International Journal of Sustainable Transportation

ISSN: 1556-8318 (Print) 1556-8334 (Online) Journal homepage: www.tandfonline.com/journals/ujst20

A SWOT analysis of stakeholder perspectives on the strategic application of economic sustainability indicators in Ghana’s road infrastructure development

George Okyere Dokyi, Kwame Kwakwa Osei, John Tookey & Funmilayo Ebun Rotimi

To cite this article: George Okyere Dokyi, Kwame Kwakwa Osei, John Tookey & Funmilayo Ebun Rotimi (28 Apr 2025): A SWOT analysis of stakeholder perspectives on the strategic application of economic sustainability indicators in Ghana’s road infrastructure development, International Journal of Sustainable Transportation, DOI: 10.1080/15568318.2025.2496894

To link to this article: https://doi.org/10.1080/15568318.2025.2496894

Published online: 28 Apr 2025.

INTERNATIONAL JOURNAL OF SUSTAINABLE TRANSPORTATION
https://doi.org/10.1080/15568318.2025.2496894

A SWOT analysis of stakeholder perspectives on the strategic application of economic sustainability indicators in Ghana's road infrastructure development

George Okyere Dokyi[a], Kwame Kwakwa Osei[b], John Tookey[a], and Funmilayo Ebun Rotimi[a]

[a]School of Future Environments, Auckland University of Technology, Auckland, New Zealand; [b]Department of Engineering and Technology, Kumasi Technical University, Ghana

ABSTRACT

This study explores the economic criterion indicators for sustainable road and highway infrastructure development in Ghana through a phenomenological research approach. Using SWOT analysis and semi-structured interviews with 14 key stakeholders, including government officials, academics, and private sector professionals, the research examines four critical economic indicators: material costs, lifecycle costs, construction time, and maintenance and operation costs Through content analysis using ATLAS.ti 9 software, the study evaluates internal strengths and weaknesses, as well as external opportunities and threats affecting each indicator's implementation. The findings reveal multifaceted challenges including insufficient expertise in lifecycle cost analysis, inadequate maintenance funding, weak regulatory enforcement, and political interference. The study identifies strategic action plans for each indicator, including local material sourcing, improved procurement practices, capacity building initiatives, enhanced stakeholder collaboration, and technological integration. These recommendations are supported by specific deliverables and expert remarks that provide practical implementation guidance. This research contributes to sustainable infrastructure development theory and practice by providing a comprehensive framework for economic sustainability in Ghana's road and highway sector. While the study's geographical focus may limit generalisability, it offers valuable insights for policymakers and practitioners in developing countries facing similar challenges. The findings suggest that the successful implementation of economic sustainability indicators requires a coordinated approach combining technical expertise, policy reform, and stakeholder engagement, while considering local contextual factors.

ARTICLE HISTORY
Received 5 August 2024
Revised 27 January 2025
Accepted 15 April 2025

KEYWORDS
Economic sustainability; Ghana; highway development; lifecycle costs; road infrastructure

1. Introduction

The sustainable development of road and highway infrastructure is paramount to the socioeconomic progress of any nation. Roads and transportation projects have been linked to the creation of jobs, promotion of the local economy, and raising the living standards of the local communities (Mahmood et al., 2022). In Ghana, the need for robust and sustainable infrastructure is particularly pressing, given the country's rapid urbanization and economic growth (Akomea-Frimpong et al., 2023). However, Ghana faces significant economic challenges in its infrastructure sector, including limited funding mechanisms, cost overruns, inadequate maintenance budgets, and inefficient resource allocation (Asiedu & Adaku, 2019), which collectively threaten the sustainability of road development projects. Sustainable infrastructure development not only addresses immediate transportation needs but also ensures long-term economic viability, environmental protection, and social equity. This research focuses on exploring the economic criteria indicators that influence sustainable road and highway infrastructure development in Ghana. Economic sustainability in infrastructure projects involves a careful balance of various cost-related factors that collectively determine the overall financial feasibility and efficiency of such projects. Key economic indicators such as lifecycle costs, maintenance and operation costs, material costs, and construction time play crucial roles in shaping the sustainability outcomes of infrastructure development (Dokyi et al., 2024).

Understanding these indicators within the specific context of Ghana is essential for formulating effective strategies and policies that promote sustainable practices in the construction and management of road infrastructure. This is particularly crucial given Ghana's economic constraints, where infrastructure projects often face challenges such as limited public funding, high borrowing costs, currency fluctuations, and inflation pressures that impact project viability (Akomea-Frimpong et al., 2024). Lifecycle costs encompass the total expenses incurred throughout the lifespan of a road project, including initial construction, maintenance, operation, and end-of-life disposal costs. Proper management of these costs ensures that infrastructure remains economically viable throughout its entire lifecycle (Altaf et al., 2023). Maintenance and operation costs are critical for sustaining

CONTACT George Okyere Dokyi george.dokyi@aut.ac.nz School of Future Environments, Auckland University of Technology, Auckland, New Zealand.

the functionality and safety of roads, whereas material costs directly impact the initial investment and long-term durability of the infrastructure (Dai & Solangi, 2023). Additionally, construction time affects the economic efficiency of projects, as delays can lead to significant cost overruns and resource waste (Purushothaman et al., 2024).

Despite the importance of these economic criteria, there is a paucity of localized research addressing how they specifically impact sustainable road infrastructure in Ghana. Specifically, there is a lack of empirical studies that holistically explore the integration of economic indicators, including the reduction in life cycle costs, material costs, construction time, and maintenance costs, into sustainable highway infrastructure development in developing countries. Most of the existing studies often focus on developed countries, thereby overlooking the unique economic, social, and environmental contexts of developing nations (Goh et al., 2020). This research aims to fill the aforementioned gap by undertaking a comprehensive exploration of the economic indicators that shape sustainable infrastructure development, taking into account, their specific strengths and weaknesses, as well as the opportunities and threats present in Ghana's road and highway sector. Through this investigation, the study aims to develop recommendations for integrating economic sustainability considerations into road and highway infrastructure projects in Ghana. By addressing these objectives, this research contributes to the growing body of knowledge on sustainable infrastructure development in developing countries while providing practical insights for policymakers, project managers, and other stakeholders in Ghana's road and highway sector.

2. Literature review

The sustainable development of road and highway infrastructure encompasses various complex aspects, including economic, environmental, and social factors. Economic criteria, in particular, play a critical role in determining the feasibility and longevity of infrastructure projects. This literature review explores the economic criterion indicators that influence sustainable road and highway infrastructure development, focusing on lifecycle costs, maintenance and operation costs, material costs, and construction time. The theoretical framework guiding this study is grounded in the principles of sustainable development and economic analysis within the context of infrastructure projects. This framework provides a structured lens through which the economic criteria indicators influencing sustainable road and highway infrastructure development in Ghana are examined. By integrating theories of lifecycle cost analysis, sustainability, and project management, this study aims to offer a comprehensive understanding of how these economic indicators can be optimised to promote long-term viability and sustainability.

2.1. Sustainable development theory

Sustainable development theory, as articulated by Brundtland (1987), emphasizes the need to meet present needs without compromising the ability of future generations to meet their own needs. This theory highlights the importance of balancing the economic, environmental, and social dimensions of development. In the context of road and highway infrastructure, sustainable development theory provides a foundation for understanding how economic indicators such as lifecycle costs, maintenance and operation costs, material costs, and construction time contribute to sustainable outcomes.

Recent studies have increasingly emphasized the importance of economic sustainability in road and highway infrastructure development, particularly in developing countries. The concept of sustainable infrastructure has evolved to encompass not only environmental considerations but also economic and social dimensions (Opoku, 2019). This holistic approach aligns with the United Nations' Sustainable Development Goals, specifically Goal 9, which aims to build resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation (United Nations, 2015). In the context of road infrastructure, economic sustainability involves optimising costs throughout the project lifecycle while ensuring long-term viability and societal benefits. Patel and Ruparathna (2023) propose a comprehensive framework for assessing the sustainability of transportation infrastructure projects, highlighting the need for integrated evaluation methods that consider economic factors alongside environmental and social impacts. Their study highlights the importance of life cycle cost analysis (LCCA) as a crucial tool for economic sustainability assessment. Material costs, a significant component of infrastructure projects, have been the subject of recent research focusing on sustainable practices. Yaro et al. (2023) investigated the potential of recycled materials in road construction, demonstrating both cost savings and environmental benefits. Their findings suggest that the use of recycled materials can reduce material costs by up to 30% while maintaining performance standards, offering a promising avenue for economic sustainability in developing countries. Construction time, another critical economic indicator, has been examined in relation to project efficiency and cost optimisation. Alaloul et al. (2020) explored the application of lean construction principles in infrastructure projects and reported that these methods can significantly reduce construction time and associated costs. Their study in Malaysia, a developing country similar to Ghana, provides insights into potential strategies for improving construction efficiency. The importance of maintenance and operation costs in the long-term economic sustainability of road infrastructure is highlighted by Mahmood et al. (2024). Their research emphasized the need for proactive maintenance strategies to reduce lifecycle costs and extend the infrastructure lifespan. They argued that inadequate maintenance funding in developing countries often leads to premature deterioration of roads, resulting in higher long-term costs.

Recent advancements in technology have also influenced economic sustainability practices in infrastructure development. (Waqar et al., 2023) explore the potential of building information modeling (BIM) in optimizing the lifecycle costs of infrastructure projects. Their findings suggest that BIM can improve cost estimation accuracy and facilitate better decision-making throughout the project lifecycle. In the

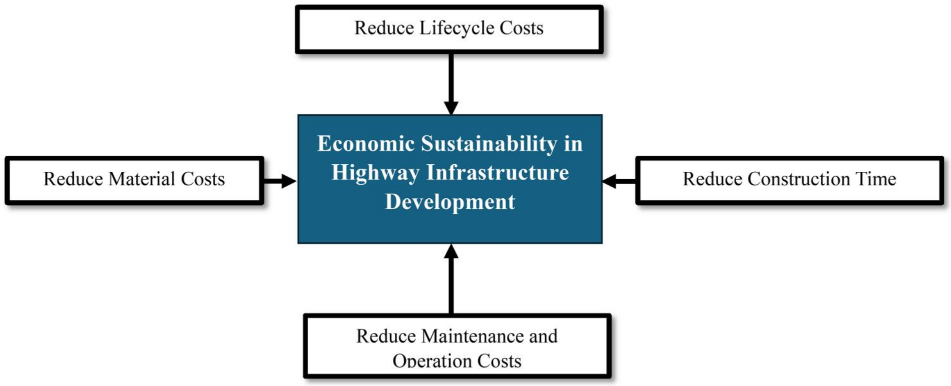

Figure 1. Conceptual framework diagram.

African context, Ametepey et al. (2023) examined the challenges and opportunities in sustainable road infrastructure development in Ghana. Their study identified funding constraints, inadequate planning, and poor maintenance practices as key barriers to economic sustainability. They emphasize the need for context-specific solutions that consider local economic conditions and resource availability.

2.2. Conceptual framework

Elkington's (1997) Triple Bottom Line theory has been applied across a wide range of sectors concerning sustainability issues. It is a framework that assesses the sustainability goals and outcomes of organisations from three perspectives: economic, environmental, social (Correia, 2019). These three dimensions interact with each other to in achieving sustainable development. Sustainable construction must ensure the delivery of environmental, social and economic sustainability in a balanced and optimal manner, without one pillar dominating any others (Goh et al., 2020). However, a critical evaluation of existing sustainability assessment frameworks in construction industry by Srivastava et al. (2021) reveals that economic sustainability is rarely evaluated. It is not surprising that several studies (e.g. Asiedu & Adaku, 2019; Ametepey et al., 2023; Gómez-Cabrera et al., 2024) highlight cost overruns as a key challenge in infrastructure projects, underscoring the need for improved incorporation of economic sustainability elements into the highway industry. The accurate evaluation of all cost components is important for making correct decisions on economic efficiency.

Economic sustainability in the construction industry represents an assessment of the long-term impact on economic activity (Alaloul et al., 2022; Spangenberg, 2005), involving a cyclical process that considers both input and output factors (Mandičák et al., 2024). Economic sustainability in highway infrastructure development can be understood through its contribution to long-term value creation, cost efficiency, and economic resilience, free of social and environmental problems (Ogunmakinde et al., 2022; Mandičák et al., 2024). The proposed framework for this study builds on the Triple Bottom Line by emphasizing economic sustainability, while incorporating a stronger focus on reduction in lifecycle costs, construction time, maintenance and operation costs, and material costs.

Figure 1 depicts the conceptual framework representing the relationships between the economic indicators and sustainable infrastructure development. This framework can be visualized as an interconnected system with reduction in lifecycle costs, construction time, maintenance and operation costs, and material costs as the pillars supporting economic sustainability in highway infrastructural development.

Life cycle cost of a highway project refers to the total cost of a project over its entire lifespan from the initial planning phase through to construction phase and to the rehabilitation phase or end life to enhance serviceability. This indicator is key to sustainable construction and has therefore received the attention of several researchers in the construction industry including Vega et al. (2022), Huang et al. (2021), Moins et al. (2020), and Heidari et al. (2020). Further, the difficulties in meeting scheduled completion time of projects have been a global problem (Rivera et al., 2020; Viles et al., 2020; Durdyev & Hosseini, 2019). In Ghana, 70% of projects have been reported to experience delays (Frimpong et al., 2003). The delays create severe dissatisfaction among road users, similar to the findings by Mahmood et al. (2020). This is an indication of the need for developing strategies to meet road project schedules and consequently reduce its negative impact on road users. Moreover, effective maintenance and operation practices extend the life of the highway infrastructure and provide a reliable roadway network but require financial resources and commitment. Studies including Ries et al. (2006), Dobiáš and Macek (2014), and Jones and Sharp (2007) have highlighted reduction of maintenance and operation cost as an essential indicator for economic sustainability of infrastructure projects. Materials make up a major cost component in any construction project, covering 50% or more of the total cost (Patil & Pataskar, 2013). Fluctuations in material prices especially have a significant effect on the life cycle cost analysis (Moins et al., 2020; Yu et al., 2015). It is therefore important for proper management of materials and its associated costs in highway construction (Adams et al., 2017).

While there is a growing body of research on sustainable infrastructure, significant gaps remain, especially regarding the economic criteria in developing countries such as Ghana. Existing studies frequently focus on developed nations, overlooking the unique challenges and opportunities presented by different economic environments. Existing literature has demonstrated the importance of economic criteria in sustainable road and highway infrastructure development, identifying critical gaps in areas such as lifecycle costs, maintenance and operation costs, material costs, and construction time. Addressing these gaps through localised, empirical studies will enhance our understanding of economic sustainability in Ghana's infrastructure development, provide valuable insights for policymakers and practitioners, and contribute to more effective decision-making and policy formulation.

2.3. Overview of selected indicators of economic sustainability of highway development

2.3.1. Lifecycle costs

Lifecycle costs are a key economic indicator for the construction of sustainable highway infrastructure in developing countries like Ghana. According to a study by Rodríguez-Fernández et al. (2020), lifecycle cost analysis (LCCA) offers a detailed assessment of the overall expenditure linked to infrastructure projects over their entire lifespan, including initial construction, maintenance and operation, as well as end-of-life disposal. This approach helps decision-makers evaluate the long-term financial viability of highway projects within a sustainability framework. The significance of LCCA is particularly evident in Ghana's context. Research estimates that Ghana could face cumulative costs of $473 million (2020–2100) for maintaining and repairing existing roads due to climate-related damages (Twerefou et al., 2015). The adaptation of design and construction methods for new road infrastructure could increase this cost to $678.47 million, highlighting the critical tradeoff between initial investment and long-term sustainability (Twerefou et al., 2015).

While LCCA is widely recognised as an essential tool, its application in developing countries faces several challenges including lack of required data. The integration of sustainability considerations adds complexity to project evaluation, and existing studies have not provided detailed guidance on identifying and managing sustainability-related costs in highway infrastructure (Goh & Yang, 2014). Furthermore, there is a lack of consensus on methodologies to guarantee sustainability assessment during the pavement lifecycle (Babashamsi et al., 2016). Research in Ghana reveals that while lifecycle cost is crucial, it operates within a broader sustainability framework. A study on urban green drainage infrastructure found that although 'Initial Construction Cost' ranked among the top five sustainability indicators, factors such as flood control and compliance with sustainable development goals received higher priority (Owusu-Manu et al., 2023). This suggests the need for a holistic approach that balances economic considerations with environmental and social factors.

To ensure infrastructure projects feasibility and sustainability goals, further research and standardisation of methodologies are required for the effective implementation of LCCA in developing countries (Acai & Amadi-Echendu, 2018; Babashamsi et al., 2016). With the aid of this balanced approach, policymakers and stakeholders can make well-informed decisions that increase resource allocation while maintaining long-term sustainability in infrastructure development.

2.3.2. Maintenance and operation costs

For the development of sustainable road and highway infrastructure in developing countries like Ghana, maintenance and operation costs are a key economic indicator. During the entirety of road infrastructure service life, maintenance and operation costs have a substantial impact on the long-term viability and performance. Research demonstrates that effective maintenance strategies can prolong the lifespan of infrastructure and decrease total lifecycle (Frangopol & Liu, 2018; Sánchez-Silva et al., 2016). Highways must be maintained in good condition to ensure safe and efficient operation over their lifespan, requiring well-planned and strict maintenance practices. Proper maintenance ensures the longevity and efficiency of roads, reducing the need for costly repairs and replacements. Yang et al. (2018) and Mazele and Amoah (2022) highlight that sustainable infrastructure requires a proactive maintenance strategy that considers long-term economic impacts.

In Ghana's context, maintenance and operation costs pose unique challenges due to resource constraints and institutional limitations. Studies show that developing countries often struggle with inadequate funding and ineffective management practices, leading to accelerated infrastructure deterioration (Mazele & Amoah, 2022; Yilema & Gianoli, 2018). These challenges include limited budgetary allocations, weak institutional frameworks, and insufficient technical capacity (Badu et al., 2012; Greenham et al., 2023).

The relationship between maintenance costs and sustainability extends beyond financial considerations. Research indicates that proper maintenance practices contribute to environmental sustainability by reducing material waste and extending pavement life, while also enhancing social benefits through improved road safety and user satisfaction (Giustozzi et al., 2012). This emphasize the need for integrated approaches that consider both immediate maintenance needs and long-term sustainability goals. There is the need for better maintenance planning systems, improved institutional capacity, and innovative financing mechanisms in developing countries like Ghana to address these challenges as suggested by research. This calls for a transformation in maintenance practices from reactive to proactive, backed by adequate financial resources and technological know-how to achieve sustainable infrastructure development.

2.3.3. Construction time

Construction duration is a key economic indicator for the development of sustainable road and highway infrastructure, especially in developing countries like Ghana. Research revealed that with an average time overrun of 17 months and cost overruns reaching US$1.15 million, or 22.5% of the initial budget, around 70% of road projects in Ghana encounter delays (Amoatey & Ankrah, 2017; Frimpong et al., 2003). These delays are caused by a number of circumstances, such as problems with finance and payments, inadequate contract management, material shortages, difficulties with utility relocation, and design modifications. Construction timetables are also impacted by uncontrollable elements like rainfall. As noted by Purushothaman et al. (2024), delays are often caused by poor planning, lack of skilled labor, and inadequate funding. These delays significantly affect project sustainability, impacting not only lifecycle costs but also contributing to environmental and health problems. The most critical causes of delays include financial issues, inadequate contractor experience, changes in project scope, site delivery delays, and inflexible funding allocation (Amoatey & Ankrah, 2017).

Efficient project management and timely completion are essential for minimising economic waste and optimising resource use. However, in Ghana, while these issues are prevalent, there is a lack of specific studies examining the impact of construction time on economic sustainability of road projects. The difficulties in meeting scheduled completion times remain a global challenge (Cai et al., 2024), requiring measures to ensure highway projects are completed on schedule. This is a serious concern, as these crucial construction delays can profoundly affect the economic feasibility and sustainability of road infrastructure projects, impacting both immediate project outcomes and long-term economic growth.

2.3.4. Material costs

The overall project expenditure comprises of 50% or more of materials, which are a significant cost factor in road and highway construction (Koushki & Kartam, 2004; Patil & Pataskar, 2013). The cost of materials has a direct influence on both construction and maintenance costs in Ghana, making it an important economic indicator for the development of sustainable infrastructure. Project costs are significantly affected by material price fluctuations, which must be considered in project cost estimates (Belachew et al., 2017). These fluctuations have a substantial effect on lifecycle cost analysis (Moins et al., 2020; Yu et al., 2015). In Ghana specifically, building material prices have been increasing due to factors including crude oil prices, energy costs, taxes, and transportation expenses (Danso & Obeng-Ahenkora, 2018).

Cost overruns remain a major challenge in highway construction (Hussin et al., 2013), closely associated with material availability and type (Koushki & Kartam, 2004). Effective material management, including coordination of purchasing, shipping, and supplier control, is crucial for cost control (Phani & Mathew, 2019). While sustainable materials may have higher upfront costs, they can reduce long-term maintenance expenses and environmental impacts. Research by Wakjira et al. (2024) emphasizes the importance of selecting materials that balance cost, durability, and sustainability. To promote sustainable construction, Ghana must address barriers such as higher initial costs and limited government support (Ametepey et al., 2015; Djokoto et al., 2014). Having rules in place that maximise resource utilisation while taking environmental impacts into account through lifecycle assessments can be facilitated by achieving a balance between economic growth and environmental stewardship in infrastructure development (Kindo et al., 2024).

2.4. SWOT analysis

The strategic instrument for assessing outcomes of projects and planning in different fields, including road and highway infrastructure development, is SWOT Analysis, which was initially created for corporate management and has become essential (Cheng et al., 2023; Hosseini Dehshiri et al., 2024). The framework systematically examines internal factors (strengths and weaknesses) and external factors (opportunities and threats) that can potentially impact project or organizational success. The internal environment consists of variables within an organisation's control, while the external environment comprises variables outside immediate organisational control. These variables collectively form the context in which projects or organisations operate (Houben et al., 1999). Through this systematic examination, SWOT analysis facilitates informed decision-making in infrastructure projects (Kamran et al., 2020).

Strategy formulation using SWOT involves developing long-term plans that effectively respond to environmental opportunities and threats while leveraging organisational strengths and addressing weaknesses (Houben et al., 1999). The framework's versatility is demonstrated through its successful application across various fields, from health technology assessment (Behzadifar et al., 2023) to construction industry planning (Lu, 2010) and sustainable agriculture evaluation (Das et al., 2022). In infrastructure development specifically, SWOT analysis has proven valuable for evaluating innovation systems (Awuzie et al., 2021) and implementing new technologies (Zima et al., 2020). The framework enables managers to identify and address key factors influencing project success and sustainability, ultimately improving environmental outcomes and mitigating negative impacts in road projects (Montgomery et al., 2014). To assist organisations in overcoming obstacles and achieving sustainable development objectives, a thorough assessment generally yields strategic methods.

This study seeks to develop strategic action plans and identify the potential deliverables to incorporate economic sustainability in the development of highway infrastructure. Although SWOT analysis is a research method, which has been generally employed in business plans, it is used, in recent times, to evaluate issues and policies related to decision-making and to evaluate sustainable highway infrastructure development (Cheng et al., 2023; Leandri et al., 2020; Qayyum et al., 2023). SWOT analysis unlike PESTEL, which focuses on only external factors, has the advantage of addressing both external and internal factors that affect projects (Kansongue et al., 2023; Pan et al., 2019). The internal and external factors serve as the foundation for the development strategic action plans for sustainable highway infrastructural development. SWOT analysis can be carried out for a product, place, industry or person by specifying the business or project objective as well as identifying the internal and external factors that promote or inhibit the process for achieving that objective (Ghorbani et al., 2015). SWOT analysis was, therefore, considered an appropriate tool for addressing the objective of this study. In this study, the main internal and external factors affecting the incorporation of each economic indicators of sustainable highway infrastructure development were studied and identified.

3. Methodology

This research adopts a phenomenological design, based on a constructivist ontological perspective, to examine stakeholders' views and perceptions concerning economic sustainability indicators that affect sustainable road and highway infrastructure development in Ghana. A phenomenological design acknowledges that the reality of economic sustainability indicators is socially constructed through the interactions, experiences, and interpretations of stakeholders involved in this sector (Hahn & Knight, 2021). The qualitative study aims to uncover how the strategic implementation of economic sustainability indicators is understood, prioritised, and enacted within the specific cultural, economic, and environmental contexts of Ghana. It recognises the diverse perspectives of stakeholders, including government and regulatory bodies (e.g., Ghana Standard Authority, Environmental Protection Agency), consultants, contractors, and academic institutions, which shape the understanding and implementation of economic sustainability in construction. Qualitative approach was utilised because this study depended on the knowledge and experiences of a smaller, purposefully selected groups of stakeholders in the Ghanaian highway industry, to explore deep insights, gain context and meaning into sustainability issues, which are difficult to quantify. The research design comprised two main phases: a comprehensive literature review and semi-structured interviews with key stakeholders and experts in the field. The process of identifying prospective indicators for economic sustainability began with an extensive literature review of existing guidelines and studies related to road and highway economic sustainability, from which a preliminary list of indicators was compiled. To ensure contextual relevance and appropriateness for Ghana, this preliminary list underwent evaluation by six highway construction professionals and three academic experts, who assessed the indicators' suitability and suggested additional relevant indicators for sustainable road and highway infrastructure development in Ghana. This methodological approach examines how stakeholders perceive and prioritize economic sustainability within Ghana's unique contexts, utilizing SWOT analysis to evaluate internal and external factors. The integration of literature review and expert evaluation resulted in a final set of indicators that was comprehensive and contextually suitable, establishing a solid basis for the ensuing semi-structured interviews and data analysis.

3.1. Instrument design

Semi-structured interviews were chosen as the primary data collection method, allowing for in-depth exploration of economic criteria indicators while maintaining relevance and coherence. An interview guide was developed to facilitate these discussions. The interview guide contained a list of four (4) highway construction/design sustainability indicators that have already been identified from the literature. These included reducing material costs; reduce life cycle costs, minimise construction time, and reduce maintenance and operation costs. The interviewees were asked to share their experiences and perspectives on each of the identified sustainability indicators by touching on the following:

i. **Strengths of the indicators** that enhance their ability to 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) which create **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) which create **negative potential** for the application of the indicators for sustainable highway infrastructure development.
v. **Actions 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?)

Under each of the four themes of SWOT framework, specific questions were asked as prompts to obtain the needed information on each indicator. These are presented below.

3.1.1. 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?

3.1.2. Theme 2 – weaknesses of the sustainability indicators

Prompts:

1. What could be improved about this indicator?
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?

3.1.3. Theme 3 – opportunities (external factors) 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, environmental, social, technological and technical, legal, and sectoral factors could promote the application of this indicator?

3.1.4. Theme 4 – threats (external factors) restricting sustainability indicator application

Prompts:

1. What are the obstacles for this indicator?
2. Are the required technical support and necessary facilities for this factor available?
3. Is the changing technology or policy threatening the factor?
4. Are stakeholders interested and willing to incorporate this indicator in highway development?
5. What political, environmental, social, technological and technical, legal, and sectoral factors could restrict/discourage the application of this indicator?

The core questions about strategies posed to the interviewees are catalogued in Table 2, serving as a foundation for in-depth discussions aimed at uncovering in-depth strategies and solutions for sustainable road and highway infrastructure development.

3.2. Participant selection

Interviewees were selected on the basis of specific criteria to ensure that they provided valuable and relevant insights for the study. These criteria included their current roles within organisations, professional expertise, experience relevant to road and highway infrastructure sustainability, and availability during the predetermined interview period. Potential candidates were purposively selected from various stakeholder organizations involved in road and highway infrastructure development in Ghana. This purposive selection aimed to capture a varied range of perspectives from different sectors within the industry, including government agencies, private sector companies, and academic institutions. The selection process was designed to ensure a comprehensive representation of viewpoints, contributing to a more in-depth understanding of the economic criteria indicators for sustainable infrastructure. A Participant Information Sheet and Consent Form, outlining the study's purpose, voluntary participation, and confidentiality, were sent to participants *via* email prior to the interviews. Additionally, the interview guide was designed with cultural sensitivities in mind to ensure respectful engagement with participants. The interviews were conducted until data saturation was achieved, meaning that no new significant information emerged from the additional interviews, ensuring the robustness and completeness of the data collected.

Table 1. Main interview questions on strategic actions.

Main interview questions
Economic criteria
i. How can life cycle cost analysis be incorporated into the planning and development phases of highway infrastructure projects to enhance sustainability outcomes?
ii. How can the management of maintenance and operation costs be optimized to enhance the long-term sustainability and efficiency of highway projects?
iii. How does the management of construction time impact the sustainability of road and highway infrastructure projects, and what strategies have proven effective in minimising construction time while ensuring sustainability goals are met?
iv. 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?

Table 2. Background of interviewees and their organizations.

ID	Stakeholder organization Type	Interviewee Position	Sector	Experience (years)	Interview type
P1	Academia / Researcher	Senior Lecturer	Government	10	Face-to-face
P2	Ghana Highway Authority	Survey & Design Manager	Government	18	Face-to-face
P3	Ministry of Road and Highway	Principal Engineer	Government	13	Face-to-face
P4	Department of Urban Roads	Regional Manager	Government	19	Phone
P5	Contractor	Project Manager	Private	21	Face-to-face
P6	Department of Feeder Roads	Deputy Regional Manager	Government	16	Face-to-face
P7	Department of Feeder Roads	Project Engineer	Government	16	Phone
P8	Environmental Agencies	Deputy Director	Government	24	Phone
P9	Ghana Highway Authority	Principal Engineer	Government	12	Face-to-face
P10	Department of Feeder Roads	Regional Manager	Government	20	Face-to-face
P11	Consultant	Project Manager	Private	14	Face-to-face
P12	Ghana Highway Authority	Contract Manager	Government	15	Face-to-face
P13	Consultant	Managing Director	Private	18	Face-to-face
P14	Academia / Researcher	Senior Researcher	Government	15	Face-to-face

Table 2 presents the professional capacities and organizational affiliations of the 14 selected interviewees, representing a wide range of individuals involved in road and highway infrastructure development in Ghana.

3.3. Data collection

Semi-structured interview was chosen as the primary data collection method, allowing for in-depth exploration of economic criterion indicators while maintaining relevance and coherence. The researchers developed an interview guide to facilitate these discussions. This format provided flexibility for the interviewer to probe deeper into specific areas of interest while allowing respondents the freedom to express detailed insights.

Prior to the semi-structured interviews, the participants were provided with a consent form, participant information sheet, and interview guide *via* email, allowing ample time for review and preparation. The interviews were conducted *via* both face-to-face meetings and telephone calls, with the latter employed when geographical constraints or personal preferences necessitated the interview to be conducted remotely. These interviews were conducted in informal settings to encourage reflective thought and lasted over an hour, allowing sufficient time for thorough exploration of the topics. With the participants' consent, all the interviews were audio-recorded and subsequently transcribed verbatim to facilitate detailed qualitative analysis.

The semi structured interviews were designed to examine each indicator and explore avenues to enhance economic 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 economic sustainability practices. Each question was targeted, asking how economic sustainability could be augmented through the specific lens of economic indicators.

3.4. Data analysis

The analysis began with the organisation of the data, where the interview transcripts were systematically arranged for streamlined referencing (Creswell, 2009). Utilizing ATLAS.ti 9 software, content analysis was performed to study the manifest content of the data. Content analysis is a social research method which helps to quantify large amounts of qualitative data for the purpose of data reduction and identifying prominent and consistent themes across the data (Thomas, 2003). It involves coding of the raw data into a standardised form within a conceptual framework. The interview transcripts were therefore coded within the SWOT framework. The strengths and weaknesses were determined by identifying the internal factors that enhance or restrict the ability to incorporate each indicator into sustainable highway infrastructure development. Correspondingly, the opportunities and threats were determined by identifying the external factors that create positive or negative potential for each indicator to be incorporated into sustainable highway infrastructure development. Findings from the content analysis were subsequently organised into a SWOT matrix, which categorizes data on the basis of their internal vs. external and positive vs. negative characteristics. This critical examination was necessary to obtain significant insights and accurately reflect the current state and prospects of the road and highway construction sector in terms of economic sustainability. This served as the foundational structure for formulating guidelines in sustainable road and highway infrastructure development.

3.4. Data validation

To ensure the validity and reliability of the data, the researchers employed several strategies. Data triangulation was used, with the interview transcripts thoroughly examined to ensure the fidelity and coherence of the respondents' statements (Ahmed, 2024). Data triangulation was achieved by cross-referencing interview data with other relevant sources, such as field notes and relevant documents, to verify the consistency and accuracy of the information. Any discrepancies identified were discussed with the participants during the member checking process, where they reviewed the interview transcripts for accuracy and clarified any points of confusion. Additionally, the research team regularly engaged in peer debriefing, discussion and review of the coding and analysis process to ensure consistency and minimise bias. Peer debriefing involved regular discussions among the research team, where the coding process was reviewed collaboratively (Ahmed, 2024). This process allowed for the identification and resolution of any inconsistencies in the interpretation of data, enhancing the overall validity of the findings.

This comprehensive methodology enabled the generation of specific recommendations for each economic indicator while also allowing for comparisons across different projects to highlight universally applicable actions in the context of Ghana's road and highway infrastructure development.

4. Findings and discussions

4.1. SWOT analysis and strategic action plan results

The semi-structured interviews with key highway professionals were subjected to SWOT analysis, which provided deep insights into the role and impact of the economic indicators on sustainable road and highway infrastructure development. The SWOT analysis results for each of the indicators are presented subsequently.

4.1.1. Reduce lifecycle costs

The SWOT analysis results for life cycle cost (LCC) as an indicator for improving the economic sustainability of highways in Ghana are presented in Table 3 and discussed in this section.

Connecting the theoretical principles of lifecycle cost analysis (LCCA) with practical implementation issues is critical

Table 3. SWOT results: Life cycle cost.

	Internal	External
Positive (+)	Strengths Provides value for money. Ensures economic sustainability. Reduces total project cost. Long-term benefits	Opportunities Advocacy for life cycle cost analysis of projects exists. Advancements in digital tools and technologies Global and regional emphasis on sustainable infrastructure financing
Negative (-)	Weaknesses 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 The focus of highway professionals is mostly on implementation phase. Lack of up-to-date data for analysis	Threats Professionals do not get enough time for thorough project preparations. Economic instability (Inflation) Lack of stakeholder /community acceptance Political influences Budgetary constraints

for Ghana's efforts to achieve economically sustainable road and highway infrastructure development. Literature establishes LCCA as a critical economic indicator, with Ghana facing projected cumulative maintenance costs of $473 million (2020–2100) for existing roads, potentially escalating to $678.47 million when incorporating climate adaptation measures (Twerefou et al., 2015). This theoretical framework finds strong validation in practitioner experiences, where highway professionals emphasize the necessity of comprehensive lifecycle planning that extends beyond initial construction costs to encompass maintenance and decommissioning expenses. The convergence of theoretical perspectives and practical implementation reveals three critical challenges in LCCA application. First, the absence of standardised methodologies for sustainability assessment during pavement lifecycle (Babashamsi et al., 2016) compounds practitioners' difficulties in forecasting long-term expenses, particularly given the dynamic nature of construction technologies and material costs. Second, professionals consistently encounter the challenge of balancing higher initial investments in durable materials against long-term sustainability benefits, reflecting the broader theoretical tension between immediate economic constraints and sustainable development goals. Third, the implementation framework requires integration of holistic sustainability assessment with practical capacity-building initiatives and supportive policy reforms.

To address these challenges, emerging solutions combine theoretical insights with practical implementation strategies. Practitioners advocate for innovative financing models, particularly public-private partnerships (PPPs), to effectively distribute lifecycle costs and risks. This approach aligns with theoretical frameworks emphasizing the need to balance economic viability with sustainability requirements. Additionally, the professional emphasis on quality material selection reinforces theoretical projections that initial quality investments significantly reduce long-term maintenance costs. Both literature and practitioner insights converge on the importance of establishing collaborative knowledge platforms and standardised methodologies to enhance LCCA implementation. The synthesis of theoretical frameworks and practical experiences demonstrates that successful economic sustainability in highway infrastructure development necessitates an integrated approach. This approach must combine robust LCCA methodologies with practical implementation strategies, supported by appropriate policy mechanisms and active stakeholder collaboration. While enhancing the economic sustainability of Ghana's highway infrastructure development, the goal is to foster a more resilient and sustainable transportation network for future generations. For effective implementation of lifecycle cost analysis, the goal is to align theoretical projections with professional insights. The insights from the interviews and the strategies outlined in Table 4 offer a practical roadmap for implementing life cycle costs analysis in road and highway infrastructure projects in Ghana.

4.1.2. Reduce maintenance and operation costs

The SWOT analysis results for maintenance and operation costs as an indicator for improving the economic sustainability of highways in Ghana are presented in Table 5 and discussed in this section.

Combining theoretical principles with practical considerations highlights the significance of maintenance and operation costs as an essential factor influencing economic sustainability in the development of road and highway infrastructure in Ghana. Research reveals that effective maintenance strategies considerably enhance infrastructure longevity and decrease total lifecycle costs (Frangopol & Liu, 2018; Sánchez-Silva et al., 2016). Highway professionals highlight this by emphasizing the importance of strategic planning for the long-term sustainability of infrastructure, illustrating the critical intersection of theoretical knowledge and practical application. The intersection of theoretical frameworks and practical challenges in Ghana's context reveals critical dimensions that shape maintenance and operation cost management. The resource-institutional nexus presents significant challenges, with literature identifying inadequate funding and weak institutional frameworks (Mazele & Amoah, 2022; Yilema & Gianoli, 2018) while practitioners highlight the complexity of forecasting long-term maintenance needs amidst evolving technologies and environmental factors. This convergence highlights the necessity for robust institutional capacity coupled with strategic financial planning. Furthermore, the quality-cost relationship emerges as crucial, with professionals advocating for higher initial investments in quality materials and innovative technologies

Table 4. Strategic action plans and expert remarks regarding life cycle costs indicator.

Action plans and deliverables	Expert remarks
Capacity building and education • Developing educational materials and programmes. • Comprehensive training programs for professionals. • Integration of life cycle cost analysis in educational curricula	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 • Investing in technological/software upgrades. • Collaboration with technology providers. • Hands-on training for professionals.	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 • Advocating for realistic project timelines. • Developing strategies to mitigate risks. • Incorporating flexibility in project budgets.	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 • Establishing protocols and systems for data collection. • Collaborating with relevant agencies for a centralised database. • Ensuring transparency in decision-making processes.	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 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
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.	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

Table 5. SWOT results: Reduce maintenance and operation costs.

	Internal	External
Positive (+)	Strengths Maintenance ensures terminal year attainment. Contributes to the design life of the project. Reduces vehicle operating cost. Reduces life cycle cost.	Opportunities Road fund concept for maintenance Improvement in road fund administration
Negative (-)	Weaknesses 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	Threats Misuse of road funds by authorities Limited funds for maintenance Absence of dedicated working road fund for maintenance Governments are very interested in road construction but not their maintenance.

to reduce long-term maintenance costs, aligning with research indicating that proactive maintenance strategies contribute to both economic efficiency and environmental sustainability (Giustozzi et al., 2012).

The implementation framework demands integrated solutions that combine theoretical insights with practical strategies. Both literature and practitioner perspectives emphasize the critical need to shift from reactive to proactive maintenance strategies, enhance technical capacity for lifecycle cost analysis, develop innovative financing mechanisms, and establish collaborative knowledge-sharing platforms. This integrated approach recognises that effective maintenance and operation cost management requires balancing immediate resource constraints with long-term sustainability goals, supported by robust policy frameworks and stakeholder collaboration. The synthesis demonstrates that successful economic sustainability in highway infrastructure development demands a holistic approach that views maintenance and operation costs not merely as expenditure items but as strategic investments in long-term infrastructure viability. The alignment between theoretical understanding and practical experience indicates that the implementation of integrated strategies may enhance the economic sustainability of Ghana's highway infrastructure. To contribute to the development of a more resilient and sustainable transportation network, ensure an approach that optimises resource utilisation throughout the infrastructure lifecycle. Table 6 presents the various action plans, their deliverables, and some of the remarks made by the highway experts about the reducing maintenance and operation costs for sustainable highway development.

4.1.3. Reduce construction time

The strength, weaknesses and weakness of the indicator as well as the external factors that pose as opportunities and threats for the incorporation of construction time in highway development in Ghana are as presented in Table 7.

With empirical evidence highlighting substantial challenges that directly affect project sustainability in Ghana, construction duration serves as a vital economic indicator in the development of road and highway infrastructure. Research indicates that around 70% of road projects encounter significant delays, with an average time overrun of 17 months and a cost overrun of US$1.15 million (22.5%) (Amoatey & Ankrah, 2017; Frimpong et al., 2003). This quantitative understanding finds strong validation in practitioner insights, which establish a direct correlation between time efficiency and comprehensive project costs, encompassing labour, equipment, and administrative expenses, while

Table 6. Strategic action plans and expert remarks regarding maintenance and operation costs.

Action plan and deliverables	Expert remarks
Commitment to infrastructure maintenance • Proactive maintenance programmes. • Undertaking life cycle cost analysis. • Funding models and special maintenance funds.	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 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
Financial management and accountability • Advocating for a road maintenance fund. • Transparency in fund administration. • Accountability measures and audits.	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 • Setting up and equipping axle load stations along major roads. • Severe penalties to discourage noncompliance. • Setting up mobile enforcement units.	…. .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 • Raising awareness on the benefits of maintenance. • Collaborating with educational institutions for maintenance education. • Predictive maintenance technologies. • Technologically advanced tools for fund tracking.	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 • Training programs for quality control personnel. • Rigorous assessment and testing protocols. • Strict maintenance schedules and adherence to 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

Table 7. SWOT results: Reduce construction time.

	Internal	External
Positive (+)	Strengths	Opportunities
	Timely completion controls costs	Improved project planning enhances construction time efficiency.
	Timely delivery satisfies the needs of the people.	Awareness of innovative construction technologies among professionals
Negative (-)	Weaknesses	Threats
	Lack of equipment and technical know-how lead to project stoppages.	Political influences can affect construction timelines.
	Inadequate personnel on the contractor's side.	Lack of government interest can lead to project delays.
	Challenges with unclear project designs.	Adverse weather conditions can limit construction activities.
	Issues with contractor qualifications and on-site efficiency.	Community resistance, especially regarding relocations.
	Poor planning as a major factor affecting construction time.	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.

highlighting the acceleration of infrastructure utilisation as a catalyst for economic development. The convergence of theoretical research and practical experience illuminates the complex challenges in managing construction time effectively. Financial and management constraints, including payment issues, poor contract management, and inadequate contractor experience, create fundamental obstacles to timely project completion. These challenges are compounded by operational issues such as material shortages, utility relocation problems, and skilled labour deficits (Purushothaman et al., 2024), while external factors including unpredictable weather, bureaucratic barriers, political interference, and community resistance further complicate project timelines. This multi-layered challenge matrix necessitates a comprehensive approach to construction time management that addresses both technical and institutional dimensions.

Professional insights align with theoretical frameworks in advocating for integrated solutions that combine enhanced project planning and management systems with innovative construction methods, including prefabricated components and modular construction techniques. The emphasis on developing reliable supply chains, streamlining governmental procedures, and implementing integrated project delivery models reflects a sophisticated understanding of the interconnected nature of construction time management and economic sustainability. These strategic interventions demonstrate recognition that effective time management extends beyond traditional scheduling considerations to encompass broader economic and social implications. The synthesis reveals that successful construction time management in sustainable highway infrastructure requires a holistic approach that recognises time not merely as a project management metric but as a fundamental driver of economic sustainability. The clear alignment between empirical evidence and practitioner experiences suggests that implementing integrated management strategies could significantly enhance the economic sustainability of Ghana's highway infrastructure projects while optimising resource utilisation and accelerating economic development benefits. It is essential to mention that sustainable infrastructure development and coordinated efforts across technical, institutional, and stakeholder dimensions support the perspective that emphasizes that construction time efficiency. Table 8 presents the remarks and the strategic action plans identified to promote the incorporation of construction time as a sustainability indicator for highway infrastructure development.

4.1.4. Reduce material costs

Table 9 presents the SWOT analysis results for reduce material cost as an indicator for improving the economic sustainability of highways in Ghana.

In Ghana, material costs account for more than 50% of total project expenses, constituting a significant economic indicator in the development of road and highway infrastructure. (Koushki & Kartam, 2004; Patil & Pataskar, 2013). This cost component connects theoretical understanding with practical insights, as practitioners validate research findings by highlighting that strategic material cost management enhances economic efficiency and facilitates resource allocation for environmental conservation and social equity initiatives. This dual perspective reveals the intricate relationship between material cost management and sustainable infrastructure development outcomes. The merging of research evidence and professional experience explains complex challenges in material cost management within Ghana's context. Price fluctuations, driven by crude oil prices, energy costs, taxes, and transportation expenses (Danso & Obeng-Ahenkora, 2018), create significant uncertainty in project cost estimates. This challenge is further complicated by the inherent tension between immediate cost reduction and long-term sustainability goals, particularly when considering sustainable materials that may have higher upfront costs but promise reduced maintenance expenses and environmental impacts (Wakjira et al., 2024). These challenges highlight the need for comprehensive approaches that balance economic viability with sustainability objectives.

Professional insights align with theoretical frameworks in advocating for integrated solutions that combine local resource utilisation, recycling initiatives, and research investment in cost-effective, durable materials. The emphasis on fostering early stakeholder collaboration among suppliers, contractors, and regulatory bodies reflects a sophisticated understanding of the interconnected nature of material cost management and project sustainability. These strategic interventions demonstrate recognition that effective material cost management extends beyond traditional cost considerations to encompass broader environmental and social implications, requiring comprehensive lifecycle cost assessments to

Table 8. Strategic action plans and expert remarks regarding construction time indicator.

Action plans and deliverables	Expert remarks
Project management optimisation • Strengthening project management practices. • Implementing advanced planning tools and technologies. • Establishing a robust project management framework.	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
Workforce development and training • Providing training programmes for construction teams. • Developing recruitment and retention strategies. • Collaborating with educational institutions to address skills gaps.	… 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 • Minimising political interference by engaging with authorities. • Undertaking thorough community engagement. • Ensuring transparent communication between government, road agencies, and contractors.	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 • Securing necessary funds before project commencement. • Advocating for streamlined fund release processes. • Monitoring material supply chains for potential delays.	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 • Undertaking comprehensive feasibility studies. • Ensuring contractors have appropriate tools and equipment. • Clearly **defining** right of way acquisition and compensation processes.	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

Table 9. SWOT results: reduce material cost.

	Internal	External
Positive (+)	Strengths • Indicates long-term value for money. • Informs material selection during planning and design.	Opportunities • Design principle seeks to balance material cost with functionality. • Every contractor considers material costs when undertaking a project.
Negative (-)	Weaknesses • Lack of local materials in close proximity. • Contractors may prioritise 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	Threats • Inflation poses a threat to material costs. • Local community or landowner involvement can influence costs. • Transportation costs and importing materials add to overall costs.

evaluate long-term material performance. The combination reveals that successful material cost management in sustainable highway infrastructure requires a holistic approach that recognises materials not merely as a cost component but as a fundamental driver of economic sustainability. The clear alignment between theoretical understanding and practical experience suggests that implementing integrated management strategies could significantly enhance the economic sustainability of Ghana's highway infrastructure while ensuring optimal resource utilisation and environmental stewardship. With suitable policy frameworks and active stakeholder involvement, this perspective emphasizes that material cost efficiency is essential for sustainable infrastructure development, necessitating coordinated efforts across technical, economic, and environmental dimensions. The strategic action plans and some of the key remarks in the interview sessions regarding the material costs indicator are set out in Table 10.

The semi structured interviews conducted 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 and Berg (2017). This methodological approach ensured the extraction of actionable intelligence from the respondents' feedback on

Table 10. Strategic action plans and expert remarks regarding material costs indicator.

Action plans and deliverables	Expert remarks
Collaboration and communication • Strengthening partnerships between designers, material experts, contractors, and suppliers. • Encouraging effective communication channels throughout the construction process.	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
Sustainable Material Innovation • Promoting the adoption of innovative and sustainable materials. • Encouraging designers to balance functionality with cost-effectiveness in material choices.	However, if we blend materials properly and ensure good supervision and compaction during construction, we can achieve a durable road … … …. P4 We must explore and understand our local materials and how we can modify them to meet specifications and industry trends … … … … P12 We should explore green alternatives and consider our local context … … … … … … P3
Local sourcing and community engagement • Investigating and utilizing local materials to reduce environmental impact. • Engaging with local communities and industries for sustainable sourcing.	… 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 … 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
Procurement and Contractual Measures • Developing procurement guidelines prioritising local materials. • Incorporating penalties in contracts to discourage noncompliance. • Considering long-term contracts or partnerships to mitigate inflation effects.	…. 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 …. 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
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.	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 • Factoring potential inflation into project contracts and budgets. • Monitoring economic indicators regularly and adjusting project budgets accordingly.	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

Table 11. Major findings of the interview study.

S/N	Sustainability indicators	Action plans
1	Life cycle costs	Capacity Building and Education Technological Advancements and Competence Project Planning and Risk Mitigation Data Collection and Transparency Stakeholder Collaboration and Advocacy
2	Maintenance and operation costs	Commitment to Infrastructure Maintenance Financial Management and Accountability Monitoring and enforcement Stakeholder Engagement, Education and Technology integration Quality Control and Standards
3	Construction time	Project Management Optimisation Workforce Development and Training Stakeholder Engagement and Relationship Management Financial Planning and Resource Allocation Risk Mitigation and Project Preparedness
4	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

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 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 a verification process. This involved retracing the analytic steps to confirm that the conclusions drawn were faithfully representative of the data collected.

Table 11 presents a concise summary of the main findings from the interviews, highlighting the proposed action plans derived from the stakeholders' input.

5. Conclusion and recommendations

This qualitative study examined the economic criterion indicators relevant to sustainable road and highway infrastructure development in Ghana, emphasizing material costs, lifecycle costs, construction time, and maintenance and operational expenses. By conducting semi-structured interviews with key stakeholders across different sectors, this study offers important insights into the challenges and opportunities for improving economic sustainability in infrastructure projects. The findings reveal that effective cost management not only enhances economic efficiency but also fosters sustainability. Strategies such as local sourcing, sustainable material innovation, and improved procurement practices were identified as crucial for optimising material costs (Koushki & Kartam, 2004). The research highlighted the importance of considering the entire lifespan of projects, from construction through maintenance to decommissioning. However, challenges such as a lack of expertise in lifecycle cost analysis and inadequate data were identified as barriers to effective implementation (Babashamsi et al., 2016). Timely completion was found to be critical for controlling costs and meeting societal needs. Challenges such as a lack of technical knowledge, poor planning, and political influence were identified as factors affecting construction time (Rivera et al., 2020). The study also emphasized the role of proper maintenance in ensuring the longevity and efficiency of infrastructure. However, issues such as weak enforcement of regulations and inadequate funding were identified as significant challenges (Mazele & Amoah, 2022).

These findings emphasize the need for a holistic approach to economic sustainability in road and highway infrastructure development in Ghana. This approach should integrate considerations of material costs, lifecycle costs, construction time, and maintenance costs from the early stages of project planning through long-term operation. To address these challenges and enhance economic sustainability, several recommendations have emerged from the research. To mention a few, the implementation of comprehensive training programmes for professionals in lifecycle cost analysis, sustainable material use, and efficient project management is crucial. Advocating for policies that incentivise sustainable practices, such as establishing a minimum requirement of 30% local material usage in highway projects and developing tax incentives for contractors using local materials and the adoption of lifecycle cost analysis in project planning, can drive systemic change. Fostering stronger partnerships between government agencies, contractors, academics, and local communities can enhance knowledge sharing and improve project outcomes. On the issue of inflation, strategies including the consideration of long-term contracts, partnerships, incorporating potential inflation into project contracts and budgets, allowing for realistic project timelines and some flexibility in project budgets were recommended. Moreover, undertaking thorough community engagement is one of the deliverables for stakeholder engagement and relationship management. This could be undertaken by several methods such as the creation of a forum or platform for the community members to share their concerns, employing questionnaire and surveys to obtain user opinions about alternative designs, and using a clear communication channel (e.g. radio stations, and newsletters) to update or inform the community about progress of works and possible impacts.

Investing in advanced planning tools and technologies, such as implementing building information modeling (BIM) for project planning and cost estimation, integrating blockchain technology for transparent procurement processes and contract management, adopting drone technology for project monitoring and maintenance inspection, and utilising asset management software like IBM Maximo or similar systems for maintenance tracking, can significantly improve project management, cost estimation, and maintenance practices. Establishing dedicated funds for infrastructure maintenance and implementing transparent mechanisms for fund allocation and utilisation are essential for long-term sustainability.

However, this study has some limitations that should be considered. We acknowledge community leaders as key stakeholders. However, they were not included as participants due to their known continuous interactions with the government officials at the local assembly. It was, therefore, assumed that the selected government officials have in-depth knowledge and experience about the community issues, and would therefore capture them in the discussions. This limitation does not invalidate the findings but may, however, restrict the generalisability of the findings. The focus on Ghana, while offering valuable insights, may not be directly applicable to other countries with different economic and regulatory environments, but provides valuable insights that can inform similar contexts. The qualitative nature of the study, while providing rich, in-depth data, lacks the statistical rigor of quantitative studies. Additionally, the study provides a snapshot of current perspectives and practices, and longitudinal studies could offer insights into how economic sustainability factors evolve over time.

Future research could benefit from quantitative studies measuring the economic impact of implementing the recommended sustainability practices. Exploring the interplay between economic, environmental, and social sustainability factors in infrastructure development would provide a more comprehensive understanding. Climate impact has been a major issue in the construction industry globally. Future studies could therefore investigate how it impacts economic sustainability of highway infrastructural development. It would be interesting to explore possible climate mitigation and adaptation actions for enhancing economic sustainability of highways in developing countries. Investigating the potential of emerging technologies, such as artificial intelligence and blockchain, in enhancing the economic sustainability of infrastructure projects could uncover innovative solutions. Conducting comparative studies across different African countries could identify best practices and opportunities for knowledge transfer. Further, other stakeholders such as community leaders and international consultants could be included in future studies to improve the findings of this study.

In conclusion, this research provides a foundation for enhancing the economic sustainability of road and highway infrastructure development in Ghana. By addressing the identified challenges and implementing the recommended strategies, stakeholders can work toward more sustainable, efficient, and cost-effective infrastructure projects that better serve the needs of society while promoting long-term economic viability. The path forward requires concerted effort, collaboration, and a commitment to integrating sustainability principles throughout the lifecycle of infrastructure projects.

Ethical approval

We confirm that the manuscript includes a comprehensive description of all necessary ethics approvals. Specifically, it details the approval granted by the Auckland University of Technology Ethics Committee (AUTEC), with the respective institution as Auckland University of Technology and the approval number 22/327.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Acai, J., Amadi-Echendu, J. (2018). Pavement infrastructure sustainability assessment: A systematic review. *2018 Portland International Conference on Management of Engineering and Technology (PICMET),* 1-–10. https://doi.org/10.23919/PICMET.2018.8481788

Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017). Circular economy in construction: Current awareness, challenges and enablers. *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, *170*(1), 15–24. https://doi.org/10.1680/jwarm.16.00011

Ahmed, S. K. (2024). The pillars of trustworthiness in qualitative research. *Journal of Medicine, Surgery, and Public Health*, *2*, 100051. https://doi.org/10.1016/j.glmedi.2024.100051

Akomea-Frimpong, I., Jin, X., & Osei-Kyei, R. (2024). Mitigating financial risks in sustainable public–private partnership infrastructure projects: A quantitative analysis. *Systems*, *12*(7), 239. https://doi.org/10.3390/systems12070239

Akomea-Frimpong, I., Jin, X., Osei-Kyei, R., & Kukah, A. S. (2023). Public–private partnerships for sustainable infrastructure development in Ghana: A systematic review and recommendations. *Smart and Sustainable Built Environment*, *12*(2), 237–257. https://doi.org/10.1108/SASBE-07-2021-0111

Alaloul, W. S., Liew, M. S., Zawawi, N. A. W. A., & Kennedy, I. B. (2020). Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders. *Ain Shams Engineering Journal*, *11*(1), 225–230. https://doi.org/10.1016/j.asej.2019.08.010

Alaloul, W. S., Musarat, M. A., Rabbani, M. B. A., Altaf, M., Alzubi, K. M., & Al Salaheen, M. (2022). Assessment of economic sustainability in the construction sector: Evidence from three developed countries (the USA, China, and the UK). *Sustainability*, *14*(10), 6326. https://doi.org/10.3390/su14106326

Altaf, M., Alaloul, W. S., Musarat, M. A., & Qureshi, A. H. (2023). Life cycle cost analysis (LCCA) of construction projects: Sustainability perspective. *Environment, Development and Sustainability*, *25*(11), 12071–12118. https://doi.org/10.1007/s10668-022-02579-x

Ametepey, O., Aigbavboa, C., & Ansah, K. (2015). Barriers to successful implementation of sustainable construction in the Ghanaian construction industry. *Procedia Manufacturing*, *3*, 1682–1689. https://doi.org/10.1016/j.promfg.2015.07.988

Ametepey, S. O., Aigbavboa, C. O., & Thwala, W. D. (2023). Sustainable road infrastructure development in Ghana. In *Sustainable Road Infrastructure Project Implementation in Developing Countries: An Integrated Model.* (pp. 121–132). Emerald Publishing Limited. https://doi.org/10.1108/978-1-83753-810-220231011

Amoatey, C. T., & Ankrah, A. N. O. (2017). Exploring critical road project delay factors in Ghana. *Journal of Facilities Management*, *15*(2), 110–127. https://doi.org/10.1108/JFM-09-2016-0036

Asiedu, R. O., & Adaku, E. (2019). Cost overruns of public sector construction projects: A developing country perspective. *International Journal of Managing Projects in Business*, *13*(1), 66–84. https://doi.org/10.1108/IJMPB-09-2018-0177

Awuzie, B., Ngowi, A. B., Omotayo, T., Obi, L., & Akotia, J. (2021). Facilitating successful smart campus transitions: A systems thinking-SWOT analysis approach. *Applied Sciences*, *11*(5), 2044. https://doi.org/10.3390/app11052044

Babashamsi, P., Md Yusoff, N., Ceylan, H., Md Nor, N., & Salarzadeh Jenatabadi, H. (2016). Sustainable development factors in pavement life-cycle: Highway/airport review. *Sustainability*, *8*(3), 248. https://doi.org/10.3390/su8030248

Badu, E., Edwards, D. J., Owusu-Manu, D., & Brown, D. M. (2012). Barriers to the implementation of innovative financing (IF) of infrastructure. *Journal of Financial Management of Property and Construction*, *17*(3), 253–273. https://doi.org/10.1108/13664381211274362

Behzadifar, M., Ghanbari, M. K., Azari, S., Bakhtiari, A., Rahimi, S., Ehsanzadeh, S. J., Sharafkhani, N., Moridi, S., & Bragazzi, N. L. (2023). A SWOT analysis of the development of health technology assessment in Iran. *PLOS One*, *18*(3), e0283663. https://doi.org/10.1371/journal.pone.0283663

Belachew, A. S., Mengesha, W. J., & Mohammed, M. (2017). Causes of cost overrun in federal road projects of Ethiopia in Case of Southern District. *American Journal of Civil Engineering*, *5*(1), 27. https://doi.org/10.11648/j.ajce.20170501.15

Brundtland, G. H. (1987). Our common future—Call for action. *Environmental Conservation*, *14*(4), 291–294. https://doi.org/10.1017/S0376892900016805

Cai, H., Bian, Y., & Liu, L. (2024). Deep reinforcement learning for solving resource constrained project scheduling problems with resource disruptions. *Robotics and Computer-Integrated Manufacturing*, *85*, 102628. https://doi.org/10.1016/j.rcim.2023.102628

Cheng, B., Huang, J., Guo, Z., Li, J., & Chen, H. (2023). Towards sustainable construction through better construction and demolition waste management practices: A SWOT analysis of Suzhou, China. *International Journal of Construction Management*, *23*(15), 2614–2624. https://doi.org/10.1080/15623599.2022.2081406

Correia, M. S. (2019). Sustainability: An overview of the triple bottom line and sustainability implementation. *International Journal of Strategic Engineering*, *2*(1), 29–38. https://doi.org/10.4018/IJoSE.2019010103

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches*. (3rd ed.). SAGE Publications, Inc.

Dai, Y., & Solangi, Y. A. (2023). Evaluating and prioritizing the green infrastructure finance risks for sustainable development in China. *Sustainability*, *15*(9), 7068. https://doi.org/10.3390/su15097068

Danso, H., & Obeng-Ahenkora, N. K. (2018). Major determinants of prices increase of building materials on Ghanaian construction market. *Open Journal of Civil Engineering*, *08*(02), 142–154. https://doi.org/10.4236/ojce.2018.82012

Das, K. P., Sharma, D., & Satapathy, B. K. (2022). Electrospun fibrous constructs towards clean and sustainable agricultural prospects: SWOT analysis and TOWS based strategy assessment. *Journal of Cleaner Production*, *368*, 133137. https://doi.org/10.1016/j.jclepro.2022.133137

Djokoto, S. D., Dadzie, J., & Ohemeng-Ababio, E. (2014). Barriers to sustainable construction in the Ghanaian construction industry: Consultants perspectives. *Journal of Sustainable Development*, *7*(1). https://doi.org/10.5539/jsd.v7n1p134

Dobiáš, J., & Macek, D. (2014). Leadership in energy and environmental design (LEED) and its impact on building operational expenditures. *Procedia Engineering*, *85*, 132–139. https://doi.org/10.1016/j.proeng.2014.10.537

Dokyi, G. O., Tookey, J., Rotimi, F. E., & Osei, K. K., (2024). A framework of indicators for sustainable road and highway infrastructure development in developing countries: The Ghana context. *Journal of Construction in Developing Countries*, *29*(2), 257–287. https://doi.org/10.21315/jcdc-12-23-0176

Durdyev, S., & Hosseini, M. R. (2019). Causes of delays on construction projects: A comprehensive list. *International Journal of Managing Projects in Business*, *13*(1), 20–46. https://doi.org/10.1108/IJMPB-09-2018-0178

Frangopol, D. M., & Liu, M. (2018). Maintenance and management of civil infrastructure based on condition, safety, optimization, and life-cycle cost. In *Structures and Infrastructure Systems.* (1st ed., p. 13) Routledge.

Frimpong, Y., Oluwoye, J., & Crawford, L. (2003). Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. *International Journal of Project Management*, *21*(5), 321–326. https://doi.org/10.1016/S0263-7863(02)00055-8

Ghorbani, A., Raufirad, V., Rafiaani, P., & Azadi, H. (2015). Ecotourism sustainable development strategies using SWOT and QSPM model: A case study of Kaji Namakzar Wetland, South Khorasan Province, Iran. *Tourism Management Perspectives*, *16*, 290–297. https://doi.org/10.1016/j.tmp.2015.09.005

Giustozzi, F., Crispino, M., & Flintsch, G. (2012). Multi-attribute life cycle assessment of preventive maintenance treatments on road pavements for achieving environmental sustainability. *The International Journal of Life Cycle Assessment*, *17*(4), 409–419. https://doi.org/10.1007/s11367-011-0375-6

Goh, C. S., Chong, H.-Y., Jack, L., & Mohd Faris, A. F. (2020). Revisiting triple bottom line within the context of sustainable construction: A systematic review. *Journal of Cleaner Production*, *252*, 119884. https://doi.org/10.1016/j.jclepro.2019.119884

Goh, K. C., & Yang, J. (2014). Importance of sustainability-related cost components in highway infrastructure: Perspective of stakeholders in Australia. *Journal of Infrastructure Systems*, *20*(1). https://doi.org/10.1061/(ASCE)IS.1943-555X.0000152

Gómez-Cabrera, A., Gutierrez-Bucheli, L., & Muñoz, S. (2024). Causes of time and cost overruns in construction projects: A scoping review. *International Journal of Construction Management*, *24*(10), 1107–1125. https://doi.org/10.1080/15623599.2023.2252288

Green, J., Willis, K., Hughes, E., Small, R., Welch, N., Gibbs, L., & Daly, J. (2007). Generating best evidence from qualitative research: The role of data analysis. *Australian and New Zealand Journal of Public Health*, *31*(6), 545–550. https://doi.org/10.1111/j.1753-6405.2007.00141.x

Greenham, S., Workman, R., McPherson, K., Ferranti, E., Fisher, R., Mills, S., Street, R., Dora, J., Quinn, A., & Roberts, C. (2023). Are transport networks in low-income countries prepared for climate change? Barriers to preparing for climate change in Africa and South Asia. *Mitigation and Adaptation Strategies for Global Change*, *28*(8), 44. https://doi.org/10.1007/s11027-023-10078-1

Hahn, T., & Knight, E. (2021). The ontology of organizational paradox: A quantum approach. *Academy of Management Review*, *46*(2), 362–384. https://doi.org/10.5465/amr.2018.0408

Heidari, M. R., Heravi, G., & Esmaeeli, A. N. (2020). Integrating life-cycle assessment and life-cycle cost analysis to select sustainable pavement: A probabilistic model using managerial flexibilities. *Journal of Cleaner Production*, *254*, 120046. https://doi.org/10.1016/j.jclepro.2020.120046

Hosseini Dehshiri, S. J., Amiri, M., & Hosseini Bamakan, S. M. (2024). Evaluating the blockchain technology strategies for reducing renewable energy development risks using a novel integrated decision framework. *Energy*, *289*, 129987. https://doi.org/10.1016/j.energy.2023.129987

Houben, G., Lenie, K., & Vanhoof, K. (1999). A knowledge-based SWOT-analysis system as an instrument for strategic planning in small and medium sized enterprises. *Decision Support Systems*, *26*(2), 125–135. https://doi.org/10.1016/S0167-9236(99)00024-X

Huang, M., Dong, Q., Ni, F., & Wang, L. (2021). LCA and LCCA based multi-objective optimization of pavement maintenance. *Journal of Cleaner Production*, *283*, 124583. https://doi.org/10.1016/j.jclepro.2020.124583

Hussin, J. M., Rahman, I. A., & Memon, A. H. (2013). The way forward in sustainable construction: Issues and challenges. *International Journal of Advances in Applied Sciences*, *2*(1), 15–24. https://doi.org/10.11591/ijaas.v2i1.1321

Jones, K., & Sharp, M. (2007). A new performance-based process model for built asset maintenance. *Facilities*, *25*(13/14), 525–535. https://doi.org/10.1108/02632770710822616

Kamran, M., Fazal, M. R., & Mudassar, M. (2020). Towards empowerment of the renewable energy sector in Pakistan for sustainable energy evolution: SWOT analysis. *Renewable Energy*, *146*, 543–558. https://doi.org/10.1016/j.renene.2019.06.165

Kansongue, N., Njuguna, J., & Vertigans, S. (2023). A PESTEL and SWOT impact analysis on renewable energy development in Togo. *Frontiers in Sustainability*, *3*. https://doi.org/10.3389/frsus.2022.990173

Kindo, M. D., Adams, A. A., & Mohammed, J. (2024). The impact of trade on environmental quality and sustainable development in Ghana. *World Development Sustainability*, *4*, 100134. https://doi.org/10.1016/j.wds.2024.100134

Koushki, P. A., & Kartam, N. (2004). Impact of construction materials on project time and cost in Kuwait. *Engineering, Construction and Architectural Management*, *11*(2), 126–132. https://doi.org/10.1108/09699980410527867

Leandri, P., Rocchio, P., & Losa, M. (2020). A SWOT analysis of innovative high sustainability pavement surfaces containing crumb rubber modifier. *Road Materials and Pavement Design*, *21*(sup1), S103–S122. https://doi.org/10.1080/14680629.2020.1736132

Lu, W. (2010). Improved SWOT approach for conducting strategic planning in the construction industry. *Journal of Construction Engineering and Management*, *136*(12), 1317–1328. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000240

Lune, H., & Berg, B. L. (2017). *Qualitative research methods for the social sciences.* (9th ed.). Pearson.

Mahmood, S., Ali, G., Menhas, R., & Sabir, M. (2022). Belt and road initiative as a catalyst of infrastructure development: Assessment of resident's perception and attitude towards China-Pakistan Economic Corridor. *PloS One*, *17*(7), e0271243. https://doi.org/10.1371/journal.pone.0271243

Mahmood, S., Misra, P., Sun, H., Luqman, A., & Papa, A. (2024). Sustainable infrastructure, energy projects, and economic growth: Mediating role of sustainable supply chain management. *Annals of Operations Research*. https://doi.org/10.1007/s10479-023-05777-6

Mahmood, S., Sabir, M., & Ali, G. (2020). Infrastructure projects and sustainable development: Discovering the stakeholders' perception in the case of the China–Pakistan Economic Corridor. *PLOS One*, *15*(8), e0237385. https://doi.org/10.1371/journal.pone.0237385

Mandičák, T., Spišáková, M., & Mésároš, P. (2024). Sustainable design and building information modeling of construction project management towards a circular economy. *Sustainability*, *16*(11), 4376. https://doi.org/10.3390/su16114376

Mazele, O., & Amoah, C. (2022). The causes of poor infrastructure management and maintenance in South African municipalities. *Property Management*, *40*(2), 192–206. https://doi.org/10.1108/PM-06-2021-0042

Moins, B., France, C., Van den Bergh, W., & Audenaert, A. (2020). Implementing life cycle cost analysis in road engineering: A critical review on methodological framework choices. *Renewable and Sustainable Energy Reviews*, *133*, 110284. https://doi.org/10.1016/j.rser.2020.110284

Montgomery, R., Schirmer, H., Jr., & Hirsch, A. (2014). *A Sustainability Rating System for Roads in Developing Countries* [Paper presentation]. ICSI,, 1086–1096. https://doi.org/10.1061/9780784478745.103

Ogunmakinde, O. E., Egbelakin, T., & Sher, W. (2022). Contributions of the circular economy to the UN sustainable development goals through sustainable construction. *Resources, Conservation and Recycling*, *178*, 106023. https://doi.org/10.1016/j.resconrec.2021.106023

Opoku, A. (2019). Biodiversity and the built environment: Implications for the sustainable development goals (SDGs). *Resources, Conservation and Recycling*, *141*, 1–7. https://doi.org/10.1016/j.resconrec.2018.10.011

Owusu-Manu, D., Seidu, S., Asiedu, R. O., Buertey, J. I. T., Danso, A. K., & Edwards, D. J. (2023). Prioritization of the key underlying sustainability indicators of urban green drainage infrastructure systems. *Urban Water Journal*, *20*(9), 1196–1206. https://doi.org/10.1080/1573062X.2023.2253213

Pan, W., Chen, L., & Zhan, W. (2019). PESTEL analysis of construction productivity enhancement strategies: A Case study of three economies. *Journal of Management in Engineering*, *35*(1). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000662

Patel, K., & Ruparathna, R. (2023). Life cycle sustainability assessment of road infrastructure: A building information modeling-(BIM) based approach. *International Journal of Construction Management*, *23*(11), 1837–1846. https://doi.org/10.1080/15623599.2021.2017113

Patil, A. R., & Pataskar, S. V. (2013). Analyzing material management techniques on construction project. *International Journal of Engineering and Innovative Technology*, *3*(4), 96–100.

Phani, M. T., & Mathew, S. V. (2019). Material management in construction-a case study. *International Journal of Research in Engineering and Technology*,

Purushothaman, M. B., San Pedro, L. N. R., & GhaffarianHoseini, A. (2024). Construction projects: Interactions of the causes of delays. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-11-2023-0334

Qayyum, M., Yuyuan, Y., Bhatti, U. A., & Shijie, L. (2023). Evaluation of the one belt and one road (OBOR) in economic development and suggestions analysis based on SWOT analysis with weighted AHP and entropy methods. *Multimedia Tools and Applications*, *82*(10), 14985–15006. https://doi.org/10.1007/s11042-022-13565-w

Ries, R., Bilec, M. M., Gokhan, N. M., & Needy, K. L. (2006). The economic benefits of green buildings: A comprehensive case study. *The Engineering Economist*, *51*(3), 259–295. https://doi.org/10.1080/00137910600865469

Rivera, L., Baguec, H., & Yeom, C. (2020). A study on causes of delay in road construction projects across 25 developing countries. *Infrastructures*, *5*(10), 84. https://doi.org/10.3390/infrastructures5100084

Rodríguez-Fernández, I., Lizasoain-Arteaga, E., Lastra-González, P., & Castro-Fresno, D. (2020). Mechanical, environmental and economic feasibility of highly sustainable porous asphalt mixtures. *Construction and Building Materials*, *251*, 118982. https://doi.org/10.1016/j.conbuildmat.2020.118982

Sánchez-Silva, M., Frangopol, D. M., Padgett, J., & Soliman, M. (2016). Maintenance and operation of infrastructure systems: Review. *Journal of Structural Engineering*, *142*(9). https://doi.org/10.1061/(ASCE)ST.1943-541X.0001543

Spangenberg, J. H. (2005). Economic sustainability of the economy: Concepts and indicators. *International Journal of Sustainable Development*, *8*(1/2), 47. https://doi.org/10.1504/IJSD.2005.007374

Srivastava, S., Raniga, U. I., & Misra, S. (2021). A methodological framework for life cycle sustainability assessment of construction projects incorporating TBL and decoupling principles. *Sustainability*, *14*(1), 197. https://doi.org/10.3390/su14010197

Thomas, D. R. (2003). *A general inductive approach for qualitative data analysis*. University of Auckland, School of Population Health.

Twerefou, D., Chinowsky, P., Adjei-Mantey, K., & Strzepek, N. (2015). The economic impact of climate Change on Road Infrastructure in Ghana. *Sustainability*, *7*(9), 11949–11966. https://doi.org/10.3390/su70911949

United Nations (2015). Transforming our world: The 2030 Agenda for Sustainable Development (A/RES/70/1). https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf

Vega A, D. L., Santos, J., & Martinez-Arguelles, G. (2022). Life cycle assessment of hot mix asphalt with recycled concrete aggregates for road pavements construction. *International Journal of Pavement Engineering*, *23*(4), 923–936. https://doi.org/10.1080/10298436.2020.1778694

Viles, E., Rudeli, N. C., & Santilli, A. (2020). Causes of delay in construction projects: A quantitative analysis. *Engineering, Construction and Architectural Management*, *27*(4), 917–935. https://doi.org/10.1108/ECAM-01-2019-0024

Wakjira, T. G., Kutty, A. A., & Alam, M. S. (2024). A novel framework for developing environmentally sustainable and cost-effective ultra-high-performance concrete (UHPC) using advanced machine learning and multi-objective optimization techniques. *Construction and Building Materials*, *416*, 135114. https://doi.org/10.1016/j.conbuildmat.2024.135114

Waqar, A., Othman, I., Hayat, S., Radu, D., Khan, M., Galatanu, T., Almujibah, H., Hadzima-Nyarko, M., & Benjeddou, O. (2023). Building information modeling—empowering construction projects with end-to-end life cycle management. *Buildings*, *13*(8), 2041. https://doi.org/10.3390/buildings13082041

Yang, Y., Ng, S. T., Xu, F. J., & Skitmore, M. (2018). Towards sustainable and resilient high-density cities through better integration of infrastructure networks. *Sustainable Cities and Society*, *42*, 407–422. https://doi.org/10.1016/j.scs.2018.07.013

Yaro, N. S. A., Sutanto, M. H., Baloo, L., Habib, N. Z., Usman, A., Yousafzai, A. K., Ahmad, A., Birniwa, A. H., Jagaba, A. H., & Noor, A. (2023). A comprehensive overview of the utilization of recycled waste materials and technologies in asphalt pavements: Towards environmental and sustainable low-carbon roads. *Processes*, *11*(7), 2095. https://doi.org/10.3390/pr11072095

Yilema, M. G., & Gianoli, A. (2018). Infrastructure governance: Causes for the poor sectoral coordination among infrastructure sectors of Addis Ababa. *Cities*, *83*, 165–172. https://doi.org/10.1016/j.cities.2018.06.019

Yu, B., Gu, X., Ni, F., & Guo, R. (2015). Multi-objective optimization for asphalt pavement maintenance plans at project level: Integrating performance, cost and environment. *Transportation Research Part D: Transport and Environment*, *41*, 64–74. https://doi.org/10.1016/j.trd.2015.09.016

Zima, K., Plebankiewicz, E., & Wieczorek, D. (2020). A SWOT analysis of the use of BIM technology in the polish construction industry. *Buildings*, *10*(1), 16. https://doi.org/10.3390/buildings10010016