastructure projects. It addresses critical environmental challenges, promotes economic and social benefits, and ensures that infrastructure development is aligned with the principles of sustainability and environmental stewardship. This approach not only benefits the current generation but also sets a precedent for responsible infrastructure development for future generations.

Actions and Deliverables

1. Promote Environmental Sustainability in Infrastructure Development:
 - Engaging experts, conducting impact assessments, and promoting eco-friendly materials highlight a focus on minimizing the environmental footprint of highway projects.
2. Develop and enforce Policy and Regulatory Framework for Sustainable Construction:
 - Collaborating with regulatory bodies, updating policies, and introducing incentives or penalties form a theme centered on creating a supportive regulatory environment for eco-friendly construction practices.
3. Research and Innovation for Sustainable Construction Technologies:
 - Providing resources for monitoring and funding research institutions underscore a commitment to advancing technologies and materials that align with environmental sustainability.
4. Community Awareness and Cultural Shift in the Construction Sector:
 - Creating awareness, fostering interest, and promoting a culture of research and innovation within the construction sector indicate a theme that emphasizes the importance of changing attitudes and practices within the industry towards sustainability.

Table 56: SWOT Framework: Ecological functions

	Internal	External
Positive (+)	Strengths Nature conservation Infrastructure protection Preservation of ecological functions	Opportunities Environmental Impact Assessments (EIA) Baseline data collection Donor-funded projects Regulatory compliance
Negative (-)	Weaknesses Implementation challenges Engineer focus Permit acquisition process. Neglect of ecological aspects Inadequate consideration Coordination issues	Threats Delay in obtaining permit. Political pressure Lack of planning Neglect of drainage structures Encroachment Illegal activities
Recommendations: actions towards sustainability		

- i. Develop and enforce Policy and Regulatory Framework
- ii. Promote Environmental Sustainability
- iii. Research and Innovation for Sustainable Construction Technologies
- iv. Community Awareness and Cultural Shift

Context

Preserving or enhancing the ecological functions of drainage corridors is a crucial determinant in the sustainable development of road and highway infrastructure. This approach emphasizes maintaining natural waterways and enhancing their ecological roles within infrastructure projects, thereby contributing to environmental conservation, biodiversity support, and sustainable water management. The focus on preserving or improving the ecological functions of drainage corridors in road and highway infrastructure development reflects a commitment to environmental sustainability and resilience. This approach not only mitigates negative impacts on the natural environment but also leverages the benefits of healthy ecosystems for infrastructure resilience, biodiversity conservation, and community well-being. It exemplifies a holistic approach to sustainable development that integrates infrastructure needs with ecological stewardship.

Actions and Deliverables

1. Develop and enforce Policy and Regulatory Framework:
 - Develop national frameworks for environmental regulations.
 - Strengthen regulatory and monitoring agencies.
 - Implement effective monitoring systems.
2. Promote Environmental Sustainability:
 - Incorporate ecological assessments into planning and design.
 - Build a skilled workforce for ecological preservation strategies.
 - Increase awareness among engineers on integrating ecological considerations.
3. Research and Innovation for Sustainable Construction Technologies:
 - Provide financial resources to institutions for research and innovation to build a critical mass of skilled environmental experts.
4. Community Awareness and Cultural Shift:
 - Engage local communities to prevent and report encroachments.
 - Work with law enforcement agencies to address illegal activities.

Table 57: SWOT Framework: Environmental Monitoring

Internal		External
Positive (+)	<p>Strengths</p> <p>Lessons learnt (positive and negative) can be applied on future projects. Identifies prospective negative impacts of projects. Provides valuable information about pollution levels. Ensures compliance of contractors Protect potential claims.</p>	<p>Opportunities</p> <p>Regulatory authorities exist. Environmentalists are involved at all stages. Road agencies have environmental units. Environmental management plans are a requirement in contract documents.</p>
Negative (-)	<p>Weaknesses</p> <p>Engineers focus more on operational aspects at the neglect of environmental impacts. Lack of compliance and commitment of contractors It requires resources and manpower to conduct field assessments and gather data</p>	<p>Threats</p> <p>Lack of commitment of government Lack of funds and resources for monitoring institutions</p>
Recommendations: actions towards sustainability		
<ul style="list-style-type: none"> i. Environmental Impact Assessment (EIA) Process Enhancement ii. Monitoring and Regulatory Strengthening iii. Contractor Compliance and Training iv. Advocacy and Policy Influence 		

Context

The use of environmental monitoring procedures after the completion of a project is of paramount importance in ensuring the sustainable growth of road and highway infrastructure. This process involves the ongoing assessment of the environmental impacts of infrastructure projects to ensure that they remain within acceptable limits over time. Environmental monitoring measures after project completion provide a mechanism for ongoing assessment and management of environmental impacts, fostering a dynamic approach to environmental stewardship, compliance, and community engagement. By continuously monitoring and addressing the environmental impacts of infrastructure, developers and managers can ensure that projects contribute positively to sustainable development goals and remain adaptable to future environmental challenges.

Actions and Deliverables

1. Environmental Impact Assessment (EIA) Process Enhancement:

- Involving experts, comprehensive analysis, and collaboration among stakeholders for effective EIA.
2. Monitoring and Regulatory Strengthening:
 - Investment in advanced technologies, personnel training, and collaboration with regulatory authorities for robust monitoring and compliance.
 3. Contractor Compliance and Training:
 - Ensuring contractors' adherence to monitoring processes through training programs and emphasizing the importance of environmental compliance.
 4. Advocacy and Policy Influence:
 - Undertaking advocacy programs, engaging in public-private partnerships, and influencing government policies to highlight the economic, social, and environmental benefits of post-project environmental monitoring.

Table 58: SWOT Framework: Flood and Surface Run-off

Internal		External
Positive (+)	Strengths	Opportunities
	Prevents future damage to road infrastructure. Eliminates safety risks to road users and communities as a whole. Prevents water pollutions from run-offs.	High level of awareness of flood issues among stakeholders Engineers incorporates drainage design in roadway projects. Manual for drainage design works exists.
Negative (-)	Weaknesses	Threats
	Lack of up-to-date data Engineers need updated knowledge and skills. Need for a revised design manual. Absence of a specific local framework or guideline Importance of tools not consistently prioritized. Limited resources for training Focus on residential facilities, neglecting waterways. Challenges in maintenance due to budget constraints	Improper waste disposal practices Poor control over land use affecting design effectiveness. Under sizing of drains during designs Building permits given without proper supervision Encroachment on riverbanks and reservations Political influence affecting resource allocation. Wetlands and reservations converted into residential buildings
Recommendations: actions towards sustainability		
<ol style="list-style-type: none"> i. Infrastructure and Engineering ii. Policy and Regulation iii. Community Engagement and Education iv. Capacity Building and Training v. Financial Planning and Budget Allocation 		

Context

The development of sustainable road and highway infrastructure that is resilient to environmental challenges, protects communities and the natural environment, and supports long-term economic and social well-being necessitates the minimising of flood and surface run-off. By incorporating effective water management practices into the design and operation of transportation projects, developers can ensure that infrastructure contributes positively to the sustainability and resilience of the built environment.

Actions and Deliverables

1. Infrastructure and Engineering:
 - Subthemes: Design standards, technology integration, drainage systems, and flood prevention infrastructure.
2. Policy and Regulation:
 - Subthemes: Land use regulations, zoning policies, approval processes, and spatial planning.
3. Community Engagement and Education:
 - Subthemes: Stakeholder awareness, public education, responsible waste management, and collaboration with local authorities.
4. Capacity Building and Training:
 - Subthemes: Skill development, engineer training programs, resource allocation for personnel, and knowledge enhancement.
5. Financial Planning and Budget Allocation:
 - Subthemes: Funding advocacy, long-term maintenance planning, and budget allocations for flood prevention measures.

Table 59: SWOT Framework: Safety Risk Assessment and Mitigation

	Internal	External
Positive (+)	<p>Strengths</p> <p>Minimizes or prevent future claims and lawsuits. Identification and mitigation of potential threats to workers and the community at risk Improve the decision-making processes and communication among stakeholders.</p>	<p>Opportunities</p> <p>Regular safety audits are conducted. Safety Commission collaborates on addressing safety issues. Safety risk assessment is a project requirement. Contract documents outline minimum safety requirements.</p>

Negative (-)	Helps prevent delays and manage costs.	Safety officer required for road certificate application.
	Weaknesses Training needed for capabilities in conducting safety risk assessment. Provision of PPE to workers challenging due to financial constraints. Lack of safety officers to review design. Weak enforcement of safety rules. Some contractors may not prioritize safety. Cost implications may lead to compromises in design.	Threats Lack of funds for safety schemes and recommendations.
Recommendations: actions towards sustainability		
<ol style="list-style-type: none"> i. Workplace Safety Improvement ii. Contractor Performance and Evaluation iii. Proactive Safety Measures iv. Protocol Development and Adherence 		

Context

Safety risk assessment and mitigation during construction is a crucial indicator in sustainable road and highway infrastructure development, emphasizing the commitment to safeguarding human life and ensuring the well-being of all involved. By systematically identifying, evaluating, and addressing potential safety hazards, construction projects can achieve higher levels of sustainability, social responsibility, and economic efficiency, contributing positively to the overall safety culture in the infrastructure sector.

Actions and Deliverables

1. Workplace Safety Improvement:
 - Training for safety risk assessments
 - Affordable PPE options
 - Safety officers for design review
 - Stricter enforcement measures
2. Contractor Performance and Evaluation:
 - Contractor performance assessment in safety
 - Stricter contractor qualification requirements
 - Assessing safety records of certified contractors
3. Proactive Safety Measures:

- Identifying emerging safety threats
 - Developing proactive mitigation strategies
 - Advocating for increased budget allocations for safety initiatives
4. Protocol Development and Adherence:
- Developing safety risk assessment protocols
 - Incorporating safety protocols into project requirements
 - Evaluating adherence to safety protocols and impact on projects

Table 60: SWOT Framework: Worker’s Health and Safety

Internal		External
Positive (+)	Strengths	Opportunities
	Ensures workers safety and overall wellbeing during and after project. Avoids future claims. Ensures smooth delivery of project to meet deadlines. Ensures quality execution of works.	Money allocation for audits and continuous monitoring There is money allocation for the contractor. Well-structured safety departments Contract provisions for worker safety. Regulatory agency oversight
Negative (-)	Weaknesses	Threats
	Worker neglect of safety measures Challenges in changing worker mindset Influence of weak construction management team Lack of monitoring and enforcement of contract specifications.	Political interference in decision-making Contractors prioritizing cost-cutting over safety. Non-payment to contractors by Government Monitoring team under-resourced
Recommendations: actions towards sustainability		
i. Workplace Safety and Training ii. Employee Well-being and Collaboration iii. Contractor Management and Safety Compliance iv. Advocacy and Policy Development		

Context

The enhancement of worker health and safety in road and highway infrastructure development not only aligns with ethical and legal necessities but also significantly contributes to the triple bottom line of sustainability: economic viability, environmental protection, and social equity. It represents a critical investment in the present and future of construction, ensuring that projects are not only structurally sound and environmentally friendly but also socially responsible and inclusive.

Actions and Deliverables

1. Workplace Safety and Training:
 - Regular safety training courses.
 - Awareness campaigns and communication strategies.
 - Strengthening monitoring teams and adherence to safety protocols.
2. Employee Well-being and Collaboration:
 - Comprehensive wellness and health programs.
 - Involvement of employees in creating safety guidelines.
 - Fostering a friendly environment for open communication.
3. Contractor Management and Safety Compliance:
 - Standardized contract templates with safety provisions.
 - Strict pre-qualification process for contractors.
 - Audits of contractor safety practices and intervention.
4. Advocacy and Policy Development:
 - Advocacy for clear safety guidelines despite political considerations.
 - Advocating for transparent and timely payment processes.
 - Collaboration with industry associations to address broader issues.

Table 61: SWOT Framework: Traffic congestion

	Internal	External
Positive (+)	<p>Strengths</p> <p>Ensures smooth traffic movement during operations. Helps identify and mitigate potential bottlenecks on roadway during construction and operations. Ensures the comfort of road users and communities. Reduces health and economic impacts associated with congestion.</p>	<p>Opportunities</p> <p>Enough awareness among engineers, planners, and project managers Traffic management and control plan for constructions are required for some projects.</p>
Negative (-)	<p>Weaknesses</p> <p>Lack of enforcement Insufficient training of flagmen Lack of and poor implementation of traffic management plans Neglect of community culture and road user behaviour design inputs. Insufficient diversions routes/detour during construction Lack of public engagements</p>	<p>Threats</p> <p>Poor land use planning Lack of consideration for traffic congestion</p>

	Lack of detailed operational analysis during design	
<p>Recommendations: actions towards sustainability</p> <p>i. Traffic Safety and Enforcement</p> <p>ii. Training and Professional Development</p> <p>iii. Community Engagement and Communication</p> <p>iv. Integrated Urban Planning and Sustainable Development</p>		

Context

The reduction of traffic congestion during the design, construction, and operational phases of road and highway infrastructure development is a critical indicator of sustainability. This approach emphasizes the importance of minimizing disruptions and optimizing flow in transportation networks, ensuring infrastructure projects contribute positively to the surrounding environment and society. It represents a holistic approach that balances the needs of the environment, the economy, and society, ensuring that infrastructure serves as a catalyst for positive change and contributes to the resilience and sustainability of urban and rural areas alike.

Actions and Deliverables

1. Traffic Safety and Enforcement:
 - Encouraging collaboration among law enforcement agencies.
 - Use of technological tools for automatic monitoring.
 - Regular traffic impact assessments and proactive measures.
2. Training and Professional Development:
 - Providing comprehensive training programs for flagmen.
 - Updating training regularly to ensure awareness of recent procedures.
 - Cultural sensitivity training for planning and design teams.
3. Community Engagement and Communication:
 - Engaging in decision-making with local officials.
 - Conducting regular town hall meetings, surveys, and online platforms for public feedback.
 - Developing and communicating clear diversion routes well in advance.
4. Integrated Urban Planning and Sustainable Development:
 - Collaborating with local government representatives and urban planners.
 - Integrating land use and transportation planning.

- Considering user behaviour during the design phase and promoting sustainable development techniques.

Table 62: SWOT Framework: Public Participation

Internal		External
Positive (+)	<p>Strengths</p> <p>Public is a major stakeholder. Incorporating public views mitigates potential issues. Public ownership enhances facility use and maintenance. Early community involvement leads to project success. Understanding needs and concerns of various stakeholders</p>	<p>Opportunities</p> <p>Policies and legal frameworks emphasize engagement. Transport policy recognizes stakeholder involvement.</p>
Negative (-)	<p>Weaknesses</p> <p>Need for early engagement to address potential issues. Financial constraints limit stakeholder consultations Limited public involvement due to inadequate engagement Lack of understanding of the importance of public involvement Importance of dedicated staff for public relations Challenges like language barriers and misinformation Underestimation of public contributions compared to experts</p>	<p>Threats</p> <p>Mistrust and lack of information from contractors. Misinterpretation of information by the public Resistance and loss of interest over time Politically motivated and poorly coordinated budget Politics hindering effective stakeholder engagement. Opposition from individuals or groups with concerns Challenges in dealing with politicians and promises. Short timeframes limiting public engagement.</p>
Recommendations: actions towards sustainability		
<ul style="list-style-type: none"> i. Stakeholder Engagement and Communication ii. Conflict Resolution and Consensus Building iii. Effective Project Management and Timelines 		

Context

Public participation in the early phases of road and highway infrastructure projects is fundamental to achieving sustainable development goals. It ensures that projects are not only technically and economically viable but also socially inclusive and environmentally responsible, leading to infrastructure that is more broadly supported and beneficial to the communities it serves.

Actions and Deliverables

1. Stakeholder Engagement and Communication:

- Resources for early and ongoing involvement.
 - Alternative funding sources or partnerships for stakeholder consultations.
 - Public awareness through communication campaigns and media channels.
 - Educational programs for stakeholders, emphasizing benefits of public participation.
 - Dedicated team for public relations and community engagement.
2. Conflict Resolution and Consensus Building:
- Formalized process for addressing concerns.
 - Dispute resolution mechanisms.
 - Inclusive project environment to minimize interference by party politics.
 - Building trust through transparent communication practices.
3. Effective Project Management and Timelines:
- Realistic project timelines advocacy.
 - Proactive communication about constraints and effective time utilization.
 - Focused strategies for engaging the public within limited time.

Table 63: SWOT Framework: Durable materials

Internal		External
Positive (+)	Strengths Reduces life cycle costs. Ensures expected lifespan of infrastructure. Minimizes maintenance costs. Reduces need for frequent repairs. Minimizes environmental impact.	Opportunities Specifications and standards exist. Existence of adequate testing capabilities and quality assurance during construction Road agencies adopt design guides and standards. There exists an authority for material quality assurance and control.
Negative (-)	Weaknesses Competent material engineers can be costly. Inadequate supervision may lead to compromises. Potential for the use of substandard materials for profit Lack of advanced testing facilities in some regions High-quality materials may be expensive and scarce. Centralized testing labs may cause delays. Distance to testing labs, especially in remote regions, can be challenging. Availability of materials specific to a particular job may be challenging.	Threats Lack of testing labs in certain areas Increased testing costs and project delays Dependency on imported materials Proximity and transportation challenges Need for checks and standards in material production. Government support for local production Financial challenges in using quality materials. Scarcity of gravel materials due to urbanization

Recommendations: actions towards sustainability

- i. Quality Assurance in Construction
- ii. Local Sustainability and Production
- iii. Innovation and Research for Cost-Effective Solutions
- iv. Regulatory Compliance and Governance in Construction

Context

The application of durable materials is crucial for achieving sustainable road and highway infrastructure development. It aligns with the principles of economic efficiency, environmental protection, and social responsibility, ensuring that infrastructure projects are built to last, with minimal impact on the planet and maximal benefits for society.

Actions and Deliverables

1. Quality Assurance in Construction:
 - Focuses on ensuring the use of durable and high-quality materials.
 - Themes include resource allocation for competent engineers, supervision mechanisms, and testing adherence to standards.
2. Local Sustainability and Production:
 - Emphasizes reducing costs and dependencies on imports through local production.
 - Themes include encouraging local sourcing, supporting local businesses, and advocating for government policies favouring local industries.
3. Innovation and Research for Cost-Effective Solutions:
 - Centres around exploring alternatives and conducting research for cost-effective yet high-quality materials.
 - Themes include investing in advanced testing facilities, researching alternatives, and anticipating the impact of urbanization on material availability.
4. Regulatory Compliance and Governance in Construction:
 - Highlights the importance of enforcing regulations, advocating for policies, and implementing financial planning.
 - Themes include establishing and enforcing regulations, advocating for government policies, and implementing financial planning for material challenges.

Table 64: SWOT Framework: Disaster (Flood) Resilient

Internal		External
Positive (+)	Strengths Supports adaptation and mitigation of climate change. Reduces economic and environmental losses. Enhances reliability and safety of highway facilities.	Opportunities Building code exists for infrastructure development in Ghana. Earthquake/Seismic zones already defined. High level of awareness of flood issues among stakeholders Manual for drainage design exist.
Negative (-)	Weaknesses Inadequate specifications in highway design manuals Lack skills and knowledge among highways professionals. Lack of tools and required software for designs. Lack of up-to-date data Inadequate local standards Designing against disasters may requires larger member sizes and hence expensive. Accommodating larger structures may conflict with other plans. Require adequate preparation and feasibility studies. Failure to consider future developments and land use changes	Threats Lack of enough funds from government Lack of synergy among highway professionals Poor control over land use development Damage to highway infrastructure by illegal activities of people.
Recommendations: actions towards sustainability		
<ol style="list-style-type: none"> i. Climate-Responsive Infrastructure Development ii. Capacity Building and Training for Disaster Response iii. Policy and Standards Enhancement iv. Financial and Governance Strategies for Resilient Infrastructure 		

Context

Disaster (flood) resilient designs play a paramount role in sustainable road and highway infrastructure development, especially as climate change intensifies the frequency and severity of flooding events. These designs are fundamental in ensuring infrastructure resilience, minimizing damage, and maintaining functionality during and after flood events. They exemplify a commitment to safety, environmental stewardship, economic stability, and community well-being, ensuring that infrastructure can adapt to and recover from flood events efficiently and effectively.

Actions and Deliverables

1. Climate-Responsive Infrastructure Development:
 - Incorporating climate projections into design standards.
 - Prioritizing resilient designs through risk assessment strategies.
 - Continuous updates and maintenance to align with changing climate patterns.
2. Capacity Building and Training for Disaster Response:
 - Training programs for highway maintenance personnel.
 - Development of skills in disaster response and recovery.
3. Policy and Standards Enhancement:
 - Updating highway design manuals with disaster-resilient specifications.
 - Advocacy for comprehensive local standards and their incorporation into building codes and regulations.
 - Collaboration with relevant stakeholders and urban planning authorities.
4. Financial and Governance Strategies for Resilient Infrastructure:
 - Investment in specialized tools and software for disaster-resilient infrastructure design.
 - Systematic data collection using modern technologies.
 - Coordination between different departments and agencies.
 - Advocacy for increased government funding and exploration of public-private partnerships.

Table 65: SWOT Framework: Climate Change Resilient

Internal		External
Positive (+)	<p style="text-align: center;">Strengths</p> <p>Long-term benefits and increased efficiency Ensure their long-term operational and safety performance and resilience. Reduces highway vulnerability to changes in climate. Improves biodiversity and social equity.</p>	<p style="text-align: center;">Opportunities</p> <p>Substantial awareness about climate change among highway professionals Ongoing review of highway design manuals for climate challenges Professional dialogue for new tools and techniques for climate change resilient design and construction Existence of organizations providing climate-related data</p>
Negative (-)	<p style="text-align: center;">Weaknesses</p> <p>Existence of outdated manuals Lack of in-depth knowledge among stakeholders Guidelines need comprehensive review. Data challenges and the need for a national database</p>	<p style="text-align: center;">Threats</p> <p>Slow institutional progress in addressing climate change. System resistance to adopting new technologies. Implementation gap in practicing research findings Lack of enough funds</p>

		Lack of government commitment
Recommendations: actions towards sustainability		
i.	Capacity Building and Training	
ii.	Guidelines and Standards Development	
iii.	Collaboration and Data Management	
iv.	Advocacy and Funding	

Context

Designing and constructing climate change-resilient roadway infrastructure is an essential indicator of sustainability in road and highway development. This approach acknowledges the increasing threat posed by climate change, including extreme weather events, rising temperatures, and sea-level rise, and aims to ensure infrastructure can withstand these changes. It represents a holistic approach that ensures the long-term viability, economic efficiency, environmental sustainability, and social inclusivity of roadway projects, making them fit for the challenges of the 21st century and beyond.

Actions and Deliverables

1. Capacity Building and Training:
 - Strengthening the skills and knowledge of highway professionals through training programs.
 - Developing educational initiatives for engineers, policymakers, and project managers.
2. Guidelines and Standards Development:
 - Creating and promoting guidelines and standards for integrating climate resilience into infrastructure development.
 - Advocating for the widespread adoption of these guidelines in industry best practices.
3. Collaboration and Data Management:
 - Collaborating with various stakeholders, including government agencies, research institutions, and private entities.
 - Developing a national database for climate-related data relevant to infrastructure planning.
4. Advocacy and Funding:
 - Advocating for increased funding for climate-resilient infrastructure projects through policy initiatives.

- Engaging in advocacy efforts to emphasize government commitment to sustainable infrastructure and exploring public-private partnerships.

Table 66: SWOT Framework: Technology in design and construction

Internal		External
Positive (+)	Strengths Efficient and cost-effective construction Optimization of resources Long-term value for money	Opportunities Designers used to the use of software for road design and analysis. Various technologies are employed during highway construction.
Negative (-)	Weaknesses New technology may be expensive. Lack of technological skills It takes time for wider acceptance of new technology. Standardization challenges due to different brands technical specifications Specific materials or resources may not be readily available.	Threats Resistance to change at institutional level about established practices. Lack of funds for acquiring necessary data Training costs Lack of funds for technology purchase and license renewal Resistance to technology and software, especially among older professionals
Recommendations: actions towards sustainability		
i. Technology Integration and Adoption Strategies ii. Change Management for Technological Innovation iii. Public-Private Partnerships and Funding for Technology Infrastructure		

Context

Incorporating technology in the design and construction of road and highway infrastructure is a pivotal indicator of sustainability. This approach leverages digital tools, software, and advanced materials to improve efficiency, reduce environmental impact, and enhance the durability and safety of infrastructure projects. It enables more efficient use of resources, reduces environmental impacts, improves safety, and ensures that infrastructure is resilient, durable, and capable of meeting the challenges of the future.

Actions and Deliverables

1. Technology Integration and Adoption Strategies:
 - Collaboration with tech providers for funding and discounts.
 - Employee training programs for skill enhancement.

- Encouraging industry-wide standards and interoperability.
2. Change Management for Technological Innovation:
 - Educational initiatives for change management.
 - Leadership engagement to address concerns and highlight benefits.
 - Gradual introduction of new technology with mentorship programs.
 3. Public-Private Partnerships and Funding for Technology Infrastructure:
 - Exploring public-private partnerships for funding.
 - Encouraging government support for technology-driven infrastructure.
 - Integrating training costs into project budgets for sustainable development.

Table 67: SWOT Framework: Adaptability and flexibility for future changes

Internal		External
Positive (+)	Strengths Allows for the anticipation of future needs. Ensures that the road infrastructure can accommodate potential changes. Minimizes life cycle cost. Allows for a more efficient use of resources.	Opportunities Continuous improvement of development
Negative (-)	Weaknesses Enforcement challenges Accurate prediction of future changes is challenges. Balancing adaptability with initial costs Lack of consistency in design standards across agencies Lack of collaboration among agencies Lack of up-to-date city strategic plans (land use)	Threats Initial costs and utility placement challenges Resource allocation constraints Challenges from existing structures Social challenges and stakeholder resistance Impact of land use patterns
Recommendations: actions towards sustainability		
<ol style="list-style-type: none"> i. Strategic Planning and Governance ii. Research and Forecasting iii. Stakeholder Engagement and Public Awareness iv. Sustainability and Retrofitting 		

Context

Allowing adaptability and flexibility for future changes is an essential indicator of sustainability in road and highway infrastructure development. This principle ensures that infrastructure is not only capable of meeting current demands but is also designed with

the foresight to adapt to future needs, technologies, and environmental conditions. It ensures that infrastructure investments are resilient, capable of integrating advancements, and remain valuable and effective for generations to come.

Actions and Deliverables

1. Strategic Planning and Governance:
 - Continuous monitoring and feedback.
 - Risk management strategy.
 - Engagement with law enforcement and regulatory organizations.
2. Research and Forecasting:
 - Specialized research and forecasting department.
 - Cost-benefit analysis and funding models.
 - Collaboration for common design standards.
3. Stakeholder Engagement and Public Awareness:
 - Early engagement with all stakeholders.
 - Public-private partnerships.
 - Open and inclusive communication with local communities.
4. Sustainability and Retrofitting:
 - Cost-benefit analysis for long-term benefits.
 - Retrofitting techniques for existing structures.
 - Alignment with sustainable land use patterns.

Table 68: SWOT Framework: Competent workforce

		Internal	External
Positive (+)		Strengths Ensures durability of roads Ensures compliance with required technical specifications and standards. Reduce corruption and maintain the integrity. Good quality of work Ensures project success. Smooth construction management Implementation according to the plan.	Opportunities Internships and national service provide skills. Training centres and schedules enhance skills. Investment made into TVET and Technical universities by government.
Negative (-)		Weaknesses Not all contractors have competent personnel. High standards Job qualification requirements are a challenge for new and young professions. Lack of qualified personnel among contractors	Threats Financial difficulties preventing continuous recruitment. Politicians interfere the works of supervisors and engineers. Payment issues indirectly affect supervision.

	New engineers sometimes lack practical understanding and experience. Lack of confidence and effective communication Lack of continuous recruitment plan and capacity building. Poor pay for supervisors	Lack of strong stakeholder commitment to competent based teaching and learning in education system Economic constraints lead to cheaper labour. Lack of enforcement for assessments and evaluations. Lack of legal support for supervisors who face political intimidations
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Recommendations: actions towards sustainability

- i. Professional Development and Training
- ii. Ethical and Transparent Practices
- iii. Collaboration between Industry and Academia
- iv. Strategic Workforce Planning
- v. Political Interference and Governance

Context

Ensuring the availability of competent supervisors, labourers, and other workforce members is a critical indicator of sustainability in road and highway infrastructure development. This aspect of project management highlights the importance of skilled human resources in achieving high-quality, efficient, and sustainable construction outcomes. It not only influences the immediate success and sustainability of individual projects but also contributes to the broader goal of advancing the construction industry towards more sustainable, efficient, and safe practices.

Actions and Deliverables

1. Professional Development and Training:
 - Includes strategies related to training sessions, qualifications for contractors, staff development, and mentorship programs.
2. Ethical and Transparent Practices:
 - Encompasses themes like transparent procurement procedures, routine audits, fair labour practices, and legislative protections.
3. Collaboration between Industry and Academia:
 - Involves promoting collaborations between academic institutions and industrial players, developing curricula, and aligning educational programs with industry needs.
4. Strategic Workforce Planning:
 - Focuses on creating and implementing a strategic workforce plan, adjusting compensation structures, and advocating for academic-industry collaboration.
5. Political Interference and Governance:

- Encompasses themes like project governance structures, reducing political interference, and establishing effective payment procedures to prevent disruptions.

Table 69: SWOT Framework: Project compliance

	Internal	External
Positive (+)	<p>Strengths</p> <p>Ensures project execution as intended. Minimizes disputes and future claims. Potential for effective project execution Quality assurance by following guidelines.</p>	<p>Opportunities</p> <p>Regulatory bodies exist. Road agencies represent government on projects. Consultants are usually employed on projects.</p>
Negative (-)	<p>Weaknesses</p> <p>Cost variations Lack of resources for monitoring teams. Environmental control measures not priority of highway professionals Road agency's reluctance to take action. Financial constraints leading to priority shifts. Contractors taking on projects beyond their capacity. Ambiguous language in specifications Lack of understanding or misinterpretation of contract documents. Lack of sufficient knowledge of contract documents and project specifications.</p>	<p>Threats</p> <p>Challenges in enforcing standards. Lack of proper mobilization and funding. Absence of legal provisions for fines for non-compliance Pressure to meet deadlines. Weak enforcement of management plans. Lack of funds for training and capacity building for stakeholders</p>
<p>Recommendations: actions towards sustainability</p> <ol style="list-style-type: none"> i. Project Management and Efficiency ii. Cost Estimation and Budget Management iii. Stakeholder Collaboration and Communication iv. Environmental Management and Sustainability v. Regulatory Compliance and Legal Aspects 		

Context

Compliance with environmental requirements, contract documents, and project specifications stands as a foundational indicator in sustainable road and highway infrastructure development. This criterion features the criticality of adhering to established guidelines, standards, and legal obligations throughout the construction process. It summarizes a commitment to environmental stewardship, legal and regulatory adherence, quality and safety, risk management, and economic efficiency. By prioritizing this indicator, projects not only contribute to sustainable development goals but also ensure successful and responsible infrastructure development.

Actions and Deliverables

1. Project Management and Efficiency:
 - Establishing strong project management systems.
 - Training teams in efficient project management techniques.
 - Improving communication and cooperation among stakeholders.
2. Cost Estimation and Budget Management:
 - Developing process improvements in cost estimation.
 - Creating backup plans and evaluating budget allocations regularly.
3. Stakeholder Collaboration and Communication:
 - Encouraging collaboration between road agencies and consultants.
 - Collaborating with all stakeholders to clarify specifications.
 - Improving collaboration between road agencies and government organizations.
4. Environmental Management and Sustainability:
 - Organizing training sessions for highway workers on environmental measures.
 - Incorporating environmental considerations in project planning.
5. Regulatory Compliance and Legal Aspects:
 - Collaborating with regulatory agencies to address enforcement challenges.
 - Facilitating the addition of legal provisions and penalties for noncompliance.
 - Advocating for stronger enforcement tactics.

Table 70: SWOT Framework: Sustainable policy and strategy

	Internal	External
Positive (+)	<p>Strengths</p> <p>Provides a sense of security and stability for professionals. Ensures synergy and coordination among activities of professionals and institutions as a whole. Provide guidance for institutions. ensures that the works of professionals are supported and protected by the law. Allows professionals to carry out their work with confidence.</p>	<p>Opportunities</p> <p>Some institutions have developed medium to long-term strategies, aligned with sustainability goals. A national transport policy exists. Performance measurement performed to ensure alignment with strategy.</p>
Negative (-)	<p>Weaknesses</p> <p>Lack of ministry-level integration Insufficient inter-agency collaboration Lack of comprehensive sustainable policies</p>	<p>Threats</p> <p>Difficulty aligning sector policy with political interests. Political factors hindering effective implementation.</p>

	challenge lies in the implementation and enforcement existing policies	Lack of political will for policy monitoring
<p>Recommendations: actions towards sustainability</p> <ul style="list-style-type: none"> i. Sustainable Infrastructure Development ii. Interagency Collaboration and Coordination iii. Capacity Building and Professional Development iv. Public Awareness and Stakeholder Engagement 		

Context

Achieving sustainable policy and strategy to improve construction efficiency is a critical indicator in sustainable road and highway infrastructure development. This indicator emphasizes the importance of strategic frameworks and policies that advocate for sustainability while enhancing the efficiency of construction processes. It sums up a holistic approach to project planning and execution, ensuring that sustainability principles are embedded in every aspect of the construction process. By prioritizing this indicator, projects can achieve a balance between environmental stewardship, economic vitality, and social equity, paving the way for a more sustainable future.

Actions and Deliverables

1. Sustainable Infrastructure Development:
 - Evaluating and updating policies for sustainability.
 - Collaborating with law enforcement for the enforcement of sustainable laws.
 - Integrating sustainability across government departments.
 - Aligning national transport strategy with sustainable goals.
2. Interagency Collaboration and Coordination:
 - Ensuring coordination among agencies working on roadway infrastructure.
 - Holding frequent meetings to enhance collaboration.
 - Aligning national transport strategy and interministerial cooperation.
 - Expanding and improving performance measurement for sustainability.
3. Capacity Building and Professional Development:
 - Providing training and resources to institutions.
 - Conducting capacity building for professionals.
 - Identifying and addressing gaps in coverage for sustainability.
 - Offering incentives for successful integration of sustainable strategies.
4. Public Awareness and Stakeholder Engagement:
 - Raising awareness among political stakeholders.

- Presenting data on the long-term benefits of sustainable infrastructure.
- Proposing explicit sustainability goals in the national framework.

Table 71: SWOT Framework: Project duration

Internal		External
Positive (+)	Strengths	Opportunities
Negative (-)	Weaknesses Late Stakeholder Involvement Lack of dedication Inadequate time for feasibility studies Poor project conception Lack of coordination among stakeholders Ineffective project management practices	Threats Delays in documentation and permit processes Resistance from the public Funding constraints Economic factors Short-term political cycles
Recommendations: actions towards sustainability		
<ol style="list-style-type: none"> i. Project Management and Planning ii. Team Collaboration and Motivation iii. Risk Mitigation and Contingency Planning iv. Financial Management and Funding Strategies 		

Context

Meeting project duration targets is a crucial indicator of sustainability in road and highway infrastructure development. This emphasis on timely completion reflects a commitment to minimizing the environmental, social, and economic impacts often associated with prolonged construction activities. It summarizes a broad spectrum of benefits, from cost savings and reduced environmental impact to improved community relations and economic advantages. This indicator highlights the importance of effective project management, planning, and execution in building infrastructure that supports long-term sustainability goals.

Actions and Deliverables

1. Project Management and Planning:
 - Stakeholder engagement
 - Documentation and permit processes

- Feasibility assessments
 - Project management framework and training
2. Team Collaboration and Motivation:
 - Team-building exercises
 - Individual responsibilities and goal definition
 - Incentives and recognition
 - Regular check-ins and communication
 3. Risk Mitigation and Contingency Planning:
 - Identifying bottlenecks
 - Contingency plans for delays
 - Economic condition monitoring
 - Legislative provisions for risk mitigation
 4. Financial Management and Funding Strategies:
 - Exploring alternate funding sources
 - Budgetary constraints and ranking project components
 - Adjusting the project budget based on economic conditions.
 - Creating financial backup plans for unforeseen difficulties

Table 72: SWOT Framework: Project risk assessment

Internal		External
Positive (+)	Strengths Provides certainty about the future of the projects. Helps in securing funds. Identification and mitigation of potential threats Improve the decision-making processes and communication among stakeholders. Helps prevent delays and manage costs.	Opportunities Risk assessment performed for most urban projects. Requirement for certain projects and their funding. Effective risk management for timely completion
Negative (-)	Weaknesses Requires knowledge and skills. Cost implications of risk assessments Gap between assessment and implementation Lack of technical know-how for comprehensive assessment Lack of up-to-date data	Threats Politically motivated projects may neglect risks. Inadequate employer response to identified risks. Resource constraints affecting risk management. Funding constraints Time constraints for conducting assessment.
Recommendations: actions towards sustainability		
i. Integrated Risk Management		

- ii. Capacity Building and Training
- iii. Knowledge Sharing and Standardization
- iv. Resource Allocation and Financial Sustainability

Context

Project risk assessment in road and highway infrastructure development acts as a predictive tool that safeguards against future uncertainties. It encompasses a comprehensive evaluation of potential challenges, uncertainties, and hazards that could impede the project's success. It ensures that projects are not only built to last but are also aligned with broader sustainability goals, covering environmental, social, and economic aspects. This holistic approach to identifying and managing potential risks is indispensable for the successful and sustainable completion of infrastructure projects.

Actions and Deliverables

1. Integrated Risk Management:
 - Proactive threat detection and regular risk assessments emphasize the importance of an integrated approach to risk management.
 - Seamless integration of risk assessment findings with project management practices is a key aspect of this theme.
2. Capacity Building and Training:
 - Continuous training programs for project teams focus on enhancing knowledge and skills in risk assessment methodologies.
 - Clearly outlining roles and responsibilities for managing identified risks contributes to building the capacity of project teams.
3. Knowledge Sharing and Standardization:
 - Creating forums for sharing successful risk assessment practices across different urban projects promotes a standardized methodology.
 - Incorporating risk assessment requirements in project funding criteria encourages widespread adoption of best practices.
4. Resource Allocation and Financial Sustainability:
 - A plan for allocating resources, giving top priority to risk management tasks, ensures that sufficient funds are set aside to counter possible threats.
 - Exploring and diversifying funding sources minimizes the impact of financial constraints on risk management measures.

Table 73: SWOT Framework: Contractor prequalification

Internal		External
Positive (+)	Strengths Potential for improvement in selection process	Opportunities Clear selection criteria exist.
Negative (-)	Weaknesses Deviation from criteria Incomplete process Requires the creation of a database of contractors.	Threats Political interference Personal preferences over competence Lack of discipline and enforcement
Recommendations: actions towards sustainability		
<ol style="list-style-type: none"> i. Process Improvement and Evaluation ii. Compliance and Monitoring System iii. Transparency and Standardization 		

Context

Contractor prequalification serves as a comprehensive tool in the sustainable development of road and highway infrastructure, ensuring that only the most qualified, reliable, and sustainability-minded contractors are entrusted with the development of critical infrastructure projects. This process not only enhances the quality and efficiency of construction but also aligns projects with broader environmental and social sustainability goals, contributing positively to the long-term viability of infrastructure investments.

Actions and Deliverables

1. Process Improvement and Evaluation:
 - Conducting routine evaluations to identify areas for improvement in the contractor selection process.
 - Seeking stakeholder feedback to enhance the overall effectiveness of the process.
2. Compliance and Monitoring System:
 - Establishing a thorough auditing and monitoring system to prevent deviations in the contractor selection process.
 - Implementing punishments for non-compliance and providing training to emphasize the importance of following established criteria.
3. Transparency and Standardization:

- Creating an independent committee to minimize political interference in the contractor selection process.
- Emphasizing accountability and transparency through clearly defined duties and responsibilities for stakeholders.
- Establishing a standardized assessment procedure based on objective criteria such as qualifications, experience, and performance history.

Table 74: SWOT Framework: Contractor Selection

Internal		External
Positive (+)	Strengths Guidelines for selection Ensures transparency and fairness. Ensures selection of competent contractors	Opportunities Existing guidelines for selection Legal framework (procurement laws)
Negative (-)	Weaknesses Lack of adherence to guidelines Time constraints Low competency of the panel Lack of comprehensive database Difficulties in verifying contractors' resources and qualification	Threats Political influence in selection Favouritism or corruption Lack of transparency
Recommendations: actions towards sustainability		
<ul style="list-style-type: none"> i. Compliance and Rule Enforcement ii. Efficiency and Optimization iii. Integrity and Political Neutrality 		

Context

The contractor selection process stands as a critical indicator in sustainable road and highway infrastructure development, reflecting a strategic commitment to ensuring projects are delivered efficiently, sustainably, and to the highest standards of quality. By prioritizing contractors who align with sustainability goals, demonstrate exceptional quality and innovation, and commit to ethical practices, project owners can ensure that their projects not only contribute to the physical infrastructure but also support environmental sustainability, economic development, and social well-being.

Actions and Deliverables

1. Compliance and Rule Enforcement:
 - Severe penalties for non-compliance.
 - Consistent enforcement of rules.
 - Adherence to procurement laws and regulations.
2. Efficiency and Optimization:
 - Streamlining the selection process.
 - Minimizing time constraints.
 - Structured database management for contractors.
3. Integrity and Political Neutrality:
 - Verification procedures with precise documentation.
 - Protection against political interference.
 - Oversight committee to monitor and prevent undue influence.

Table 75: SWOT Framework: Supply chain

Internal		External
Positive (+)	Strengths Cost and quality management Project delivery time impact Profit margin maintenance. Efficiency in coordination	Opportunities Government policies on material import Certifications and incentives for contractors Discounts on duties for equipment/materials
Negative (-)	Weaknesses Cost challenges Bureaucracy in procurement Lack of proper planning Low contractor knowledge of supply chain management Requires conducting quality checks. Requires establishing efficient communication with suppliers.	Threats Dependency on external resources Price fluctuations
Recommendations: actions towards sustainability		
i. Supply Chain Optimization ii. Cost Efficiency and Analysis iii. Quality Assurance and Collaboration		

Context

The integration of supply chains is a critical indicator in the development of sustainable road and highway infrastructure, highlighting the importance of seamless coordination and management of materials, services, and information from suppliers to the final project

delivery. It requires strategic planning, collaboration among stakeholders, and the use of advanced technologies to optimize the flow of resources from origin to end-use, ensuring that infrastructure projects are sustainable, resilient, and beneficial to all involved parties.

Actions and Deliverables

1. Supply Chain Optimization:
 - Streamlining procurement processes.
 - Utilizing project management methods for coordination.
 - Diversifying the supplier base.
2. Cost Efficiency and Analysis:
 - Implementing advanced cost-tracking tools.
 - Conducting thorough cost analysis.
 - Negotiating favourable contracts and exploring alternative sourcing options.
3. Quality Assurance and Collaboration:
 - Implementing a robust quality assurance program.
 - Collaborating with suppliers to establish quality standards.
 - Offering training programs for contractors on supply chain best practices.

Table 76: SWOT Framework: Local materials

	Internal	External
Positive (+)	<p style="text-align: center;">Strengths</p> <p>Supports local economy. Environmental and sustainability benefits Stimulates economic growth. Reduces transportation costs. Creates opportunities for small-scale businesses.</p>	<p style="text-align: center;">Opportunities</p> <p>Collaboration with research unit</p>
Negative (-)	<p style="text-align: center;">Weaknesses</p> <p>Financial investment for research Contractor acceptance of local materials Difficult to obtain permits from road agencies to pilot research findings on roads. Guidelines and documents need to be comprehensive. Limited state-of-the-art testing facilities in Ghana Need for skilled personnel in material quality control. Need to know test competent and suitability of materials are before usage. Local materials may not always meet specifications.</p>	<p style="text-align: center;">Threats</p> <p>Government or ministry advocacy needed. Production costs impact Advocacy for adoption after research Cost and time impact Flexibility in design expectations Research gap. Lack of policy direction</p>

Recommendations: actions towards sustainability

- i. Regional Development and Collaboration
- ii. Promotion of Local Economy
- iii. Capacity Building and Training
- iv. Policy Advocacy and Research Enhancement

Context

Local materials in road and highway infrastructure development support global sustainability goals and generate community pride and ownership, improving integration. While challenges such as quality consistency, availability, and regulatory compliance may arise, strategic planning and collaboration among stakeholders can mitigate these issues, maximizing the benefits of local material use in infrastructure projects.

Actions and Deliverables

1. Regional Development and Collaboration:
 - Establishing collaborations with regional research centres and governmental organizations.
 - Providing incentives to local businesses for regional development.
2. Promotion of Local Economy:
 - Promoting the use of locally produced goods and materials.
 - Emphasizing long-term advantages for the economy, environment, and society.
3. Capacity Building and Training:
 - Training sessions and awareness campaigns for contractors.
 - Investing in the development of comprehensive guidelines and workforce training.
4. Policy Advocacy and Research Enhancement:
 - Engaging policymakers for supportive policies.
 - Investing in research to enhance the quality of local materials.

Table 77: SWOT Framework: Material quality control and assurance

	Internal	External
Positive (+)	Strengths	Opportunities
	Ensures that the materials or resources meet the required standards. Ensures that the project maintains the desired level of quality.	Ministry of Roads and Highway Technical specification exist. Excising practice of preliminary and post-testing with consultant approval

Negative (-)	Minimize costs and ensure the project's longevity.	Some materials labs exist. Existence of Ghana Standards Authority
	Weaknesses Need for competent supervision. Requirement for well-equipped labs Cost of quality control Lack of motivation among staff Resource and time challenges	Threats Political influence affecting adherence to quality control measures. Political persecution of engineers Staffing challenges at every project stage Lack of appreciation for quality control Lack of commitment to quality
Recommendations: actions towards sustainability		
i. Quality Control and Assurance ii. Strategic Resource Management iii. Ethical and Unbiased Practices iv. Organizational Culture of Quality		

Context

Material quality control and assurance stand as a cornerstone in sustainable road and highway infrastructure development, ensuring that the materials used meet strict standards for durability, safety, and environmental impact. It requires collaboration among project managers, engineers, suppliers, and regulatory bodies to ensure that every material used contributes positively to the infrastructure's sustainability, durability, and safety. This comprehensive approach to material quality is essential for delivering road and highway projects that meet the highest standards of excellence and sustainability.

Actions and Deliverables

1. Quality Control and Assurance:
 - Updating protocols, investing in supervision, and allocating funds for training all revolve around maintaining and assuring the quality of products or services.
2. Strategic Resource Management:
 - Themes such as dedicating funds for labs, collaborating for financial support, and creating workforce management plans highlight the strategic allocation and management of resources.
3. Ethical and Unbiased Practices:
 - Emphasizing independence in quality control, providing ethical standards, and protecting professionals from political persecution highlight a commitment to ethical and unbiased practices.
4. Organizational Culture of Quality:

- Encouraging a quality commitment culture through communication strategies, training, and integrating quality objectives into performance measurements is a central theme focused on shaping the organization's culture.

Table 78: SWOT Framework: Recycle construction materials

Internal		External
Positive (+)	Strengths Environmental benefits Cost savings Resource conservation Market promotion	Opportunities Exploration of scarified surface material exists. Bitumen reuse in milling
Negative (-)	Weaknesses Research and piloting challenges. Lack of standards Expertise and equipment gaps Limited industry attention Expense and challenges in separation	Threats Resistance to change. Regulatory challenges Material standards and regulations Poor government commitment Lack of financial investment
Recommendations: actions towards sustainability		
i. Dedicated Research ii. Provision of Resources iii. Development of Standards, regulations and protocols iv. Training and awareness creation		

Context

Utilising recycled construction materials is a crucial measure of sustainability in the construction of road and highway infrastructure. It signifies the ideals of conserving resources, reducing waste, and promoting environmental stewardship. Despite its benefits, the use of recycled construction materials faces challenges such as variability in material quality, the need for rigorous testing and certification, and market perceptions about their performance. Overcoming these barriers requires the development of robust standards and regulations, increased investment in research and development, and efforts to raise awareness among industry professionals about the benefits and potential applications of recycled materials. Incorporating recycled construction materials into road and highway projects represents a strategic move towards sustainable infrastructure development, offering a practical solution to environmental and economic challenges while supporting the transition towards a more sustainable construction sector.

Actions and Deliverables

1. Dedicated Research:
 - Provide funding for research and development to solve challenges with recycling materials. Create pilot programs to evaluate and demonstrate these materials' efficacy in practical settings.
 - Organize conferences and industry forums to highlight the advantages of utilizing recycled materials. Present compelling case studies and inspire business executives to support recycling for highway projects.
2. Provision of Resources:
 - Engage with government agencies to highlight the long-term benefits of usage of recycled materials. Advocate for policy incentives and funding for projects utilizing recycled construction materials.
3. Development of Standards, regulations and protocols:
 - Proactively engage with all stakeholders to influence the development of standards and specifications that promote the use of recycled construction materials.
 - Collaborate with regulatory bodies, industry associations, and experts to develop and implement standards for the use of recycled construction materials. Advocate for the adoption of these standards across the construction industry.
 - Provide standards and recommended procedures for the effective use of recycled materials in road projects. Encourage construction firms to adopt cost-effective strategies by providing training courses.
 - Develop supportive policies and regulations at both local and national levels. Collaborate with regulatory bodies to streamline permitting processes for projects using recycled materials.
4. Training and awareness creation:
 - Offer training programs and workshops in order to bridge the knowledge gaps in the field of dealing with recycled materials. Work with manufacturers of equipment to develop and market machinery made to handle recycled construction materials.
 - Work together with environmental groups to emphasize the advantages of recycling materials when building new roads. Launch awareness campaigns aimed at the general public as well as professionals in the business.

Chapter 7 : Conclusion

7.1 Introduction

Chapter 1 of this thesis begins with an initial exploration of the research problem and articulation of objectives. Chapter 2 built upon these foundations by conducting a thorough review of the literature, identifying key sustainability indicators for further investigation. The methodology underpinning this research was developed and discussed in Chapter 3, leading to the empirical analysis and presentation of findings from a questionnaire survey in Chapter 4 and from semi-structured interviews in Chapter 5. Chapter 6 put all of these results together and talked about how sustainability indicators could be used in the development of road and highway infrastructure.

The final chapter explores a critical evaluation of the research objectives in light of the study's findings. It provides a synthesised overview of the conclusions, outlines the limitations encountered during the research process, and proposes recommendations for augmenting sustainability in road and highway infrastructure projects. Furthermore, this chapter reveals the significance of this dissertation's contributions to the existing body of knowledge and its practical implications for the construction industry.

7.2 Review of research objectives and development processes

The review of research gaps outlined in Chapter 2 revealed significant potential, which allowed the author to establish three key research objectives, as outlined below:

- **Objective 1:** To identify critical sustainability indicators for road and highway infrastructure development.
- **Objective 2:** To examine the perceptions of highway construction professionals about the sustainability criteria and indicators related to their support for climate action.
- **Objective 3:** To develop decision-support guidelines for sustainable road and highway infrastructure development.

These objectives served as a foundational compass, guiding the research towards its overarching aim, as articulated in Chapter 1. This aim was to develop a comprehensive set of sustainable guidelines through analysis of sustainability's integration within road and highway construction, viewed through the lens of designers and project managers.

The subsequent research design was instrumental in defining the methodological pathway for this inquiry. A combined quantitative and qualitative methodological approach was employed to systematically address the stated research objectives. This dual-pronged approach, encompassing a questionnaire survey combined with semi-structured interviews, was selected to capture a wide spectrum of insights and perspectives on sustainability within the context of road and highway construction. Figure 20 illustrates the methodical framework underpinning the study by depicting the combination relationship between the research objectives and the chosen methodologies.

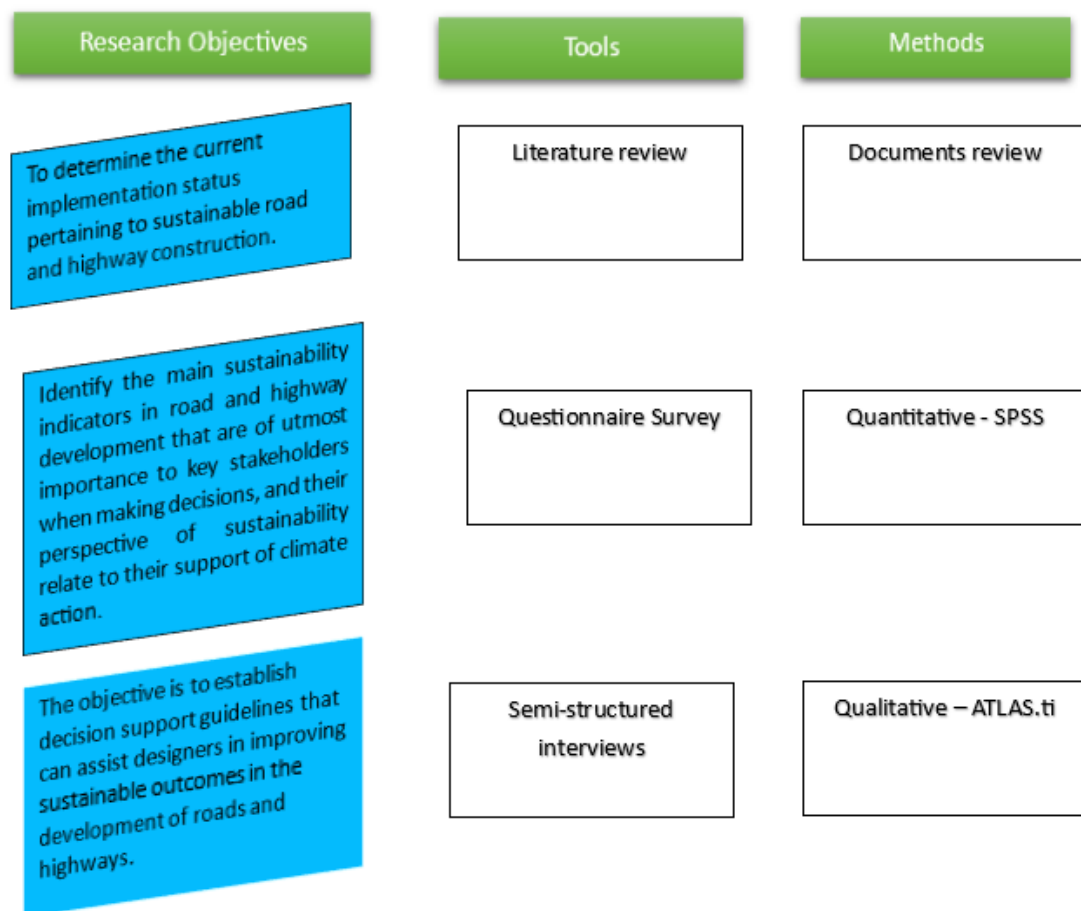


Figure 21: Relationship between research objectives and research design.

An exhaustive literature review compiled an extensive array of sustainability indicators recognised by both academics and industry practitioners. In pursuit of the first objective, the literature review facilitated the identification of 80 potential sustainability indicators relevant to road and highway construction. Based on these indicators, a survey was crafted and disseminated to evaluate their significance within the field of road and highway construction. The survey data was statistically analysed, resulting in the identification of 29 critical sustainability indicators and the formulation of a conceptual model to navigate these indicators, thereby fulfilling Objective 1. Furthermore, the perception of highway

construction professionals on sustainability criteria relate to their support for climate action was thoroughly explored to augment the efficacy of synergistic efforts towards achieving the second objective.

The execution of semi-structured interviews with 14 practitioners involved in road and highway infrastructure development within Ghana was fundamental in realizing the third objective. This interaction provided the foundation for formulating decision-making guidelines. The insights derived from this research offer invaluable guidance to designers and project managers in making informed decisions at the project's inception, aiming to elevate sustainability deliverables for road and highway infrastructure development in Ghana by addressing critical sustainability indicators.

7.3 Conclusions on Research Questions

7.3.1 Research Question 1

Question 1: What are the criteria and indicators used to assess sustainability in highway construction projects that are critical to highway professionals?

Despite an increasing emphasis on sustainability across various industries, there is still a significant gap in its implementation and understanding within road and highway infrastructure development, particularly in Sub-Saharan Africa. The literature review highlighted a fragmented consensus amongst stakeholders concerning the methodologies and benefits of sustainability in road and highway construction, despite a growing global consciousness of sustainability's significance within the construction milieu. Most road and highway construction projects in Ghana continue to employ a conventional approach, segregating design and construction phases and impeding contractor involvement at the design stage, thereby stifling stakeholder collaboration, escalating costs, and prolonging project timelines. Enhancing sustainability necessitates implementing integrated design processes with sustainability indicators from the project's inception, embracing the unified perspective of various stakeholders.

Empirical evidence on the adoption of sustainable practices in Ghana's road and highway construction is scant, with literature often overlooking the role of indigenous knowledge in fostering sustainability in infrastructure construction. The integration of local knowledge into established sustainability indicators could offer novel, culturally attuned approaches to sustainable construction, leveraging Ghana's rich indigenous knowledge base. Literature also talks about the new sustainability assessment tools made just for

building roads and highways. These tools set standards for building infrastructure, but they don't always take into account all aspects of sustainability, and they might not work perfectly in developing countries because of differences in geography and culture.

This study identified 80 potential sustainability indicators capable of enhancing road and highway infrastructure development in Ghana. Through a survey among local industry stakeholders and subsequent statistical analysis, 29 critical indicators were distilled. These indicators, summarized within a conceptual model, aim to streamline sustainability in road and highway construction by aligning with the local context and addressing various sustainability dimensions. These indicators have been categorized into six fundamental criteria: economic value, environmental impact, social equity and culture, technical quality, project implementation and management, and resource utilization and management.

This study's findings demonstrate a comprehensive and balanced appraisal of sustainability dimensions within the context of road and highway infrastructure development. The discernment of these critical indicators facilitates the formulation of effective sustainability strategies for road and highway construction endeavours. Such a strategic formulation is instrumental in advancing towards the creation of decision-making guidelines that summarise sustainable practices in the construction of road and highway infrastructure.

7.3.2 Research Question 2

Question 2: How do the perceptions of highway construction professionals about the sustainability criteria and indicators relate to their support for climate action?

Exploring the intersection of highway construction professionals' perspectives on sustainability and their support for climate action forms the crux of Research Question 2, framed within the ambit of the United Nations' 2030 Agenda for Sustainable Development. Goal 13 of this agenda posits climate action as integral to achieving the Sustainable Development Goals (SDGs), spotlighting the global importance of confronting climate change and its far-reaching implications. The academic literature outlines a marked synergy between efforts aimed at climate mitigation and the broader spectrum of sustainable development, advocating for a collective endeavour from all societal sectors to diminish the impacts of climate change. This analysis ventures into understanding how perceptions held by professionals in road and highway construction—

spanning environmental, economic, and technical domains, alongside considerations of social equity, project management, and resource utilisation—align with their inclination towards climate action.

Utilising structural equation modelling (SEM), this study scrutinises the analogy between highway professionals' valuation of sustainability indicators and their commitment to climate action efforts. This investigation proceeds in two pivotal phases: the initial development of a measurement model, followed by the establishment of a structural model. Through this analytical lens, the research unravels the complex relationship between professionals' appraisal of sustainability criteria and their endorsement of climate action measures. SEM's robust capability to identify latent correlations and model complex relationships offers profound insights into the dynamic interplay between sustainable practices in road and highway infrastructure development and the advocacy for climate action among construction professionals.

7.3.3 Research Question 3

What would guide the decisions of highway construction professionals for sustainable road and highway infrastructure development?

Addressing Research Question 3, this inquiry explores the mechanisms that could inform the decisions of professionals involved in the construction of sustainable road and highway infrastructure. It is critical to underline that mere high scores on sustainability assessments do not unequivocally translate to "more sustainable construction." The devised assessment tools clarify that such scores primarily serve as quantitative reflections of the extent of incorporation of certain sustainable practices and characteristics within the construction process, rather than offering a comprehensive measure of sustainability.

The core of this investigation involved an in-depth exploration of critical sustainability indicators pertinent to road and highway construction, facilitated through a series of semi-structured interviews with industry stakeholders. The insights gathered from these discussions were instrumental in the formulation of decision-making guidelines, detailed in Chapter 5, grounded on the contributions and perspectives of the interview participants.

A notable feature of these guidelines is the integration of SWOT analysis, which evaluates the strengths, weaknesses, opportunities, and threats associated with each identified sustainability indicator specific to road and highway construction. This analytical

framework enriches the decision-making process by juxtaposing the benefits and challenges of each indicator, thereby enabling designers and project managers to make informed choices that enhance the sustainability measure of their projects.

The guidelines are envisioned to foster a holistic and coherent approach among construction professionals, ensuring that sustainability considerations are prioritized and embedded in the project planning and execution phases. By advocating for an early and consistent integration of sustainability criteria, the guidelines aim to bridge the gap between sustainability ambitions and practical implementation, ensuring that the interests and concerns of all stakeholders are addressed. This strategic orientation highlights the imperative for construction professionals to adopt more integrated, informed, and sustainable practices in the development of road and highway infrastructure.

7.4 Research contributions.

The comprehensive examination of sustainability considerations, coupled with the broad engagement of industry practitioners within this research, facilitates significant contributions to both the academic sphere and practical applications in the industry.

7.4.1 Contribution to Academic field

This research significantly enriches academic understanding by identifying a gap in the comprehensive assessment of sustainability in road and highway infrastructure development, particularly in Ghana. Previous research efforts have predominantly focused on singular aspects of the Triple Bottom Line (TBL) framework, such as economic or social dimensions, without adopting an integrative approach that encompasses the full spectrum of sustainability concerns. In Ghana, the development of road and highway infrastructure has largely been associated with government initiatives, making political landscapes and governmental backing crucial elements in their execution. This research advances the discourse by investigating the environmental, economic, and social pillars of sustainability in road and highway construction and broadening the scope to include critical aspects such as "technical quality," "project implementation and management," and "resource utilisation and management." By incorporating all aspects of project delivery, including deadline adherence, budget management, stakeholder involvement, and seamless integration of sustainability goals into project management methods, these extra dimensions enhance the sustainability assessment framework. Furthermore, "resource utilisation and management" emphasises the judicious use of resources, waste minimization, and recycling, advocating for

sustainability across the project lifecycle. By incorporating these additional dimensions, the study introduces a novel perspective to the sustainability discourse in road and highway infrastructure development. It offers a holistic view that integrates managerial, technical, and resource-oriented strategies, thereby contributing a unique paradigm to academic literature. The Ghanaian context, where road and highway construction projects deeply integrate with governmental policies and initiatives, underscores the significance of a comprehensive approach to sustainability that takes into account political, social, and environmental factors.

This study makes a significant academic contribution by presenting critical sustainability indicators within the context of road and highway infrastructure development in Ghana, a developing nation. The synthesis of empirical findings and extant literature reveals notable differences in the prioritization of sustainability indicators between developed and developing countries. In particular, this research highlights the paramount importance of “material costs” as a sustainability indicator within the Ghanaian construction industry—a perspective that differs markedly from the consensus in developed countries. In regions with well-established supply chains and economic stability, the cost of materials often does not emerge as a critical concern in the sustainability discourse, a contrast starkly highlighted in this study. This discrepancy stresses the in-depth nature of sustainability challenges and priorities across different geographic and economic contexts, contributing to a deeper understanding of global sustainability practices in the construction sector.

This research marks the first comprehensive exploration into how highway construction professionals' perceptions of sustainability criteria influence their advocacy for climate action within the framework of sustainable development in road and highway infrastructure. The analysis, rooted in a review of scholarly literature and empirical data, reveals a sophisticated interplay between professionals' views on sustainability and their support for climate initiatives. It notably identifies economic factors and resource management as key drivers of climate action endorsement, highlighting their crucial contribution to the advancement of sustainable infrastructure practices. Conversely, the impact of environmental sustainability criteria on climate action advocacy was found to be less significant than initially expected, pointing to a compelling area for further scholarly exploration to unravel the dynamics at play. The research highlights the fundamental interconnectedness of climate action with the wider spectrum of sustainability objectives in infrastructure development, emphasising the imperative for a

cohesive integration of climate considerations into sustainability strategies for road and highway construction.

This research extends the current body of knowledge by offering a comprehensive examination of both the potential benefits and the challenges associated with pursuing sustainability in the context of road and highway infrastructure development. Unlike prior studies, this investigation explores the perceptions of key stakeholders regarding the opportunities and barriers to sustainability, offering pragmatic guidelines tailored for practitioners in developing countries like Ghana. Significantly, this study enriches academic discourse by integrating various perspectives across various professions, emphasising the importance of recognising both the positive and negative facets of sustainability initiatives. Furthermore, it highlights the importance of prioritising sustainability in developing economies, which are still navigating the complexities of implementing effective, contextually appropriate solutions. Through this in-depth approach, the research presents a more holistic view of sustainability, advocating for comprehensive strategies that address the unique challenges faced by developing regions in their quest for sustainable development in road and highway construction.

7.4.2 Contribution to Practice

In this research, the application of SWOT analysis emerged as a central framework for comprehensively understanding the internal and external dynamics affecting each critical sustainability indicator. By evaluating both the advantages and challenges associated with sustainability efforts, this analytical approach facilitates an in-depth decision-making process that aids in selecting the most effective sustainability strategies. Within this framework, the integration of action plans provides detailed guidance on enhancing the sustainability of each critical indicator, proposing a systematic methodology for designers and project managers to incorporate sustainability considerations into project planning and execution. Project briefing documents should ideally incorporate this structured approach to decision-making as a reference point for implementing sustainability solutions. Additionally, this study spells out the clear duties of everyone involved in road and highway infrastructure projects when it comes to achieving sustainable results. It suggests that these duties could be written into contracts. As a result, this study equips contractors and project designers with a strategic tool to assess and optimize the sustainability potential of road and highway construction projects, promoting a comprehensive approach to sustainable infrastructure development.

This study furnishes actionable guidelines designed to serve as a practical resource for designers and project managers, who occupy critical roles in shaping the sustainability outcomes of road and highway infrastructure projects. The guidelines have the potential to improve the dynamics of collaboration, consultation, and communication among stakeholders involved in the decision-making process of road and highway infrastructure development. By focusing on the integral positions these professionals hold, the guidelines aim to equip them with a structured approach to incorporating sustainability considerations effectively into project planning and execution phases. As a result, this research contributes to the operationalization of sustainability principles in the construction sector, offering a framework for integrating sustainable practices within the ambit of road and highway construction projects.

7.5 Research Limitations

This research has formulated comprehensive guidelines to aid decision-making, offering a structured methodology for designers and project managers to enhance the sustainability of road and highway construction projects. However, this research drew some boundaries to maintain a specific focus on its objectives. This implied that there were five limitations to the research:

One of the limitations of this research is the absence of case studies to supplement the quantitative and qualitative analyses. The use of surveys and interviews yielded significant insights into professionals' perceptions and attitudes towards sustainability in road and highway infrastructure development. However, the incorporation of case studies could have enhanced the findings by providing tangible examples of the application of sustainability indicators in real-world scenarios. Case studies could have served as practical illustrations of the challenges and successes encountered in integrating sustainability practices, thereby providing a more in-depth understanding of the theoretical concepts discussed. The absence of such detailed, context-specific explorations means that the research might lack the depth of understanding that comes from examining the application of sustainability principles to specific, tangible projects. Future research could address this gap by incorporating case studies that demonstrate the implementation of sustainability indicators, thereby enhancing the applicability and comprehensiveness of the research findings in practical settings.

This study's notable limitation is the exclusion of road users from the stakeholder group. Although the research thoroughly examines the viewpoints of professionals in highway

construction, such as engineers, project managers, and contractors, it fails to consider the crucial insights that end-users of the infrastructure could provide. Road users, as primary beneficiaries and interactants with the highway infrastructure, possess unique perceptions and experiences that could significantly inform the sustainability and usability aspects of road and highway development projects. Their exclusion means that the study may not fully capture the comprehensive impact of sustainability practices on user satisfaction, safety, and the overall utility of the infrastructure. Incorporating road users' viewpoints could have provided a richer, more holistic understanding of the effectiveness of sustainability indicators in meeting the needs and expectations of the broader community. Adding road users to the stakeholder analysis in future studies could make the research more useful and broaden its scope. This would make sure that the sustainability frameworks and guidelines created take into account the different wants and needs of everyone who is affected.

A third limitation concerns the relatively small number of interviewees (14) involved in the research framework validation. While these participants were carefully selected based on their expertise and experience in road and highway construction, the limited sample size may affect the generalisability and robustness of the qualitative findings. A larger pool of interviewees could have provided more varied perspectives and potentially uncovered additional insights into the practical implementation of sustainability indicators. The small sample size might have implications for the reliability and validity of the recommendations, as the experiences and viewpoints captured may not fully represent the broader spectrum of industry professionals.

A fourth limitation relates to the disproportionate representation among the interviewed stakeholders. The study included nine participants from government agencies, compared to only one contractor and two consultants from the private sector. This imbalanced distribution could potentially skew the findings towards perspectives predominantly held by public sector professionals. The underrepresentation of private sector viewpoints might limit the comprehensive understanding of sustainability implementation challenges and opportunities across different sectors of the industry. The potential bias in the qualitative data towards public agency perspectives could affect the broader applicability of the research findings and recommendations.

7.6 Recommendations for future research

This study offers more prospects for investigating sustainability advancements that specifically target the construction of roads and highways. A number of suggestions are offered for prospective investigations:

In order to enhance future research endeavours, it is advisable to broaden the purview of stakeholder participation to encompass road users. Their inclusion is crucial for obtaining a more comprehensive understanding of sustainability impacts and user satisfaction. Road users' experiences and feedback can provide valuable insights into the practicality, safety, and environmental aspects of road and highway infrastructure, which are crucial for developing more sustainable and user-centred design strategies. This approach will ensure that future studies address the needs and preferences of all stakeholders, contributing to the creation of more inclusive and sustainable road and highway infrastructure projects.

Future research should ensure balanced representation across different stakeholder groups, particularly between public and private sector participants. A more proportionate distribution (e.g., equal representation from government agencies, contractors, consultants, and other relevant stakeholders) would provide more comprehensive insights and reduce potential bias in the findings. This balanced approach would better capture the diverse perspectives and challenges faced by different sectors of the industry in implementing sustainable practices.

Future research should endeavour to validate and test the findings of this study within various developing country contexts beyond Ghana. This expansion is crucial to ascertaining the universal applicability and adaptability of the developed guidelines, recognising that modifications may be essential to aligning with local specificities and practices. Thus, ensuring that the insights gained can confidently be extrapolated to other African nations and beyond. Further studies are recommended to undertake a comparative analysis incorporating the industrial conditions of various developing countries. Such an approach will significantly enhance the breadth of applicability of this research's outcomes, fostering a more comprehensive understanding of sustainable road and highway infrastructure development across different geopolitical and socio-economic landscapes.

Future studies should explore the integration of decision-making guidelines into a digital framework, creating a comprehensive tool that streamlines the analysis of constraints and scenarios at the project level. This digital tool would significantly support project managers and designers in navigating the complexities of sustainable road and highway construction projects. Moreover, the implementation of an automated reporting mechanism could transform the communication of outcomes, delivering clear and concise reports that aid in informed decision-making. Further exploration could also lead to the development of a knowledge management platform aimed at fostering the exchange of insights and experiences from previous projects. Such an innovation would not only enhance the collective understanding of sustainable practices but also encourage the adoption of proven strategies across the construction industry.

7.7 Conclusion

There is a growing global recognition of the necessity of including sustainability ideas in construction processes. Particularly in developing nations like Ghana, there's an increasing demand to enhance construction efficacy. Within such a context, this thesis explores the critical domain of decision-making and knowledge facilitation concerning road and highway construction. Through statistical analysis, the research examines the significance of various sustainability indicators pertinent to road and highway infrastructure development. This investigation's questionnaire responses identified 29 critical indicators, which were further scrutinised through semi-structured interviews. A conceptual framework emerged, organised into six sustainability categories: economic value, environmental impact, technical quality, social equity and culture, project implementation and management, and resource utilisation and management. These findings informed the establishment of comprehensive guidelines designed to aid the decision-making process in sustainable construction practices.

SWOT analysis was employed in this context to assist decision-makers in comprehending how to capitalise on opportunities by leveraging existing strengths, mitigating weaknesses, and identifying potential threats in the analysed matters. This decision-making tool is proposed to be integrated into project briefing documents to inform and guide sustainability initiatives by project managers and designers. Furthermore, it outlines the explicit responsibilities of professionals within road and highway construction towards sustainability goals, suggesting their integration into contractual obligations.

The thesis is centered on the advocacy for an integrated assessment process and the critical role of collaborative engagement among key stakeholders. This approach is critical for a comprehensive evaluation of sustainability indicators and fostering effective construction practices. The decision-making guidelines developed herein offer a shared platform for stakeholder consensus, providing a cohesive methodology for sustainable decision-making in the field of road and highway infrastructure development.

“Like the art of sausage-making, a PhD journey may seem messy and daunting at first, but with patience and dedication, it transforms into something refined and worthy of pride.”

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Appendix A - Tools & Sample of Test Results

(a) Ethics Approval



9 May 2023

John Tookey
Faculty of Design and Creative Technologies

Dear John

Re Ethics Application: **22/327 Developing an enhanced framework of Sustainability deliverables in Ghanaian highway construction projects.**

Thank you for your responses to AUTEK's conditions.

Your ethics application has been approved for three years until 9 May 2026.

Non-Standard Conditions of Approval

On the survey Information Sheet remove the reference to keeping the Consent Form and include the researchers' professional affiliations if any.

Non-standard conditions do not need to be submitted to or reviewed by AUTEK unless requested but must be completed before commencing your study.

Standard Conditions of Approval

The research is to be undertaken in accordance with the [Auckland University of Technology Code of Conduct for Research](#) and as approved by AUTEK.

All public facing documents must have the AUTEK approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.

Any amendments to the project must be approved by AUTEK prior to being implemented. A progress report is due annually on the anniversary of the approval date.

A final report is due at the expiration of the approval period, or, upon completion of project.

Any serious or adverse events must be reported to AUTEK, this includes unforeseen issues that might affect continued ethical acceptability of the project.

AUTEK grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online <http://www.aut.ac.nz/research/researchethics>

For any enquiries, please contact ethics@aut.ac.nz

(This is a computer-generated letter for which no signature is required)

The AUTEK Secretariat

Auckland University of Technology Ethics Committee

Cc: george.okyere.dokyi@autuni.ac.nz

(b) Questionnaire Survey



21 April 2023

Dear Madam / Sir,

My name is George Okyere Dokyi. I am doing a PhD at Auckland University of Technology on the topic "Developing an enhanced framework of sustainability deliverables in Ghanaian highway construction projects". Because of your expertise in the field, I am asking if you can participate in my research project. Your participation includes a short questionnaire survey, which will take 20–30 minutes to complete.

If you are interested, here is the link to the participant's information sheet and the questionnaire. https://qfreeaccountssjc1.az1.qualtrics.com/survey-builder/SV_2mGoZYPWpTNKR9Q/edit

The information provided by you will be treated with the strictest confidentiality, with no references will be made to specific individuals in the thesis document, journal publication, or conference presentations.

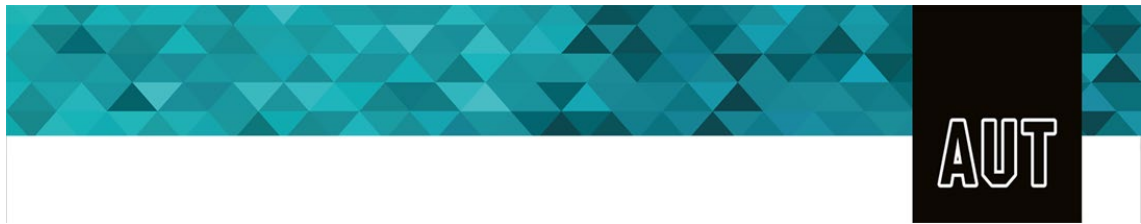
Should you have any questions or would like further information, please do not hesitate to contact me through email at george.okyere.dokyi@autuni.ac.nz .

Thank you in advance for your participation.

Yours truly,

George Okyere Dokyi

(c) Interview guide.



Introduction

Thank you for agreeing to participate in the interview. We are interviewing you as part of a PhD research project that is being conducted with the main goal of developing an enhanced framework and guidelines for ensuring sustainable highway infrastructure development in Ghana. At this point, your participation in this interview will contribute to the establishment of guidelines or action plans for a number of identified critical sustainable indicators that could be applied during the planning, design, construction, and operational phases of highway infrastructure development in Ghana.

The interview will take approximately one hour, depending on how much information you would like to share. With your permission, I would like to audio record the interview because I don't want to miss any of your comments. All responses will be kept confidential. This means that your interview responses will only be shared with members of the research team, and we will ensure that any information we include in our report does not identify you as the respondent. You may decline to answer any question or stop the interview at any time and for any reason. May I turn on the digital recorder? Are there any questions about what I have just explained?

Establishing rapport

- It would be nice if you could tell me a little bit about yourself.
- How long have you been working in the road and highway industry?

Main interview

Figure 1 and Table 1 show a list of highway construction and design sustainability indicators that have already been identified through a questionnaire survey. Can you share with us your experience, views, and perspective on each of the identified sustainability indicators by touching on the following:

- i. **Strengths of the indicators** that bring a positive influence on sustainable highway infrastructure development.
- ii. **Weaknesses and challenges associated with the indicators** that restrict their ability to bring a positive influence on sustainable highway infrastructure development.
- iii. **Opportunities** (i.e., political, environmental, institutional, technical, technological, economic, social, sectoral, and/or cross-sectoral features) that create the **positive potential** for the application of the indicators for sustainable highway infrastructure development.
- iv. **Threats** (i.e., political, institutional, environmental, legal, technical, technological, economic, social, sectoral, and/or cross-sectoral features) that create the

negative potential for the application of the indicators for sustainable highway infrastructure development.

- v. **Action plans** (i.e., what should be done based on the above issues to ensure the application of the indicators for sustainable highway infrastructure in Ghana?)

Theme 1: Strengths of the Sustainability Indicators

Prompts:

1. What are the advantages?
2. What can this indicator do well?
3. What are the elements supporting this indicator?

Theme 2: Weaknesses of the Sustainability Indicators

Prompts:

1. What about this indicator could be improved?
2. What is not being done properly about this indicator?
3. What should be avoided?
4. What obstacles prevent the incorporation of this indicator in highway infrastructure development?
5. Which elements need to be strengthened to promote the incorporation of this indicator in highway infrastructure development?
6. What are the complaints from industry professionals about this indicator?

Theme 3: Opportunities (external factors) for Promoting Sustainability Indicator Application

Prompts:

1. Where are the good chances facing the application of this indicator?
2. What benefit may occur if this indicator is applied?
3. What political factors could promote the application of this indicator?
4. What environmental factors could promote the application of this indicator?
5. What social factors could promote the application of this indicator?
6. What technological and technical factors could promote the application of this indicator?
7. What legal factors could promote the application of this indicator?
8. What sectoral and/or cross-sectoral factors could promote the application of this indicator?

Theme 4: Threats (external factors) restricting sustainability indicator application.

Prompts:

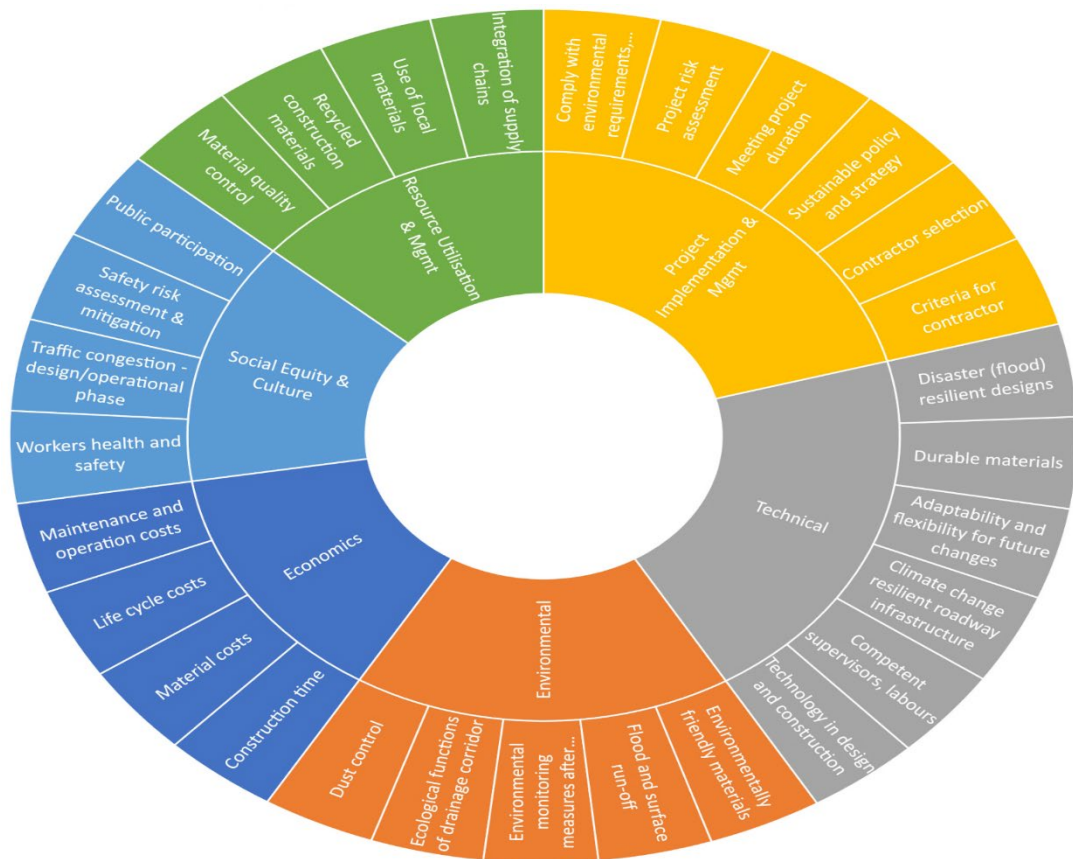
1. What are the obstacles to this indicator?

2. Are the required technical support and facilities for this factor available?
3. Is changing technology or policy threatening the factor?
4. Are stakeholders interested and willing to incorporate this indicator in highway development?
5. What political factors could restrict or discourage the application of this indicator?
6. What environmental factors could restrict or discourage the application of this indicator?
7. What social factors could restrict or discourage the application of this indicator?
8. What technological and technical factors could restrict or discourage the application of this indicator?
9. What legal factors could restrict or discourage the application of this indicator?
10. What sectoral and/or cross-sectoral factors could restrict or discourage the application of this indicator?

→ Thank you very much for your time and the information you shared today!

Demographic information

Demographics	
Name:	
Organisation:	
Years of experience in highway	
Qualification:	



Framework for developing guidelines on critical sustainable deliverables for Ghanaian road and highway infrastructure.

Table 1: Framework for developing guidelines on critical sustainable deliverables for Ghanaian road and highway infrastructure.

Criteria	Indicators
Economics	Reduce Life cycle costs
	Reduce Material costs
	Reduce Construction time
	Reduce Maintenance and operation costs
Environmental	Dust control
	Use of Environmentally friendly materials
	Preserve or improve ecological functions of drainage corridor
	Environmental monitoring measures after project completion
	Minimize flood and surface run-off
Technical	Application of durable materials
	Disaster (flood) resilient designs
	Design and construct climate change resilient roadway infrastructure
	Incorporate technology in design and construction
	Allow adaptability and flexibility for future changes
	Ensuring availability of competent supervisors, labours, etc
Project Implementation & Management	Comply with environmental requirements, contract documents and project specification
	Accomplish sustainable policy and strategy to improve construction efficiency
	Meeting project duration (completing the project on schedule)
	Project risk assessment

	Approach / Criteria for contractor (e.g., prequalification)
	Contractor selection
Social Equity & Culture	Safety risk assessment and mitigation during construction
	Improve worker's health and safety
	Reduction of traffic congestion - design/operational phase
	Public participation in early project phase
Resource Utilization & Management	Integration of supply chains- smooth flow of highway materials and other resources
	Use of local materials
	Material quality control
	Use of recycled construction materials

(d) Participant Information Sheet



Highway construction professionals in Ghana

Date Information Sheet Produced:

20 February 2023

Project Title

Developing an enhanced framework of sustainability deliverables in Ghanaian highway construction projects

An Invitation

I am George Okyere Dokyi, a PhD candidate at the School of Future Environment at Auckland the University of Technology (AUT) in Auckland, New Zealand. I cordially invite you to take part in stage one of this research. I am conducting this research to improve the sustainability deliverables framework in Ghanaian highway construction projects.

This research is a civil engineering doctoral dissertation about sustainability in highway construction projects.

What is the purpose of this research?

The purpose of this research is to develop a framework and guideline for improving sustainability deliverables in highway construction projects with special emphasis on the critical criteria and indicators used to assess sustainability and how these criteria and indicators related to the support of actions undertaken to achieve the Sustainable Development Goal 13.

The findings of this research will be used for academic publications and presentations.

How was I identified to participate in this research?

You were identified to participate in this research because you are a highway construction professional with both qualification and experience, and an employee of an organisation that is involved in the planning, design, and construction of highway projects in Ghana. You were identified through your publicly available email address on your organization's website, which identifies you and your role in the organization.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You may choose to quit the survey now and continue later by closing the browser and as the survey is anonymous, data is unable to be withdrawn after submission. Please note that this survey must be completed from the same computer to avoid losing previously given responses. Completion of this survey is considered as indicating your consent to participate.

What will happen in this research?

It is important to understand that your involvement in this study is voluntary. While I would be pleased to have you participate, I respect your right to decline. If you agree to participate in this project, I will invite you to participate in this survey, which will take approximately 30 minutes to complete. The research will ask questions about your opinions on sustainability in highway construction.

What are the discomforts and risks?

There are no discomforts and risks. The survey is anonymous and no personal information is sought that may divulge a participant's identity.

What are the benefits?

It is expected that this project will not directly benefit you except for receiving a copy of the completed guidelines. However, it may benefit the body of knowledge pertaining to sustainable development in highway construction, mainly through the identification of crucial attributes in the highway construction project. The result directly increases the stakeholders' awareness and knowledge, which will persuade them about the importance of sustainable development in their decision-making.

How will my privacy be protected?

The participants will be anonymous, and their responses will be kept confidential. The data from participants would be kept confidential by being stored in secured databases or cabinets with limited access. The data would be stripped of any identifying information. All digital files would be password-protected.

What are the costs of participating in this research?

There is no financial cost involved in participating in this research. The only cost of participating is the time you would spend answering the question which is estimated to be 30 minutes.

What opportunity do I have to consider this invitation?

This survey will take about 30 minutes to complete. However, the survey is open until June 30, 2023. Within this time, you can exit the survey by closing the browser and as the survey is anonymous, data is unable to be withdrawn after submission. A summary of the research will be available by bookmarking a link at the end of the survey.

In the new future, I may wish to conduct an interview to capture a deeper understanding and provide guidelines for the identified critical sustainability indicators to improve sustainable highway infrastructure development in Ghana. I would like to invite you to participate in the interview that would be structured in advance to minimize the discussion time and to maintain a standard format for the information required. Your time to assist with this research by sharing information about your experience would be much appreciated.

If you are willing to participate in the interview, kindly bookmark a link on the survey to provide your contact details to be contacted to give additional information about what this participation would involve so that you can make an informed decision about whether or not to participate.

Will I receive feedback on the results of this research?

In the questionnaire survey, a tick box will be available for participants to tick if they would like to receive a summary of the survey results in their emails.

In addition, this research will produce theses and conference presentations that will be publicly available.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified to the Executive Secretary of AUTECH, ethics@aut.ac.nz, (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Prof. John Tookey, Professor, School of Future Environments and Dr Funmilayo Egun Rotimi, Senior Lecturer, School of Future Environments

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Primary Researcher Contact Details:

George Okyere Dokyi
Email: george.okyere.dokyi@autuni.ac.nz

Project Supervisor Contact Details:

Prof. John Tookey
Professor, School of Future Environments
Email: john.tookey@aut.ac.nz

Dr Funmilayo Egun Rotimi
Lecturer, School of Future Environment
Email: funmilayo.egun.rotimi@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*,
AUTEC Reference number *type the reference number*.

(e) Consent form.

Project title: *Developing an enhanced framework of sustainability deliverables in Ghanaian highway construction projects.*

Project Supervisor(s): *Prof. John Tookey and Dr Funmilayo Egun Rotimi*

Researcher: *George Okyere Dokyi*

- I have read and understood the information provided about this research project in the Information Sheet dated 01 May 2023.
- I have had an opportunity to ask questions and to have them answered.
- I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- I agree to take part in this research.
- I wish to receive a summary of the research findings (please tick one): Yes No

Participant's signature:

Participant's name:

Participant's Contact Details (if appropriate):

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on *type the date on which the final approval was granted* AUTEK Reference number *type the AUTEK reference number.*

Note: The Participant should retain a copy of this form.

(f) Kruskal-Wallis Test

Ranks			
	Stakeholders	N	Mean Rank
Life cycle costs	Researchers/Academia	13	88.23
	Road Agencies	38	67.20
	Contractors	86	85.05
	Consultants	18	81.50
	Environmental Agencies	7	103.00
	Total	162	
Material costs	Researchers/Academia	13	105.58
	Road Agencies	38	62.49
	Contractors	86	85.97
	Consultants	18	78.81
	Environmental Agencies	7	92.07
	Total	162	
Construction time	Researchers/Academia	13	85.27
	Road Agencies	38	72.43
	Contractors	86	83.83
	Consultants	18	86.00
	Environmental Agencies	7	83.57
	Total	162	
Maintenance and operation costs	Researchers/Academia	13	90.85
	Road Agencies	38	68.74
	Contractors	86	80.55
	Consultants	18	93.11
	Environmental Agencies	7	115.21
	Total	162	
Dust control	Researchers/Academia	13	64.35
	Road Agencies	38	80.82
	Contractors	86	85.32
	Consultants	18	78.17
	Environmental Agencies	7	78.71
	Total	162	
Recycled construction materials	Researchers/Academia	13	84.38
	Road Agencies	38	73.01
	Contractors	86	82.64
	Consultants	18	94.25
	Environmental Agencies	7	75.43
	Total	162	
Environmentally friendly materials	Researchers/Academia	13	103.31
	Road Agencies	38	76.92

	Contractors	86	78.07
	Consultants	18	82.22
	Environmental Agencies	7	106.14
	Total	162	
Durable materials	Researchers/Academia	13	90.31
	Road Agencies	38	81.74
	Contractors	86	77.62
	Consultants	18	86.53
	Environmental Agencies	7	98.64
	Total	162	
Restoration possible vegetation	Researchers/Academia	13	78.73
	Road Agencies	38	82.05
	Contractors	86	79.18
	Consultants	18	94.83
	Environmental Agencies	7	77.86
	Total	162	
Ecological functions drainage corridor	Researchers/Academia	13	79.12
	Road Agencies	38	78.96
	Contractors	86	83.67
	Consultants	18	72.69
	Environmental Agencies	7	95.64
	Total	162	
Environmental monitoring measures	Researchers/Academia	13	75.42
	Road Agencies	38	65.67
	Contractors	86	86.52
	Consultants	18	93.22
	Environmental Agencies	7	86.93
	Total	162	
Groundwater management	Researchers/Academia	13	77.77
	Road Agencies	38	73.41
	Contractors	86	81.18
	Consultants	18	91.56
	Environmental Agencies	7	110.43
	Total	162	
Safety risk assessment	Researchers/Academia	13	75.12
	Road Agencies	38	77.46
	Contractors	86	84.66
	Consultants	18	84.42
	Environmental Agencies	7	69.00
	Total	162	
Minimize flood surface run-off	Researchers/Academia	13	86.00
	Road Agencies	38	78.89

	Contractors	86	75.86
	Consultants	18	104.00
	Environmental Agencies	7	98.71
	Total	162	
Comply environmental requirements project specification	Researchers/Academia	13	86.00
	Road Agencies	38	77.34
	Contractors	86	81.67
	Consultants	18	74.19
	Environmental Agencies	7	112.36
	Total	162	
Project control and monitoring guidelines	Researchers/Academia	13	66.73
	Road Agencies	38	68.04
	Contractors	86	85.83
	Consultants	18	84.06
	Environmental Agencies	7	122.29
	Total	162	
Sustainable policy and strategy	Researchers/Academia	13	69.92
	Road Agencies	38	70.09
	Contractors	86	85.15
	Consultants	18	84.11
	Environmental Agencies	7	113.36
	Total	162	
Competent supervisors labours	Researchers/Academia	13	106.65
	Road Agencies	38	90.55
	Contractors	86	74.07
	Consultants	18	83.94
	Environmental Agencies	7	70.64
	Total	162	
Worker's health safety	Researchers/Academia	13	87.88
	Road Agencies	38	78.18
	Contractors	86	80.54
	Consultants	18	87.75
	Environmental Agencies	7	83.36
	Total	162	
Traffic congestion-design/operations	Researchers/Academia	13	78.38
	Road Agencies	38	71.11
	Contractors	86	87.02
	Consultants	18	78.17
	Environmental Agencies	7	84.43
	Total	162	
Traffic congestion-construction	Researchers/Academia	13	80.96
	Road Agencies	38	68.14

	Contractors	86	87.13
	Consultants	18	81.08
	Environmental Agencies	7	86.93
	Total	162	
Public participation	Researchers/Academia	13	88.85
	Road Agencies	38	69.47
	Contractors	86	82.45
	Consultants	18	87.36
	Environmental Agencies	7	106.36
	Total	162	
Disaster resilient designs	Researchers/Academia	13	107.27
	Road Agencies	38	81.32
	Contractors	86	74.45
	Consultants	18	96.00
	Environmental Agencies	7	83.93
	Total	162	
Durable cost-effective highways	Researchers/Academia	13	122.54
	Road Agencies	38	91.18
	Contractors	86	65.92
	Consultants	18	99.64
	Environmental Agencies	7	97.50
	Total	162	
Climate change resilient designs	Researchers/Academia	13	124.62
	Road Agencies	38	66.99
	Contractors	86	80.31
	Consultants	18	78.58
	Environmental Agencies	7	102.29
	Total	162	
Technology design construction	Researchers/Academia	13	92.92
	Road Agencies	38	76.74
	Contractors	86	79.23
	Consultants	18	87.28
	Environmental Agencies	7	99.14
	Total	162	
Adaptability and flexibility	Researchers/Academia	13	98.46
	Road Agencies	38	69.26
	Contractors	86	84.07
	Consultants	18	84.03
	Environmental Agencies	7	78.36
	Total	162	
Supply chains	Researchers/Academia	13	76.69
	Road Agencies	38	65.76

	Contractors	86	87.61
	Consultants	18	82.75
	Environmental Agencies	7	97.57
	Total	162	
Meeting project duration	Researchers/Academia	13	72.96
	Road Agencies	38	77.92
	Contractors	86	81.51
	Consultants	18	89.78
	Environmental Agencies	7	95.36
	Total	162	
Project risk assessment	Researchers/Academia	13	84.38
	Road Agencies	38	71.64
	Contractors	86	83.56
	Consultants	18	85.47
	Environmental Agencies	7	94.14
	Total	162	
Criteria for contractor (prequalification)	Researchers/Academia	13	76.73
	Road Agencies	38	73.34
	Contractors	86	83.17
	Consultants	18	94.33
	Environmental Agencies	7	81.07
	Total	162	
Contractor selection	Researchers/Academia	13	76.73
	Road Agencies	38	80.78
	Contractors	86	80.26
	Consultants	18	85.89
	Environmental Agencies	7	98.21
	Total	162	
Local materials	Researchers/Academia	13	95.27
	Road Agencies	38	75.21
	Contractors	86	82.75
	Consultants	18	76.72
	Environmental Agencies	7	87.00
	Total	162	
Material quality control	Researchers/Academia	13	94.65
	Road Agencies	38	86.39
	Contractors	86	79.59
	Consultants	18	67.94
	Environmental Agencies	7	88.79
	Total	162	

(g) Mann-Whitney Test

Ranks				
	Stakeholders	N	Mean Rank	Sum of Ranks
Material costs	Researchers/Academia	13	11.12	144.50
	Environmental Agencies	7	9.36	65.50
	Total	20		
Project control and monitoring guidelines	Researchers/Academia	13	8.19	106.50
	Environmental Agencies	7	14.79	103.50
	Total	20		
Durable cost-effective highways	Researchers/Academia	13	11.69	152.00
	Environmental Agencies	7	8.29	58.00
	Total	20		
Climate change resilient designs	Researchers/Academia	13	11.73	152.50
	Environmental Agencies	7	8.21	57.50
	Total	20		

(h)Regression Weights

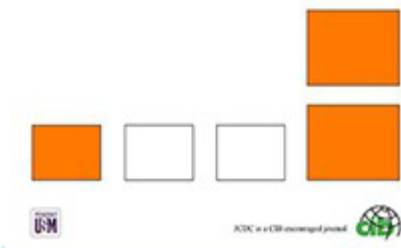
		Estimate	S.E.	C.R.	P
EC3_Construction_time	<--- ECON	.948	.135	7.007	***
EC2_Material_costs	<--- ECON	.602	.117	5.145	***
EC1_Life_cycle_costs	<--- ECON	.831	.136	6.104	***
EN4_Environmental_monitoring_measures	<--- ENVRN	1.036	.103	10.064	***
EN3_Ecological_functions_drainage_corridor	<--- ENVRN	1.000			
EN2_Environmentally_friendly_materials	<--- ENVRN	.836	.101	8.296	***
PM4_Project_risk_assessment	<--- PM	.911	.110	8.311	***
PM2_Sustainable_policy_and_strategy	<--- PM	1.008	.119	8.487	***
PM1_Comply_environmental_requirements_project_specification	<--- PM	1.000			
T5_Adaptability_flexibility	<--- TECH	.896	.095	9.428	***
T4_Technology_design_construction	<--- TECH	1.000			
T1_Durable_materials	<--- TECH	.730	.107	6.838	***
SC5_Public_participation	<--- SC	1.000			
SC4_Traffic_congestion_construction	<--- SC	1.367	.179	7.645	***
SC3_Traffic_congestion_design_operations	<--- SC	1.399	.185	7.574	***
RM3_Material_quality_control	<--- RM	1.000			
RM2_Local_materials	<--- RM	.992	.145	6.854	***
RM1_Supply_chains	<--- RM	.987	.150	6.589	***
M8_Consider_number_types_wattage_hours_oflights	<--- MTG	.998	.121	8.268	***
M7_Use_design_software_identify_energefficient_route	<--- MTG	1.246	.135	9.209	***
M6_Apply_monitor_climatechange_mitigation_plans_policies	<--- MTG	1.149	.142	8.066	***
M5_Construction_methods_social_context	<--- MTG	1.393	.160	8.707	***
M4_Incorporate_emissions_criteria_procurement	<--- MTG	1.318	.162	8.114	***
M3_Implementation_performance_based_award_criteria	<--- MTG	1.195	.149	8.020	***
M2_Incorporate_needs_of_vulnerable_people	<--- MTG	1.048	.137	7.671	***
EC4_Maintenance_and_operationcosts	<--- ECON	1.000			
AD1_Appropriate_network_data_hazard_assessment	<--- MTG	1.253	.154	8.113	***
AD2_Education_climate_change_adaptation	<--- MTG	1.259	.151	8.345	***
AD3_Use_natural_vegetation_sustainable_drainage_system	<--- MTG	1.000			
T3_Climate_change_resilient_designs	<--- TECH	.696	.098	7.071	***
PM3_Meeting_project_duration	<--- PM	.808	.107	7.578	***
PM5_Criteria_for_contractor_prequalification	<--- PM	.811	.104	7.837	***
EN1_Dust_control	<--- ENVRN	.659	.110	5.982	***
M1_Harness_local_topography	<--- MTG	1.153	.157	7.344	***

Appendix B Research paper submitted.

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Framework for Sustainable Road and Highway Infrastructure development in Developing Countries: The Ghana Context

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Framework for Sustainable Road and Highway Infrastructure development in Developing Countries: The Ghana Context

Abstract

There is a global rise in concern about sustainability issues across all sectors. Therefore, adopting sustainable highway infrastructure development is a huge success part of achieving sustainable transport, which is an integral component of several Sustainable Development Goals (SDGs) and the targets in the 2030 Agenda for Sustainable Development. However, most developing countries face sustainability challenges in the developing roads and highway infrastructure due to lack of a comprehensive framework for sustainable road infrastructures. The purpose of this study was to develop a framework for sustainable roads and highways development. Through a questionnaire survey, data were obtained from highway professionals including contractors, consultants, environmental agencies, road agencies and researchers and/or academics. Inferential statistics were performed using SPSS Statistics 26 to obtain the indicators considered critical by all highway professional groups. The findings revealed 31 critical indicators, out of which reduce material cost; complying with environmental requirements, contract documents and project specifications; and disaster- resilient designs emerged as the top three (3) critical indicators, highlighting the importance of economic efficiency, responsible project execution and infrastructure resilience. Apart from bridging the gap in literature from developing countries, the developed conceptual framework offers a structured approach to guide future initiatives in highway infrastructure development, emphasizing the integration of diverse criteria for a holistic and sustainable approach.

Keywords: Sustainability indicators, Highway development, Climate change resilience, Ghana

INTRODUCTION

Sustainable transport is considered an integral component of several Sustainable development goals (SDGs) and targets in the 2030 Agenda for Sustainable Development. Sustainable transport, however, cannot be achieved without sustainable road infrastructure (United Nations, 2023). This is envisioned in the 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". However, there is a global rise in concern about sustainability issues across all sectors (Owusu-Manu et al., 2023). Most developing countries, including Ghana, face sustainability challenges concerning the development of sustainable roads and highway infrastructure (Fuso Nerini et al., 2019; Xiao et al., 2020). These challenges cut across the various stages of the development of the road infrastructure (i.e., planning, design, construction, maintenance and operation). All these stages involve the roles of several stakeholders, and as urged by Bühler et al. (2023), all parties involved—local governments, contractors, consultants, and project managers must act rapidly to address the sustainability issues.

Ghana Road infrastructure has three main departments (i.e., Ghana Highway Authority,

Department of Feeder Roads, and Department of Urban Roads) who have been mandated to manage the roads and highway development in Ghana. As of 2017, the total road networks size in Ghana was 78,402km. The Ghana Highway Authority, the department of Feeder Roads, the Department of urban roads respectively had about 14,583km, 48,383 km, and 15,462km of the road network under their jurisdiction (Frimpong, 2022; Yeboah, 2022). These road agencies have been mandated with the requisite human and technical resources to ensure the sustainability of roads and highway infrastructure projects by collaborating at all stages of the road infrastructure development with state and non-state actors who play important roles in highway sustainability. There is however lack of a locally developed framework for sustainable roads and highways infrastructure development, a situation not only in Ghana but most sub-Saharan African countries. The results of this are lack of synergy among the activities of various road stakeholders and various highway professionals attempting to implement what they believe are the best-known standards of sustainability. There appears to be different stakeholder interests and multi-dimensional viewpoints on highway development. According to Mok et al. (2015), the inclusion of diverse perspectives and opinions from stakeholders in a comprehensive manner is necessary when making decisions regarding sustainable highway infrastructure development. It is worth mentioning that a search through the literature reveals that researchers have given little attention to enhancing sustainability in highway infrastructure development, especially in sub-Sahara Africa. Most of the sustainability frameworks for highway development from the literature are however, from developed countries from the USA and Europe, which may have different issues and indicators, compared to Africa and particularly Ghana. Issues studied in developed countries are unlikely to be applicable or even relevant to developing countries (Polat et al., 2006). There are different approaches as well as priorities to sustainable construction in different countries. It is important that to incorporate the local and regional characteristics in the physical environment when measuring the level of sustainability (Adler, 1998; Yunus & 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 main aim of this study is to develop a framework for the development of sustainable roads and highways. Specifically, this study seeks to 1) explore the attitudes and perceptions of the roads and highway professionals towards sustainability indicators. 2) identify the indicators considered critical by roads and highways professionals for sustainable roadway development. This study is distinct in its investigation of the concerns within the framework of project-level context, encompassing planning, design, construction, maintenance and operations. It contributes to the knowledge of sustainable highway infrastructure development in developing countries, with a particular focus on the identification of critical indicators in road and highway infrastructure development in developing countries. The findings of this study can serve as a valuable source of information for all stakeholders in the road infrastructure sector of developing countries, offering guidance on effectively implementing sustainable practices and assessing progress in road and highway development.