Developing a sustainability rating framework and indicator decision sub-logic for highway design and construction sector in Nigeria.

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DEVELOPING A SUSTAINABILITY RATING FRAMEWORK AND INDICATOR DECISION SUB-LOGIC FOR HIGHWAY DESIGN AND CONSTRUCTION SECTOR IN NIGERIA

UCHEHARA IKECHUKWU

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DEVELOPING A SUSTAINABILITY RATING FRAMEWORK AND INDICATOR DECISION SUB-LOGIC FOR HIGHWAY DESIGN AND CONSTRUCTION SECTOR IN NIGERIA

by

Uchehara Ikechukwu [BEng], [MSc], [LL.M], [MCIHT]

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STATEMENT OF ORIGINAL AUTHORSHIP

Declaration

I certify that the entire work in this thesis has not been previously submitted for a degree award at any other higher education other than at Robert Gordon University for the award of Doctor of Philosophy. The thesis has no materials previously published by other authors except where due reference is made.

Signed: ____

Date: ____

PROLOGUE

"In nature, nothing exists alone". That was Rachel Carson's critique of anthropogenic activities across the natural world.

(The Silent Spring — Rachel Carson 1907 - 1964)

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We, the undersigned committee, hereby approve the attached thesis,

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Presented by

Uchehara Ikechukwu

Accepted style and content by

Head Graduate School, Robert Gordon University

Professor Andrew Lamb (PhD)

Dr David Moore (PhD)

Principal Supervisor

Robert Gordon University, School of Scott Sutherland

Dr Naeimeh Jarfarifar (PhD).

Supervisor

Robert Gordon University, School of Scott Sutherland

Dr Huda Salman (PhD).

Head Research Degree Coordinator

Robert Gordon University, School of Scott Sutherland

ABSTRACT

Purpose - The need to improve living standards across communities and cities using highway infrastructure development projects increases economic growth and societal expectations of a country. Due to anthropogenic activities, sustainability strategies are encouraged to be utilised for highway infrastructure development. However, the knowledge and practical approach towards sustainability implementation across highway development is lacking in the literature for Nigeria.

Design/methodology– Through literature, the sustainability gaps in Nigeria's highway development are categorised under four groups for design, namely, technical, environmental, economic, and social, and six groups for construction, namely, social, environmental, economic, engineering, project management, health, and safety. A mixed-method approach is implemented for data collection. A questionnaire survey was issued to 33 design and 100 construction project-level participants to assign values to the indicators using the psychometric Likert scale. Afterwards, the analytical hierarchy process (AHP) was utilised to determine pairwise comparison data collection to measure the weighting values of each indicator. Fifteen (15) experts participated in qualitative interviews, and data was analysed using thematic analysis. A face-to-face project case study interview was conducted with 14 project-level experts in ongoing highway projects in Nigeria to measure the effectiveness of the indicators developed in this research.

Findings –Correlation variance of the indicator results between the Likert scale and AHP aided in selecting 36 design and 53 construction indicators using low, middle, and high priority ranking. This research identified project-level participants' expectations on the sustainability agenda, such as sustainability should be considered a world-view requirement for project development and human survival. From the project case studies, sustainability gaps were identified. This research developed an integrated highway sustainability framework and indicator decision sub-logics.

Practical implications - This research argues that implementing an integrated framework and indicator decision sub-logics promotes sustainability awareness and reduces unsustainable highway development practices across the Nigerian environment.

Originality/value – This thesis has provided insight adding to the existing body of knowledge on innovative sustainability practices for Nigeria and established an integrated sustainability framework to reduce the adverse impact of unsustainable construction practices across Nigeria's highway development.

Keywords: - *Sustainability, Highway Infrastructure, Rating System, Design, Construction, Strategies, Project case study, mixed-method, Triangulation, and Analytical hierarchy process.*

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AHP	Analytical Hierarchy Process
AIJ	Aggregation of Individual Judgement
AIP	Aggregation of Individual Priority
BREEAM	Building Research Establishment Environmental Assessment Method
CBA	Cost-Benefit Analysis
CBP	Cow Bone Powder
CEEQUAL	Civil Engineering Environmental Quality Assessment and Award Scheme
COREN	Council for the Regulation of Engineering for Nigeria
CPD	Continuous Professional Development
DMRB	Design Manual for Roads and Bridges
EIA	Environmental Impact Assessment
EURORAP	European Road Assessment Programme
FCDA	Federal Capital Development Authority
FCT	Federal Capital Territory
FGON	Federal Government of Nigeria
FHWA	Federal Highway Authorities
GHG	Greenhouse Gas Emission
GMM	Geometric Mean Method
GREENLITES	Green Leadership-in-Transportation Environmental Sustainability
I-LAST	Liveable and Sustainable Transportation Rating System
INVEST	Infrastructure Voluntary Evaluation Sustainability Tool
IPCC	Intergovernmental Panel on Climate Change
KM	Kilometre
LCA	Life Cycle Analysis
MCDA	Multi-Criteria Decision-Making Analysis
MDG	Millennium Development Goals
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
PCM	Pairwise Comparison Matrix
PW	Plastic Waste
RAP	Reclaimed Asphalt Pavement
SDG	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SLCA	Social Life Cycle Analysis
SPSS	Statistical Package for Social Science Software
SURF	Sustainable Road Forum
UNDESA	United Nations Department Of Economic And Social Affairs
UNDP	United Nations Development Programme
UN-ECOSOC	United Nations Economic and Social Council
WCED	World Commission on Environment and Development

CHAPTER 1: INTRODUCTION

"Research is formalised curiosity; it is poking and prying with a purpose" — Zora Neale Hurston (1891 – 1960).

This chapter presents the background of the research, an overview of highway infrastructure development, the research problem statement, central research questions, aim and objectives, the contributions of the research, the research design, the structure of the thesis and the chapter summary.

The research background begins with an overview of highway transportation's significance within the global context and the adverse impacts of unsustainable development across the fabric of societies. Summarized are the barriers preventing the implementation of sustainability practices within highway development in Nigeria.

1.1 Background of the research

In the past decades, the proposal to adopt the sustainability model, such as, (social, environmental, and economic concepts) emerged in 1987 during the global environmental inquiry by the Brundtland Commission, which gave rise to a report called "Our Common Future". The contents and recommendations made in this report triggered sustainability awareness and practices across a wide range of sectors (Palmer, 1992; Handl 2012: 2). Earliest known sustainability strategy emerged from Green Building in the early 1990s (Kibert, 2007; Hill and Bowen, 1997). Transportation sustainability evolved in 1992 during the United Nations Conference on Environment and Development. It was acknowledged that transportation development requires sustainable initiatives to reduce environmental risks associated with unsustainable development (Mead, 2021). According to Weiner (2016), sustainability concepts in roads and highway development emerged in America in the mid-2000s due to the need to resolve environmental challenges created due to the adverse impacts of transportation development across the environment. As a result, sustainable highway design and construction have, until recently, been a dominant discussion across the academic sphere (Rooshdi et al., 2014; Ibrahim and Shaker, 2019; Uchehara et al., 2022). The significance and benefits of sustainable highway infrastructure development have predominantly been focused on reducing adverse impacts across society's environmental, social, and economic fabrics (Lee et al., 2011; Rooshdi et al., 2014; El-Kholy and Akal, 2020).

Some of the notable adverse impacts of unsustainable highway development across the society’s environmental, social, and economic fabrics include—changes to the natural landscape due to habitat fragmentations which resulted in the formation of small pockets of isolated habitation patches (Rooshdi et al., 2014: 181). In addition, Van Der Ree et al., (2015), Koemle et al., (2018), and Xu et al., (2021) respectively outlined other notable infrastructure adverse development impacts across society. This list is by no means exhaustive but covers categories of the most relevant aspects; —

- water, air, and noise pollution.
- ineffective land use.
- design barriers hindering the movement of endangered species.
- a source of contamination to habitats.
- erosion, siltation, and impact on wetlands.

Sustainable highway construction requires a trade-off in making effective decisions across the triple bottom line of social, environmental, and economic concepts (Song et al., 2021). The sustainable trade-off comprises how to accomplish reduction of the adverse impacts of unsustainable development practices during highway design and construction, considering factors such as—reduction of travel time, lessening carbon emission and pollution, utilizing recycled by-product material instead of extracting natural raw material, reduction of noise and energy consumption, and waste minimizations (Tsai and Chang 2012; Ibrahim and Shaker, 2019; Uchehara et al., 2022).

These trade-offs and sustainability best practices in highway projects have been achieved in some developed societies, for instance, across some countries of Europe, employing the European Road Assessment Programme (EuroRap). EuroRap is aimed at developing safe, risk-free and sustainable road development, providing guidelines for contracting authorities to address environmental issues during highway development. According to Garbarino et al. (2016), in some European Union countries, the contracting organisations (tenderers) are selected based on their sustainability competencies at diverse levels of ambition in achieving sustainable design solutions across the project lifecycle. These criteria are considered voluntary but essential in enabling development towards improved environmental performance for the intended road and highway projects.

In the United Kingdom, the Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL, at present integrated with BREEAM, —Building Research Establishment Environmental Assessment Method) is an evidence-based sustainability assessment rating and award scheme for infrastructure and highway development. In the United States, various private institutions and governmental transportation agencies are committed to highway sustainability assessment practices using rating systems such as Greenroads, INVEST, GreenLites, and I-Last (Montgomery et al., 2015).

Given the multiple fragilities and slow development of some sub-Saharan African nations, there is a lack of sustainability awareness and knowledge within those nations. Hence, highway sustainability development is far from a certainty across most sub-Saharan African countries. It has been noted from the literature that South Africa is the only country in Africa conducting research with a pilot study on the use of a sustainability tool called the Sustainable Road Forum (SuRF) to develop sustainable highway construction (Nkabinde, 2019). In Egypt, there is literature evidence proposing the adoption of sustainable highway development using a sustainability rating system (Ibrahim and Shaker, 2019).

In other countries of the sub-Saharan African region, the use of traditional highway infrastructure development continues to impose adverse impacts on the environment due to inadequate policies, and non-inclusive nature of relevant organisations, and the lack of research on highway sustainability. These factors restrict sub-Saharan African nations from pursuing common national and global environmental sustainability goals (Gelbard et al., 2015).

Nigeria is one of the sub-Saharan nations that has been considered as making progress in building sustainability resilience across its industries (Gelbard et al., 2015: p.8). Despite the aforementioned generalised assertion, there is evidence of noted gaps in sustainable development in construction, which requires awareness of prioritised sustainability practices in developing infrastructures across Nigeria (Olayeni et al., 2018; Haider et al., 2019). The hindrances persist, such as the inability to adopt sustainability practices because of stakeholders' lack of experience and the non-existence of sustainable measurement criteria

(Olowosile et al., 2019; Coker et al., 2021). According to Chen et al., (2021), the readiness to improve sustainability practices ranks low in developing countries. In such a context, implementing highway sustainability is a relatively new challenge to engineers and contractors (Kehagia, 2009).

Given the above-mentioned concerns, there are sustainability suggestions in the existing research; for instance, contemporary literature has been published for sustainable roads and highway development in Nigeria. Ojuri et al., (2022) proposed reducing high clay content in lateritic raw materials using lime cow bone powder (CBP) and plastic waste (PW) for roads and highways. Oluwatuyi et al., (2018) attempted to use lateritic soil stabilised with cement for highway construction materials. In another related study, Bamiaboye et al., (2021) explored avenues to reduce the consumption of natural raw materials for highway pavement construction using plastic bottles, waste rubber tyres, glass waste, steel slag, fly ash and cement kiln dust. Another parallel study proposed recycling plastic waste and using modified polymer bio asphalt (as a by-product) to construct and restore defective asphalt pavement in Nigeria (Oke et al., 2013; Adedayo et al., 2017; Emmanuel, 2019).

These noted road and highway pavement proposals do not conclusively cover the overall sustainability agenda for the Nigerian environment. A noted drawback to the novel sustainability research findings is the ignored opportunity to assess best practices using the highway measurement rating framework for Nigeria. Given the afore-reviewed, the impact on the environment and associated cost of recycling are uncertain for Nigeria. Thom and Dawson (2019) advocate the adoption and use of technical design methodology and contractual arrangements to incorporate sustainability in using recycled industry by-products (in-situ and ex-situ recycling) for road maintenance. The adoption and use of large-scale in-situ and ex-situ recycling can be useful for Nigeria. It is noted that deteriorated milled asphalt pavement in Nigeria is instead disposed of, which has a direct negative environmental impact (Oke et al., 2013; Thom and Dawson, 2019).

The issue of sustainability practice has grown in importance along with an awareness towards protecting our planet. This is evidenced by the recently published red alert climate change data by the Intergovernmental Panel on Climate Change (IPCC AR6, 2021). As part of environmental awareness, the

United Nations proposed a noteworthy 2030 environment agenda for its Member States to pursue sustainable development goals (United Nations SDRs Report, 2015; Nigeria Voluntary National Review Report, 2022). According to Olowosile et al., (2019) and Coker et al., (2021), the much-debated matter is whether an appropriate amount of academic research relevant to adopting sustainable development has been achieved across Nigeria.

Sustainability knowledge gaps, unclear concepts and lack of awareness have been identified as the inability to embrace sustainability practices across Nigerian projects (Zuofa and Ochieng, 2016). Past research from Nigeria offered divergent solutions and interpretations toward sustainable highway development, such as adopting policy financing as a form of sustainable solution (Effiom and Ubi, 2016). There have been debates in literature attempting to determine a sustainability framework for infrastructure development across Nigeria (Nwokoro and Onukwube, 2011; Dania et al., 2013). However, there are noted drawbacks attributed to past research, including the inability to assess sustainability issues through the lens of the Nigerian environment using indicators.

Furthermore, within the Nigerian context, the occurrence of sustainability knowledge gaps is attributed to past research focusing on technical factors, traditional project management and procurement criteria, while neglecting the sustainability measurement criteria using the triple bottom-line concepts of social, environmental, and economic concepts in project development (Abiodun, 2013; Ademila, 2021).

A systematic understanding of how sustainability contributes to overall highway development is unclear and lacking in the literature for Nigeria. Considering the strings of evidence reviewed from the literature suggests there is little published research investigating sustainable highway infrastructure development for Nigeria. The few research publications offering advice towards implementing sustainability concepts during highway development across Nigeria, lack measuring metrics and indicators to analyse when and how sustainability concepts can be applied. A potential problem that emerges when highway rating systems are not utilised is the omitted opportunities to develop resilient highway projects that reduce adverse impacts across the environment (Mattinzioli et al., 2020).

This research argued to develop an integrated sustainability assessment rating framework for Nigerian highway development. The research critically evaluated current global sustainability strategies, challenges within Nigeria's context, and local contents to reduce the impacts of unsustainable development across the Nigerian highway sector, and to enhance sustainability knowledge.

1.2 Overview of highway infrastructure development

It is useful to provide an overview of the highway design and construction processes to contextualise the different development phases. Primarily, highway design is a subcategory of highway engineering that comprises planning, design, construction, and operation, which account for solving transportation problems for effective safe traffic flow using the designed geometric elements (Roger and Enright, 2016; Findley et al., 2022). Highway engineering design and construction practices pay attention to the use of philosophical methods to achieve specific works (Shi 2021). The philosophical methods in highway engineering involve processes such as identifying travel data to determine and forecast traffic distribution, economic appraisal, establishing necessary highway traffic design elements, and analysing the structural integrity of the pavement (Roger and Enright, 2016).

Figure 1.1 displays the stages involved in highway design, namely, planning, preliminary design, and final design, comprising concept design and detailed design (Boyle, 2016). In the planning phase of highway design, the feasibility report is provided by the transportation agency or external consultants to define the nature and scale of the project (Boyle, 2016). During the planning stage, inputs are elicited from appropriate communities and members of the public in reaching a consensus to select the best alternative design solutions. These decisions in selecting alternative designs are related to fulfilling different transportation needs and determining their effects and mitigation on society, existing land, health and safety, and economic, environmental, and social issues (Rogers, 2016:9).

The preliminary design phase progresses after the planning phase, which involves the analysis of each design alternative to determine its impact and potential mitigations on the environment, including safety measures. The preliminary design phase is aimed at developing to achieve agreed-upon requirements during the planning stage (Findley et al., 2022).

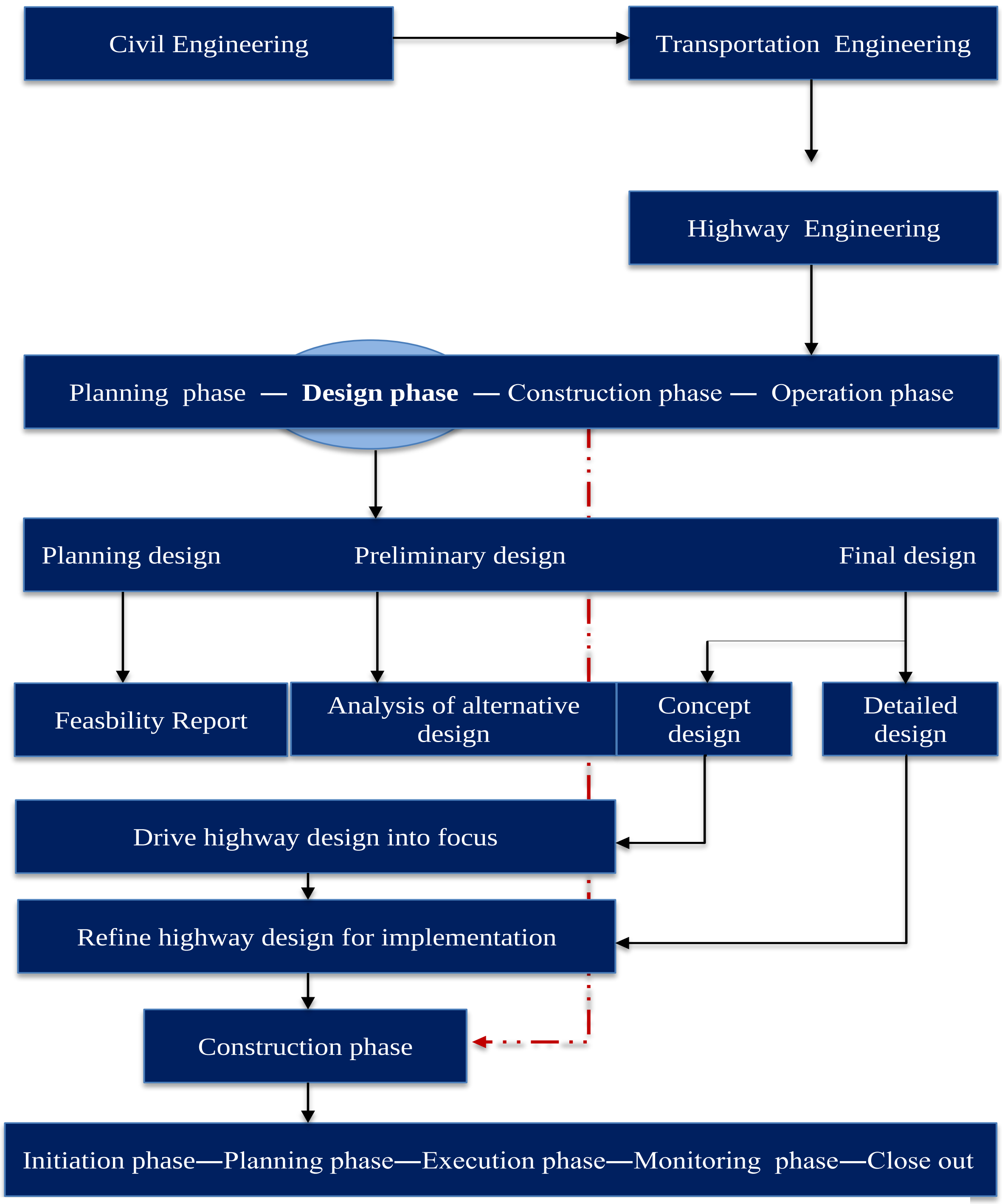


Figure 1.1 Flowchart highway design and construction **Source: Author generated**

Concept design in highway development drives the development cycle into a specific focus and direction (Boyle 2016). Concept design helps outline the highway's overall framework structure in terms of functionality, classification, type and the number of pavement lanes, width, shoulders, technology, ditches, curves, and alignments.

The detailed highway design can only commence after the approval of the concept design phase. In the detailed design stage, the overall design is refined and set to proceed with implementation. Detailed design involves specific construction information based on the detailed geometric design, layout, plan and profiles, hydraulic structures, policies, procedures, processes, schedule, and all required to implement a highway project successfully. The construction phase generally commences after the detailed design, although it depends on the type of procurement route utilized for development. The stages typically associated with the construction phase are — planning, execution, monitoring/controlling and project closeout (refer to Figure 1.1 for a flowchart).

Across the globe, highway transportation engineers strive to meet the planned design needs while attempting to maintain the integrity of the environment as well as social and economic values (Rogers and Enright, 2016; Fields et al., 2020). In addition, the unique combination of these design criteria and constraints often leads to the need for legislative guidance, sustainability concepts and standards to achieve design and construction goals.

The conventional design criteria for highways are found within manuals, such as the American Association of State Highway and Transportation Officials (AASHTO) published in 2011, which is called "A Policy on Geometric Design of Highways and Streets", to aid in administrative works, planning, and design formulation. The guiding document for transportation development in the United Kingdom is the "Design Manual for Roads and Bridges" (DMRB), with the latest edition published in 2020. In Nigeria, the highway development standard is guided by Volume I – VII of various "Nigerian highway design manuals" published in 2013.

1.3 Problem statement

According to the United Nations Department of Economic and Social Affairs (UNDESA, 2018; UNDESA, 2022), 55% of the world population (roughly 4.2 billion) currently lives in cities, and that will increase by an additional 2.5 billion (32%), bringing it to a total of 6.7 billion, by 2050. Currently, the world's major cities occupy 3% of the planet's landmass, and this portion of cities consume 76% of global energy and emits nearly 77% of the planet's carbon emissions (United Nations Habitat Annual Report, 2010; 2021; UNDESA, 2018).

It is revealed by the United Nations Department of Economic and Social Affairs (2022) that new megacities will emerge and that will concentrate in fewer countries like Nigeria, India, Ethiopia, Congo, Egypt, Tanzania, Pakistan, Philippines, and China, and that will account for a 32% - 36% urban increase. A megacity is typically having approximately 10 million inhabitants (Molina and Molina, 2012: 644). According to Taubenbock et al. (2012), in the past, there was twenty-seven (27) megacities globally, which has increased due to the attraction for a better living standard in urban areas. According to the United Nations (2018), currently, 37 megacities exist globally, and by 2050, the new megacities will appear across the above nine countries earlier identified.

Pre-independence in 1960, the population of Nigeria was 45 million, and the latest population data of Nigeria is 205 million (Statista, 2022). Current forecasts suggest the Nigerian population will double by the end of 2050 to 401 million, which will surpass the United States' current population size of 335 million (Statista, 2022), and a total of 183 million is expected to dwell in megacity areas by 2050 across Nigeria. Due to the growing population across Nigeria, there is an emergence of megacities, namely, Lagos, Kano, Port Harcourt, and other states across Nigeria, which are fast growing in population size (Obia, 2016).

Currently, there are 195,000 km of roads in Nigeria, the paved roads in lengths of 63,000 km (Oyedele, 2019). The unpaved road section is 132,000 km, partly belonging to the rural government and these roads are deteriorated due to poor quality development (Enwerem and Ali, 2016; Oyedele, 2019). Globally, 12 million km of paved road has been built since the year 2000, and another 25 million is anticipated to be built by 2050 (Dulac, 2013; Meijer et al., 2018).

Africa has an extensive plan for road expansion, including Nigeria (Mahmoud et al., 2017).

It is acknowledged that the rapid urbanization growth and megacities' emergence will exert pressure on the existing biodiversity of Nigeria (Molina and Molina, 2012; Taubenbock et al., 2012; UNDESA, 2018:43). Besides, countries with better transport infrastructures are in a better position to experience socioeconomic growth (Amadi, 2018). Mega infrastructure projects and urbanization development are contributory causes of environmental degradation, resource depletion and greenhouse gas emissions (Abubakar & Aina, 2019; Abubakar, 2021).

Evidence suggests that Nigeria is the second-biggest emitter of greenhouse gases (GHG) in Africa, and globally is in the 17th position (Hamilton and Kelly, 2017; Carbon brief, 2020; Ritchie and Roser, 2021). Study findings in Nigeria predict a temperature increase of up to 3.2°C by 2050 and a further regional increase of 4.5°C between 2081-2100 (Haider, 2019). Nigeria is expected to overtake many other countries' annual carbon emissions by the end of the century (Haider, 2019). The Nigerian government has continually pledged to the United Nations that efforts will be made to reduce greenhouse gas emissions by 20% before 2030 (Carbon Brief, 2020). Currently, Nigeria's annual carbon emission across all sectors is estimated at 120 million tons from a value of fewer than 20 million tons in 1960, and it is noted that in Nigeria, the construction industry and manufacturing sector collectively contribute roughly 6.7 million tons of carbon annually (Ritchie and Roser, 2021).

In a parallel development issue, roads and urbanization development account for the loss of forest cover, release of pollution such as noise and dust, wetland impacts, waste generation, loss of agricultural land, social disintegration, and degrading natural habitats (Adebayo, 2012; Opoku and Fortune, 2013; Wu et al., 2019). In Nigeria, urbanization-related activities and development between 2002 and 2021 caused the loss of hectares of humid forest at the rate of 3.5% per year (Mfon, 2014; Laurance et al., 2017; Global Forest Watch, 2022).

Traditional highway design and construction techniques are beneficial but lack insight into practical sustainability assessment strategies. These traditional practices strain the world's available resources (Ofori, 1998). The focus of traditional highway development is more on the triple constraint of time, cost and scope. For instance, traditional highway development has no compatibility with achieving a net zero carbon reduction. This is because there is no consideration for sustainability practice using social, environmental and economic concepts. According to Ejem et al. (2018), unsustainable transportation projects are among the major sources of carbon emissions across Nigeria. Also, the development of urbanisation and infrastructure in Nigeria continues to fragment the ecology (Mfon, 2014). Unsustainable practices in infrastructures across the Nigerian environment result in project failure due to cost overrun (Anigbogu et al., 2019; Obianyo et al., 2022). The root cause of project failure is the lack of an economic sustainability project model.

Therefore, Nigerian designers, project decision-makers and contractors should progress from a traditional design and construction approach to sustainable development practices, considering social, environmental, and economic sustainability factors. The identified sustainable considerations with the associated sustainability benefits helped to nurture innovative solutions towards building a sustainable resilient city (Ifije and Aigbavboa, 2020). There is literature evidence that public opinion and inputs are not fully integrated during highway development in Nigeria (Ikioda, 2016). Besides, the Nigerian government continues to source for infrastructure development techniques from overseas, which are incompatible with the Nigerian environment (Odediran et al., 2012).

What is needed for the highway development sector across Nigeria is to adopt eco-friendly development strategies using renewable energy, recycling, economic models, environmental management practices and social inclusion to enhance sustainability implementation practices during highway design and construction across Nigeria.

The above-noted challenges call for establishing a development approach to fill the sustainability knowledge gaps presented in this research. Therefore, this research seeks to develop a sustainability assessment rating framework to reduce the adverse impacts of unsustainable highway development in Nigeria and to enhance sustainability awareness and knowledge among project-level participants across Nigeria.

1.4 Central research questions

Below are the considered research questions; —

1. What are the current sustainability strategies utilised for highway development globally?
2. What are the benefits and disbenefits of sustainable highway development?
3. What are the critical issues influencing the implementation of sustainable highway development in Nigeria?
4. What are the appropriate sustainability indicators that can resolve unsustainable highway development practices across Nigeria?
5. What is the sustainable framework adequate in reducing the impact of unsustainable highway development practices across Nigeria?

1.5 Research aim and objectives

The aim is to develop a sustainability rating framework that can reduce the impact of unsustainable highway infrastructure development in Nigeria. In pursuit of this aim, the following research objectives was achieved; -

1. To identify and critically explore highway sustainability development concepts globally.
2. To appraise benefits and disbenefits associated with sustainable highway design and construction development.
3. To examine factors affecting the implementation of sustainable highway development in Nigeria.
4. To identify local sustainability indicators for reducing adverse impacts due to unsustainable highway development.
5. To establish a sustainability framework and indicator decision sub-logic for Nigerian highway development, and to address unsustainable development practices across Nigeria.

1.6 Contribution of research

The core contribution of this research is in two distinct categories, namely, contribution to the highway infrastructure sector to adopt sustainable practices and research benefits for academic knowledge enhancement within this field: —

First identified through literature are 17 highway sustainability strategies utilised globally. The purpose is to understand what type of sustainability measures are currently implemented in developing highway projects globally and the need to integrate the benefits within Nigeria's highway sustainable project development framework. A mixed method approach was used for collecting quantitative and qualitative data to develop 36 designs and 53 construction indicators for Nigeria highway projects. The contributions of the developed sustainability indicators at the project level area are; —

1. It enables project-level participants to design and build resilient highway projects with recognition for making sustainability contributions.
2. It provides a collaborative platform enabling project-level participants to contribute ideas in achieving best practices during highway development.
3. Using the indicators will not only reduce adverse impacts across the environment but also help conserve energy and natural resources.
4. It creates sustainability awareness, both for the project participants and the general public.
5. It provides an avenue to implement, monitor and share best practices.
6. It promotes the design and implementation of sustainability across project management, technical, safety, social, environmental, economic, and engineering-related areas during highway development.
7. Sustainability is mandatory for implementation towards infrastructure development, and all these benefits guarantee resilient developed infrastructure and protection of the global natural environment.

In addition, this research contributes to the existing body of knowledge on sustainability development for highways, as it creates awareness among researchers on steps that can be taken to continue further research on highway sustainability (this is the knowledge created using the data and methodology identified in this research).

1.7 Research design approach

Different methods have been proposed and utilised in developing sustainability assessment rating frameworks in literature for roads and highway development (Tsai and Chang, 2012; Rooshdi et al., 2014; Yang et al., 2018; Ibrahim and Shaker, 2019; El-Kholy and Akal, 2020; Oragbune, 2022). One of the well-known tools for assessing sustainability in highway sustainability development is the quantitative approach using an analytical hierarchy process (Ibrahim and Shaker, 2019; El-Kholy and Akal, 2020). Tsai and Chang (2012) proposed using interviews and checklists to determine sustainability in highway design. Also, Oragbune (2022) used a multi-criteria decision model to determine sustainability criteria for road infrastructure delivery. The identified methods are well-established approaches, but the use of similar methods to answer this research question will be a drawback in achieving the aim of this research.

Therefore, due to the absence of highway design and construction sustainability rating framework research for Nigeria, this research design approach considers achieving results using a mixed-method approach and project case study to answer this research questions.

1.8 Structure of the thesis

This research thesis is categorized into eight distinct chapters, and a summary is outlined below; —

Chapter 1 — This chapter is an introduction to this research. The contents of this chapter consist of the research problem statement, the research aim, questions and objectives, a summary of the significance of the research undertaken, the research design approach, scope boundaries and structure of the research.

Chapter 2 — This is a literature review chapter which critically assesses the current state of knowledge within highway design and construction. Also, sections considered for a review include critically exploring highway development strategies utilized globally and appraising benefits and disbenefits associated with sustainable highway design and construction development. Examined are factors influencing the implementation of sustainable highway development in Nigeria.

Chapter 3 — This chapter outlines the research plan and strategies, including the research philosophy, research component, research design, sampling method, and analysis of results. The research method adopted is mixed methods comprising quantitative and qualitative, including a project case study. The data collection methodology is a questionnaire survey, interview, and project case study interview, respectively. Also, different concepts were laid out for the data analysis, result presentation, and validation.

Chapter 4 — This chapter focuses on presenting achieved quantitative results, which include online questionnaire surveys and the analytical hierarchy process (AHP) using a pairwise comparison matrix.

Chapter 5 — This chapter is the qualitative interview utilized to gain insight from project-level participants from highway design and construction in Nigeria. The emphasis is to gain their opinion towards awareness of sustainability in projects and to identify factors influencing the implementation of sustainability practices. The indicator validation was achieved through inclusion and exclusion by the selected project practitioners.

Chapter 6 — This chapter presents the case study employed in assessing current research-developed sustainability indicators at the highway project level. It assisted in determining the extent of the variances (unsustainability practices) and noted best practices in terms of sustainability performance across highway design and construction projects in Nigeria.

Chapter 7 — This chapter discusses the achieved results from Chapter 4, Chapter 5, and Chapter 6. The integration of research findings and results in developing a sustainability framework, with indicator decision sub-logics supported with recommendations for a better understanding of sustainability implementation at the highway design and construction project level.

Chapter 8 — This chapter concludes what was achieved regarding the research objectives, aim and offers closure with the research outcome based on the research questions and the overall contributions made to the existing body of knowledge. Identified is the significance of research findings towards the project-level practitioners, academics, and transportation agencies. Finally, the contribution to knowledge, limitations and recommendation for future research is identified and summarized.

1.8.2 Summary of chapter

The chapter lays the groundwork for the thesis; foremost, it introduces the background of the research and points to the issue concerning challenges associated with traditional highway design and construction across the fabric of Nigerian society and the noted adverse impacts. Presented are the problem statement, research questions, aim and objectives, research design and structure of the thesis.

CHAPTER 2: LITERATURE REVIEW

“A literature review provides a sound base upon which new research can be found” — Oliver Paul (2012:7).

2.1 Introduction

This chapter presents a summary of the reviewed literature. Section 2.2 discussed sustainable development and the United Nations' milestones in promoting sustainable development agendas. Section 2.3 presents sustainable development interpretations, definitions, dimensions, and principles of sustainable development. Section 2.4 examined sustainable construction strategies. Section 2.5 presented sustainability strategies utilized in highway design. Section 2.6 is the sustainability strategy utilized in highway construction, and section 2.7 is the Nigerian perspective on highway development.

2.2 Emergence of sustainable development

The root of sustainable development emerged in continental Europe between the 17th and 18th centuries when John Evelyn was put in charge of stopping the exploitation of timber resources in England (Ulrich, 2007; Purvis et al., 2017; Sturup and Low, 2019). It is a widely held view that “scarcity is the mother of invention”, and collectively these eras of forest management in England marked the origin of the use of the term sustainable forest management (Ulrich, 2007; Sturup and Low, 2019). A similar event occurred in another part of continental Europe in the 1770s; this involved the use of timber for the mining and smelting of ores, which led to the consumption of parts of the forest of Saxony (called Tharandt Forest) in present-day Germany. A mining administrator named Hans Carl Von Carlowitz was concerned by the level of environmental deforestation as he commenced managing and re-seeding the Saxony Forest (Sturup and Low, 2019: 10). In those early days, the primary focus of the environmental reformists was preserving the environment for economic benefits (Sturup and Low 2019: 10), which is a form of encouraging a damaging vicious cycle to the natural environment.

The modern concept of sustainable development, in a global sense, emerged in the late 20th century (Purvis et al., 2019: p.682). The awareness of sustainable development continues to draw considerable attention across industries and the scholarly sphere (Sturup and Low, 2019; El-Kholy and Akal, 2020; Song et al., 2021). Over the years, there have been debates about sustainable development with varying degrees of insight and interpretations (Pearce, 2006; Kibert, 2007; Waas et al., 2010; Klarin, 2018). This section needs to identify the consistency between 'development which is sustainable' and 'development which is sustainability'. Although the two terminologies seem straightforward to distinguish, their meaning and interpretation are slightly different, yet both terms harmonize with each other (Purvis et al., 2019).

Sustainable development is "meeting the needs of the present generation without compromising the ability of the future generation to meet their own needs" (Bruntland, 1987). Glavìc and Lukman (2007) stated that sustainability terms have interconnection, which is crucial for understanding a better way of moving our planetary environment towards a sustainable developed place. According to Zabihi et al., (2012), sustainability across the construction sector aims to achieve a design product that complies with the triple bottom line of social, environmental, and economic factors. In comparison, sustainable development refers to several processes and pathways towards achieving sustainability. Likewise, sustainability is a broad term that encompasses development. Ruggerio (2021) gave a robust definition of sustainability, which is a concept to achieve 'resilience', 'adaptability' and 'transformation'. Therefore, both sustainability and sustainable development are synonymous within the context of this research. Currently, the United Nations developed 17 Sustainable Development Goals (Pradhan et al., 2017). The aim of the Sustainable Development Goals is for the member nations belonging to the United Nations to adopt and implement seventeen interlinked objectives required to solve a wide range of issues under sustainable development strategy.

Figure 2 illustrates Zamora-Polo and Sánchez-Martín (2019) concisely outlined sustainable development timelines; the primary focus of the illustration is to examine sustainable development between 1962 and 1987. Rachel Carson (an American marine biologist, 1962) published a book called "Silent Spring", which uncovered unforeseen environmental dangers. Carson's (1962) main concern was preserving the planet. Consequently, humankind's gross tampering with the physical environment was spotted due to awareness raised earlier by Carson, and this discovery triggered floodgates of inquiry in the 1990s into underlying reasons concerning environmental contaminants and their effect on humans and the environment (Stein, 2012: p.112).

Figure 2 Sustainability construct milestone Adapted from Zamora-Polo and Sánchez-Martín (2019)

In another event that led to sustainable development emergence, a group of students in 1967 Sweden raised awareness on how to prevent "plundering and poisoning across nature and its environment" (Heidenblad, 2021: 5). The pressure group raised environmental concerns in Sweden, which demanded legislative reformation towards reducing adverse impacts of human activities across their environment. As a result of the raised concerns, the Swedish government proposed to the United Nations Economic and Social Council (UN-ECOSOC) — to investigate human interactions with their environment.

As a follow-up to the raised environmental depletion concerns, in 1972, the United Nations General Assembly convened in Stockholm to investigate the impact of humans on their environment, and evidence was presented and analysed (Bodansky, 1993). The UN General Assembly's findings and conclusions revealed that human development actions impacted the environment (Palmer, 1992: 109). In Figure 2, another documented timeline evidence of sustainable development emergence is by Schumacher (1973), who published a collection of essays called "Small is Beautiful", which critiques the lack of sustainable development across the modern global economy post World War II. Other environmental reformists continued to argue for the need to protect the environment. For instance, Pope Francis, in his encyclical *Laudato Si' (English meaning "Praise Be to You)*, called out to the global community to save our planet from anthropogenic activities (Schneck, 2016). Lastly, in Figure 2, Cortina (2007) believed that development across the environment is a function of peace and minimum ethical conduct and implementation in achieving sustainability and global stability.

2.2.1 United Nations sustainable development agenda

Every five years, the United Nations and the International communities debate how to improve sustainable environmental development (Keong, 2020). Table 2 is the timeline of how the concepts of sustainable development continue to evolve under the leadership of the United Nations General Assembly.

Table 2. Sustainable development timeline by the United Nations

Year	Event	Outcomes
1972	First held United Nations Conference on the Environment, Stockholm, Sweden	Declaration concerning the environment and development.
The existing sustainability framework		
1987	World Commission on Environment and Development (Brundtland)	Sustainability development is initiated. Promoting a framework of economic, social, and environmental criteria for sustainable development.
1992	Rio Earth Summit Brazil	Agenda 21 for sustainable development globally & transportation sustainability initiative.
1997	Kyoto Protocol	Achieved agreement on carbon reduction across nations.
2000	United Nations Millennium Summit	Set Millennium Development Goals (MDGs) on environmental
2002	Rio + 10 Johannesburg Summit	Launch of partnerships in a new form involving civil society aimed at implementing sustainable development goals.
2009	UN Climate Change Conference	Discussions of climate change.
2012	Rio + 20 de Janeiro Brazil	Agreement to address new challenges in building sustainable development.
2015	Paris Agreement + 17 SDGs	Carbon emission reduction.
2021	United Nations Climate Change Conference Glasgow, Scotland	Greenhouse gas emission reduction strategies.

Adapted from: Klarin (2018) and Zhang (2018)

2.2.2 Section summary

The root of sustainable development emerged in continental Europe between the 17th and 18th centuries, and the focus was to bring to a halt deforestation carried out at an unprecedented scale. Literature review evidence suggested that in 1962, Rachel Carson, an American biologist, first brought the issue of environmental challenges to the spotlight. Subsequently, a group of Swedish environmental activists and their government raised noted environmental issues to be examined by the United Nations General Assembly. In 1972, in Stockholm, the United Nations inaugurated an environmental enquiry, which resulted in holding subsequent summits, conferences and protocols every five years for the past thirty years. In 1987, the Brundtland Commission identified environmental challenges and proposed sustainable development concepts to reduce adverse impacts of human development across all sectors (due to anthropogenic activities). The United Nations General Assembly currently recommends its member nations to adopt and implement seventeen SDG goals. What is noted is the consistent drive for the United Nations member countries to unify in achieving a common goal through implementing regional and global sustainable development strategies. These sustainable development efforts are evident in published United Nations agreements such as Agenda 21, Millennium Development Goals, carbon emission reduction agreement of the Kyoto Protocol. With the latest Conference of Parties (COP26) held in Glasgow, sustainable development approaches continue to be a key focus within the global context.

The next section examined what is sustainable development, its interpretations, definitions, components, and associated principles. This review progressively helped to understand knowledge evolution within the field of study.

2.3 Sustainable development – a variety of interpretations

It is noted from the literature that industry practitioners and scholars provided different points of view and interpretations for sustainable development (Purvis et al., 2019: 691; Luczak and Just, 2021). According to Purvis et al., (2019), it is debated that the variety of sustainable development interpretations is attributed to the inability of the literature to shed light on a universal standard version of sustainable development concepts. This is a result of the vested interest of stakeholders leading to an unwillingness to accept the validity of anyone else's perspective on either the problem(s) or the solution(s) when dealing with sustainable development issues (Bal et al., 2013).

Some authors continue to argue that sustainable development's definition has somewhat moved on since Brundtland in 1987 (Pearce, 2006; Klarin, 2018). This is because the understanding of sustainable development increases with different concepts due to noted environmental challenges that evolve differently. As a result, different definitions and interpretations of sustainable development continue to evolve globally. Similarly, Kläy et al. (2014) believed the definition generates an important theoretical concept, but the impact of that concept has been limited until now. It could be argued that the United Nations and the international communities should equally amend and update sustainable development definitions to reflect the reality of current environmental development impacts and the level of challenges globally (Purvis et al., 2019).

The fact that environmental circumstances vary from location to location across the globe justifies balancing the sustainable development definitions. These differences and unwillingness to accept anyone's validity about sustainable development are evident across many nations (Bal et al., 2013). For instance, within the developing countries of Africa, sustainable development and its interpretations signify poverty alleviation and reduction of social inequality. In contrast, it can be implied that sustainable development in advanced countries focuses more on fighting against climate change catastrophes through sustainable development strategies (Uddin, 2017; Balogun et al., 2020).

2.3.1 Sustainable development definitions

Authors have different views, meanings and interpretations of sustainable development, for instance; —

"Contemporary society considers sustainable development to be the best way to address complex and interrelated problems for current and future generations for the integrity of the planet" (Waas et al., 2010: 629).

The above definition used "complex" and "interrelated" as the primary factors in accomplishing sustainable development. However, a different definition of sustainable development was given by Luczak and Just (2021); —

"Sustainable development is not a process that can be measured directly, and it is only feasible to characterize it with certain quantitative variables using adequate measurement methods and tools" (p.2). In this context, Klarin (2018) summarised significant sustainable development definitions across various scholarly publications (see Table 2.1).

Table 2.1 Overview of sustainable development definition

Author/publication year	Meaning of sustainable development
WCED, 1987	Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Harwood, 1990	Sustainable development is an unlimited developing system where development is focused on achieving greater benefits for humans and more efficient resource use to balance the environment and human needs with other ecological species.
UNDP 1991	Sustainable development is a process of improving the quality of human life within the framework of carrying capacity for a sustainable ecosystem.
Lele, 1991	Sustainable development is a process of targeted changes that can be repeated forever.
Meadows, 1998	Sustainable development is a social construction derived from the long-term evolution of a complex system – human population and economic development integrated into ecosystems and biochemical processes of the Earth.
PAP/RAC, 1999	Sustainable development is development given by the carrying capacity of an ecosystem.
Vander-Merwe & Van-der-Merwe, 1999	Sustainable development is a programme that changes the economic development process to ensure the basic quality of life, protecting valuable ecosystems and other communities at the same time.
Beck & Wilms, 2004	Sustainable development is a powerful global contradiction to the contemporary Western culture and lifestyle.

Pearce et al., 2006	Sustainable development implies a conceptual socio-economic system that ensures the sustainability goals in the form of real income achievement and improvement of educational standards, health care and the overall quality of life.
Vare & Scott, 2007	Sustainable development is a process of changes where resources are raised, the direction of investments is determined, the development of technology is focused, and the work of different institutions is harmonized; thus, the potential for achieving human needs and desires is increased as well.
Marin et al., 2012	Sustainable development gives a possibility of time-unlimited interaction between society, ecosystems, and other living systems without impoverishing the key resources.

Adapted from: Klarin (2018)-modified.

The definitions outlined in Table 2.1 differ in their interpretations. The noted overall trends across each definition are sustainable development ambitions, which are interwoven in three-dimensional concepts of social, environmental, and economic aspects, which represent the triple bottom line model (refer to Figure 2.1). It is useful to note that the above definitions continue to inspire inquiries to use a variety of measurement criteria in promoting sustainable development for both theoretical and practical implementations.

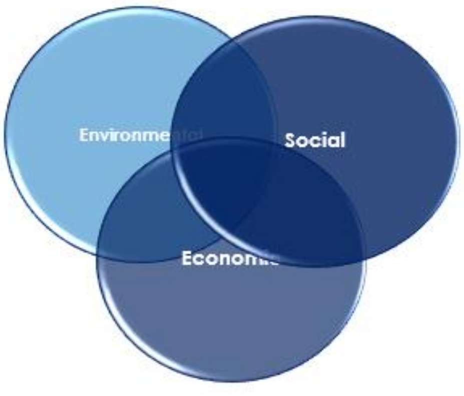


Figure 2.1 Three dimensions of the sustainable development model (triple-bottom-line)

2.3.2 Dimensions of sustainable development

Early studies that examined the need for sustainable development suggested the use of four pillars of sustainability, social, economic, biophysical, and technical factors in managing sustainable development (Hill and Bowen, 1997). According to Hill and Bowen (1997), the "technical factor" is ignored during development because it lacks clarity and cannot be determined. Technical pillars of sustainability are related to concepts of performance of a structure, the quality and service life (Hill and Bowen, 1997). Technical sustainability focuses on ensuring the project is designed to withstand destructive forces due to changes and weather impacts due to anthropogenic activities (Gardoni and Murphy, 2020). In the past decades, the concept and three dimensions of sustainable development were poorly understood. This noted gap resulted from insufficient motivation to adopt sustainable development in a robust context. Kibert (2003: 1) argued that in the early days of sustainable development's emergence, renewable materials, energy, and ecological design were more of articulation than reality.

Modern society relies on large-scale infrastructure systems, which are critical to economic growth. These complex development processes consume natural resources and release greenhouse gas emissions, and the infrastructures are made vulnerable due to the adverse weather impact resulting from anthropogenic activities (Hassan and Lee, 2014; Gardoni and Murphy, 2020). The three dimensions of sustainable development, social, environmental, and economic, are currently made more practical in resolving development issues such as waste reduction, lessening the use of natural resources, eliminating carbon emissions, using renewable energy, and creating a healthy and non-toxic environment (Purvis et al., 2019; Gardoni and Murphy, 2020).

In considering the above, it can be implied that the triple bottom line concept should be made more practical, considering the multidimensional aspects of highway development. The significance of the multidimensional aspect identified through literature is the concept of using integrated sustainable development goals to achieve a facility that will resist the impact of climate change (Rodriguez, 2018). It may be worth reflecting on adding additional sustainability categories, such as technical and technological, necessary to resolve environmental challenges (Hill and Bowen, 1997; Arukala et al., 2019). These propositions are now noted to evolve through the literature in having the triple bottom line social, economic, and environmental plus technical, which helps to assist other multidimensional aspects associated with development (Arukala et al., 2019). The benefit associated with the triple bottom line describes the various interwoven dimensions of the commonly accepted sustainability model (Correia, 2019). The triple bottom line is a model utilised to measure sustainability practices. Brundtland (1987) stated sustainable development can only be achieved through the protection of the environment, ensuring social equity and economic benefits that will ensure coexistence for future generations in achieving their development strategies and goals.

2.3.3 Principles of sustainable development

The primary aim of sustainable development is to assist in preserving the limits and regenerating the planet's environment while meeting the diverse needs of the populations (Hassan and Lee, 2014; Klarin, 2018). The United Nations and the international communities recommended 17 Sustainability Development Goals, which are core principles of achieving sustainable development. These seventeen (SDG 17) principles conveyed actionable statements to enable the operation, analysis, and implementation of sustainable development across many sectors (United Nations Sustainable Development Goals, 2018).

The principles of sustainable development provided a new way of thinking in solving environmental-related issues. According to the United Nations Department of Economic and Social Affairs (2018) and Fioramonti et al. (2019), the old traditional economic models are (slowly) being discarded, and a new model of development is (slowly) emerging in the form of sustainable development concepts and principles. There is now a frontier of global unity movement pointing out the aftereffects of environmental pollution and challenges (IPCC AR6, 2021; Zhang et al., 2022). These global movements tend to provide initiatives on how to tackle climate change catastrophes due to human activities by presenting scientific data collected from the environment (IPCC AR6, 2021). International environmental policies are made aware by the global sustainability unity movements to reduce adverse environmental impacts due to unsustainable development activities (Lopez-Claros et al., 2020).

2.3.4 Section summary

Literature evidence suggests sustainable development continues to evolve due to varying development interests vested by stakeholders, resulting in different views on the interpretation of sustainable development. The main issue is that developing countries should integrate sustainable development goals across their day-to-day living to enhance eco-friendly growth. On this note, developing countries across sub-Saharan Africa perceived sustainable development as a platform for poverty alleviation and reducing social inequalities. Although the aforementioned is still part of the overall sustainable development goals stipulated by the United Nations, there is a need for sub-Saharan African nations to do more in adopting a wider context of sustainability in other industry sectors. In avoiding climate change impact, there is a need to emulate standard practices in developed countries in developing in an eco-friendly way. These standard practices in sustainable development can be achieved using three pillars of the sustainable development model, namely, social, environmental, economic, plus technical.

2.4 Review of sustainable construction strategies

Sustainable construction strategies comprise practices employed in construction, such as using recyclable and renewable materials, reducing raw material carbon footprint, cutting down on waste generated on-site and avoiding depletion of natural raw materials. The underpinning philosophies for these practices are reviewed in this section. The purpose is to evaluate primary sustainable development principles and concepts utilised during sustainable construction. The core definitions of sustainable construction are examined. The sustainable construction benefits and challenges are assessed to understand the significance of implementing sustainable development goals. The sustainable construction strategies within developed and developing countries are reviewed, followed by the section summary.

2.4.1 Evolution of sustainable construction

The primary motivation behind the green construction movement has been traced to originate from below following; -

- Kibert (2004:492) identified the primary motivation for green building, which emerged considering the high performance achieved in green building design, using ecological principles to promote occupants' health, resource efficiency and minimal adverse impacts of the developed facility across the environment. To consolidate the standards of sustainable construction in the 1990s, the United States government established the U.S. Green Building Council (USGBC) for green certifications of building facilities using the (LEED) Leadership in Energy and Environmental Design (Kibert, 2004; Kibert, 2016).

- Gudmundsson et al. (2016: 82-84) pointed out that after the Brundtland Commission report of 1987, the United Nations conference held in Rio 1992 reached a consensus among its Member States to develop sustainable urban transportation projects, and that gave rise to sustainable transportation planning. Furthermore, the evolution of road and highway sustainability concepts emerged in America in the mid-2000s (Weiner, 2016).

- The evolution of highway sustainability emerged from the following sources; - Greenroads, a sustainability rating system utilised in road and highway projects in America, was introduced in 2007 (Muench et al., 2009). STARS, Sustainable Transportation Analysis and Rating System utilised for developing and planning, was established in 2008 by the Portland Oregon Bureau of Transportation staff (Dendero et al., 2012). "GreenLITES"- Green Leadership In Transportation and Environmental Sustainability was established in 2008. GreenLITES is committed to improving the quality of transportation infrastructure building in a way that minimises development impacts across the environment (Mcvoy et al., 2010; Gudmundsson et al., 2016).

- Some notable highway sustainability systems that led to the evolution of sustainability in highway projects are "I-LAST" - the Illinois Liveable and Sustainable Transportation Rating System developed by the Illinois Department of Transportation. Envision is utilised for highway and infrastructure development and is a sustainable development tool used in America. "STEED" is a sustainable Transportation Engineering and Environmental Design tool, which utilises a checklist for sustainable development requirements for planning and developing transportation projects.

2.4.2. Definition of sustainable construction

There is literature stretching over several decades suggesting how sustainable construction interpretations should be undertaken, both in theoretical and practical approaches (Hill and Bowen, 1997; Bourdeau, 1999; Zabihi et al., 2012; Opoku and Fortune, 2013; Coker et al., 2021). The literature is not uniform in their arguments, including their offered solutions (Du Plessis, 2007: 68). In terms of clarity from experts in the field of scholarly 'definition, Buckland (2000) argued that several definitions describing a system exist in the literature, with some appearing more commonly than others, while some definitions are not exclusive enough (lacking precision and misleading). Buckland (2000) suggested that any definition describing a system must be comprehensive in the conveyed definition.

Given the above, critics continue to argue that the definition of sustainable construction should consist of operational theories and practical applications (Kaatz et al., 2005:444; Coker et al., 2021). Likewise, previous literature has a variety of interpretations; a good starting point is to examine sustainable construction definitions, which are summarised in Table 2.2.

Table 2.2 Sustainable construction definitions

Definer	Definitions
Du Plessis (2007) and (2005)	"a holistic process aiming to restore and maintain harmony between the natural and the built environment, and to create settlements that affirm human dignity and encourage economic equity."
Nelms et al., (2007)	"implied that strategic frameworks in screening and evaluating sustainable construction development", such as—reduce ecological impact, improve human health and environmental lifecycle".
Bourdeau, (1999: 358)	"sustainable construction is reducing the use of energy sources, reduce depletion of mineral resources, conserving natural areas and biodiversity—maintaining the quality of the built environment and managing healthy and indoor environments".
Zabihi et al., 2012 cited Kamar et al, 2009	"sustainable constructions are activities whose negative impacts are minimised and positive impacts maximised to achieve balance across the project lifecycle."
Opoku and Fortune, 2013	"sustainable construction offers to strike a balance across the three dimensions of sustainability during development."
Coker et al., 2021	sustainable construction is the creation and liable administration of a healthy built environment based on resources efficient and ecological principles

Source: Author generated

Given the varying definitions in Table 2.2, it is evident that the definition is helping to place sustainable construction into context, considering the description provided by each definition. A noted consistency in the definitions of sustainable construction development is the concise description of effects given to reduce the impact of adverse development on the ecology using three pillars of sustainability, namely social, environmental and economic concepts.

2.4.3 Benefits and principles of sustainable construction

There are benefits and costs associated with sustainable construction; on this issue, Zhou and Lowe (2003) and Goh and Yang (2010) acknowledged that increased costs associated with green development discourage investors. Well-noted economic benefits of sustainable construction are improved building performance, which enhances durability, and reduced maintenance and operational costs (Dobson et al., 2013; Azazga, 2019). In contrast, the non-implementation of sustainable construction strategies due to stakeholders' knowledge barriers is considered a disbenefit.

Arukala et al., (2019) and Hill and Bowen (1997) described the framework for the benefits of sustainable construction in four categories, namely, biophysical, technical, social, and economic''. The biophysical category is the need to ensure less damage to the ecosystem, for instance, to minimise the use of natural resources, water, and energy during construction and to improve the quality of human life (International Union for the Conservation of Nature, IUCN, 1991; Munro 1991; Hill and Bowen, 1997; Gengatharen et al., 2021).

The technical category of sustainable development considered is durability, reliability, and quality in promoting functional structures (Hill and Bowen, 1997; Mavi et al., 2021). The social category ensures that the infrastructure improves human life, protects human health, and seeks equal distribution of social benefits (Raheem and Ramsbottom, 2016). The economic category intends to achieve affordability, effective lifecycle costing, and promote employability during facility development (Hill and Bowen, 1997). According to Zabihi et al., (2012), sustainability principles and concepts equally affect how the goals of sustainable construction are fulfilled. Some of the principles of sustainable construction are summarised below (Akadiri et al., 2012); —

a) Halliday (2008) proposed six principles of sustainable construction, namely economy, resources, and communities, creating healthy environments, enhancing biodiversity, and reducing pollution.
b) Miyatake (1996) proposed minimising resource consumption, implementing recycling, using renewable energy, protecting the environment, and creating a healthy quality lifestyle.
c) Hill and Bowen (1997) advocate for the use of four pillars of principles of sustainable construction, namely, biophysical, social, economic, and technical.

d) Kibert (1994) identified six principles which are to conserve, reuse, recycle, protect nature, the use of non-toxic materials, and quality.

What stands out in the above descriptions is the generalised pattern of principles of sustainable construction across the various scholarly publications. There appear to be similarities in patterns in describing concepts and principles of sustainable construction. However, similarities are expected considering the use of a subject-specific field of vocabulary, which has emerged over time. These words are primarily environmental, economic, technical, and social-related lexicons.

2.4.4 Global sustainable construction programmes

Some developed countries at their regional level have taken pragmatic steps towards implementing sustainable construction strategies (Otaibi et al., 2022). The United Kingdom established "Construction 2025", a strategy aimed at defining the aspiration of delivering sustainable construction within and across the globe (HM Government 2013). According to the United Kingdom Construction 2025 strategies, which aimed to achieve a 50% reduction in greenhouse gas by 2030 and net-zero emissions by 2045. It is anticipated that because of the construction 2025 strategies, approximately, it is estimated that 50% faster delivery of projects will be achieved from inception to completion, with an accompanying 33% reduction in whole project lifecycle cost. There is also anticipation that UK construction companies will participate in 70% growth of global sustainable construction projects worth over £200 billion before 2025.

Recent literature showed progress achieved across the United Kingdom's Construction 2025 strategies proposed in 2013. The evidence noted from the literature suggested that the modern method of construction (MMC) is helping the construction industry achieve sustainable development goals across the UK society (Maqbool et al., 2023). Furthermore, the findings from Maqbool et al. (2023) identified that using MMC reduces project costs, the use of fewer construction materials, and less carbon emissions. It is noted that the UK Government Construction 2025 strategies are beneficial, and these strategies are utilised to set out targets, ensuring the construction industry "thrives" in the continued face of increasing global competition" (Nazir et al., 2020, cited Glenigan 2019).

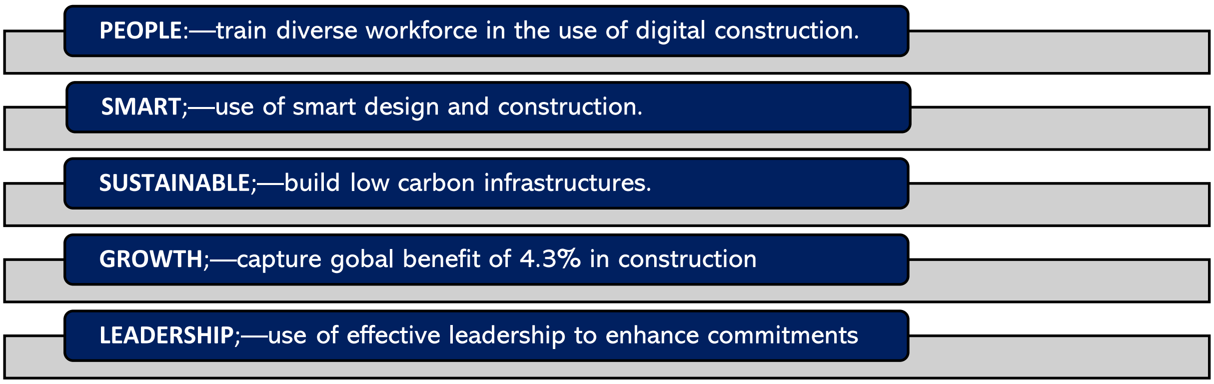


Figure 2.2 United Kingdom sustainable construction model **Adapted from: HM Government 2013**

Figure 2.2 displays the UK Government's model for investing in people to enhance digital knowledge in managing carbon technology (Giest, 2017). The use of sustainable concepts aims to deliver low-carbon infrastructure using social, economic, and environmental opportunities for development (Huang and Hsu, 2010; Wu et al., 2019). The benefits associated with smart design and construction include providing local and international opportunities to develop solutions concerning climate change impact because of development activities (Chen et al., 2015; Montgomery et al., 2015; Haider, 2019).

In a similar development, the Australian Government established the concept of using a circular economy model, which is a system of reusing, repairing, and recycling existing waste materials as a way of tackling global warming, reducing the impact of biodiversity loss, and decreasing pollution (Geissdoerfer et al., 2020). Figure 2.3 displays the circular economy process, which is primarily focused on achieving three principles, namely, the need to eliminate waste and pollution, circulating materials and products, and the regeneration of nature. Another significance of circular economy is that it is perceived as a model of consumption and production, as against the use of a linear economy. The concept of a "linear economy" is a traditional model where the raw material is utilised to deliver a product that is consumed and has no consideration of reducing the ecological footprint after the expiration of the product (Sariatli, 2017).

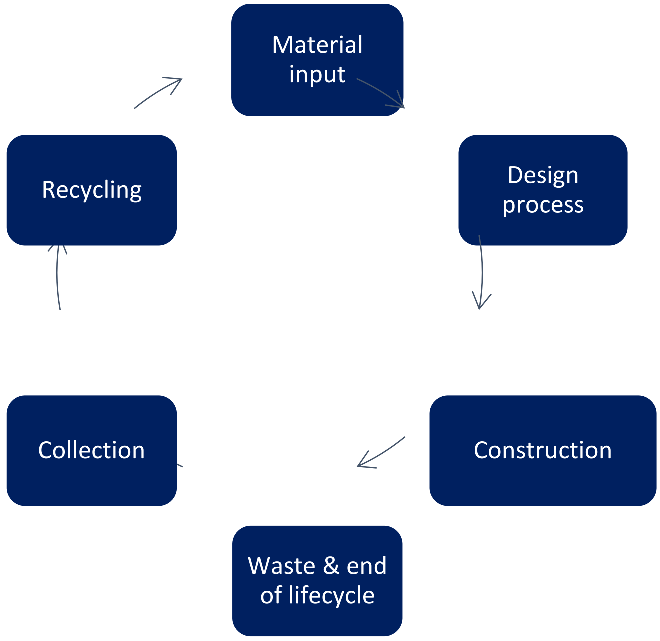


Figure 2.3 Use of circular economy in Australia's construction model.

Du Plessis (2005) pointed out that sustainable development scope, definition, and priorities vary between developed and developing countries. In Africa, the inability to adopt sustainable construction is due to a lack of knowledge. Across the sub-Saharan African nations, poor economic growth and deficiencies in the engineering and management of local construction firms weaken infrastructure development due to sustainability knowledge gaps (Zawdie and Langford, 2002: p169). According to Addy et al., (2021), the sub-Saharan Africa region is currently faced with development challenges as the population and economy continue to emerge. The needed infrastructure development requires the implementation of eco-friendly development concepts. The noted impediments are the lack of awareness of sustainability theories. In the argument of Du Plessis (2005), there should be a consideration in establishing a solid knowledge base for African sustainable construction practices. Similarly, some identified issues have been classified as a source of influence, negatively affecting the direction and development of sustainable construction across some African regions (Munysya and Chileshe, 2018; Opoku et al., 2019; Ifije and Aighavboa, 2020; Coker et al., 2021). These classified influences are the lack of sustainability strategies and regulations that are created to enhance sustainable construction growth. These gaps result in various challenges hindering sustainability implementation in Africa (Coker et al., 2021). These identified hindering factors are disparities in ideology, lack of measurement standards, and policies that prevent achieving sustainable construction priority across African nations and within the sub-Saharan region (Ofori, 1998; Zawdie and Langford, 2002; Du Plessis, 2005; Adebayo, 2012; Addy et al.,2021).

Other notable hindering barriers are the lack of understanding in developing eco-friendly constructions, the lack of motivation, and weak legislation to implement an eco-friendly design (Mashwama et al., 2020: 305). The gap in sustainable construction across most African countries echoes similar hindering problems and challenges. Nikyema and Blouin (2020) pointed out barriers affecting developing countries towards achieving green design in infrastructure projects are; —

- Government-related issues, such as lack of sustainability policies,
- Human-related barriers, including the absence of knowledge to initiate sustainability,
- Nonexistence of a database supporting knowledge and information sharing.

The much-identified environmental solution for construction strategies has been achieved from the implementation of the Environmental Impact Assessment (EIA), which is a measure to mitigate environmental development impacts across projects in African countries, in this process, there are limitations. According to Kokonge (2006), the countries in the sub-Saharan region are at a crossroads to benefit from the use of EIA concepts. The identified limitation is the lack of public participation and inadequate legislation leading to poor enforcement of the EIA policies. EIA lacks a sustainable construction strategy (Koemle et al., 2018). Using environmental reports helps identify reasonable alternatives for development, such as avoiding adverse impacts on the environment and society. The EIA assessment report covers the significant effect and mitigation of development on biodiversity, health, fauna, flora, soil, water, material assets, cultural heritage, and landscape. EIA has been criticised for being inadequate in preventing harmful practices to the environment (Nita et al., 2022). These uncertainties in using EIA are not fully addressed in sustainable decision-making processes (Nita et al., 2022; Dai et al., 2022).

2.4.5 Section summary

Sustainable construction is helping to reduce the adverse impacts of development across the built environment, considering the efficient use of resources and sustainable principles. There are identified benefits associated with sustainable construction. The financial implications of achieving these sustainable development benefits are lacking and unclear to the project owners. The associated disbenefits resulted from stakeholders' lack of knowledge and the non-existence of sustainable construction principles. Globally, there is evidence of genuinely sustainable construction programmes established in advanced countries.

On the contrary, some African countries are behind in adopting and implementing sustainable construction strategies. This is because of —the absence of knowledge to practice sustainability. This research was developed to integrate a highway sustainability framework with suitable strategies and principles that benefit the development of highway projects in Nigeria.

This section provided insight into the general sustainable construction strategies, the evolution, an understanding of sustainable construction, its benefits, an idea of what developed countries are practising, and challenges faced by developing countries in the sub-Saharan Africa region, (such as Nigeria).

The next section examined sustainability highway design strategies, highway classification, pavement types, sustainability design strategies and noted gaps.

2.5 Sustainability strategies for highway design

This section examined the varieties of sustainability assessments utilised for highway design projects. The review begins by identifying highway classifications and pavement types. Discussed is an overview of the sustainability highway design concepts and gaps in the use of highway design sustainability assessment.

2.5.1 Highway classification and pavement types

The functional classification of highways is the grouping and associated services provided. The functional classification of a highway depends on the size and density of traffic flow using the facility (Fwa, 2006: 2-4; FHWA, 2013; Hiep and Sodikov, 2017). Roads and highways' functional classification is associated with the different types of design geometry, such as cross-section, vertical and horizontal alignment, and other highway furniture (Todorova, 2009: 98). During highway planning stages, the design and development of sustainable highway projects takes into consideration the functional classifications to identify the resources required and their impacts across the fabric of society (Heip and Sodikov, 2017). The functional classification consists of varying types of services required for highway development. For instance, some of the attributes of highway functional classifications that influence the impact on resources are; —

a) Freeway traffic uninterrupted movement.
b) Different Arterial speeds across highway facilities.
c) Collector road movement within residential neighbourhoods.
d) Local access roads to individual residences.

Silyanov and Sadikov (2017) argued that the classification of highways enhances economic growth and societal development. Highway classifications vary from country to country. In the United States, the Federal Highway Authorities (FHWA, 2013) distinguished classes of highways, for instance, — local, collector, and arterial categories (refer to Figure 2.4). The roads and highway classification in the United Kingdom are of four primary categories (see Table 2.3).

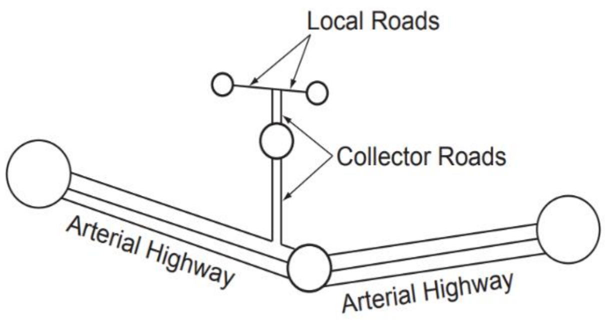


Figure 2.4 Schematic roads and highway network **Adapted from AASHTO (2011)**

Table 2.3 Motorways and local roads classification in the UK

Road classification Description	**classification**
'A' Roads	Major roads that provide a large-scale transport link.
'B' Roads	Connect smaller road networks across different areas.
Classified unnumbered	Connectivity of unclassified roads, linking houses.
Unclassified	These are local roads, comprised of 60% across the UK.

Figure 2.5 displays an illustration of the functional classification of roads and highways in the United States of America, which helps in decision-making towards highway sustainability development in terms of impact on resources and ecology.

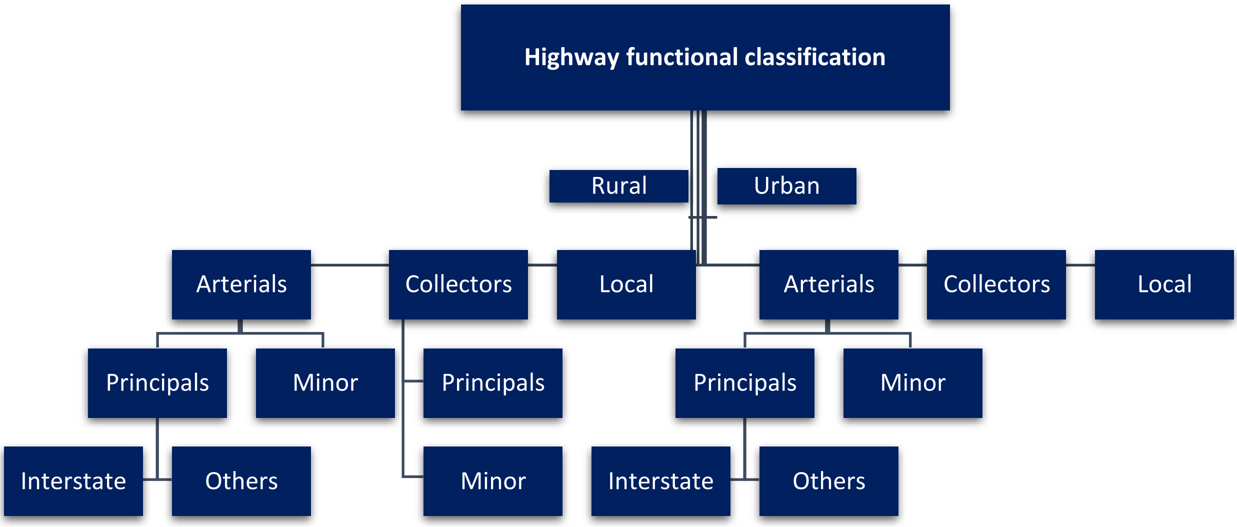


Figure 2.5 Highway and road classifications **Adapted from: FHWA (2013)**

2.5.2 Definition and types of highway pavement

The much-debated terms that need to be clearly defined and given meaning are 'highway' and 'roadway' respectively (Yazici et al., 2014; Chakraborty and Das, 2017). It is necessary here to make clear how both terms are utilised in this thesis. The literature lacks a commonly accepted definition of highways and roadways. The term 'highway' is a word utilised to describe a public route owned by the government, with several lanes connecting major cities (U.S Department of Transportation Federal Highway Administration, 2013). Highways are used to facilitate fast-moving traffic without any restrictions (Findley, 2022). According to the definition provided by FHWA (2013), highways are primarily principal arterial, which includes freeways, interstates, or expressways. See Figure 2.6 for an example of a principal arterial road.

In the United Kingdom, the UK Design Manual for Roads and Bridges (2020) uses the term "motorway" as it represents a "highway" or "roadway". Figure 2.7 is a typical cross-section of the highway, motorway, and highway traffic with flexible pavement, respectively.

Figure 2.6 Typical principal Arterial Road

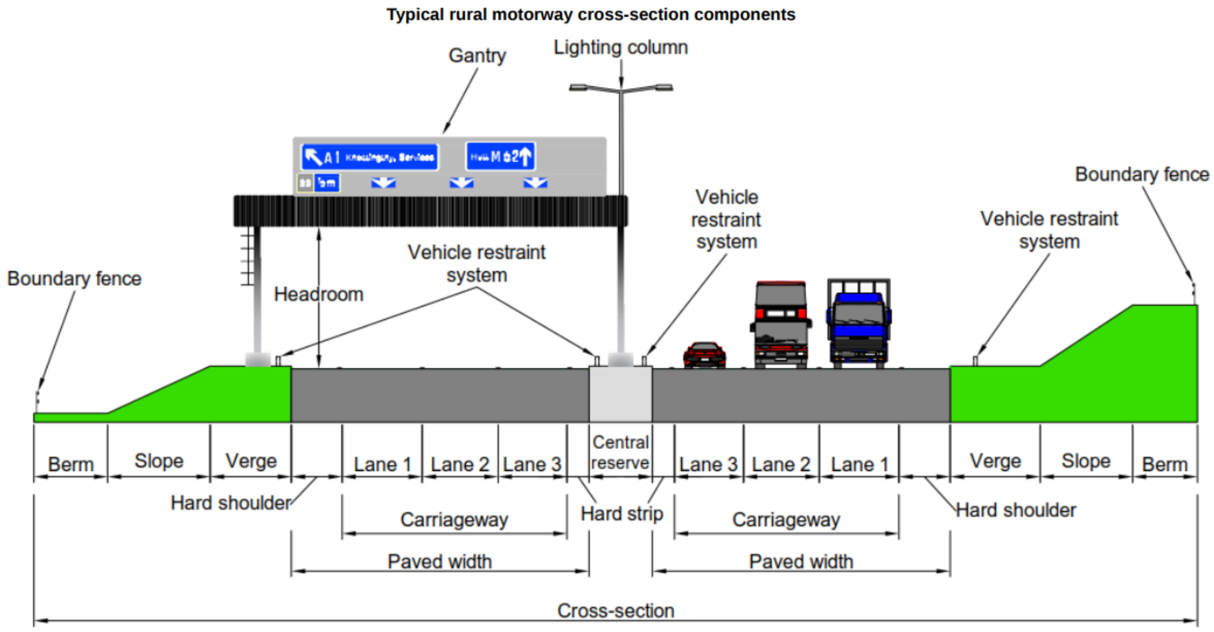


Figure 2.7 Typical motorway cross-section **Adapted from: the UK DMRB (2020)**

The term "roadway" has been characterized by different concepts and definitions as commonly used. For instance, according to the Organisation for Economic Co-Operation Development (OECD, 2007), a roadway encompasses a line of the travelled path used by moving traffic.

The Vienna Convention on Road Traffic (1968) and the UK Convention on Road Traffic (2018) gave insight into different categories and definitions of a roadway. When considered collectively, these definitions revealed that roadway, highway, motorway, and transport all represent the same characteristics and features of a road. The differences between these terms are the functional classifications, the number of lanes, and the nature and extent of designed road furniture. The terms such as motorways, highways, roadways, and transport systems are used interchangeably in the literature and this thesis.

Given the above clarity on the definitions, the motorways, highways, and roadways, roads, are collectively developed using different materials. For instance, roads and highways pavement constructed wholly using asphalt materials is called flexible pavement, whilst highways or roads built using cement materials are called rigid pavements (Walsh, 2011: 325). The highway pavement types have a variety of layers and properties beneath them. According to Jafarifar (2012), rigid pavement is designed to have a thinner cross-sectional thickness than flexible pavement. See Figures 2.8 and 2.9 for the different pavement types and thicknesses. It is worth noting that these pavement structures have been the subject of debate in terms of their service life, maintenance routine, and impact on their environment during and after development (Walsh, 2011; Jafarifar, 2012).

Jafarifar (2012) established, through research, the use of recycled steel fibre for rigid highway pavement construction; this type of pavement development is built on the site using Self Compacting Concrete. The research findings revealed that rigid fibre-reinforced concrete pavement achieves higher durability using recycled steel by-products, which helped to enhance the shrinkage and fatigue resistance of the concrete pavement. Although rigid concrete pavement incurs higher construction costs and generates more traffic noise, it requires less maintenance than flexible asphalt pavements, thus resulting in fewer traffic delays due to the required maintenance period (Inti and Tandon, 2021).

Figure 2.8 Flexible pavement section

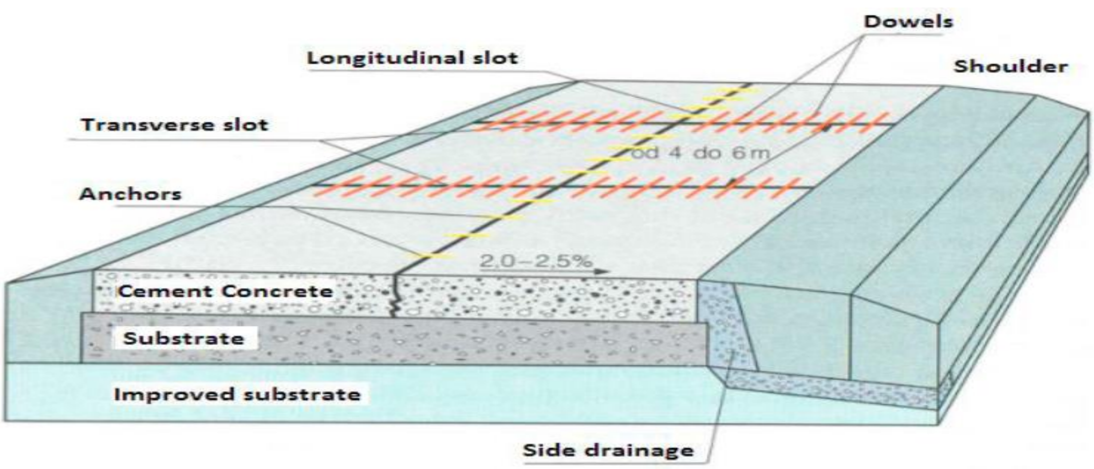


Figure 2.9 Concrete rigid pavement

2.5.3 Sustainable highway design strategies

Tsai and Chang (2012) described sustainability in highway design as a concept relevant to eco-friendly planning, design and, afterwards, construction. Jha et al. (2014) stated that highway sustainability design results in eco-friendly development and contributes minimal damage to the ecosystem. Vezzoli et al. (2018) stated that sustainability in the design of highway projects enables the designers to consider the adverse impact of their design concepts across the socio-economic context of the environment.

Sustainability highway design comprises part of the initial steps taken during the feasibility study to determine the alternative design's adverse and positive impact(s) across the triple bottom line and to develop robust assessment criteria to alleviate these impacts (Tsai and Chang, 2012; Rooshdi et al., 2014; Tsai and Chang, 2015; Ibrahim and Shaker, 2019; Findley, 2022). While sustainability in highway design is a relatively new concept (two decades old and still evolving), sustainability in highway development integrates transportation functionality impacts into consideration to alleviate any negative effects across the biodiversity, social, and economic factors (Montgomery et al., 2015). The literature suggested that sustainable development needs to go beyond and above the bare minimum environmental regulation during highway design (NCHRP, 2019 Report 916). Table 2.4 presents a sustainable highway design structure proposed by Shi et al. (2013).

Project Brief	**Concept design**	**Detailed design**	**Technical design**
Project objectives	Initial response to a brief	This stage is after an approved concept design. All dimensions and coordinates are correct and accurate. Establish sustainability compliance with social, environmental, and economic concepts. Identify sustainable maintenance.	Specialist subcontractors
Functional definitions			Develop design matrix
Analyse land use			Sustainable procurement
Energy use	Horizontal alignment		Develop programme
Water efficiency	Vertical alignment		Sustainability strategy
Reduction of pollution	Intersection elements		Maintenance strategy
Recycling process	Enhance safety		Risk assessment
Social design strategy	Minimize impact		Execution plan
Economic analysis	Enhance topography		Health safety plan
Alignment analysis	Economic factor		**SUSTAINABLE CONSTRUCTION**
Runoff control	Define road furniture		
Connectivity	Cross-section		
Habitat conservation	Sight distance		
Noise and glare control			
Quality control			
Community engagement			

Table 2.4 Sustainable highway design structure **Adapted from: Shi et al. (2013)**

Table 2.4 contents are valuable and provide insight into sustainability highway design. However, the contents in Table 2.4 appear generic in achieving sustainability in highway design. There is a need to develop a detailed integrated highway indicator decision sub-logic for the process involved in achieving sustainability.

2.5.4 Gaps in highway design sustainability

The United Nations — Sustainability Development Goals (SDGs) strive to provide initiatives to decarbonise the global atmosphere to reduce climate change due to anthropogenic activities before 2050 (Romito, 2021). The identified roads and highway environmental challenges opened a wide range of research across the following areas:

- Reducing carbon emissions during highway development (Karlsson et al., 2022).
- Promoting sustainability strategies for highway construction (Montgomery et al., 2014; Zhang, 2018; Ibrahim and Shaker, 2019).
- Using recycled by-product materials for sustainable pavement construction and maintenance (Lee et al., 2010; Jafarifar, 2012; Thom and Dawson, 2019).
- Automated algorithms to optimise highway design alignment for sustainability development (Maji and Jha, 2011).
- Sustainability construction indicators as an alternative measure in developing highway design sustainability (Mattizioli et al., 2020).
- Minimising development impact by using robust highway sustainability design concepts (Rooshdi et al., 2018, cited the work of Griffith and Bhutto, 2009).

It is noted from the above literature that relatively few studies in the past considered research to assess the implementation of integrated sustainable highway design and construction (Tsai and Chang, 2012; Jha et al., 2014; Mattizioli et al., 2020).

2.5.5 Section summary

Different highway functional classifications assisted in determining the type of design geometry, such as cross-section, vertical and horizontal alignment, pavement lane, median and shoulders. In highway development planning, the resources needed and the impacts of development are determined and analysed to identify avenues to reduce the effect across society. The literature review identified highway sustainability design, including eco-friendly planning and construction. The concept of eco-friendly development during this stage (design stage) involves minimal land use, reduced energy consumption, reduced pollution, recycling of industry by-products, economic considerations, stormwater runoff control, connectivity structures across communities and ecology. The literature review findings revealed that the existing sustainable highway design structure represents more of a generic framework towards achieving sustainability at the project level. The next section is a review of sustainability strategies for highway construction.

2.6 Sustainability strategies for highway construction

This section begins with a review of global strategies utilised during highway construction, followed by the principles of sustainability assessment for highway projects, appraisal methods for highway sustainability assessments, and the section summary.

2.6.1 Strategies utilised for highway construction.

Sustainable strategy inspires real opportunities across the built environment to potentially address climate change to pursue an innovative world-class environment (UK HM Government, 2013). Sustainable strategies are considered due to the adverse impacts of highway and road developments across society, which results in an urgent need for green procurement (Butt et al., 2015). Green procurement is "guaranteeing and encouraging sustainable construction in the process of drawing up contracts" (Lenferink et al., 2013, cited Russel, 1998; European Commission, 2004). Green procurement in highway projects sets out requirements that primarily address environmental improvements (Garbarino et al., 2016). This set of project requirements utilized for sustainable procurements determines how the tenderers are selected in executing highways and road projects, which is based on the contractor's technical ability to foster innovative design solutions at different levels of ambition, thus reducing climate impact due to unsustainable highway development (Garbarino et al., 2016).

According to the literature, organizational learning aligned with achieving the concept of sustainable development strategies assists in the delivery of a sustainable project (Opoku and Fortune, 2011). This type of organizational learning is aligned with the need for continuous professional development (CPD), 'especially when the CPD material is specific to sustainability learning objectives', which is a driving tool towards achieving knowledge and skills in a sustainability strategy. The CPD concept is structured to enable professionals to keep improving their skills and knowledge. The fact remains that professional qualifications achieved in the past need knowledge updating, considering changes due to regulations, technological advancement, and environmental climate change (Ajayi, 2022). The use of CPD within the highway construction environment is essential as it enables the sharing of knowledge and information regarding sustainability development concepts and strategy.

The adoption and use of low-carbon material emissions for transportation project construction are now evolving (Shi et al., 2012; Karlsson et al., 2020; Uchehara et al., 2020; Peng et al., 2020). These low-emission construction materials are helping to accomplish targets to prevent the earth from heating up to more than 1.5^{0}C. Similarly, the use of recycled material in roads and highway pavement development results in the reduction of generated waste and pollution reduction, with lesser emissions (Oluwatuyi et al., 2018; Emmanuel, 2019; Thom and Dawson, 2019; Bamiboye et al., 2021; Ojuri et al., 2022).

Weiner (2016) stated that context-sensitive solutions (CSS) are a means needed to engage with the communities as a social form of gathering inputs and suggestions for protecting the environment during highway development. A context-sensitive solution is a form of practical collaborative approach required in integrating communities and stakeholders during the inception of transportation project planning sessions.

A further identified sustainability strategy from the literature is sustainable safety management, utilised within the supply chain to enhance a sustainable work environment (Lee, 2018; Chigara and Smallwood, 2019). In the context of safety and a sustainable workplace environment, the guiding principle is to use models such as the Plan-Do-Check-Act management framework to ensure the sustainable management of occupational health and safety-related risks. So, it is essential to establish health safety guiding principles to achieve sustainability in projects.

Sustainable governance in projects helps to achieve various identified sub and main categories of sustainability strategies (Mohandes et al., 2023). Sustainable project governance at the project level helps accomplish stability in managing the goals and aims of the sustainability agenda. According to Zhang et al. (2023), sustainable governance is considered when a designer is making engineering decisions concerning the environment, and this is called "thinking green" in a project design. The insight provided by Hwang and Ng (2013) suggested that;-

(1) sustainable project governance is required to manage innovative solutions considering there are no existing universal sustainability standards. Therefore, it requires a longer time to plan the sustainable project governance process; for instance, in selecting supply chains and subcontractors that will comply with

sustainability implementation, as they have to demonstrate knowledge and skills in sustainability, and that may take a longer time,

(2) there is a need to plan for uncertainty with green equipment needed, which is scarce to procure,

(3) to determine the increased number of planned meetings to discuss sustainability and shared best practices,

(4) putting together specifications supporting sustainability, accumulating sustainability best practices and documenting frequent changes with green design, which requires coordinated meetings and discussions,

(5) Determine risks associated with green projects execution, and

(6) there is a need to determine a plan on how to integrate the overall sustainable project governance sequence.

Also, there are noted benefits associated with sustainable project governance, for instance, project control using three pillars of sustainability over the implementation of sustainability innovations (Kivilä et al., 2017; Derakhshan et al., 2019; Godenhjelm et al., 2019; Zhang et al., 2023). There is a need to use an integrated approach of information transfer, communication, learning from past experiences and new adaptive solutions for sustainable project governance (Arts and Faith-Ell, 2012).

2.6.2 Sustainability assessment for highway construction

Bond et al., (2012) stated that sustainability assessment is yet to reach maturity level across the project life cycle. As pointed out in the literature, there are noted delays in projects; with increased demand to plan projects for sustainability and to achieve climate target path, therefore the issue of reaching maturity level in project sustainability is essential (Scherz et al., 2022). The insight provided by Scherz et al., (2022) revealed that sustainability criteria are needed early in the design phase to achieve maturity level and tracking of sustainability progress as part of learning and improvement.

Literature evidence suggests that methodological pluralism alongside expert opinion is essential in achieving a sustainability maturity level (Browne and Ryan, 2011; Jerneck and Olsson, 2020). According to Gasparatos et al., (2009:456), assessing sustainability progress as a form of attaining maturity in sustainability implementation requires a plethora of considerations across social, environmental, and economic concepts. In some cases, it is very difficult to measure progress made or achieved using a single metric to measure what is accomplished in sustainability. So, the use of methodological pluralism and stakeholders' participation is an improved path towards achieving a sustainability maturity level. Popa and Guillermin (2017) argued that methodological pluralism benefits the use of uncontrolled sustainability processes, which are specific ways of combining different methods of sustainability practices in the field.

Methodological pluralism uses various methods within a boundary, for instance, implementing "waves of sustainability innovations" in a project. A drawback in using such a solution in determining sustainability is how it can be quantified and measured. The challenge faced by project-level practitioners towards implementing the sustainability assessment for highways is identifying a reliable sustainability assessment rating framework (Poveda, 2017; Vassallo and Bueno, 2021).

2.6.3 Principles of a sustainability assessment for Highway

The implementation of sustainability assessment cannot be emphasized enough in this section. According to Sala et al., (2015), incorrectly measuring sustainability assessment is not because of the theories applied but because of the knowledge gaps in using sustainable principles to aid in the assessment of a project. Vassallo and Bueno (2021) stated that it is significant and essential in considering transportation projects to take into consideration the basic principles of sustainability assessment. These principles consist of standards and theories that guide project-level participants in implementing sustainable development.

Bueno et al., (2015) identified that one of the reasons for implementing principles of sustainability assessment is to provide the enabling concepts in the development of transportation design, construction, maintenance, and operation. Other reasons include ensuring control of land acquisitions, reducing air pollution reduction, use of recycled materials, and less energy consumption. Therefore, across infrastructure projects, sustainability assessment should consider the concept of social awareness, environmental responsibilities, and economic profitability.

2.6.4 Highway appraisal development tools

This section reviewed existing methodological processes utilized to implement highway sustainability assessment. The review aimed to gain insight from the study of Bueno et al., (2015), others authors and Vassallo and Bueno (2021). These authors critically reviewed highway sustainability assessment tools applied in infrastructure transport projects. Their work supports this research in identifying limitations and modalities using relevant principles to propose a robust sustainability assessment tool for developing highway projects.

The growing interest in integrating sustainability concepts into infrastructure projects necessitates using decision-making protocols. Likewise, to enhance the implementation of the decision-making protocols, several tools and methodological frameworks are identified as being available, such as a rating system, checklist, and other traditional decision-making techniques (Bueno et al., 2015).

Furthermore, Bueno et al., (2015) identified that, by using these tools, the concept of sustainability assessment is better understood in a specific context but is still far from being well designed. The argument suggests that using these tools is valuable, but knowledge gaps still exist. Even though, no matter the limits, the generally accepted consensus in using these tools is to implement the concept of social, environmental, and economic assessments in projects. Due to a lack of standardisation, these methods frequently offer unreliability in measuring sustainability assessment across the transport project lifecycle (George, 2012; Bueno., et al., cited Stamford and Azapagic, 2011). Figure 2.10 is an overview of assessment tools utilized for transport projects.

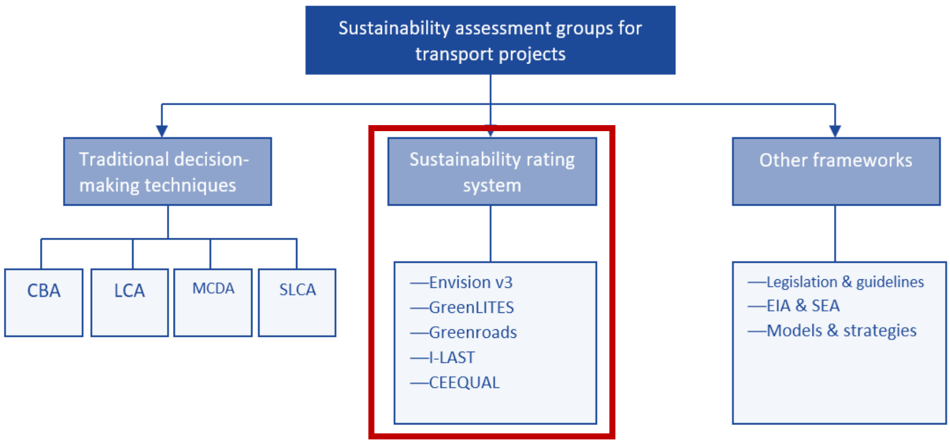


Figure 2.10 Assessment strategies utilized during highway transport projects.

In reference to Figure 2.10, the various types of transportation assessment tools and techniques are reviewed and presented below.

2.6.4.1 Traditional decision-making techniques: —

Cost-benefit analysis technique (CBA), according to Vassallo and Bueno (2021), is the most popular technique for appraising transportation projects and policy measures in supporting project-level decision-making. CBA involves a process, such as evaluating both present and future benefits using a discounted rate. It measures costs and benefits through monetary terms, and the use of monetary terms is a limitation towards achieving sustainability assessment across areas like the environment and social context. CBA compares different alternatives to develop the best values in selecting a project economically.

CBA has been criticised on many fronts, as it does not account for openness, equity, and fair interpretation across three pillars of sustainability (Jones et al., 2014). CBA has a disadvantage in assessing sustainability in transport, as established in the study of Vassallo and Bueno (2021). The disadvantage of CBA is the difficulty of accurately estimating the costs and benefits of alternative sustainability over the life cycle of the project's three pillars of sustainability (Vassallo and Bueno 2021 cited Lacono and Levinson, 2015: 27). CBA is primarily based on quantitative analysis to measure the economic viability of public projects in terms of initial construction cost, agency cost, and maintenance cost.

The lifecycle analysis (LCA) technique is well structured in assessing the environmental impacts of product activities and processes (Stripple and Erlandsson, 2004: 2; Vassallo and Bueno, 2021: 27). LCA is primarily utilised in decision-making related to environmental performance, such as using evaluations to determine performance (from cradle-to-grave). LCA has the concept metrics to measure environmental product performance (Baker and Lepech, 2000: 1; Samiadel and Golroo, 2017). LCA involves whole-life cycling processes, such as the environmental impact involved in raw material extraction, transportation of the raw materials to the processing plant, the material quality control selection, production of the construction materials, the transportation of the product, the placing of products at the project site, the operation and maintenance, end of life of the products, and recycling and reuse of materials (Stripple and Erlandsson, 2004: 20). Furthermore, LCA provides valuable input toward the sustainability assessment across the environment. LCA suffers from a drawback because of uncertainty in assessing other sustainability concepts, for instance, social and economic sustainability assessment (Vassallo and Bueno, 2021: 28).

Multi-criteria decision-making analysis (MCDA) benefits are well-researched in the literature (Dean, 2020). Furthermore, MCDA is suitable for decision-making and addressing complex criteria selection. According to Bueno et al., (2015) and Browne and Ryan (2011). MCDA can deal with different components of sustainability. An identified problem of MCDA is the subjective qualitative nature of assessment, which lacks focus on identifying impact and accurate measurement in obtaining weight for the indicator criteria. Bueno et al., (2015) argued that the use of MCDA hybrid in decision-making is beneficial because it integrates social, environmental, and economic concepts in resolving sustainability issues.

Social lifecycle analysis (SLCA) is an effective decision-making technique often used to assess projects' social sustainability impact. SLCA has been proposed to be utilised as a framework for developing pavement structures for transportation projects (Inti and Tandon, 2021). For instance, SLCA is used to measure pavement relationships with traffic tyre noise and health and safety impact on road users and pedestrians. Bueno et al. (2015) pointed out the limitation of the SLCA technique as being less developed to cater for an economic and environmental assessment approach. Likewise, the use of social sustainability to determine life cycle analysis is still at the early stage of development (Inti and Tandon, 2021). Only recently, attempts have been made to demonstrate the use of SLCA to determine the social impact of pavement design alternatives. The use of SLCA in the construction assessment of project phases as an integrated system is, therefore, it is still evolving.

2.6.4.2 Sustainability rating systems

A sustainability rating system is essentially a composite of best practices associated with standard metrics, enabling practitioners to incorporate sustainability principles into a project (Muench et al., 2012; Bueno et al., 2015). According to Pearce et al. (2010), the project-level construction best practices in sustainable development are;— (1) selecting at project inception the supply chains and subcontractors with sustainability experience, (2) developing explicit goals of sustainability to be detailed in the contract documentation, (3) incentives, and penalties are issued for achieving or deviating from sustainable performance goals, and (4) evidence of achieved sustainability goals are communicated.

In the literature, it has been advocated that project financing should be linked to a project achieving sustainability best practices to enable stakeholders' buy-in (Shan et al., 2017). These best practices are procedures and measures needed to award points called credits in a wide range of construction-related activities such as designing and implementing sustainable stormwater runoff control, sustainable pavement design life cycle, waste material recycling, energy conservation, protecting the ecosystem against harm, and connectivity for displaced biodiversity.

Furthermore, developed countries have made efforts to adopt and implement highway sustainability rating systems at the local, regional, and national levels (Rooshdi, 2014; Mattinzioli et al., 2020; Szpotowicz et al., 2020). Such an effort to select best practices for developing a sustainable highway project using a rating system is appropriate (Lee et al., 2011; Ibrahim and Shaker, 2019). Across developed international communities, sustainability implementation is a critical tool utilised in fighting climate change due to anthropogenic activities (Szpotowicz and Tóth, 2020). Table 2.5 displays existing highway sustainability rating systems, the associated sustainability development focus, and benefits.

Table 2.5 Advantages of existing sustainability rating systems

Rating system	Sustainability focus	Benefits
Envision_v3	✓ Quality of life ✓ Leadership ✓ Resources allocation ✓ Natural world ✓ Climate & risk	• Build resilient and equitable infrastructure projects. • Gives recognition for making sustainability contributions. • Provide a familiar platform for team collaboration. • Enhance the low cost of projects through stakeholders' control. • Reduce negative impact across the environment and community. • Potential to save owners money over long-term efficiency.
GreenLITES	✓ Sustainable sites ✓ Water quality ✓ Material & resource ✓ Energy & atmosphere ✓ Innovation	• Protect and enhance the natural environment. • Conserve energy across the natural environment. • Preserve to enhance the historic, scenic and aesthetic of projects.

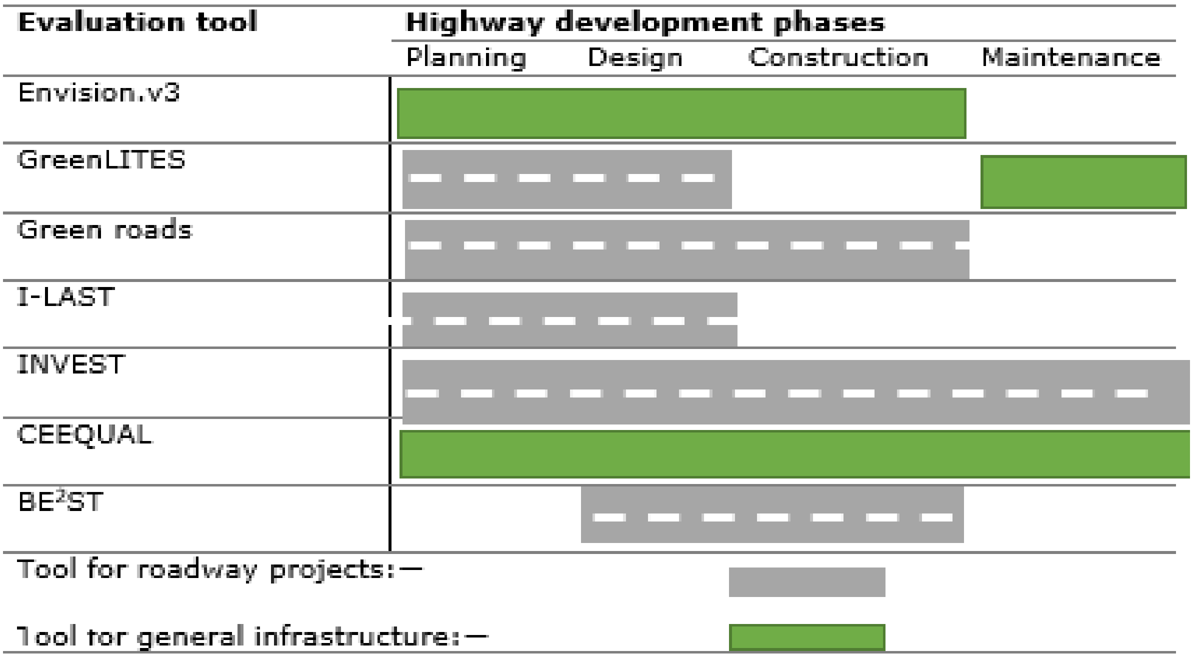
		• Encourage modern innovation in sustainable design. • Integrate smart growth and sound land practices.
Green roads	✓ Environment & water. ✓ Access & Liveability ✓ Construction & Activity. ✓ Creativity & Mobility. ✓ Materials & Production. ✓ Procurement & delivery.	• Enables cost-cutting during construction and maintenance. • Promote safety and community health. • Engage stakeholders. • Create green jobs. • Improve resilience and durability. • Reduce environmental pollution.
I-LAST	✓ Context-sensitive solution. ✓ Land use community plan. ✓ Alignment selection.	• Bringing sustainable results to highway projects. • Establish efficient methods in transport evaluation. • Encourage the use of innovation in developing projects.
INVEST	✓ Integrated planning ✓ Access & Affordability. ✓ Safety planning.	• Helps quantify and balance sustainability benefits. • Systematically monitoring to share best practices. • Helping internal groups & stakeholders share goals.
CEEQUAL, now BREEAM	✓ Project management. ✓ Land use. ✓ Ecology & Biodiversity.	• Promote strategic development of the environment. • Support in asset credentialing of projects and contracts.

Source: Author generated

The purpose of the above-outlined information in Table 2.5 is to summarise various benefits associated with the implementation of the existing highway and infrastructure sustainability ratings systems. For instance, envision_v3 and GreenLITES have five core benefit areas. Similarly, the Greenroads rating system, I-LAST, and INVEST, CEEQUAL, now called BREEAM, has each sustainability focus area and its respective benefits.

Table 2.6 displays the existing highway sustainability rating models and the various applications of each system across the highway infrastructure project lifecycle. These sustainability rating systems are categorised as third-party assessment, voluntary and self-assessing rating systems. For instance, INVEST and I-LAST are voluntary rating systems, Greenroads and Envision are third-party rating systems, GreeLITES and CEEQUAL are self-certification programs, and BE^{2}ST-IN-Highway is an internal research-oriented rating system. These identified rating systems offer wide-ranging benefits, such as reducing pollution, preserving natural resources, recycling waste, enhancing ecological connectivity, and best practices (Lee et al., 2011; Bueno et al., 2015).

Table 2.6 Sustainability rating models across the highway project cycle



Adapted from: U.S DOT, FHWA

2.6.4.3 Other highway assessment frameworks —

Different forms of legislation, policies, decision-making and law are provided to enforce legal instruments to support sustainable development. According to the literature, legislation is seen in some countries as a primary form of encouraging the implementation of sustainable transport infrastructure projects (Kehagia, 2009). Some of these environmental legislative policies are found within Environmental Impact Assessment (EIA), while Strategic Environmental Assessment (SEA) is more of a decision-making tool before EIA is considered to be implemented in the project.

The EIA implementation strategies vary from project to project across different countries (Nita et al., 2022). In the United States, EIA was enacted on 1st January 1970 to adopt the National Environmental Policy Act 1969 (NEPA)—The primary purpose is to use the broad policy to eliminate development damages to the environment (Weiner, 2016: 76).

The European Commission (2017) has an Environmental Impact Assessment policy under Directive 2011/92/EU. The Directive aimed to provide a form of guidance document at the various stages of using EIA. However, EIA has been criticised as unable to provide a feedback loop in protecting biodiversity, such as preventing habitat fragmentation, reducing wild fauna, and groundwater adverse impacts (Loro et al., 2014). Bassi et al., (2012) reiterated another drawback of EIA, such as the inability to follow up procedures. For instance, every EIA in a project is an end to its cycle, and no identified best practices are worth emulating for future implementations in other upcoming projects (Therivel and Paridario, 2013).

According to Fischer (2007), the use of strategic environmental assessment (SEA) is a decision to support a process aimed at ensuring the environment and other aspects of development are considered effective in the plan, policy, or programme. While EIA is driven by legislation, the use of SEA falls outside this spectrum; instead, SEA is viewed as a decision-making tool for the environment (Kulsum, 2008). SEA is beneficial in safeguarding and integrating environmental development. SEA facilitates providing evidence-based decision-making opportunities to prevent costly environmental mistakes and enable transboundary cooperation (OECD SEA Guideline, 2006).

2.6.5 Section summary

Sustainability strategies inspire real opportunities to address climate change issues within the project development sector. Strategies such as context-sensitive solutions, the use of recycled low-carbon emitting materials, and sustainable project governance are the different forms of concepts considered in advanced countries. The sustainability strategy is the implementation of green procurement, which allows tenderers to address potential environmental issues using sustainability concepts. The use of organisational learning is achieved using continuous professional development to gain and share knowledge on how to address sustainability in project development.

Sustainability within the industry is yet to attain maturity level across the project lifecycle. The required maturity level is integrating a triple-bottom-line of social, economic, and environmental, plus technical aspects across design and planning, including the execution phases. Suggestions offered in the literature are to adopt the use of a sustainability rating system certification, organisational learning and tracking of sustainability progress to measure what is achieved, variance and areas for improvement.

It is noted that the use of methodological pluralism is encouraged for sustainability achievement in projects. The aim of methodological pluralism is that,— it helps project-level practitioners to adopt many ways of achieving sustainability best practices in the project, considering there are no existing universal standards. Appraisal tools utilised in transportation development were reviewed, the strengths and drawbacks were identified, and the sustainability rating system was considered beneficial in achieving sustainability best practices within the context of three pillars of sustainability.

The following final section of the literature review is about highway development within the Nigerian context.

2.7 HIGHWAY DEVELOPMENT IN NIGERIA

2.7.1 Introduction

The literature review aimed to identify existing highway development strategies in Nigeria, which helped to draw insight into developing a sustainability rating system for highway design and construction. The previously reviewed sections provided insight and understanding of global sustainability strategies, tools and concepts utilised in assessing sustainable highway design and construction. This chapter examined the significance, impacts, and challenges of highway infrastructure development across the socioeconomic fabric of Nigeria.

2.7.2 Background of Nigeria

Nigeria is a country in West Africa, refer to Figure 2.11, positioned geographically between the Sahel to the north of Africa and the Atlantic Ocean to the south. According to Ofem (2017), the land mass of Nigeria is 923,769 square kilometres (which is roughly 356,669 sq mi), and the current 2022 population statistics are 205 million (Statista, 2022). Nigeria is a diverse state inhabited by 371 ethnic groups with various cultures (Adegbami and Uche, 2015). Nigeria has a varied landscape within the far south, and the area is well-defined by a tropical rainforest climate with an annual rainfall of 1,500 to 2000 mm (Nigerian Highway Environmental Management Manual, 2013). The Nigerian border to the east with a country called Cameroon has dense biodiversity full of different species of drill primates (Waltert et al., 2002:257). The far Nigerian north border with Niger country is covered with Savanna, which is an insignificant tree cover between grasses and flowers (Ayinde et al., 2010). The rainfall within the northern region of Nigeria is 500 to 1,500 mm per annum (Nigerian Highway Environmental Management Manual, 2013).

Major environmental challenges in Nigeria are pollution, unsustainable development, and poor waste management due to anthropogenic activities linked to the process of deforestation, soil degradation and climate changes, which are contributing to global warming (Isife, 2012; Obiechina and Joel, 2018; Akpuogwu and Egbekpalu, 2022). According to the Food and Agriculture Organisation of the United Nations, Nigeria has the highest rate of deforestation globally. Between 1990 and 2000, Nigeria lost an average of 409,700 hectares (4,097 sq/km) of forest. By 2005, Nigeria in the past lost 35.7% of its forest, meaning Nigeria has a Forest Landscape Integrity Index of 6.2 / 10, ranking 82nd globally out of 172 countries.

Nigeria has the largest road network in West Africa, covering roughly 195,000 km, and 90% of the highway is utilised for passenger and freight traffic, contributing to $6.4 billion Gross Domestic Product (Okigbo, 2013; Olaniyi et al., 2017; Jacobs et al., 2020). In another literature review finding, across Nigeria, the present deforestation rate due to anthropogenic activities is put at 350,000 – 400,000 hectares per year (Deekor, 2022).

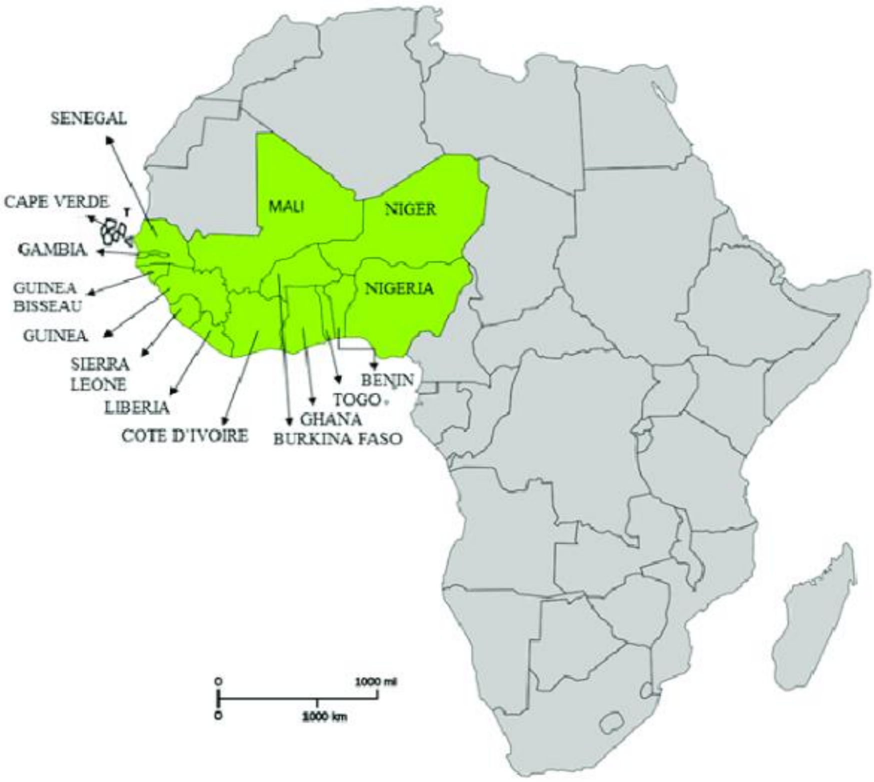


Figure 2.11 Location of Nigeria in West Africa

The rapid growth in population and economy exerts pressure on biodiversity. It is estimated the population of Nigeria ranges from 100 people per km^2 in the northeast and towards the west, south, and northern regions is 500 people per km^2 (Nigerian Highway Environmental Management Manual, 2013). Across Nigeria, there is increased urbanisation, and places like Lagos have a population of 25 million. With other mega-cities coming up, there are currently 36 States across Nigeria. The environmental impact effects are gradually building up, and scholarly evidence suggests potential future climate change catastrophes in Nigeria are anticipated due to poor management of the environment (Haider, 2019). For instance, according to the Climate Change Vulnerability Index survey of 2017, when compared with other countries, Nigeria is classified as one of the ten most vulnerable to extreme weather events, and 6% of the landmass is estimated to be severely degraded (The World Bank, 2019), therefore, the aforementioned is adverse and it demands a mitigation plan.

2.7.3 Highway strategy in Nigeria

After 1960 Nigeria gained its independence, the highway infrastructure development rose from 11,000 km to 195,000 km, which supports the economic and social benefits of the society (Olubomehin, 2015). Some of the conditions of these roads are inadequate because of poor workmanship and unsustainable development practices, which results in a loss to the economy and an increase in vehicular operating costs estimated at $1 billion per annum (Okigbo, 2012; Olubomehin, 2015; Enwerem and Ali, 2016). In some cases, due to the high rate of inflation and lack of project funding, the State and Federal governments of Nigeria partnered with foreign investors and the World Bank to develop Nigeria's highway infrastructure, which came at the cost of dealing with varieties of development strategies, such as diverse design which are unsuited in reducing the adverse impact of unsustainable development across the Nigerian environment (Nweze, 2016).

Within the Nigerian highway development sector, most of the contractors are foreigners (Akinsiku and Oyediran, 2020; Eja and Ramegowda, 2020). The consultants and clients at the project level are the representatives of the Nigerian government (Yusuf et al., 2022). A major noted challenging factor is the design and supervision of these highway projects are handled primarily by foreign companies, while Nigerian highway engineers occupy supervisory roles. Thereby depriving Nigerian engineers of the opportunities to contribute to making informed decisions on the mitigation of the highway's development adverse impact across the society (Yusuf et al., 2022). The lack of highway design and supervision is also noted among the local contractors involved in developing highways in Nigeria (John et al., 2019). The local highway contractors primarily have no option but to execute shady jobs due to insufficient knowledge, corruption, and the lack of experience in developing sustainable highway projects across Nigeria (John et al., 2019).

With a low knowledge base in highway development among practitioners in Nigeria (Eja and Ramegowda, 2020)— there is a general lack of modern methods of infrastructure and construction development among indigenous contractors (Olayeni et al., 2018; Eja and Ramegowda, 2019; Ifije and Aigbavboa, 2020). In most cases, the design is unsuitable for the environmental conditions due to the lack of a sustainable feasibility study, thereby promoting poor workmanship, deterioration, and failure of the projects. Also, the Nigerian local contractors still depend on the use of the traditional construction method, which has little or no innovative construction strategy. The noted negative impacts of highway development in Nigeria are summarised in Table 2.7.

Table 2.7 Negative Impacts of Highway and roads development in Nigeria

Highway development impact
• Ecological impacts, such as soil erosion, pollution of water bodies
• Carbon footprint and energy loss
• Lack of community engagement
• Inadequate lifecycle cost analysis
• Poor quality control and workmanship
• Excessive air pollution, noise & glare
• Poor waste management & recycling
• Lack of ecological connectivity
• Poor habitat conservation
• Poor land use enhancement
• Inadequate sustainable procurement
• Lack of multimodal connectivity

Adapted from: Obunwo et al.,2015; Enwerem and Ali, 2016

2.7.4 Highway challenges in Nigeria

Between the 1900s and 1930s, the Nigerian existing colonial roads and pathways were utilised for commerce. Between inter-regional areas of Nigeria, the old roads across the East-West and North-South of Nigeria were all connected with the seaport and major market spots across Nigeria. Between 1946 and 1960, the 45 million population of Nigerians began to increase, and due to the 1960 independence, economic opportunities began to flourish, and investment was dedicated to expanding existing single carriageways to dual carriage highways. At this point, road classification was designed for Nigeria. The road classifications are Trunk ‘A’ roads, which are highways controlled by the Federal government; Trunk ‘B’ consists of the regional highways roads managed by the state governments; and Trunk ‘C’ managed by the local government authorities across Nigeria.

Table 2.8 displays identified challenges in road and highway development across Nigeria. As the development of highways evolves, their adverse impacts continue to spread across society.

Table 2.8 Infrastructure development challenges in Nigeria

Problem Categories	Contents
Societal challenges	• Lack of community inclusion. • Community development impacts. • Inability to preserve the cultural heritage. • Lack of inclusive infrastructure development. • In consideration of the community's access to well-being and social integration.
Technical challenges	• Literacy gaps in sustainable design. • Lack of innovative solutions.
Environmental challenges	• Excessive use of natural ecology. • Pollution, and waste generation. • Lack of measurement strategies. • No agenda for recycling waste.
Economic challenges	• Lack of economic model. • Inadequate lifecycle cost analysis.
Engineering challenges	• Recycling of old traditional knowledge. • Inadequate relevant research approach. • Lack of sustainable agendas. • Poor pavement design.
Project management challenges	• Poor quality control systems. • Lack of stakeholder involvement. • No modern method of development.
Safety and health challenges	• Poor pavement surface design. • Hazardous materials.

Adapted from: Okigbo, 2012; Ede, 2014; Emesoba, 2014; Ohwo and Abotutu, 2015; Abiodoye and Olalekan, 2017; Enwerem and Ali, 2016; Oraegbune, 2022.

The above-listed challenges within the Nigerian highway development are examined in the below sections.

2.7.4.1 Social challenges

The social dimension of highway projects promotes respect, awareness, inclusion, and responsibility in protecting the workforce and communities without harming the ecology (Raheem and Ramsbottom, 2016). During construction activities, it has been noted that social challenges faced by the host communities range from traffic diversion issues, halting economic activities, and excessive pollution due to construction equipment (Celik and Budayan, 2016). Road and highway construction are considered to add to the quality of life (Sipes and Sipes, 2013) rather than constitute a simple nuisance to the public. One of the social challenges noted within the Nigerian context during highway construction is the lack of integration of the community's needs and ideas. These noted gaps are, for instance, the lack of preservation of cultural resources (prehistoric and historic shrines with deep cultural beliefs). In most highway projects, the proposed route alignment is marked for demolition before compensation is issued to enable the eviction of existing businesses (Ikioda, 2016). A noted issue is the inability of the government to integrate public opinion and inputs during highway development to accommodate public interest and views on how to develop a road project for social equality.

2.7.4.2 Technical and engineering challenges

In developing infrastructures in Nigeria, the government retained borrowed technical concepts from overseas (Odediran et al., 2012). As a result, several studies have identified significant causes of highway pavement failure, for instance, inadequate design, lack of research towards feasibility, inadequate geological investigation, and lack of experience in the use of recycled materials (Okigbo, 2012; Abiodoye and Olalekan, 2017; Oke et al., 2018; Jacob et al., 2020). A few of the identified technical failures are associated with the lack of robustness of the developed highway infrastructure projects, for instance, poor feasibility studies, omitted topographical terrain analysis, and inadequate stormwater drainage design (Afolayan et al., 2017).

Road and highway engineering-related failure is associated with the use of raw materials such as soil parameters with off-limit properties, which are unsuitable sub-base materials and subgrades due to the poor California bearing ratio (Daramola et al., 2018). Within the Nigerian context, there is evidence of overloading which resulted in the failure and rutting of the pavement sections along the Lokoja-Abuja expressway. There is also identified inadequate traffic volume count during the feasibility study, which affects the overall lifecycle performance of the highway project (Jacob et al., 2020). There are other case studies of highway pavement failure at the Nsukka-Adoru-Idah highway Southern part of Nigeria due to the poor California bearing ratio and high clay contents of the base materials (Maduka et al., 2017).

Given the above, it is important to explore through sustainability practices the various technical design solutions and aspects of building resilient projects. These are not limited to;— (1) to determine sustainable design speed, the impact of design, pollution and the mitigation factors, (2) to determine adequate highway capacity based on the sustainable feasibility study on the traffic volume, the alignment selected, (3) to determine elements of design such as the sight distance, the horizontal and vertical alignments, superelevation's, and (4) to determine the cross-section, the cross slopes, skid resistance, lane width, shoulders, cross-section, pavement type, strength, drainage and traffic barrier for the safety of vehicular users, and overall pavement thickness reduction using sustainable pavement recycled materials.

2.7.4.3 Environmental challenges

Figure 2.12 displays the Nigerian landmass, which is densely populated with woodland, forest, and shrubland, as indicated in the legend. Previously, the percentage of the agricultural portion was barely 20% (see yellow patch areas in the map reference to map legend). In the year 2000, the agricultural portion was estimated at 130,000 sq km, and by 2013, the total area for the agricultural portion increased to 380,000 sq km, which is roughly 40% of the total land mass of Nigeria of 923 769 sq km.

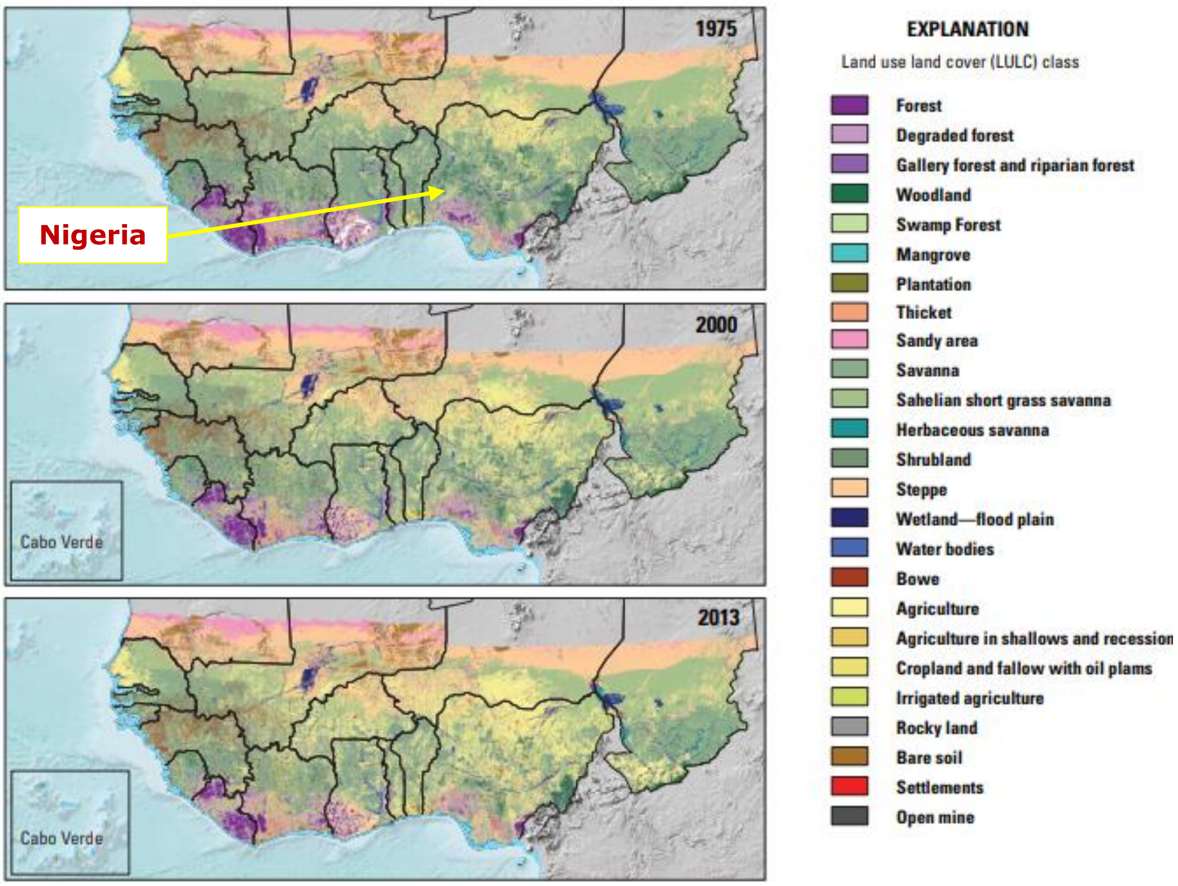


Figure 2.12 West Africa Land Use Cover Source: USAID USGS Cotillon (2017)

With the increasing urbanisation activities and the development of infrastructure across Nigeria, the ecology continues to be fragmented (Mfon, 2014). Nigeria's population growth increased over time (Statista, 2022),— this resulted in the development of infrastructures, including highway projects (Davies et al., 2019). The estimated road density of Nigeria (road density is the ratio of the total length of the road network to the country’s area), in this case, is 195,000 km / 923,769 sq. km which is 21 km per 100 sq. km. See Figure 2.13 for the various types of roads and highways across Nigeria. These are Trunk ‘A’, ‘B’ and ‘C’ local roads belonging to the Federal government, Regional State, and lowest arm of the government. In addition, more fragmentation of the ecology is anticipated considering population growth across Nigeria by 2050, highway infrastructure development will exert more adverse impacts across the environment (Dulac, 2013; UNDESA, 2018; Statista, 2022).

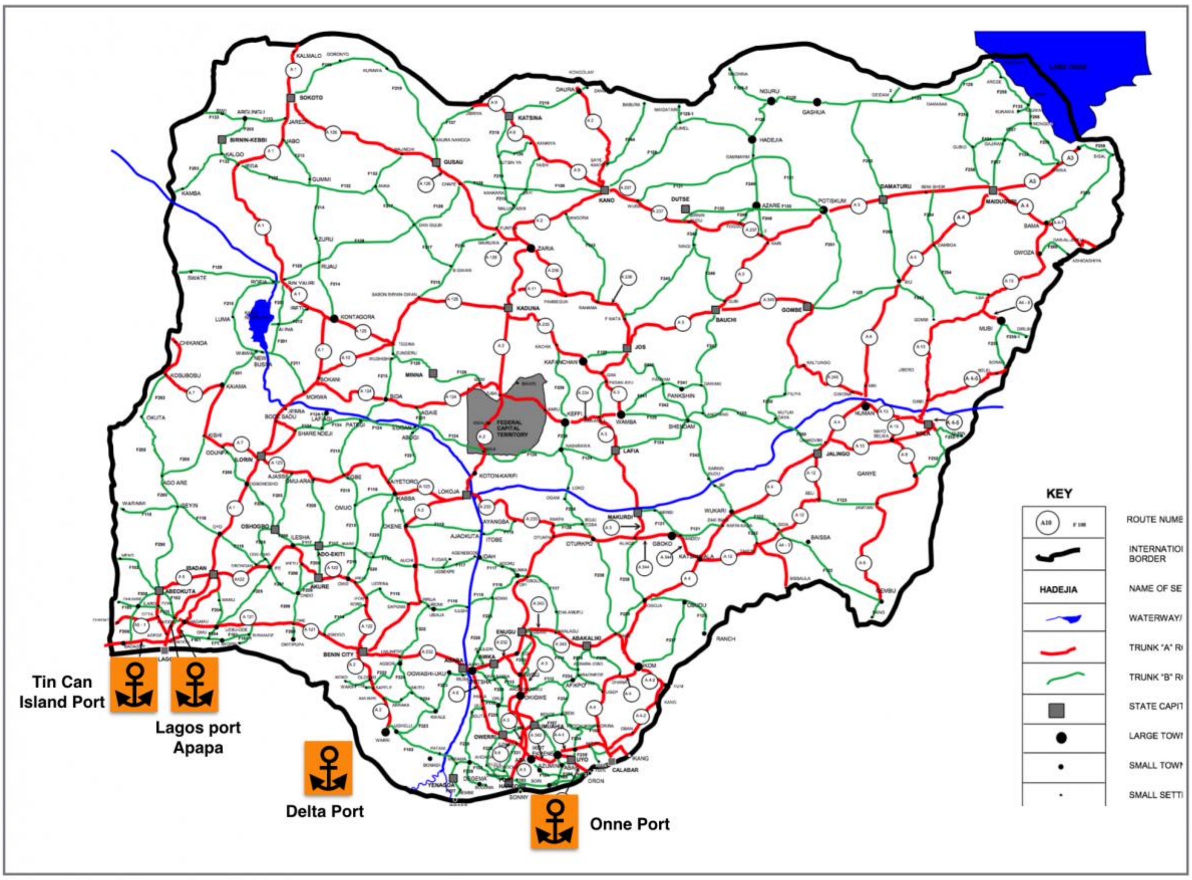


Figure 2.13 Nigeria types of road network **Adapted from: Nigeria highway (2017)**

Nigeria is highly endowed with biodiversity; before the independence of 1960, Nigeria's known national parks[1] (refer to Figure 2.14) had many existing forest reserves all diminished by the early 1990s. The areas have been deforested due to development and increasing population. To this effect, the development of highway projects which involves the removal of trees and extraction of raw materials for subgrade, subbase, and roadbase, gradually altered the terrain and topographical surface across the Nigerian environment.

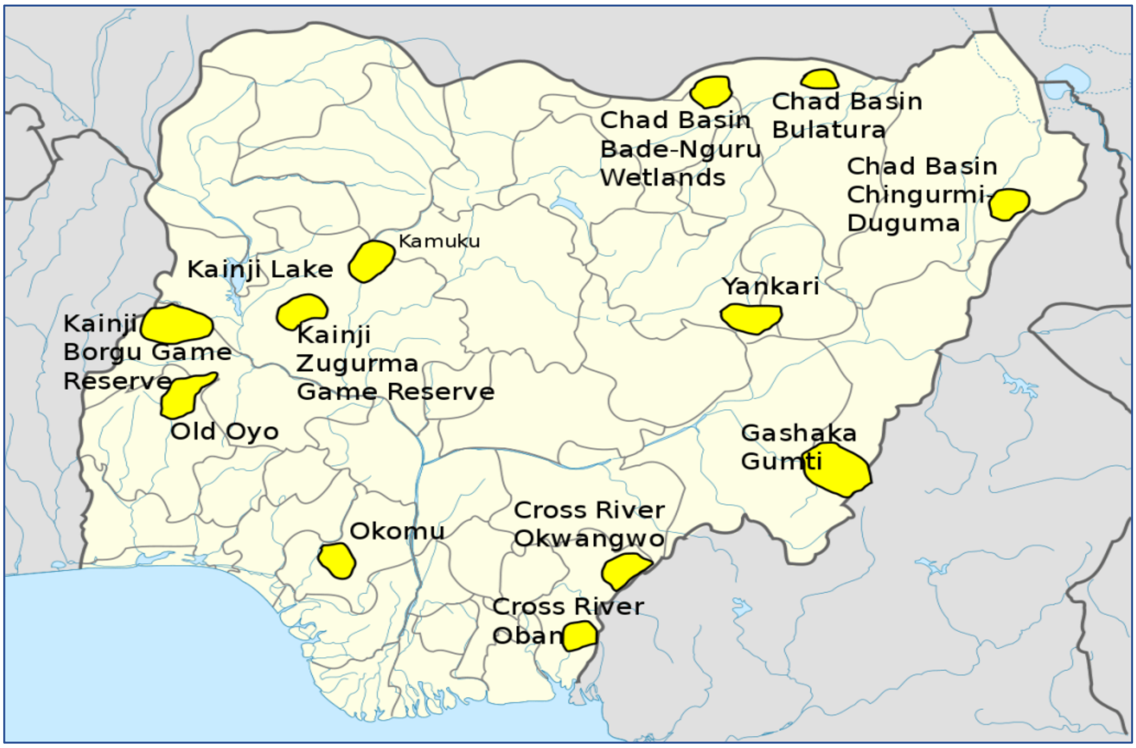


Figure 2.14 Location of previous national parks in Nigeria

2.7.4.4 Economic and project management challenges

The Nigerian infrastructure project failure is associated with cost overrun, and it is well documented by these authors (Anigbogu et al., 2019; Obianyo et al., 2022). The primary identified causes of project failure are a lack of knowledge in the use and implementation of economic project models for estimation. According to Eja and Ramegowda (2020), many failed highway public infrastructure projects have cost the Federal government of Nigeria billions of

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[1] Gashaka gumti National Park, Cross River National Park, Chad basin National Park, Kainji Lake National Park, and Kamuku old Oyo and Okomu National Parks.

dollars, denying the citizens a decent quality standard of living. The root causes of adverse impacts of highway development projects are associated with poor economic development models and inadequate traditional project management strategy (Anigbogu et al.,2019). Similarly, Eja and Ramegowd (2020) also pointed out that the cause of economic challenges in developing projects in Nigeria is poor financial capacity, which is attributed to a lack of economic evaluation models, such as the use of lifecycle cost analysis strategy. Nweze (2016), Obebe et al., (2020), and Eja and Ramegowd (2020) pointed out various problems within economic and project management issues in infrastructure development across Nigeria, which are displayed in Table 2.9.

Table 2.9 Economic and project management challenges in highway development

Categories	Challenges
Economic challenges	1. Inaccurate cost analysis. 2. Scope design and changes. 3. Political interference. 4. Lack of funding model.
Project management challenges	1. Poor project management and inefficient resource allocation. 2. Inadequate planning and poor scheduling. 3. Value, governance, collaboration, modern method of development, procurement, supply chains.

Source: adapted from (Nweze, 2016; Eja and Ramegowd, 2020; Obebe et al., 2020).

2.7.5 Highway assessment in Nigeria

The Nigerian Federal Ministry of Works document called "Environmental Management" for Highway Manual Part 1 Volume VII of 2013 outlined the standard to be adopted to develop sustainable highways for national economic and socio-political assets development (thereby contributing to Nigeria's rapid economic growth). The standard also aimed to harmonise professional highway practices in Nigeria by applying the required level of safety and social and economic benefits during development (Federal Ministry of Works Highway Manual Volume VII Environmental Management, 2013). The highway design manual also seeks to ensure that information collected from the environment is assessed and used in making informed decisions on the selection of highway alignment, geometric design, and construction of projects. These anticipated benefits are to avoid adverse impacts during the design and development of the highway projects. A critical identified issue is the lack of sustainable development knowledge among the contractors and project-level participants concerning Nigeria's highway sustainable design solutions.

2.7.6 Local conditions for highway projects in Nigeria

According to Mattinzioli et al., (2020), a varying number of developed countries have implemented different focus and methods in developing sustainability assessment strategies for road projects. Some developed countries are exploring highway development strategies using local conditions to achieve long-term and inclusive sustainability highway improvement. This is a result of considering their local conditions, resources, skills, and collaborative best practices to enhance sustainability development for the highway assessment. Figure 2.15 depicts the current roads and highway sustainability assessment model by global location.

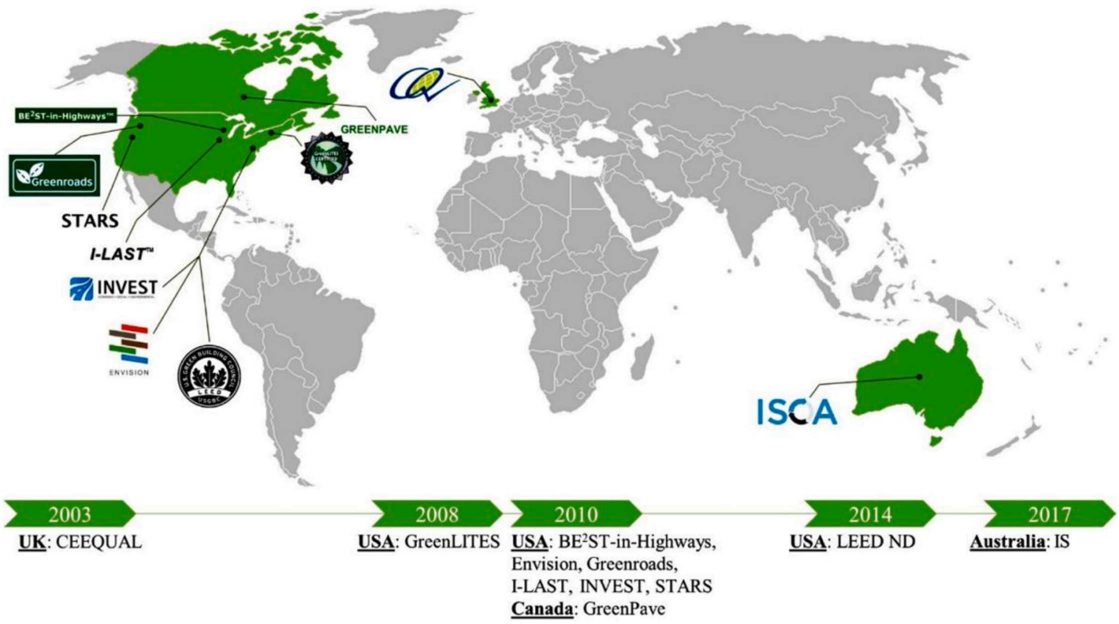


Figure 2.15 Existing highways sustainability system globally Source: adapted from Mattinzioli et al. (2020).

The use and implementation of a sustainability assessment system are non-existent in Nigeria, according to the map in Figure 2.15. The below-outlined Table 2.10 contains sources of literature summarised with evidence of sustainability expectations needed to be achieved in project development across Nigeria. These sources of literature are summarised in addition to categorising identified challenges and sustainable development issues within Nigerian infrastructure development.

Table 2.10 Sources of highway sustainability indicators for Nigeria's Highway

Standard	Evaluation aspect
The Federal Republic of Nigeria Official Gazette #46 Volume 98, Government Notice No.133, National Environmental Construction Sector Regulation 2011	• The Regulation aimed to prevent and minimize pollution from construction activities across the Nigerian environment. • Prevent soil contamination, and water runoff, control drainage system, control dust emission, control noise pollution, control emission from equipment, and waste recycling.
The Federal Republic of Nigeria, Federal Ministry of Works Highway Design Manual Part 1 Volume III- Pavement and Material Design, 2013	• The intended benefits of implementation of the highway design manual are harmonization of professional practices, using the application of unified safety design, economic, sustainability, lifecycle strategy, sound geometric design, and climate impact on pavement design, • Realistic structural design period, design traffic, the strength of materials for pavement design, workmanship, poor soil enhancement, material sampling and testing, recycled asphalt,
National Environmental Standards and Regulations FGP105/1020091/1000(OL 52) Enforcement Agency (Establishment) Act, 2007 National Environmental (Wetlands, Riverbanks And Lake Shores Protection) Regulations, 2009	• This applies to all wetlands across Nigeria. Ensure the conservation of wetlands and their resources, ensure catchment flood control, and use wetlands for ecological and tourism purposes. • Protect wetlands for species of fauna and flora.
National Environmental Standards and Regulations, FGP 112/102009/1000(0l 53) Enforcement Agency (Establishment) Act, 2007 National Environmental (Mining and Processing Of Coal, Ores And Industrial Minerals) Regulations 2009	• Land use in watershed areas, mountainous locations, and hilly or catchment areas should observe the land's carrying capacity. • Carry out soil conservation measures, protection of catchment and ecological and landscape areas, and maintain adequate vegetation cover.
The Federal Republic of Nigeria Official Gazette, #142, volume 21, the National Environmental Air Quality Control Regulation 2014; FGP154/102015/300	• Control of nations' air quality using sustainable development. Be well informed of the potential risks associated with some tasks and activities and minimize carbon and pollution emissions.
The Federal Republic of Nigeria, Environmental Impact Assessment Act #86 of 1992.	• Deal with environmental issues due to activities.
The Federal Republic of Nigeria, Federal Ministry of Works Highway Design Manual Part 1 Volume VII- Environmental Management, 2013	• Minimize the impact of highway design and construction across the environment.

	• Reflect on the legislative instrument and use of the best practice in highway development decision-making. • Use of environmental best practices, avoid deforestation, destruction of natural habitat, avoid air pollution, noise pollution, restore the ecosystem, protect biodiversity, implement education measures, traffic control measures, lower speed, design for ditches, shoulders, • Protect species, ecological connectivity, vegetation management system, habitat restoration, environmental impact prevention due to construction, erosion control, vegetative cover, increase soil roughness, • Reduce water resources consumption, watercourse management, stormwater management, best practice management, compensation measures, and waste management plan such as construction waste. Material borrows pit planning and economic management.
The Federal Republic of Nigeria, Federal Ministry of Works Highway Design Manual Part 1 Volume IV Drainage design, 2013 Greenroads, GreenLITES	• Control of water runoff from the pavement surface, provide a stormwater facility, avoid hydroplaning, provide side drain, edge drain, catch water basin, median drain, cost consideration in the drainage system, maintenance and operation cost, net present value, Present Worth Cost, Benefit-Cost Ratio, Internal Rate of Return. • Hydrological analysis, climate change considerations, storm sewers.

Source: Author-generated

2.7.7 Section summary

This chapter examined the background, socioeconomic, technical, safety and health, project environment and environmental conditions of Nigeria due to highway infrastructure development. The insight achieved from the review identified the non-existence of sustainable development strategies for transportation projects across Nigeria. The project-level practitioners do not have the knowledge and experience towards a sustainable modern form of construction. The well-known approach utilized in development is a traditional form of construction that focuses on the cost and scope strategy. The noted gaps resulted in the depletion of natural resources, among other adverse impacts of development. The adverse impacts of unsustainable infrastructure highway design and construction development were integrated and summarised, and the core areas were identified to be addressed in this research, namely, social, environmental, economic, project management, engineering, technical and health and safety. To determine sustainable local content to resolve identified sustainability drawbacks, pertinent literature sources related to highway and road development in Nigeria were summarized for further consideration (refer to Table 2.10). Table 2.10 displays sources of literature used to determine sustainability indicators for the design and construction of highways, which is further examined in Chapter 3 under the indicator's formulation process. Chapter 4 consists of the details of the indicators.

The above-completed literature provided an understanding to help design this research by using relevant philosophies, methods, data collections and result analysis, as developed further in Chapter 3.

CHAPTER 3: RESEARCH DEVELOPMENT

3.1 Introduction

This chapter focused on the research scope by examining existing pertinent research theories, approaches to research design, the philosophical research methodology, data collection strategies and analysis.

The aim is to design a research framework for developing a sustainability rating framework and indicator decision sub-logics for highway design and construction in Nigeria. According to Strang (2015), the research approach considers the plan and procedures spanning from broad assumptions to detailed methods of data collection, analysis, and interpretation of results. To achieve the aim of the current research, a four-stage research approach is established. Stage 1 is the literature review to gain preliminary background information on current industry sustainability strategies, concepts, indicators, and principles. Stage 2 consists of methods and data collection approaches. In stage 3, the collected datasets are interpreted and analysed. Stage 4 is a project case study carried out on-site in highway projects in Nigeria, and the purpose was to determine the reliability level of the sustainability indicators developed in this research. Findings gained through the quantitative, qualitative and case study results enabled the integration and development of the sustainability framework and indicator decision sub-logic for highway development in Nigeria.

3.1.1 Research aims and scope

This research utilised pertinent literature and research design to answer research questions and to contribute to knowledge by arguing to develop a sustainability rating framework and indicator decision sub-logic for highway design and construction for Nigeria. This is in bridging the noted knowledge gaps between theory and practice, using collected data to determine a practical and theoretical approach to reducing unsustainable highway development in Nigeria.

3.2 Research philosophy, method, and methodology.

Figure 3 displays the wide range of research strategies available to a researcher, which are classified under different headings, such as case study, ethnography, survey study, experimental, grounded theory, action research, cross-sectional and longitudinal studies, exploratory and descriptive studies (Creswell and Creswell, 2018; Saunders et al., 2019).

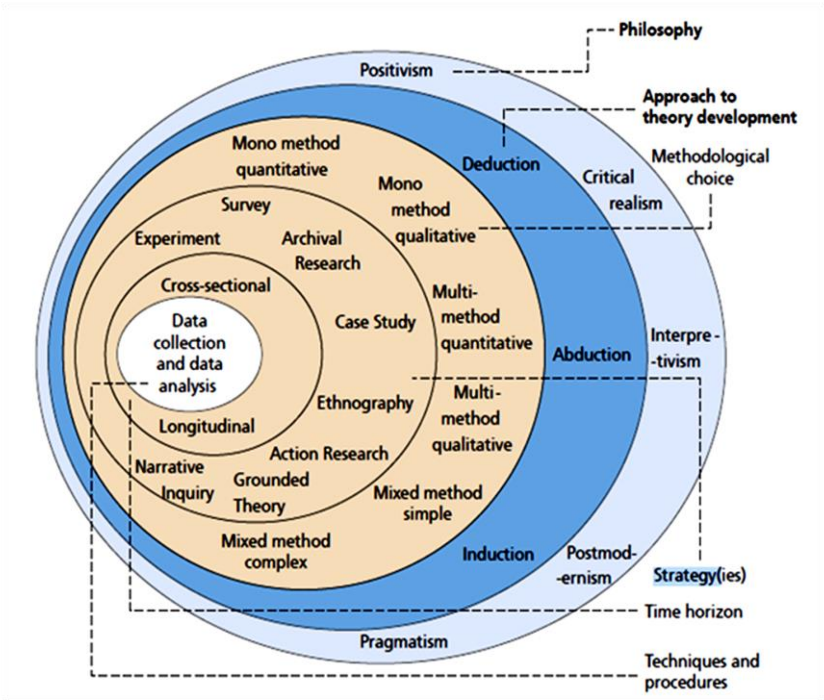


Figure 3 The research onion **Source: Adapted from Saunders et al. (2019).**

According to Strang (2015: 4), "research strategy is the focal point driven by the researcher's ideology". Strategy in research is the concept and application of analysis and decision-making toward answering research questions. As indicated by Fellows and Liu (2015), research across built environments is still gathering momentum. Toit and Mouton (2013) debated that research design is less known in the built environment as compared to social sciences. In consideration of this research aim and scope, there is a need to develop a research framework (philosophy, method, and methodology) to support answering the research questions.

Research design simply describes how data will be collected and analyzed in answering the research questions (Akhtar, 2016; Creswell and Creswell, 2018). In addition, research design provides a framework within which to undertake research. Research design can only be effective by adhering to the process of theory development; ignoring pertinent research processes will compromise the research objectivity (Byrne, 2016; Sileyew, 2019).

Toit and Mouton (2013) concluded from several authors' contributions (De Vaus, 2001; Bryman & Teevan, 2005, Creswell, 2009) that research design defines a logical plan for effective decision-making and contributes to maximizing the validity of findings. As the definitions of research design vary, so do the various research design frameworks. Creswell (2018) developed a research design structure that suggests an approach to be utilized for inquiries across surveys, experiments, narrative research, phenomenology, ground theory and ethnology types of research. In a simple explanation, research design and approaches are planned to aid in making decisions about research methods, data collection and analysis (Strang, 2015; Creswell, 2018). Figure 3.1 is a generic design research framework in which current research focuses on developing an overall research context.

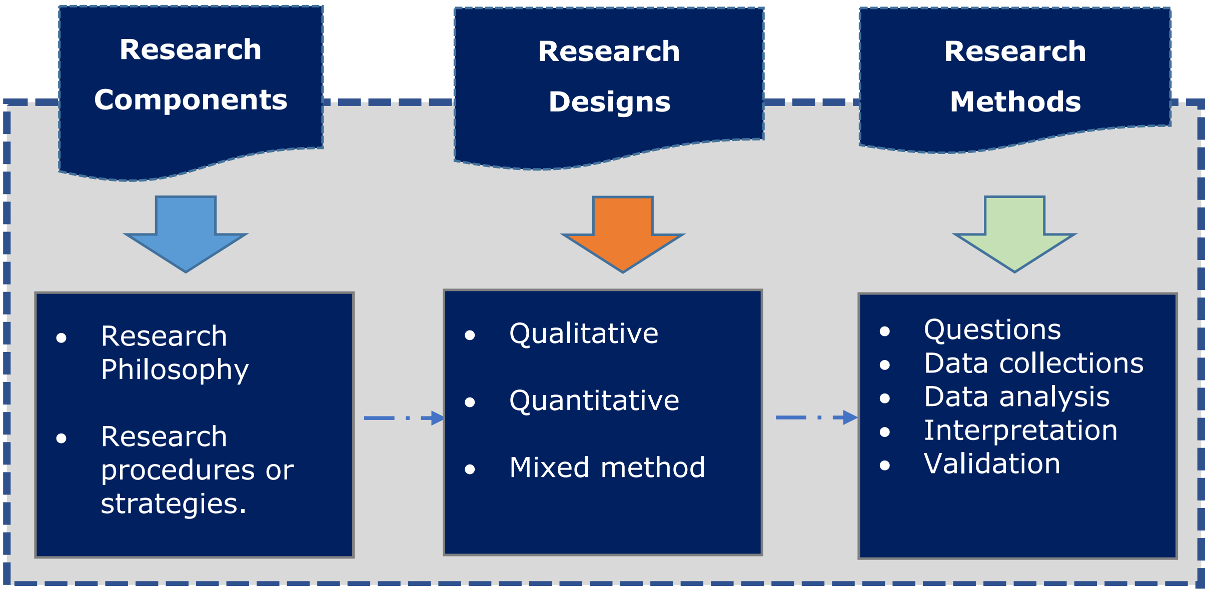
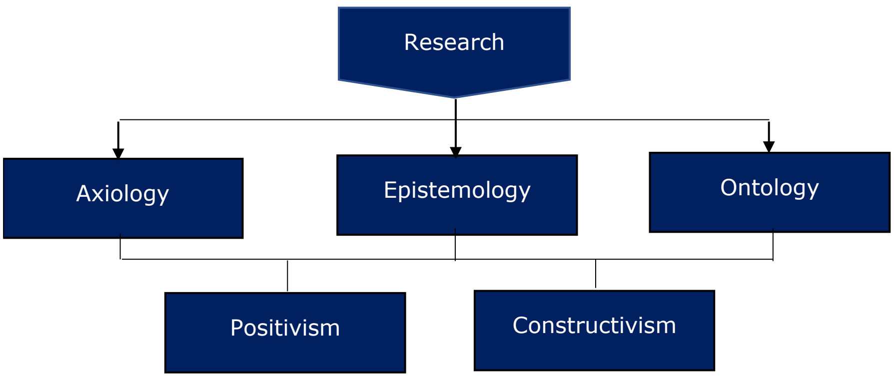


Figure 3.1 Generic research design framework **Source: Adapted from Creswell (2018)**

3.3 Philosophical assumptions

Research philosophy is associated with a specific way of developing knowledge. Saunders et al. (2019) stated that research philosophy is a system of beliefs and assumptions in developing knowledge. According to Mkansi and Acheampong (2012;139), the choice of research philosophy classification, such as ontology, epistemology, and axiology, must be achieved using a planned systematic framework and procedures that show a consensus. The purpose of research philosophy assumptions is to help influence how a researcher designs, executes and reports a scholarly study. Also, it is a medium in which scholars communicate to understand each other's academic works. Creswell and Creswell (2018) summarized that a research philosophy provides the platform by which a researcher believes that a research problem can be solved using either qualitative, quantitative, or mixed methods. Strang (2015) put forward a need to ensure research philosophical concepts are aligned properly with the research problem to be solved. The research philosophical views are developed in collecting and analysing data to gain insight into answering the research questions. The philosophical research assumptions helped structure researchers' understanding of the relationships between the research questions and the choice of research methods, methodology and result interpretations. The next section examined the various concepts associated with research philosophy, as summarized in Figure 3.2.

Figure 3.2 Framework of research philosophical assumptions



3.3.1 Axiology factor

Axiology is a branch of research philosophy that considers the importance of values in the researcher's mind (Strang, 2015; Biedenbach and Jacobsson, 2016). This includes the moral beliefs of a researcher and how these moral beliefs influence ethical conduct during the research. Saunders et al. (2019) pointed out that axiology (role of values and ethics) refers to the choices made by the researcher to deal with research values and the values of those involved in the research. Within this context, axiology factors consist of what makes a good researcher impartial, curious, caring, and diligent in adopting legitimate knowledge, tools, procedures, and research design in conducting research (Strang, 2015; Biedenbach and Jacobsson, 2016; Saunders et al., 2019; Park et al., 2020). On this note, Robert Gordon University's current research ethical code of conduct guided this research (refer to Section 3.11 Ethical Consideration and Appendix B). This code of conduct and ethical consideration comprises how research should be performed ethically.

3.3.2 Epistemology factor

Epistemology is defined as the theory of knowledge (Strang, 2015; Biedenbach and Jacobsson, 2016). According to Saunders et al., (2019), epistemology is assumptions about knowledge. There is a need to consider what constitutes acceptable, valid, and legitimate knowledge and how that knowledge is communicated to others. Creswell (2014: 54) used a phrase to summarise epistemology, "how we know what we know". Putting this statement into context means the various methods utilised in searching for knowledge information, such as 'informal observation', 'selective observation', 'generalisation', and other research methods (quantitative and qualitative). Regarding this research, epistemology addresses how knowledge can be achieved through methodologies, such as interviews, literature reviews, project case studies, quantitative data collection and observing people/projects in their natural environment.

3.3.3 Ontology

Ontology shapes the way researchers approach the study of research objects (Saunders et al., 2019; Al-Ababneh, 2020). According to Saunders et al. (2019), ontology helps a researcher examine data to determine real versus imagined, true versus false, or conscious versus unconscious (this is not an exhaustive list). For instance, this research adopted a quantitative approach (positivistic-oriented research) to examine and develop highway assessment sustainability indicators using numerical data through a quantitative questionnaire survey. Also, the qualitative approach considered in this research is to engage in selecting pertinent participants in contributing their real-world knowledge and experience to achieving sustainable highway construction development in Nigeria, for instance, using qualitative interviews.

The use of qualitative and quantitative research is valuable when an area has a knowledge gap and has not been fully appraised robustly to deduct full understanding and information about the field (Creswell, 2018). Similarly, the mixed method approach assisted in taking advantage of both methods' integrated benefits, which cannot be achieved using a standalone quantitative or qualitative method (Creswell, 2014; Creswell and Creswell, 2018). Table 3 displayed an interconnection of how the research method and the research questions supported achieving the right research data.

Table 3 Consideration in selecting qualitative and quantitative approaches.

Q1. What are the current sustainability strategies utilised (Quantitative) for highway development across the globe?
Q.2 What are the benefits and disbenefits associated (Qualitative) with the sustainability assessment of highway development?
Q.3 What are the factors influencing the implementation of sustainable highway development in Nigeria (Qualitative)?
Q.4 What are the appropriate sustainability indicators for the development of an assessment framework for Nigerian highway development (Quantitative and qualitative)?
Q.5 What is the sustainable framework adequate in reducing the impact of unsustainable highway development in Nigeria (Qualitative, quantitative & case studies)?

3.4 Branches of research philosophy

Research philosophy is all about beliefs and assumptions on how to develop knowledge, and there are different types of research philosophies, positivism, constructivism, and pragmatism (Strang, 2015). According to Saunders et al. (2019), research philosophy reflects values and a choice determined by a researcher for data collection. It is an assumption about how the research is viewed to be solved. Johnson and Clark (2006) stated that researchers should be able to determine philosophical research preferences with the justification of how their choice of research philosophy was achieved. Table 3.1 shows the two selected research philosophies considered for this research. The selection made is based on the ability to answer research questions using quantitative and qualitative approaches.

Table 3.1 Various research philosophies

Philosophies	Definitions and characteristics
Positivism	The traditional form of research comprises more quantitative study than qualitative, and it is called positivist research (Pathirage et al., 2005; Sutrisna, 2009; Creswell, 2014; Fellows and Liu, 2015; Park et al., 2020). Strang (2015) stated that positivism is the oldest known research philosophy, and it is evidence-based and theory-driven. In this philosophy, the world is viewed as being systematically "deductive," which means that investigation involves scientific evidence, relying on theories to explain concepts under investigation. This philosophy is utilised in collecting quantitative questionnaire data from project-level participants on highway projects.
Constructivism	In constructivism, it is assumed that the researcher believes reality is formed through subjective experiences of the external world (Strang 2015). Constructivism is qualitative, hence "inductive" — it is a systematic approach utilised in developing a new theory through the participant's subjective experience. Another primary goal of constructivism research is to create a new, richer understanding of the environment and its context (Saunders et al., 2019). This philosophy is utilised to gain insight into real-world views of highway sustainability from the highway project level.

Table 3.2 summarizes aspects of positivism and constructivism. The focus of this research design is highlighted in red borders.

Table 3.2 Difference between positivism and constructivism

Types	Positivism	Constructivism
Basic concepts	• Objective • Generalization • Scientific • The observer is independent.	• Subjective • Individual motives • Humanistic • The observer is regarded as a part of the object.
Research approach	• Quantitative with a large sample	• A qualitative approach with a small sample but in-depth analysis
Research methods	• Mathematical modelling & simulation • Controlled experiments • Field experiments • Quasi-experiments • Testing • Survey using questionnaires. • Observation	• Case study • Focus group. • Ethnography • Documents & artefacts studies • Unstructured interviews

3.4.1 Synthesis of research philosophies and assumptions

Table 3.3 first and second columns displayed positions of positivism and constructivism (highlighted in red borders) compared with philosophical research assumptions of (ontology, epistemology, and axiology). These selected adopted different research philosophies (positivism and constructivism), enabling the researcher to answer the research questions outlined in Chapter 1 section 1.4. Given the above proposals in Table 3.2. The methods selected for this research are based on the type of data collection required to answer the research questions, which are both qualitative and quantitative. The quantitative method involved the use of a questionnaire survey to gather the opinion of highway project participants across Nigeria regarding how to reduce the adverse impacts of unsustainable highway development across Nigeria.

The qualitative method considered in this research is utilised in collecting non-numerical data, opinions, and experiences from the project-level participants in Nigeria regarding the need to implement sustainability practices using the right indicators.

Table 3.3 A synthesis of selected research philosophies and assumptions
Adapted from Strang (2015) and Saunders et al. (2019)

Ontology (Nature of reality)	**Epistemology** (What constitutes acceptable knowledge)	**Axiology** (Role of values)	**Typical methods**	**Justification for selecting research philosophy**
Positivism				
The ontology considered here is real, external, and independent in examining data to determine real versus imagined, true versus false, or conscious versus unconscious.	From an epistemology point of view, measurable facts with generalisation purpose and causal explanation predict the contributions.	From an axiology point of view, it requires the researcher to establish a reasonable moral belief to be impartial, curious, caring, and diligent in adopting legitimate knowledge, tools, procedures, and research design in conducting research.	Typically deductive, large samples, measurement type is quantitative.	The researcher is independent; - data helped to generalise findings using a large sample population to determine highway sustainability using project participants' level of opinion from the issued survey.
Constructivism				
Ontology, considered here, is data socially constructed through language, experiences, and practices to enable multiple interpretations.	From an epistemology viewpoint, theories and concepts are regarded as simple. The focus is on narratives, perceptions, and interpretations.	Within this context of an axiology point of view, the researcher is part of the subject researched. The researcher's interpretations are critical to the contribution.	An in-depth qualitative data analysis investigation requires a typically inductive, using a small sample size.	Due to new understandings and viewpoints as a contribution to knowledge, this philosophy is selected to determine highway sustainability for Nigeria.

3.5 Approach to research theory development – mixed method.

There are three primary approaches to research theory development which are deductive, inductive, and abductive (Kennedy and Thornbury, 2018; Mitchell, 2018). Saunders et al., (2019: p.153) pointed out that if research starts with a theory, which is using academic literature to design a research strategy to test a theory, then the researcher is using a deductive approach (quantitative). In contrast, inductive reasoning is a specific observation that leads a researcher to determine a conclusion from the results (Mitchell, 2018). Saunders et al., (2019) admit that the inductive approach consists of when a researcher collects data to explore a phenomenon; this is to generate and build a theory. Instead of moving from theory to data (as in deduction) or data to theory (as in induction), the abductive approach moves back and forth in the effect of combining deduction and induction (Saunders et al., 2019, cited Sudday, 2006: p.155). The abductive approach is an optional consideration for research to move from theory to data or vice versa.

To achieve the research objectives outlined (Chapter 1 Section 1.5 of this thesis), the combination of quantitative and qualitative approaches is utilised to develop a research theory. The reason is that this research started with a literature review to identify issues associated with unsustainable highway design and construction across Nigerian society, which was followed by the identification of practical sustainability indicators using the backcasting technique. These indicators are issued to project-level participants online, using a questionnaire survey to enable participants to assign Likert values (data collection), and further, the indicators are validated by the interviewees.

Given Creswell and Creswell's (2018) generic research design framework previously shown in (Figure 3.1), a structure is developed for this research. Figure 3.3 presents the research structure created to aid in collecting data to answer research questions and in achieving the research aim. According to Fellows and Liu (2018), research in the construction sector is multidimensional, and it is only through robust methodologies and methods that a contribution can be made to knowledge.

The flowchart in Figure 3.3 provides the below stages of research strategies performed, which are structured as follows—

- stage 1A (literature review),
- stage 1B (formulation of research justification),
- stage 2 ({2A} Quantitative and {2B} Qualitative, data collection respectively),
- stage 3 (analysis, validity, and reliability check), and
- stage 4 (project case study, results, framework development, conclusion).

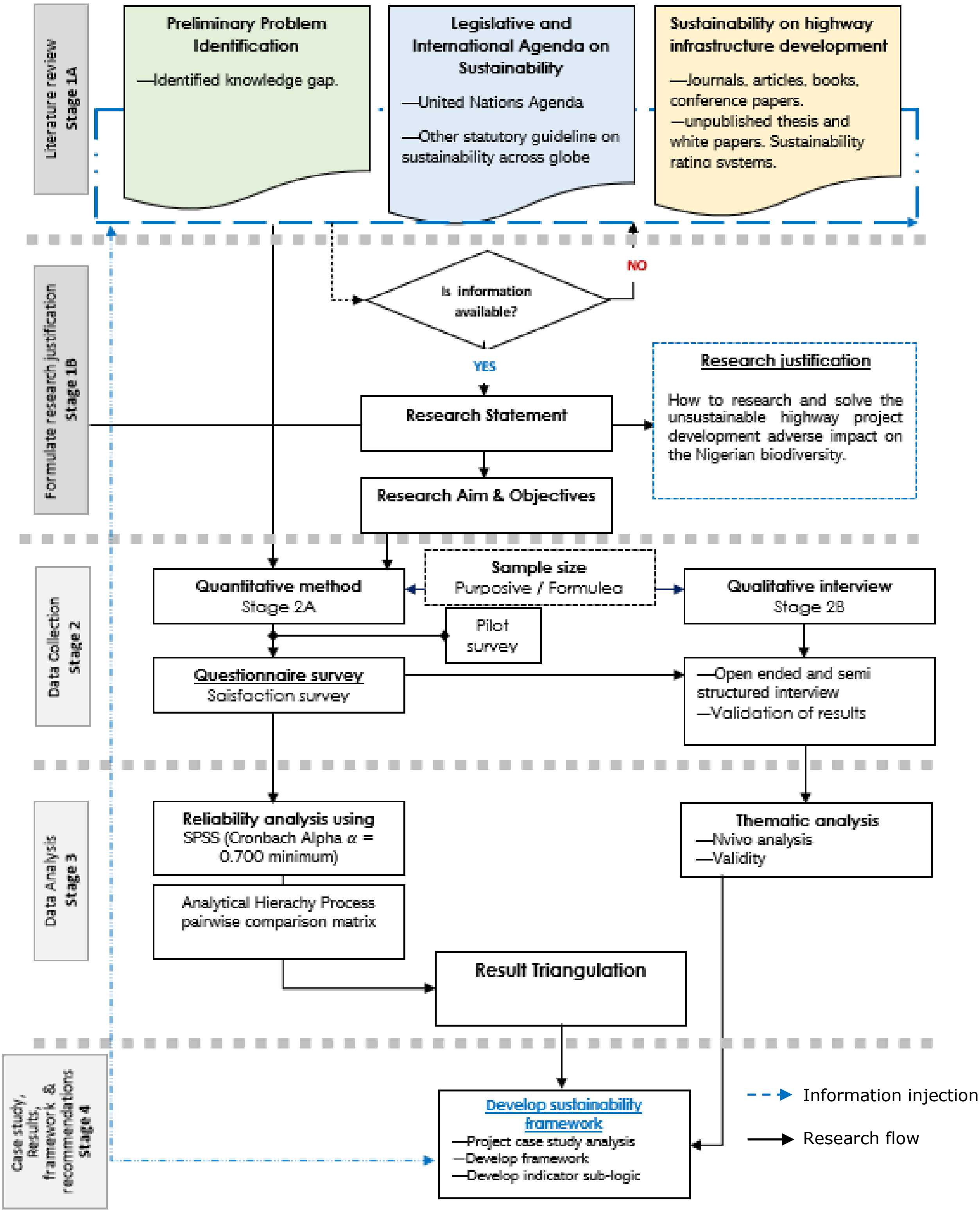


Figure 3.3 Research framework to develop highway sustainability for Nigeria.

3.5.1 Formulating research justification (Stages 1A & 1B)

Figure 3.3 (represents stage 1A), the literature review examined existing theories to help create an overview of a knowledge area to enable critical evaluation by the researcher to identify gaps in filling it with knowledge (Booth et al., 2012; Aarseth et al., 2016). A literature review provides a core foundation for existing data information appraisal. Literature review in research helps in establishing the depth and breadth of existing knowledge within highway design and construction sustainability development. The literature review in Chapter Two identified existing information that helped to understand underpinning knowledge that relates to determining research questions, objectives and the method and methodological concept for this research.

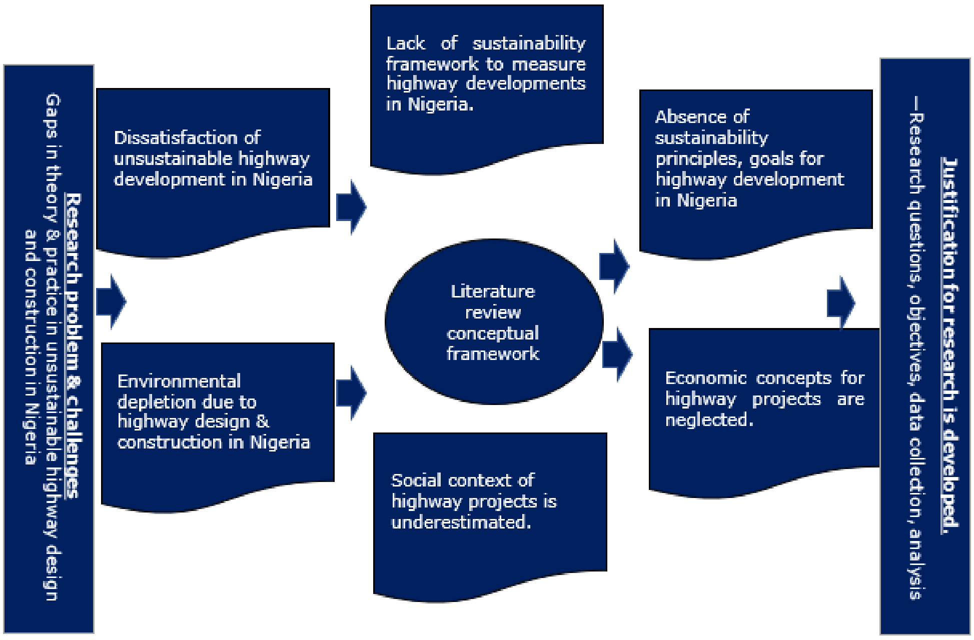


Figure 3.4 Conceptual research justification statements from literature (Stage 1B)

Sources; adapted from Okigbo, 2012; Ede, 2014; Enwerem and Ali, 2016; Abiodoye & Olalekan, 2017

In stage 1A, to review conceptual knowledge, the sources of literature in chapter two originate from pertinent academic articles, journals, published theses, reports, conference proceedings, books, United Nations legislative instruments on sustainability concepts, and other existing highway infrastructure sustainability rating systems globally. Figure 3.4 (Stage 1B) provides the conceptual framework of problems and issues within the challenges presented in literature due to unsustainable highway development in Nigeria and the identified knowledge gaps to justify this research; please refer to Section 1.3 for details.

3.5.2 Literature search parameters

The literature review conducted in Chapter 2 was achieved using a set of guidelines outlined below. These identified literature review guidelines were previously used by Tranfield et al., (2003) and later by De Carvalho et al., (2017). The steps involve(s); — (1) planning the review, (2) conducting the review, and (3) result reporting, see Table 3.4.

Table 3.4 Systematic literature review process

Step 1 Planning the review	• identification of the need for a review.
	• development of a review protocol.
Step 2 Conducting the review	• identification of search database.
	• selection of studies.
	• study quality assessment.
	• data extraction.
	• data synthesis.
Step 3 Reporting	• the report and recommendations.
	• getting evidence into practice.

Source: adapted from Tranfield et al., (2003) and Carvalho et al., (2017).

Step 1 of Table 3.4, the literature review planning, involved determining the inclusion of pertinent articles, journals, and reports for a review. According to Booth et al., (2012), planning and conducting a literature review requires strategies and protocols for — (1) determining the research objectives, methods, and methodology, (2) establishing the review search engine strategy, and (3) determining the concepts for the exclusion and inclusion for the systematic literature review.

Step 2 of Table 3.4, conducting the literature review, is to examine previous knowledge using the objectives of this research to critically examine highway sustainability strategies and to identify factors influencing sustainable highway development in Nigeria. The identification of the search database for article sampling is accessed across Scopus, Web of Science, ScienceDirect, and Google Scholar. These databases are selected because each covers publications on highway and road sustainability, methods, and methodology in academic research. During conducting the literature review, the search string applied is uniform across the listed database. Jesson and Fiona (2006) stated that the application of unified information in data search helped gain details to a greater height.

Step 3 of Table 3.4 is the reporting stage of the literature reviewed, which involves establishing to apply each reviewed literature across the thesis.

3.6 Research approaches-mixed method (stages 2A & 2B)

Creswell and Creswell (2018) identified three distinct research approaches, namely, qualitative, quantitative, and mixed methods. A concise research philosophical structure is shown in Figure 3.5. It is argued that the use of a single research method in the construction and built environment is often unable to explore all the research components (Amaratunga, 2002). Therefore, the use of mixed methods often mitigates the weakness in the use of a single research strategy and in providing a stronger understanding of construction and built environment research (Creswell and Creswell, 2018).

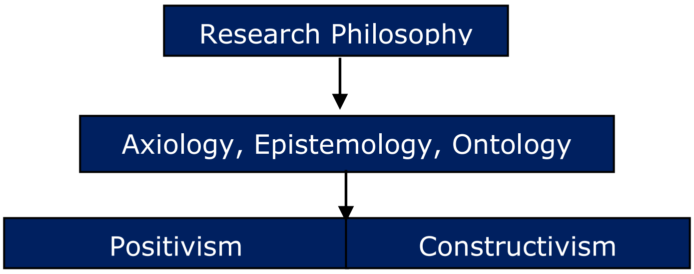


Figure 3.5 Framework of research approaches using a mixed method.

This research uses a mixed method comprising quantitative and qualitative methods. The use of mixed methods to develop a highway sustainability rating system for Nigeria provided this research with in-depth data for analysis and findings in answering research questions. A mixed research method helped balance the limitations of each method to provide confidence in the findings (Creswell, 2014; Mitchell, 2018). The qualitative research approach provided a breadth of study by looking at small sample size. In contrast, the quantitative research approach utilised a large sample size. In comparison, the use of the qualitative approach considers gathering in-depth information about human observations and experiences across workplace environments using small, sampled sizes (Amaratunga et al., 2002).

Each research approach utilised different techniques. For instance, in this research, the quantitative research approach utilised a survey questionnaire, while the qualitative research approach utilised an interview approach. The data from the quantitative method is processed through statistical analysis, while other techniques, such as thematic analysis, are used in processing qualitative data for current research. Table 3.5 displays the differences between the three research approaches.

Table 3.5 Qualitative, quantitative, and mixed-method differences.

Qualitative approach	Quantitative approach	Mixed Methods approaches
✓ Constructivist knowledge. ✓ Involves acquiring rich and complete real-world experience which cannot be gained using a large sample size. ✓ Subjective in nature ✓ Open-ended questions, text, and image data. ✓ Validate the accuracy of findings. ✓ Collaborate with the participant.	✓ Positivist knowledge claims. ✓ Survey and experiments. ✓ Pre-determined approaches and numeric data. ✓ Observe and measure information numerically. ✓ Employ statistical procedures.	✓ Both open-ended and closed-ended questions. ✓ Integrate data from different stages of inquiry. ✓ Employ practices of both qualitative and quantitative approaches.

Source: Adapted from Creswell (2014).

For this research, a sequential explanatory technique is used to integrate the quantitative and qualitative outcomes in a mixed-method approach. This is where quantitative data is collected and analysed first, and then qualitative data is used to help explain the findings of a quantitative study. Figure 3.6 displays the explanatory mixed-design strategy for this research.

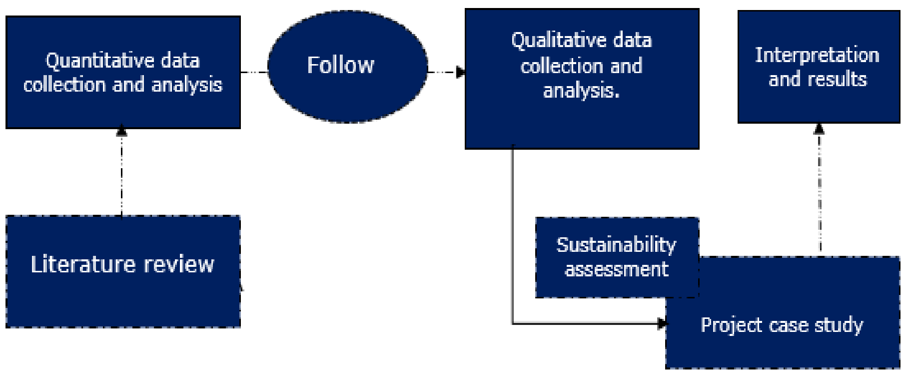


Figure 3.6 Mixed-method research design concept (Quantitative to Qualitative)

Othman et al. (2021) stated that the use of a sequential explanatory mixed-method design is fit to answer research questions and draw broader conclusions. The logic behind the use of a sequential explanatory mixed method is collecting quantitative data first before collecting qualitative data, which is to analyse project participants' level of opinion with the presented design and construction sustainability indicators. This is to draw preliminary insight into the viability of the indicators further to the interview to validate the sustainability indicators.

In the use of the sequential explanatory mixed method approach, the use of a qualitative method helped to take a deep dive into collecting data on how to reduce the adverse impact of unsustainable highway development, and it helped to contextualise the results from the quantitative result approach. The proposed sequential explanatory mixed method is appropriate for this research because it helped to draw on a broader conclusion of findings, and the qualitative results helped to justify and provide a more comprehensive meaning of findings and interpretations drawn from the quantitative results (Othman et al., 2021: p.76). Explanatory research is where qualitative research is employed to substantiate findings generated in population-level surveys (Kroll and Neri, 2009: p.38).

Figure 3.7 displays the processes involved during the sequential explanatory mixed method approach.

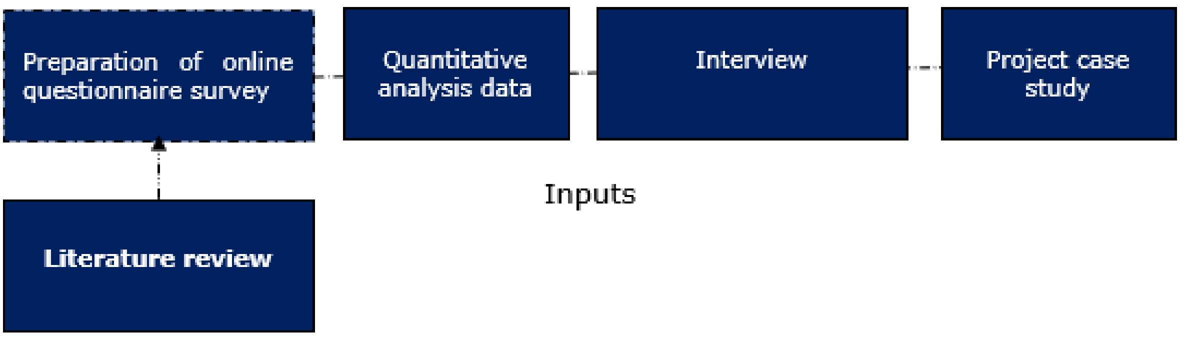


Figure 3.7 Process of data collection approach

3.6.1 Overview of building sustainability indicators

According to Wu and Wu (2012), sustainability indicators are representations of attributes of a system and goals to be achieved. Sustainability indicators provided information on the dynamics and underlying drivers of human-environmental systems management. The basis of sustainability indicators determined for this research emerged as a result of the negative impacts of unsustainable highway development as outlined in Tables 2.7 and 2.8 in Chapter Two literature review.

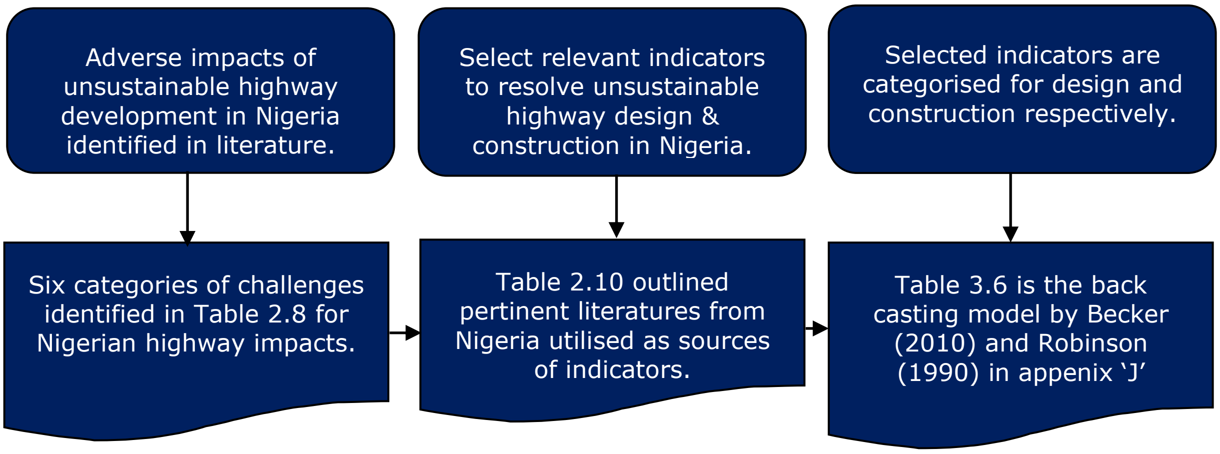


Figure 3.8 Sustainability indicator formulation steps

Figure 3.8 displays the sustainability indicator formulation process, which consists of three distinct steps. The first phase consisted of the various adverse impacts of unsustainable highway development impacts across Nigeria, which was outlined in Table 2.8 of Chapter Two, literature review. The identified adverse impacts of unsustainable highway development are in six categories, namely social, technical, environmental, economic, engineering, project management and safety and health. What was considered for effective sustainability solution in this research is the categorised highway design criteria into four areas, which are social, environmental, economic, and technical. The highway construction phase was categorised as; — social, environmental, economic, engineering, project management, and health and safety.

The second phase in the formulation of the highway sustainability indicator in Figure 3.8 consisted of sourcing suitable sustainability indicators from the literature, which are displayed in Table 2.10 of Chapter 2. The emerged indicators was formulated using steps in Figure 3.8 which was analysed using the backcasting model (see Table 3.6 and Appendix 'J'), and later in Chapter Four, the achieved sustainability indicators was presented to project-level participants using a questionnaire survey to gain their level of opinion regarding the acceptance of the presented indicators for highway design and construction.

According to Becker (2010), there are numerous indicators used to evaluate sustainable development, but when these indicators are selected without considering their effect on achieving sustainability, environmental problems continue to be on the rise. Backcasting is a tool utilised to reduce the impact of anthropogenic activities in promoting sustainability (Vergragt and Quist, 2011). Adopted for this research is the backcasting method developed by Robinson (1990:824); see Appendix 'J' for flowchart and description, and backcasting model developed by Becker (2010) is integrated into selecting adequate sustainability indicators capable of reducing unsustainable highway development in Nigeria.

The backcasting model has no formula for achieving sustainability. Becker (2010) stated that the ecological framework (refer to Table 3.6) is utilised to determine the relevance of indicators to ensure optimal performance. In Table 3.6, according to Becker (2010), the first column is the preliminary target category, and the indicators have to fulfil the three principles, namely (resilience, collaboration and auto sufficient). These preliminary highway sustainability indicators were sourced from literature in Table 2.10, highway manuals and existing sustainability rating systems and indicators thematically presented for highway design and construction in Chapter 4. This sustainability indicators' information is utilised in preparing a questionnaire survey issued to highway project-level participants in Nigeria to determine their level of opinion and to gather AHP pairwise comparison matrix data for a comparative analysis between the outcome of the questionnaire survey and AHP results.

Preliminary Target category	Future and present impacts	Criteria for present and future solutions		
	Indicators	**Resilience**	**Collaboration**	**Auto sufficient**
Pollution	Reduce pollution, avoid soil contamination, and limit noise from equipment.	✓	✓	✓
Carbon emission	Due to trucks, raw materials processing	✓	✓	✓
lack of social context management	Accepting inputs into design and development from stakeholders.	✓	✓	✓
Depletion to the natural environment	Recycling process and gaps in material design reuse. Reuse topsoil, clearing and grubbing,	✓	✓	✓
Stakeholder's low experience	Engage with the supply chain.	✓	✓	✓
Lack of sustainability frameworks	Gaps in sustainability assessment models	✓	✓	✓
Economic success	Models in lifecycle analysis, the extent of return on investment, and innovative ideas to generate economic success using a sustainable model.	✓	✓	✓
Environmental degradation	Erosion control, habitat protection, protection of the wetland, protection of farmlands, and reduction of habitat fragmentation.	✓	✓	✓
The dissatisfaction with developed highway projects	Gaps in intermodal connectivity across communities, long travel distances, no travel rest areas and recreational parks, no scenic views, and cultural inclusions. Congested traffic, underdeveloped speed limits, poor topographical sections, unsafe stopping car distance, dangerous curves, no catchment basin for water runoff, pavement is poorly designed	✓	✓	✓

Table 3.6 Allocation of indicators to component of ecological framework

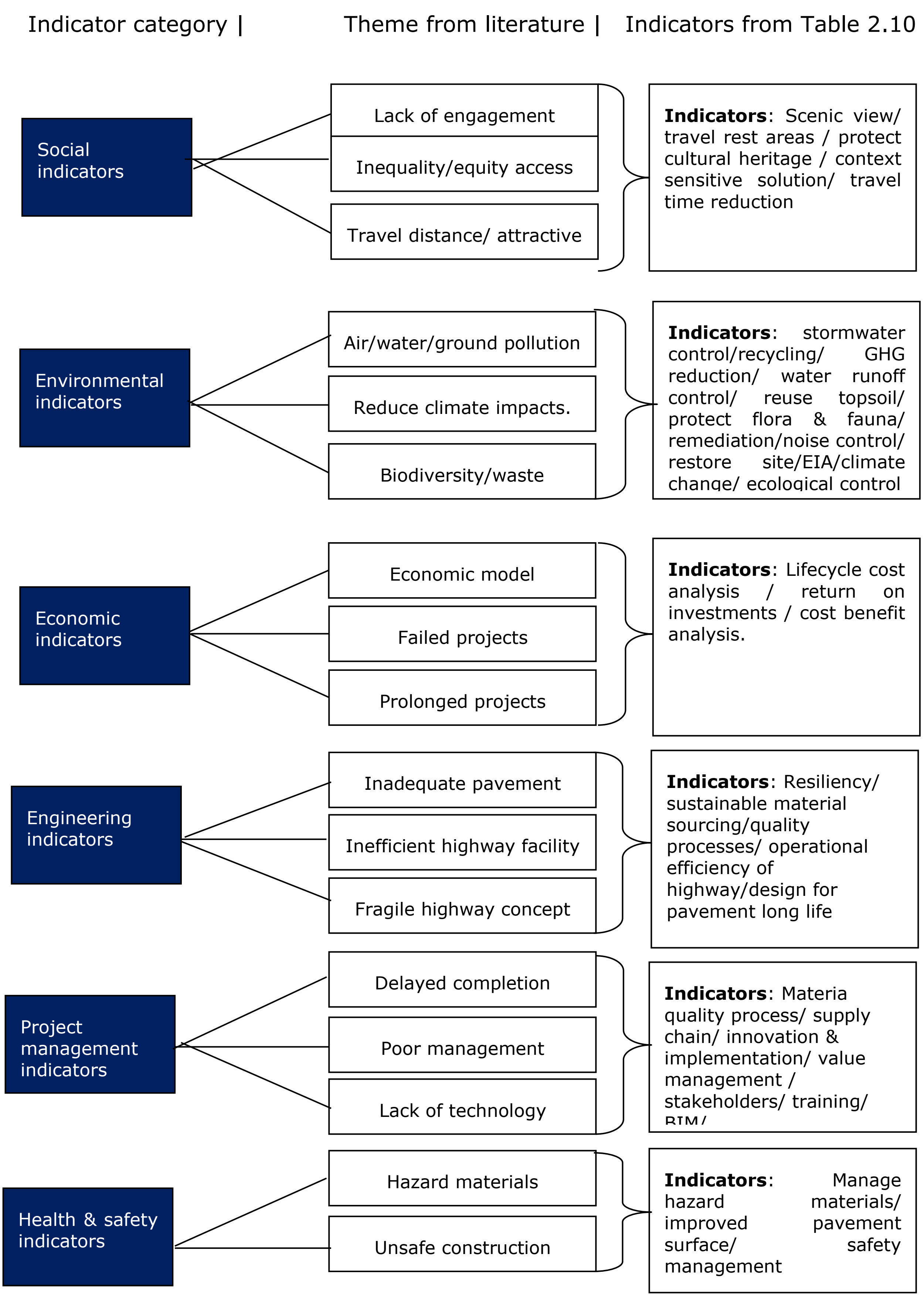


Figure 3.9 Emerging theme for highway construction sustainability indicators

Figures 3.9 and 3.10 display the process of the emerging theme in selecting indicators for sustainable highway design and construction. Figure 3.9 consists of six categories of indicators for highway construction, which was identified through a literature review summarised in Table 2.8 of Chapter Two. The themes are the various categories of challenges identified because of unsustainable highway development impacts across the Nigerian environment. The indicators identified from the literature summarised in Table 2.10 are utilised as a countermeasure against unsustainable highway development practices. A similar procedure is outlined in Figure 3.10, consisting of processes utilised to generate the indicators for sustainable design.

Indicator category | Theme from literature | Indicators from Table 2.10

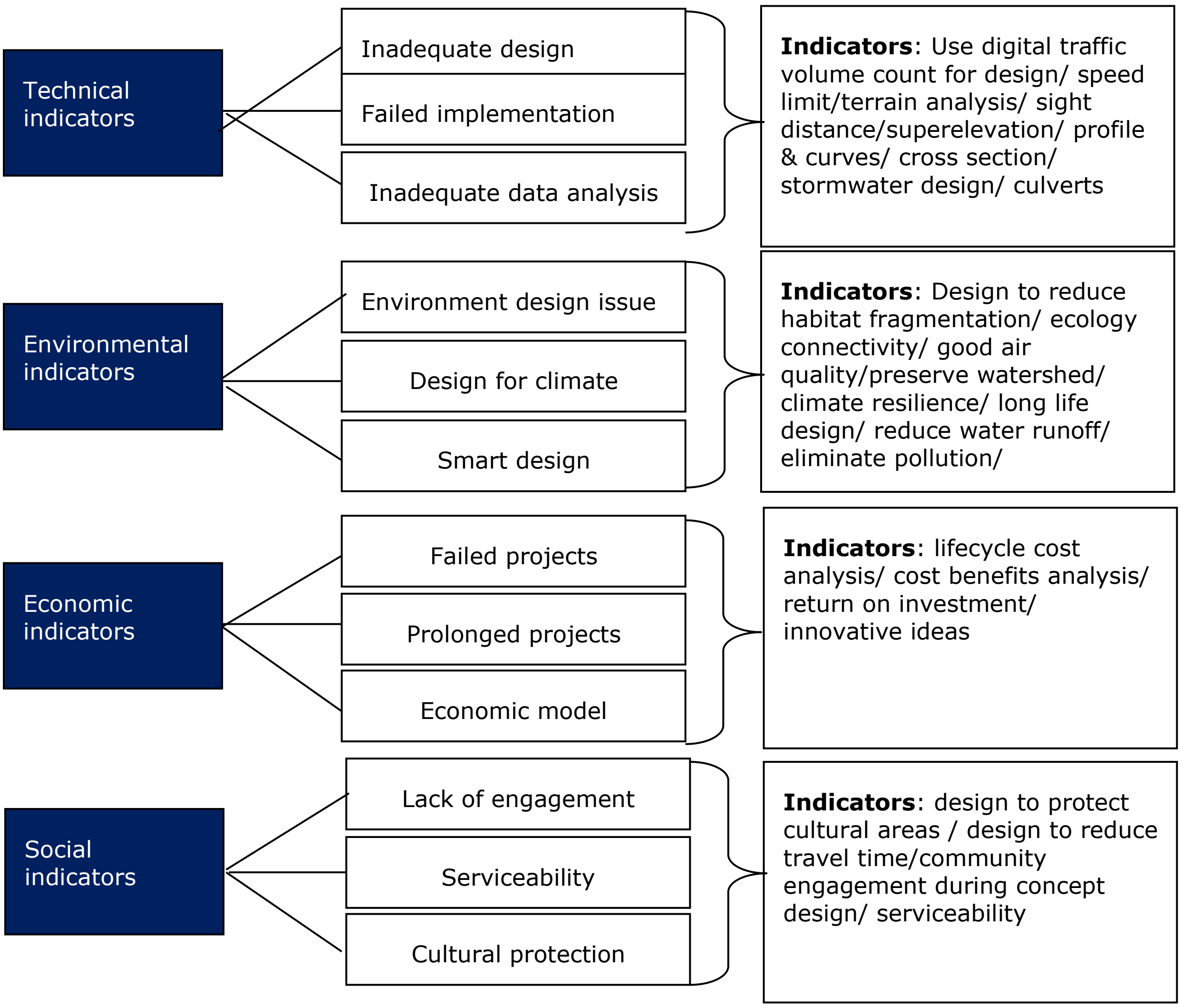


Figure 3.10 Emerging Theme for Highway Design Sustainability Indicators

3.6.1.1 Quantitative – questionnaire survey

A questionnaire survey is a primary input for quantitative research. The benefits of questionnaire surveys provide an opportunity to build knowledge from data, which involves collecting facts that are measurable and calculated to make a deductive conclusion in answering research questions (Strang, 2015; Fellows and Liu, 2018; Ikart, 2019).

Using an online questionnaire survey approach helped to reach selected participants remotely across a large area of Nigeria and globally (to answer only research objective 1). The use of an online questionnaire survey for this research, helped in the optimal delivery of the dataset which was viewed in real-time via online, which is cheaper, quicker, and cost-effective (Nayak and Narayan, 2019). The questionnaire survey for the analytical hierarchy process (AHP) pairwise comparison matrix for the indicators was issued to selected project-level participants. A questionnaire survey provided equal opportunities and openness for the participants to provide factual feedback anonymously.

The limitations inherent in the use of a questionnaire survey could adversely influence the quality of data collected. For instance, respondents' personal biases could affect the accurate response rate and affect the quality of data (Andrade, 2020). These anticipated biases could influence the judgement of a participant in answering the questions for the survey. This bias can be attributed to how the adverse impact of highway infrastructure development has affected people and professionals across Nigerian society.

To minimise bias and increase the credibility of the data collection among project-level participants, categories of approaches are employed for this research. According to Andrade (2020), the first condition is that the sample population should be known and identified (using a generalisation of the sample population is not permitted); in this case, the sample population were taken from the society's membership of the Nigerian Society of Civil Engineers. The second considered condition is that a valid method of sampling is utilised, alongside generating data from the demographic information for the generalisation of roles, experience, and designation. Another notable implemented condition to mitigate bias in answering the questionnaire survey is the inserted caveat within the questionnaire survey on the need for the sample population to provide good quality information to the best of their expert knowledge during the survey (this statement is directed to the participants). As an additional measure, a reliability analysis check was conducted using the SPSS software to measure the consistency of the data collected from the sample population.

Please refer to Appendix C, from Table C1 – C3, for a questionnaire survey regarding design, construction indicators and highway sustainability strategies utilised globally. According to Joshi et al. (2015), the Likert scale is a commonly used approach to summarise and calculate feedback and responses. The Likert scale measures the degree of disagreement or agreement with a statement regarding varieties of attitudes, objects, or events. The Likert scale is a simple construct utilised to measure subjective decisions and opinions on a subject matter (Taherdoost, 2019). For instance, this research utilised a Likert scale to represent 1= insignificant to 5 = very high significance to enable data collection. Sometimes, the Likert scale can represent strongly agree = 5 and Strongly Disagree = 0, or yes = 1 and no = 2. The scale was developed by Likert (1932) to simply collect opinions and information from research participants. The feedback in the Likert scale enabled researchers to use an analytical approach to compute collected data.

To increase the response rate, a five-point Likert was used within this research questionnaire survey. Using a higher Likert scale like 10 or 11 points, according to psychometric literature, is very encouraging but diminishes the return rate, as it is unable to fit in well in most mobile smartphones (Joshi et al., 2015; Chyung, 2017; Taherdoost, 2019). The use of smartphones for online learning is becoming very popular in Nigeria, considering over 170 million mobile subscribers (Oyelere et al., 2016), and that makes it more convenient for most project-level participants to use in answering the questionnaire surveys.

3.6.2 Questionnaire pilot design

A questionnaire pilot survey was conducted during the research process to test the research questionnaire procedure and to measure the data collection strategies. The questionnaire pilot survey objectives include ensuring effective data collection from a sample population. It helped in identifying potential problem areas of deficiencies across the questionnaire and the data collection procedure. The questionnaire pilot survey assisted in determining if the sample population would become familiar with the procedure (Schattner and Mazza, 2006).

A pilot survey provides a warning of where the questionnaire could fail in collecting data (Teijlingen et al., 2001). In De Vaus' (2016) statement, researchers should not take the risk but “pilot test first, before proceeding with the main survey”.

The pilot survey for this research was undertaken with a representative sample of 10 highway construction project level participants and 3 highway design participants, respectively, from Nigeria. The pitfalls and feedback identified from the pilot survey helped to improve the online questionnaire survey, for instance, by shortening the text wordings within the questionnaire and adding the Likert scale range 1 - 5, where 1 = not significant and 5 = very high significance, which was omitted initially, in so doing, making it easier to code and analyse in the SPSS software.

3.6.3 Multiple criteria decision analysis (MCDA)

A multiple-criteria decision-making analysis (MCDA) is explicitly utilised in evaluating multiple conflicting criteria to enable decision-making. The use and application of MCDA enable decision-makers to resolve a problem involving judgements (Ssbuggwawo et al., 2009). The MCDA methods have been successfully applied in different fields and disciplines (Salabun et al., 2020). MCDA is increasingly used for decision-making in environmental aspects due to the complexity of the issues identified (Browne and Ryan, 2011). MCDA is the most appropriate tool for decisions based on integrated sustainability appraisals (Bueno et al., 2015). This tool can help to evaluate priorities, preferences, and objectives to solve a problem. Research in the past utilised the MCDA model using an analytical hierarchy process (AHP) to perform quantitative-related analysis (Abadi and Moore, 2021).

Table 3.7 displayed various identified MCDA tools utilised across a wide range of interdisciplinary sectors, including management and business models, to determine conflicting criteria.

Type of MCDA	Decision-making type	Author(s)	Advantages	Disadvantages
TOPSIS	This tool is associated with the subjective and objective determination of weights for the selected indicators.	Vavrek (2019). Hwang and Yoon:1981	TOPSIS is used as a hybrid allowing integration with other MCDA tools, such as; - ELECTRE, VIKTOR, PROMETHEE, and AHP.	There are noted scattered results between weight results for subjective and objective values for the indicators.
ELECTRE	Utilised for decision-making solution, using a maximum of thirteen indicator criteria	Figueira et al., (2016). Benayoun Roy: 1968	Data can be generated using ELECTRE, even if there is no data	It is based on a mathematical model using software; carrying out manual computation is complex
AHP	Used for decision-making in a wide range of fields, AHP is used to model a problem in a hierarchy structure. The formula is proven, has many uses, and offers many criteria, there are checks for consistency. There is a choice, ranking, prioritization, and aggregations.	Han et al., (2020). Thomas Saaty: 1970	There is achieved goal using criteria to assess pairwise comparison matrix analysis to determine the weight of the indicators	The analysis becomes complex to achieve consistency if the criteria and indicator increases. This can be mitigated by minimizing indicators integrated for evaluation.
PROMETHEE	This is used across the industry to determine, choice, ranking, prioritization, resource allocation and conflict resolutions. This tool uses qualitative and quantitative	Behzadian et al., (2010). Brans and Vicke: 1982	Good results can be achieved with limited criteria, and high numbers of criteria become complex.	Analysis requires an additional hybrid tool to achieve results called the out-ranking method.

Table 3.7 Summary of various types of MCDA used in industry and research

TOPSIS technique is a technique for the order of prioritization by similarity to the ideal solution). This is the primary method among the MCDA, and the origin is attributed to Hwang and Yoon. TOPSIS concepts are based on the chosen alternative for decision-making to have the shortest geometric distance from the possible ideal solution (Vavrek, 2019), and the longest geometric distance becomes negative from the ideal solution. TOPSIS utilises a scale of preferences to normalise the scores for geometric calculation. TOPSIS technique can be integrated to achieve a hybrid solution using other MCDAs such as ELECTRE, VIKTOR, PROMETHEE, and AHP. One of the drawbacks of TOPSIS, according to Vavrek (2019), is that scattered results are noted when the technique is utilised for subjective and objective analysis of the indicators.

ELECTRE technique (ÉLimination Et Choix Traduisant la REalité: Elimination and Choice Translating Reality) belongs to the family of MCDA. The concept was established by Bernard Roy in 1965, and the development criteria involves selecting the best-required criteria from a given set of scales. According to Figueira et al. (2016), ELECTRE is utilised in problem-ranking solutions. ELECTRE has a drawback because it cannot determine the weight of criteria in a system. However, other MCDAs, such as AHP and OPA (Ordinary Priority Approach), can be integrated to make ELECTRE achieve a ranking solution. Achieving the goals of ELECTRE requires the use of related software. Using manual computation for ELECTRE becomes complex with random errors. The benefit of using this tool is that random data could be generated to commence analysis using computer software (Emovon and Oghenenyerovwho, 2020).

AHP (analytical hierarchy process) enables decision-makers to operate subjectively by choosing various alternatives from a set of criteria (Saaty & Vargas, 2012; Brunelli, 2015; Omotayo et al., 2020). AHP is designed to cope with logical and insightful thinking and has been utilised across a wide range of industries and in different research contexts. Handfield et al. (2002) used AHP to determine criteria for selecting suppliers' procurement strategies; AHP has been utilised to select competency amongst contractors (Fong & Choi, 2000). Omotayo et al. (2020) utilised AHP and other techniques to determine critical factors influencing the effective implementation of kaizen costing. Uchehara et al. (2020) applied AHP to propose reducing carbon emissions using a process management approach. AHP is appropriate because the use of Saaty's (1980) consistency ratio is used to verify and determine a pairwise comparison matrix to determine the consistency of the achieved weighting system.

PROMETHEE technique (Preference Ranking Organisation Method for Enrichment Evaluation) belongs to the family of MCDA used in a wide range of decision-making such as in transportation, education, healthcare, business, and governmental institutions. According to Behzadian et al. (2010), the application of PROMETHEE is used for ranking alternatives.

Table 3.6 shows the MCDA decision-making types, their strength and noted drawbacks based on the synthesis for the MCDA. For this research, the AHP technique is selected because it is suitable for contributing to answering the research questions. In this case, the Likert scale and AHP are the quantitative tools considered for current research.

3.7 The analytical hierarchy process

Figure 3.3 (Stage 3), under the quantitative approach, indicates that AHP is utilised to collect pairwise comparison matrix data for the highway design and construction sustainability indicators that emerged from the online questionnaire survey. The primary aim of using the AHP in this research is to determine the weighting of design and construction indicators.

What is considered during the stage of result analysis is the consistency of the high, middle, and low ranking for each indicator result for both the AHP and online questionnaire survey. This is to enable analysis of reliability and cluster of data using a correlation approach. The selection of the quantitative results is based on defined acceptance criteria for high, middle, and low-priority ranking results for both AHP and the online questionnaire survey.

3.7.1 Determine pairwise comparison matrix.

Weighting is considered a capable tool for determining the relative importance of sustainability indicators (Gan et al., 2017; Yang et al., 2018). According to Gan et al. (2017: 492), there are different types of sustainability weighting, namely, (1) equal weighting, (2) statistic-based weighting, and (3) public/expert opinion weighting.

Equal weighting is used when all the indicators are considered equally important. Statistic-based weighting is typically derived from data characteristics, which is based on empirical and mathematical derivation of weighting established on assumptions. These statistic-based weightings fall into the categories of hypothetical assumptions, such as collecting observed variables and unobserved variables to conclude the findings.

Likewise, another form of weighting is through public/ expert opinion, which considers the decision-making inputs from relevant participants. Public and expert opinion weighing has been utilised in developing sustainability strategies. For instance, Amen and Mourshed (2019), in assessing the unique contribution of urban sustainability assessment, suggested that expert opinion judgement is critical to identifying relevant sustainability dimensions and ranking. The expert opinion represents a type of pairwise comparison approach utilised in comparing indicators within an entity to judge which entity is preferred (See Appendix 'C' for the AHP pairwise comparison sample data collection questionnaire). Sometimes, these indicator entities might be less preferred, equally, or greatly preferred in pairwise comparison.

Singh et al. (2009) pointed out that the weightings of indicators are, to some extent, associated with general subjective judgement. Therefore, it is necessary to establish a rational way of determining the weightings of the indicators to reflect effective, sustainable impact (Yang et al., 2018). In their views, Poveda and Lipsett (2015) suggest that weighting assists practitioners by taking onboard inputs and suggestions from co-participants in determining values for the sustainability assessment process.

Figure 3.11 displays the AHP framework for determining design and construction weighting for this research.

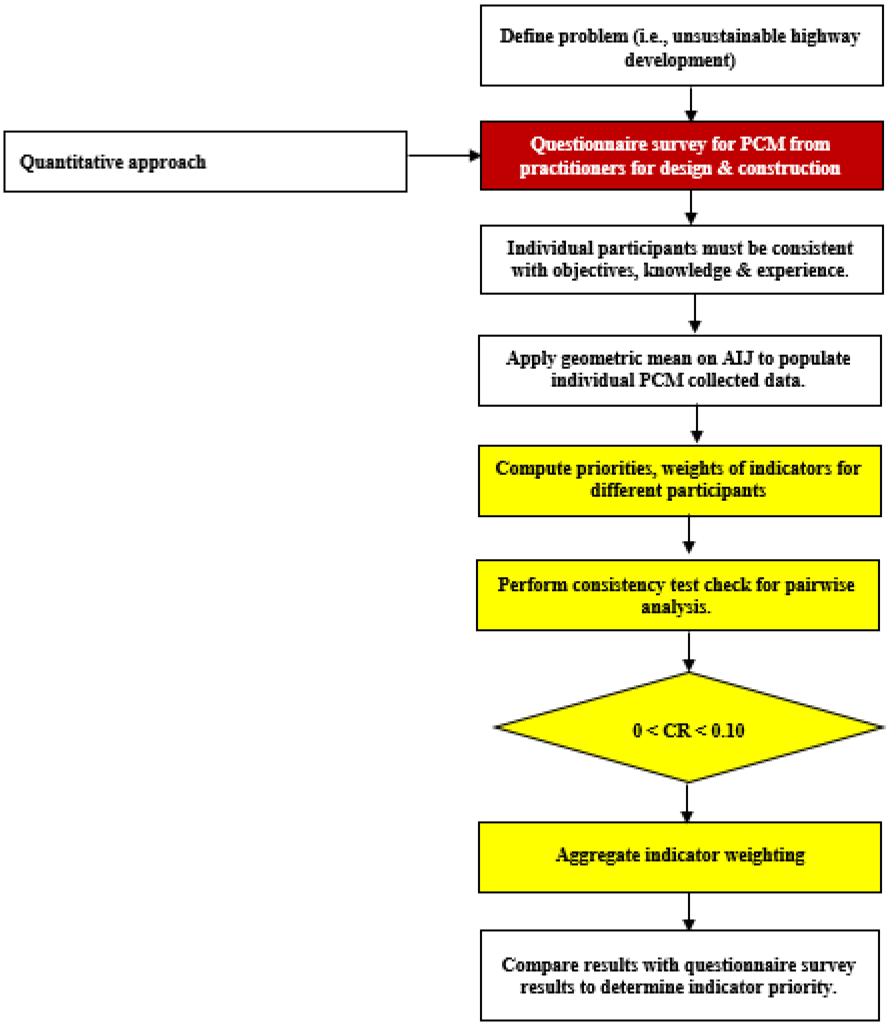


Figure 3.11 Adopted framework for Analytical hierarchy process.

Figure 3.11 displays the approach to determining the AHP weighting values outlined in the below-following section.

3.7.2 Defining the problem in the AHP structure

There is a recognised need to adopt sustainability practices in developing highway infrastructure projects across Nigeria (Oraegbune, 2022). Previous studies documented the unsustainable adverse impact of highway construction across Nigerian society (Ohwo and Abotutu, 2015). Previous studies have not examined highway solutions through the lens of environmental impact with the intent of reducing development impacts across Nigeria (Okigbo, 2012;

Emeasoba, 2013; Ede, 2014; Enwerem and Ali, 2016). AHP structure is used to determine weighting value using a pairwise comparison matrix and analysis.

3.7.3 Aim of AHP structure

AHP aims to guide this current research in determining the weight of indicators.

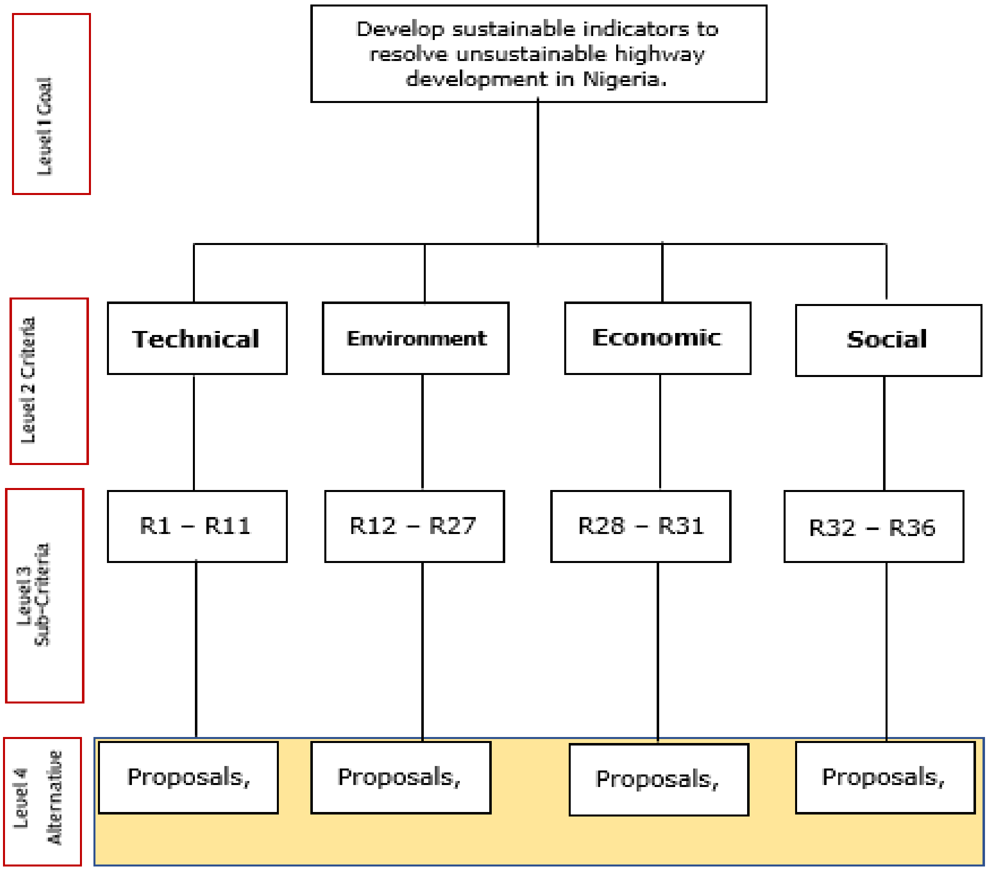


Figure 3.12 AHP structure for sustainable highway design

- In Figure 3.12, level 1 aimed to develop indicators needed to achieve sustainable highway design to reduce unsustainable development practices in Nigeria.
- Level 2 is the main criteria for the various categories called multi-dimensional pillars for achieving sustainable development for highways in Nigeria. Level 2, for highway design, consists of four categories, namely, social, environmental, economic, and technical.
- Level 3 consists of sub-criteria contributing to clusters per each key criterion in level 2. These listed sub-criteria are the indicators selected from the literature based on the back casting model, which consists of 36 indicators for highway design.

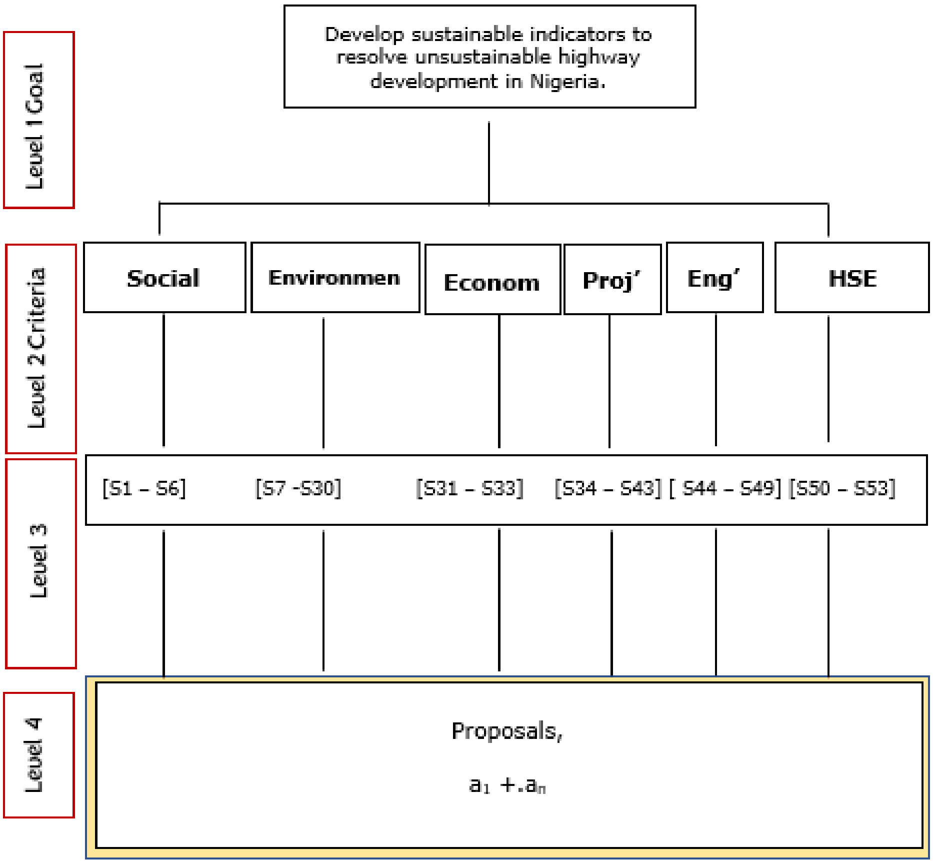


Figure 3.13 AHP structure for sustainable highway construction

- In Figure 3.13, level 1, the goal of the model is to develop indicators needed to achieve sustainable highway construction through the reduction of unsustainable development practices in Nigeria.
- Level 2 is the main criteria for the various categories called multi-dimensional pillars for achieving sustainable development in highways in Nigeria. Level 2 consists of six categories for construction, namely, social, environmental, economic, engineering, project management and health and safety for highway construction.
- Level 3 consists of sub-criteria contributing to clusters per each main criterion in level 2. These listed sub-criteria are the indicators selected from the literature, and this is based on the back casting model, which consists of 53 indicators for highway construction.

3.7.4 Pairwise comparison matrix sampling

A pairwise comparison matrix is utilised in AHP to compute the relative priorities of indicators. It is a process of comparing indicator entities to determine which indicator entity is preferred over the others. In this research, the selected participants assigned relative 'more importance' 'equal', or 'less importance' based on project experience in identifying indicators that are more or less important. In Table 3.8 the indicator 'J1' is compared relatively across J2, J3, J4, J5, and vice versa. Table 3.9 displays the sample indicators and their attributes.

Table 3.8 Sample pairwise comparison matrix

Indicators	More Importance								Equal	Less importance								Indicators
J1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	J2
J1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	J3
J1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	J4
J1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	J5

Table 3.9 Sample Indicators and Attributes

J1 = Traffic volume count
J2 = Speed limit
J3 = Topographical terrain analysis
J4 = Stopping sight distance
J5 = Safe radius of a curve

Another area worth pointing out is the required simplicity of the pairwise comparison matrix (PCM) questionnaire structure in Table 3.8; it enabled the participant to assign the PCM adequately. The researcher is aware of the potential inaccuracy that might occur in having a low number of participants for the quantitative research. However, the AHP technique is not the main quantitative method for this research, and it played a complementary role. Therefore, any potential inaccuracies was closely monitored by the researcher in comparison with the main outcome of the quantitative method, which is an online questionnaire survey. Therefore, two participants each was selected for highway design and highway construction for the AHP. The collected data for the aggregation of individual judgement (AIJ) is analysed to gain the final weight per each indicator.

3.7.5 Application of pairwise analysis

A pairwise comparison within a matrix consists of a rectangular array of real numbers represented mathematically as an upper-case letter '*A*', while the corresponding lowercase letters represent the entries in the matrix, consisting of '*i*' rows and '*j*' columns, with number factors *(a_1, a_2, a_3, $a_4 \ldots a_n$)*. A rectangular array matrix consists of an equal number of rows and columns having order *i x j*. Therefore, considering the matrix row and matrix column have the same number, the matrix is said to have an order of '*n*'. Each entry of number factor a_{ij} into *i x j* matrix '*A*', represents the "more importance" or 'less importance' of factor '*i*' in the row relative to the number factor '*j*' in the column, see Equation 3.0.

$$A = \left[\begin{array}{cc|ccc} & \textit{Column} & j & j & j \\ \textit{Row} & i & a_{11} & a_{12} & a_{1n} \\ & i & a_{21} & a_{22} & a_{2n} \\ & i & a_{n1} & a_{n2} & a_{nn} \end{array} \right]$$

Equation 3.0

In this research, the typographic style is adopted to represent the PCM matrix for highway design and construction for representation only. See below equation 3.1. Each entry in the matrix is represented as *WR* $_{i,\,j}$

A=

	R1	R2	R3	R4	R5
R1	WR1/WRI	WR1/WR2	WR1WR3	WR1/WR4	WR1/WR5
R2	WR2/WR1	WR2/WR2	WR2/WR3	WR2/WR4	WR2/WR5
R3	WR3/WR1	WR3/WR2	WR3/WR3	WR3/WR4	WR3/WR5
R4	WR4/WR1	WR4/WR2	WR4/WR3	WR4/WR4	WR4/WR5
R5	WR5/WR1	WR5/WR2	WR5/WR3	WR5/WR4	WR5/WR5

=

	R1	R2	R3	R4	R5
R1	1	WR1/WR2	WR1WR3	WR1/WR4	WR1/WR5
R2	1/WR1,R2	1	WR2/WR3	WR2/WR4	WR2/WR5
R3	1/WR1,R3	1/WR2,R3	1	WR3/WR4	WR3/WR5
R4	1/WR1,R4	1/WR2R4	1/WR3,R4	1	WR4/WR5
R5	1/WR1,R5	1/WR2,R5	1/WR3,R5	1/WR4,R5	1

Equation 3.1

In the above sample matrix, on the left-hand side is the average ratio of PCM weight assigned by the individual survey participant. According to Saaty and Vargas (2012:3), all the values in the matrix factor values are positive $a_{ij} > 0$ and should fulfil the below requirements; —

$a_{i \times j} = 1$ pairwise values to contribute equally to objectives…… Equation 3.2

$a_{ij} = \frac{1}{a_{ij}} \ (i, j = 1, 2, 3 \ldots . n)$ diagonal Equation 3.3

3.7.6 Computing the geometric mean.

AHP pairwise comparison displays each indicator's level of importance within a matrix frame. This is used to determine the weighting within a matrix. The geometric mean method (GMM) was developed by Saaty (2008). This GMM involves the data collected from the questionnaire pairwise comparison survey tabulated using the geometric mean method of individual judgement. Below are the steps utilised to determine the geometric method; —

The initial step involves the multiplication of every value in each row of the pairwise comparison matrix, adding the $1/n^{th}$ (which *'n'* signifies the total number per row) needed to obtain total values per row. The multiplication is achieved using the below formula; —

$\mathbf{Mi} = \prod_{i=1}^{n} a_{ij} \ (i = 1, 2 \ldots \ldots n)$ Equation 3.4

Where: —

- Π =This is pi, the product of values in a PCM rows
- n = total number of values per each row of PCM
- i = factor values in each row, for instance $(i = 1, 2 \ldots \ldots n)$
- j = factor values in each column, for instance (j =1,2……n)
- $\frac{1}{n}$ = reciporcal of n is the total number per each row of PCM

Mi denotes the products in a PCM row only, which represents *'i'* values in rows.

Calculate the *n*th root of the above multiplication of PCM in rows: —

$\mathrm{Mi} \ \overline{\mathrm{W}}\mathrm{i} = \sqrt[n]{\mathrm{Mi}}$ Equation 3.5

Where: —

- Mi only represents the products in a PCM row, which represents 'i' in rows.
- $\overline{\mathrm{W}}\mathrm{i}$ denotes the total values achieved after the multiplication of each PCM in rows.
- $\overline{\mathrm{W}}\mathrm{j}$ denotes summation as a column due to normalisation.

To determine the priority vector, the results achieved in the above multiplication of the above pairwise values in each row are divided by the sum of the total rows via the column. This is called the normalisation stage, which is called the weighting.

$$\text{Normalisation} = \frac{\overline{W\iota}}{\sum_{j=1}^{n}\overline{Wj}}\ (i = 1, 2, 3 \dots \dots n) \qquad \text{Equation 3.6}$$

The priority vector is achieved by adding all the results achieved in the division above, which must be equal to 1.00.

3.7.7 Computing AHP acceptance criteria

Considering the participants' pairwise comparison values and ensuring the result is consistent, the final achieved priority vector must satisfy the consistency ratio (CR); —

$$\text{Consistency index (CI)} = \frac{\lambda_{max} - n}{n-1} \qquad \text{Equation 3.7}$$

For instance, lambda is λ_{max}. The total rows divide the summation of the normalisation of each column *'j'* and, '*n*' is the number of total rows considered per sub-criteria.

The Consistency Ratio (CR) is calculated using the below; -

$$\text{Consistency ratio (CR)} = \frac{\text{Consistency Index |(CI)}}{\text{Random Index (RI)}}, \qquad \text{Equation 3.8}$$

The random index (RI) in the above equation is represented in the above equation 3.8 and can be viewed in (Appendix D) where the consistency ratio must be less than CR < 0.10.

3.8 Qualitative interview

Research interviews enabled interviewees to speak to express their thoughts and viewpoints regarding feelings and thoughts about events within their environment (Alshenqeeti, 2014). A research interview allows the interviewer to elicit useful information from the interviewee; the purpose is to identify content supporting in answering research questions (Saunders et al., 2019). Interviews in research enabled participants to openly discuss a topic (Braun and Clarke, 2013; Castleberry and Nolen, 2018). The use of open-ended and semi-structured questions in this research helped to reveal new theories through the experiences, opinions, and suggestions of the participants.

Figure 3.14 is a flow chart of an interview process for this research (see highlighted activities in red rectangle). According to Saunders et al. (2019), there are two distinctive types of interviews, structured and non-standardised. The structured interview is a pre-determined set of identical questions, which is used in collecting quantifiable data, referred to as a quantitative research interview. While a non-standardised interview is supported for qualitative data collection. The interview for this research achieved below following: -

(1) the interviewees at the project level validated the sustainability indicators that emerged from the questionnaire survey (quantitative),

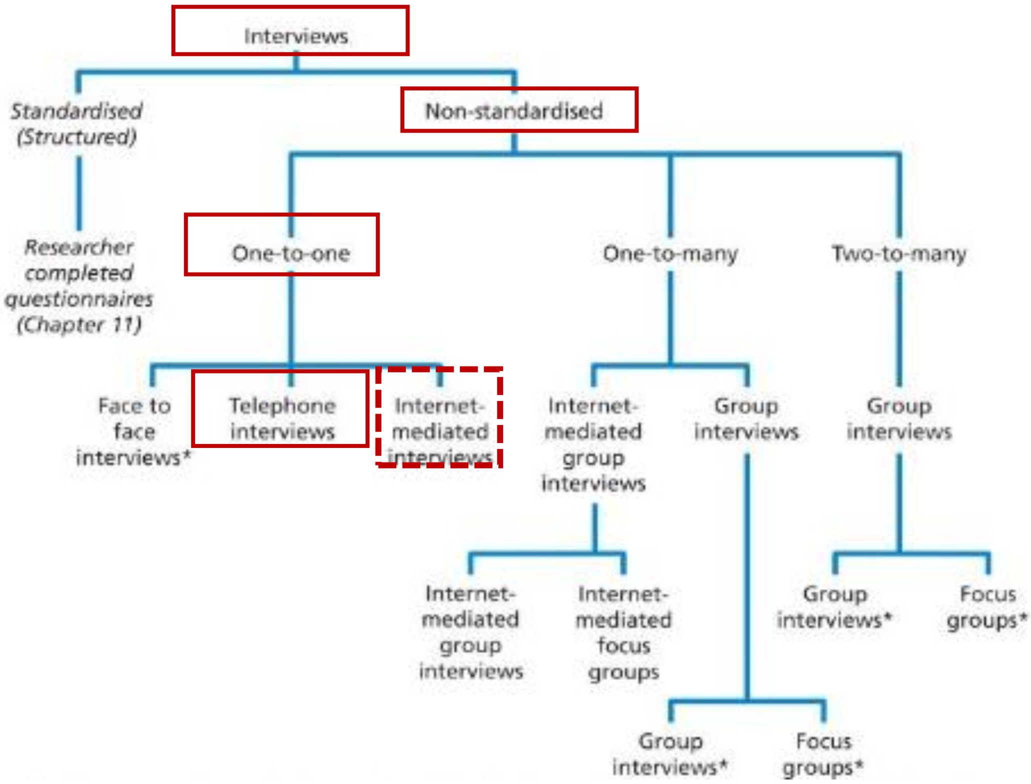
(2) interviewees provided an in-depth insight into sustainability awareness and factors hindering sustainability practices at the project level in Nigeria.

(3) to contextualise the highway design and construction indicators that emerged from an online questionnaire survey.

Therefore, it is optimal for this research to adopt a non-standardised interview process, using semi-structured and open-ended questions to collect data using one-on-one telephone interviews.

At the time the interview process was conducted was the peak of the COVID pandemic, in addition to time constraints and resource accessibility. The use of the online telephone was a much better and safer approach, which was chosen over the use of the face-to-face interview process. In other sectors, the use of telephone and video interviews during Covid pandemic achieved optimal results (Saarijärvi and Bratt, 2021).

Figure 3.14 Interview selection path



Sources: Adapted from Saunders et al., (2019)

During the interview, a digital voice recorder was utilised with the consent of the interviewee to be recorded. The transcribed text was issued to participants for validation.

3.9 Sampling for mixed methods

Figure 3.15 displays the classification of sampling techniques. According to Stratton (2021), in non-random sampling with subsets, namely convenience sampling, the researcher announces the study, and participants self-select if they wish to participate. In purposive sampling, participants are directly selected by the researcher. Quota sampling is the type organised as a street interview, with participants fit to be interviewed. In snowball sampling, the participants are selected by the researcher through recommendations from other participants.

According to Etikan et al. (2015), convenience sampling is the type that targets a population with certain criteria, proximity to geographical location and willingness of the sample population to participate in the interview. Convenience sampling is affordable and easy to implement due to the availability of the interviewee to the interviewer. The sampling strategy (convenience) is not good enough for this research because the inclusion of anybody without related experience will not make any contribution to the data collected.

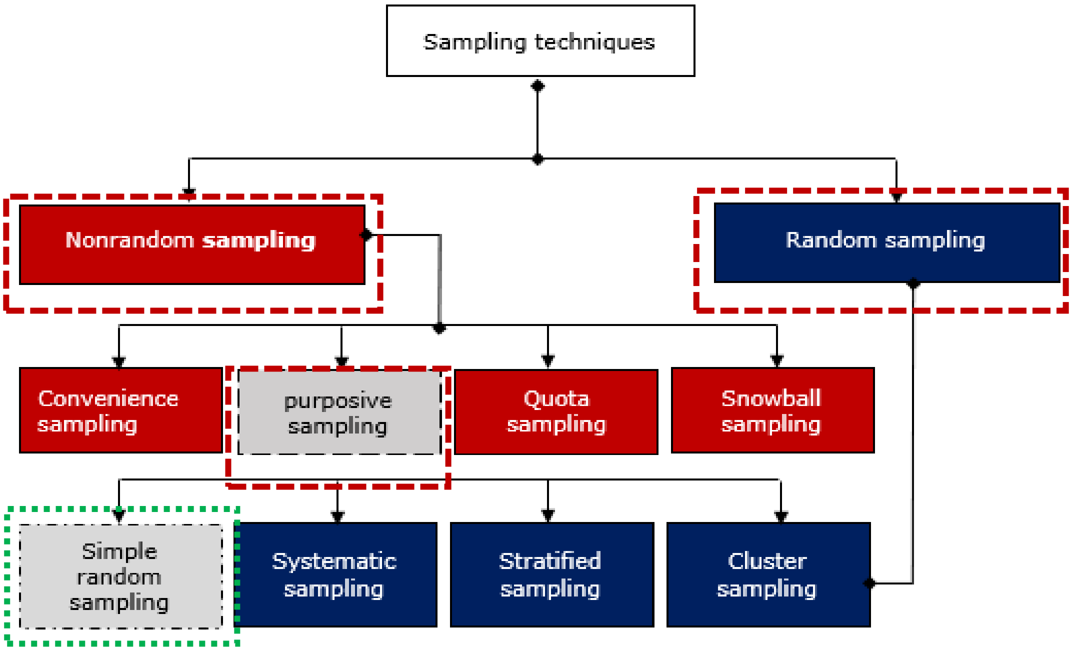


Figure 3.15 Classification of sampling technique

Purposive sampling supported the researcher in identifying individuals who could provide the information needed to answer research questions (Etikan et al., 2015). Patton (2002: 244) stated,— "There are no rules for sample size inquiries" in the qualitative research approach. The logic and power in the selection of purposive sampling are in a bid to gather in-depth information (Saunders et al., 2019). The in-depth, rich information enabled the researcher to focus on a sample population whose members share similar traits and characteristics as regards sustainability development in highway design and construction across Nigeria. The sample population is chosen based on their knowledge and active participation in the development of highway projects. The Nigeria Society of Civil Engineers Office was contacted, and they provided information (seeking participant consent) to be interviewed. Table 3.10 displays types of random and non-random sampling, showing their strengths and weaknesses. Considering the advantages and disadvantages associated with non-random sampling, purposive sampling is selected for this qualitative research approach.

-What informed what to enable achieve research findings are summarised:—

The identified highway development sustainability knowledge gaps across Nigeria in Chapter 2 are summarised in Tables 2.7 and 2.8. In Figure 3.16, what was considered in this research to answer the research questions was to utilise the quantitative method first to enable project participants in Nigeria to assign a Likert scale to the design and construction indicators assigned with values. The purpose is to achieve results using statistical analysis.

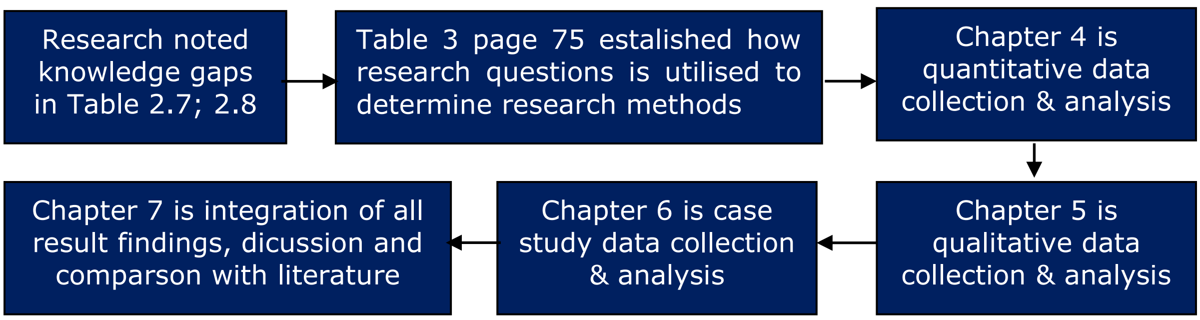


Figure 3.16 How research findings was achieved

The qualitative method was utilised to collect verbal data for thematic analysis to achieve results. The case study was conducted to measure sustainability practices, knowledge and gaps in highway projects in Nigeria. What informed the method selected in the research were the research questions in section 1.4. The findings was achieved through data collection and analysis of quantitative, and qualitative methods and lastly, the project case study. The case study was utilised to measure achieved practices to identify gaps and to bridge the gaps using a decision sustainability sublogic solutions and framework.

Table 3.10 Strengths and weaknesses of sampling techniques

Types of non-random sampling		
Technique	Strength	Weaknesses
Convenience sampling	Least cost and time, the most convenient	The bias in the selected samples might not be representative.
Purposive Sampling (or judgmental sampling)	Low cost, convenient, not time-consuming, ideal for exploratory research design	Variations in attitudes and opinions of the target population are difficult to determine
Quota sampling	Samples are controlled for certain characteristics	Selection bias, no assurance
Snowball sampling	Estimate characteristics, same as purposive sampling in nature	Time-consuming, from small to large samples
Types of random sampling		
Technique	Strength	Weaknesses
Simple sampling	Easily understood, results projectable	Difficult to construe a sampling frame, and expensive.
Systematic sampling	Can increase representativeness, easier to implement	Can decrease representativeness
Stratified sampling	Includes all important subpopulations, precision	Difficult to select relevant stratification variables.
Cluster sampling	Easy to implement, cost-effective	Imprecise, difficult to compute and interpret results

Source: Adapted from Taherdoost (2020)

Table 3.10 displays different types of random sampling, which are suitable for the quantitative approach; the subset consists are; - simple sampling (when a subset of the population is randomly selected), systematic sampling(the researcher selects a sample population at regular intervals from an alphabetical list), stratified sampling (sample population is divided into race, age, or gender), cluster sampling (when a researcher divide the population samples into a cluster to reflect entire population).

According to Sharma (2017), for simple random sampling, each population has an equal chance of being selected to participate in the quantitative data collection. This helped to ensure adequate representativeness of the population samples. For the quantitative data collection, simple random sampling is proposed for the current research. Simple random sampling is utilized to select a subset population from the Nigerian highway design and construction participants across Nigeria. Simple random sampling provided the opportunity for equal chances of sampling project-level participants from the list of the Nigerian Association of Civil Engineers (these participants were involved in design and construction development).

Berndt (2020) identified that systematic sampling is selecting every 5th or 10th person in a sample population list. The sampling method is easier to conduct by selecting an even number of interviewees from the list of the sample population. The drawback associated with systematic sampling is that the essential sample population might be systematically omitted because of the random selection process. This sampling method is not adequate for current research because a significant sample population that should make contributions might be omitted.

Wang and Cheng (2020) identified that in stratified sampling, the population to be sampled is divided into a non-overlapping group, for instance, using age, race, or gender to categorise the sample population. This type of sampling technique uses the attributes and characteristics in selecting the samples. According to Sharma (2017), stratified sampling drawback occurs when the sample subgroups are disjointed and not properly partitioned. The stratified sampling technique cannot be utilised in this research, considering that project-level participants in highway design and construction projects are not separate entities but are collaborative.

In cluster sampling, according to Berndt (2020), the naturally occurring sample population are selected in groups of clusters; this is highly economical and feasible in dealing with a large population size. In this sampling technique, simple random samples of clusters are selected in units rather than individually (Wang and Cheng, 2020). The challenge associated with cluster sampling is that if the selected cluster group have a biased opinion, then the result is affected, which is a major disadvantage of cluster sampling (Sharma, 2017). Therefore, this sampling method is not adequate for current research, considering that selecting clusters of biased and different intolerant groups will not contribute to answering the research questions.

Below is the sampling population formula utilised to determine the quantitative method using "simple random sampling" of project-level participants in Nigeria for the online questionnaire survey.

Sample size (*n*) is determined using the below formula: -

$\boldsymbol{n}$ = [z^2 * p(1-p)] / e^2 / 1+ [z^2 * p(1-p)] /e^2 * N] Equation 3.9

Where; —

$\boldsymbol{n}$ = sample size, and *N* = overall sample population.

z = 1.96 confidence level (α) of 95%, please refer to Appendix 'I'.

p = proportion of population selecting a given choice (%), 50% = 0.05

e = margin of error (%) output of a sample population reflects the overall population

The above summarised is a simple random sampling approach applied to determine sample survey participants. The sample size participating during the online survey is the total number targeted to complete the survey process.

The margin of error, measured in percentage, reveals the outputs of a sample population, which is a reflection of an entire overall population. A smaller margin of error results gives more accurate answers. On a Likert scale, 45% sample agree with option 'A', with a margin of error of ± 5%. Therefore the researcher is confident that if the entire population are asked the same question, there is a confidence level that 50%= (45 + 5) and 40% =(45 – 5) would agree with option 'A' (*theoretically*).

The confidence level expressed in percentage describes the extent the researcher is sure the responses received are the representation of the targeted sample population. The confidence level is the frequency of how true the sample population would select responses to be within the confidence interval. Therefore, for this research, a 95% confidence level is selected to sample project-level participants; even if this survey is conducted 100 times, the survey will yield the exact results 95 times out of these 100 times survey. It also means that there is a 95% confidence level that 50% to 40% of the total sample population will agree with option 'A' as stated under the margin of error above.

3.9.1 Data analysis strategy

Data analysis is a systematic process of inspecting, cleansing, transforming, and modelling collected data to find valuable information in resolving a phenomenon or problem (Islam, 2020). Data analysis involves evaluating collected raw data using analytical methods to answer research questions and to make contributions to knowledge (Zhang, 2018). The purpose of data analysis in this research is to analyze the collected data by drawing inferences to gain knowledge and insight on how to achieve the aim of the research in developing a highway sustainability rating system and indicator decision sub-logics.

3.9.2 Reliability and validity

For collected data to achieve meaningful insight, it is significant to check the consistency, reliability and validity of data using standard research instruments (Alshenqeete, 2014; Strang, 2015; Creswell and Creswell, 2018).

The reliability approach is utilised for quantitative data to measure internal consistency. For instance, to assess and measure the attributes of the data collected across the questionnaires, Statistical Package for Social Science (SPSS) is utilized for the analyses. After coding the datasets in SPSS software, Cronbach Alpha is utilised to measure the reliability of the data, and the acceptance criteria is that the dataset should not have values less than 0.700 (Pallant, 2020).

For the qualitative, the validity approach is utilised. A statement of qualitative validity indicates that the researcher checks the accuracy of the data by employing certain procedures (Alshenqeete, 2014). Validity in qualitative research can be verified using the "Triangulation" of different data sources of information or by examining evidence and justification to build a coherent theme (Strang, 2015).

There are different types of tools used in checking qualitative validity, which are "bias clarification", an "expert member checking information", "peer debriefing", and the use of an "external auditor" (Creswell and Creswell, 2018; Saunders, 2019). For this research, member checking is selected for the qualitative data collected. The reason for selecting member checking as a form of validity check is that it provides an opportunity to reaffirm the positions of the project-level participants during the interview. This position reaffirmation includes checking for errors for correction of what might be a wrong interpretation during thematic analysis.

3.9.3 Qualitative data analysis and thematic application

The data analysis allows a researcher to reduce rigorously collected data to a much simpler form to give insights into the findings (Creswell, 2014). Many forms and approaches have been utilised for data analysis and presentation. The types of methods selected for data analysis equally influence the resulting outcome (Fellow and Liu, 2018; Saunders, 2019). The methods used in the qualitative approach are content analysis, grounded theory and thematic analysis; see Table 3.11 for the description, criticism, and inclusion.

Nvivo 20 and Maxqda software are used to analyze the interview using thematic analysis. The NVivo 20 is a residual cloud software made available for researchers at Robert Gordon University, which is used to carry out a thematic analysis of the interview collected data. The aim is to identify emergent themes from the interview data.

The selected qualitative analysis technique is displayed in Table 3.11. The thematic analysis utilised a hierarchy in the form of a coding process to facilitate the data analysis for better interpretation of themes and relationships (Castleberry and Nolen, 2018). According to Kiger and Varpio (2020), thematic analysis is -

1. A flexible method is utilised for qualitative data analysis and can be used within a variety of epistemological orientations.
2. It is a method appropriate to seek an understanding of the collected qualitative dataset.
3. The theme that emerges in forming theory is a result of the data set analysed thematically through coding categorization and theme identification.

Braun and Clarke (2006) stated that thematic analysis is a method seeking to understand themes, experiences, thoughts, and behaviour across data sets. Thematic data analysis is a key analytic tool supported by using software such as MAXQDA and NVIVO (Oliveira et al., 2015).

NVivo 20 computer software package is used for organizing and analysing to gain insight from open-ended and unstructured data collection. The benefits of using NVIVO for the analysis of qualitative datasets are; —

1. for the analysis of unstructured text through a qualitative interview, it played back audio sound so that interview data could be transcribed into text,
2. It helped to develop a mind map strategy along with the interview questions.
3. It performed query analysis to classify word frequencies for better understanding and to gain insight into the collected data.

NVivo is a digital package software that allows the researcher to analyse content like video, images, audio, and video. It also helped to model mind maps needed to create coding and nodes to interpret qualitative data. In this research, NVivo software is used for the importation of the qualitative dataset to develop the nodes, the classification, and analysis to determine word clusters for the emergent themes in helping to answer research questions.

According to Oliveira et al. (2015), the MAXQDA software package is utilised in qualitative data analysis and has below functions; -

1. There is an in-built interface that offers a learning experience for the researcher similar to WINDOWS.
2. The structure of MAXQDA consists of four WINDOWS; these are the interface to extra data, document data, and structure for coding and categorisation.
3. MAXQDA has colour coding creation that enables the user to analyse thematically and to identify emergent themes through word clusters.
4. The MAXQDA is utilised to gain further insight into the word frequency regarding qualitative datasets and to determine trends on the theme that emerged from the interviewees'.

Table 3.11 Data Description and Criticism

Data analytical method	Description and criticism	Challenges and inclusion
Content analysis	Content analysis is an efficient approach utilised to investigate a large amount of recorded data to determine relationships, trends, patterns of words and frequency within a given set of data collected (Vaismorandi et al., 2013). Content analysis is primarily a method utilised in research to distinguish patterns in the form of collected data, oral, written, or visual information, it can be either qualitative or quantitative (Wilson, 2011).	**Challenges; —** Content analysis is time-consuming and labour-intensive, (Wilson, 2011: 178) cited Beck & Manuel, 2004. Content Analysis can increase errors. The disadvantage of this approach is that subjectivity is adopted for implementation.
Grounded theory analysis	Grounded theory has been debated in literature as specifically suitable for research focusing on systematically collecting only data. Critics claimed the interpretation, and analysis can be weakened considering no existing data to compare the findings (Tilki and Taylor, 2014).	Grounded theory is used where little is known about the study area, it assumes that prior information and knowledge are discarded and a new theory is developed (Birks and Mills, 2015). It is time-consuming, and it has been debated that the method is based on data rather than trying to emerge theory from data (Khan, 2014: 224). This method may cut off existing knowledge upon which incremental and consistent knowledge advancement might be missed using grounded theory.
Thematic analysis	This form of data analysis underlined the identification, assessment, and interpretation of data through patterns or themes (Braun and Clarke, 2006). Thematic data analysis is a unique method, and it is multidimensional because it has a variety of methods rather than a singular method (Vaismorandi et al., 2013).	This method of data analysis is adopted for this research because it is well-suited for large data analysis. There is coding reliability due to the flexible and simple data analysis design sequence. The interpretation and theory emergence are supported by data. Thereby this method enables the determination of relationships from the theme determined from the collected data to contribute to the existing body of knowledge.

Sources: Author generated

3.9.4 Triangulation of data

The triangulation of data sources is a means for seeking to combine data to ascertain if findings from one method mutually collaborate with the findings of the other method (Saunders et al., 2019).

Triangulation enhances the accuracy of findings, and below is implemented for this research; -

1. The use of triangulation to measure results achieved from the quantitative approach between the Likert scale results and analytical hierarchy process weighting to confirm or disconfirm outcomes.
2. To triangulate the highway design and construction indicator results with other existing highway sustainability rating systems to determine conformity or variance.
3. The achieved quantitative design and construction indicators results were compared with the qualitative results of this research to ascertain findings from each method.

According to Creswell (2014: 269), the key assumption of this approach (triangulation of quantitative and qualitative) is that both data provided different types of information. The different type of information considered for triangulation in this research is data from the participants, such as AHP achieved values, the level of opinion measured quantitatively on a Likert scale and qualitative interview of participants on sustainability in Nigerian highway projects.

Figure 3.17 displayed four types of triangulation design; the sequential explanatory design option was selected for this research. The use of 'triangulation design' (refer to the rectangular shape highlighted in red in Figure 3.16), is most suitable because it involves the triangulation of quantitative and qualitative data only.

The use of triangulation design is suitable where mixed-method quantitative and qualitative data are collected in the same phase so that the data can be compared to see where they converge or diverge in addressing research questions (Saunders, 2019; p.799). The benefit considered here is to utilise triangulation design to confirm the credibility of research data, trustworthiness, analysis, and interpretations (Renz et al.,2018; Saunders et al., (2019).

Triangulation helped decrease bias by providing multiple perspectives of the subject under study.

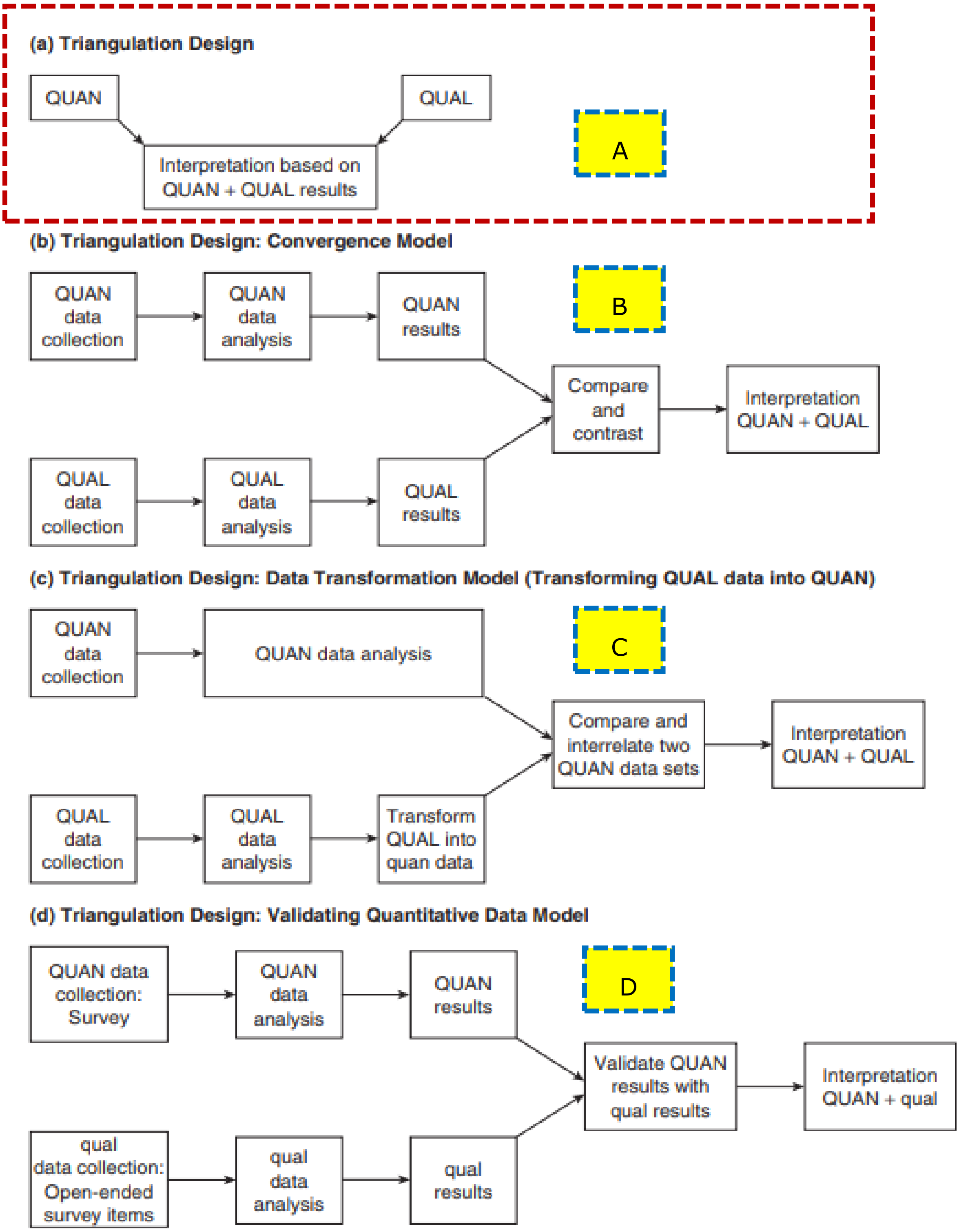


Figure 3.17 Four variants of triangulation design **Source:** Adapted Creswell 2006

The "triangulation design in 3.17'A' is selected due to the justification provided in the previous paragraph. The other three triangulation design variants in 3.17 B to D are not considered because the research design option is a sequential explanatory mixed design approach for the quantitative approach first and the qualitative approach second.

3.9.4.1 Triangulation data analysis – a mixed method

According to Creswell (2014:269), triangulation of data between quantitative and qualitative can assume any form. While qualitative is associated with instruments such as interviews, observation, and documents. The quantitative data is related to numeric and statistics. The key concept of triangulation is to use the same construct to seek answers from different instruments.

Finally, the following triangulation comparison supported to achieve research results; —

1. The AHP weighting results were compared to determine the correlation of achieved results among the selected project-level participants.
2. The Likert scale opinion level of the design and construction indicators compared with the results from AHP weighting values to determine if the findings confirmed or disconfirmed each distinct method and results achieved.
3. The outcome of quantitative results between the correlation of the Likert scale and AHP results compared with existing sustainable highway rating systems globally.
4. The thematic contents of the qualitative interview were compared with the quantitative results to find underlying relationships.
5. The outcome of the results (quantitative and qualitative) was implemented for verification using the project case study (please find the project case studies procedure in the next section, 3.10).

3.10 Case studies

A case study is considered an in-depth study of an event, community, or group. This is to learn as much as possible about the subject (Yin, 2009). The use of a case study allowed the researcher the opportunity to collect focused needed information. Flyvberg (2011) pointed out that case studies are intensive, which comprise more details, richness, in-depth, and completeness to understand development factors and strings of interrelated events that occur over time.

The objective of a case study is to gain insight into how things work and why the subject worked in a way. A better way of understanding a case study is to observe to determine the interaction of how things work differently and under distinct conditions (Dubois and Gadde, 2002). Case study findings are used for generalisation over several units, and it helped understand complex phenomena within a natural setting to gain in-depth data (Heale and Twycross, 2017). In the setting of case study-related investigations, there are certain probing keywords very common in gaining in-depth insight into the subject under investigation (Yin, 2009; Flyvberg, 2011).

Table 3.12 Situations for different research methods

Methods	**Form of research questions**	**Requires control of behavioural events**	**Focuses on contemporary events**
Experiment	How, why?	Yes	Yes
Survey	Who, What, Where, How many, how much?	No	Yes/No
Archival analysis	Who, What, Where, How many, How much?	No	Yes/No
History	How, Why?	No	No
Case study	How, Why?	No	Yes

Adapted from Source Yin (2009) cited COSMOS Corporation.

Table 3.12 outlined three basic conditions required for the control of case study-related investigation (refer to highlighted red rectangle). The use of "how" and "why" related questions is more of an 'explanatory' finding. The interpretation is finding out why and how something happened (Mills et al., 2010). The third column is the extent the researcher has control over behavioural events, but in this research, behavioural content is not required. The focus of this case study is on a contemporary event, which is a need for the research to grasp in-depth information on the current trends of events under investigation. This research focused on investigating trends happening in Nigerian highway design and construction projects to measure best practices and sustainability knowledge gaps using the design and construction indicators developed in this research.

3.10.1 Types of case studies

Debates and disagreements exist on the types of case studies and the implementation approaches (Yin, 2009; Flyvbjerg, 2011; Starman, 2014; George, 2018). Yin (2009) identified four different types of case studies integrated into two distinct groups, namely; -

(1) Embedded and holistic case studies, and

(2) Multiple and single case studies.

The embedded case study involves the use of several units of investigation within the same institution, for instance, a collection of investigations of different departments within an institution; Yin (2009) called it a case study of a sub-unit. A holistic case study is associated when the investigator or researcher focuses on the entire investigation of a system wholly.

In multiple case studies, the researcher conducts an in-depth analysis of several cases. According to Hunziker and Blankenagel (2021:176), multiple case study is conducted to solve problems that a single case study cannot solve. So multiple case study involves investigating to compare the cases (Starman, 2013:33). A Single case study is utilised where comprehensive information is required (Wynsberghe and Khan, 2007; Starman, 2013; Hunziker and Blankenagel, 2021:176). According to Saunder et al. (2019: 199), the implementation of multiple case studies is not likely to produce data evidence similar to the single case study. This is because the approach is different, and the range of data collected is based on the research questions guiding the case study between multiple and simple case studies.

While the positions of these authors remained unified across different types of case studies (Starman, 2014; George, 2018). The position of Flyvbjerg (2011) within the case study took a different turn in pointing out drawbacks associated with a case study. For instance, his argument points to the generalisation in the use of a single case study, which falls short of making contributions to the body of knowledge. To mitigate this area identified from the literature, this research adopted multiple case studies to investigate Nigerian highway design and construction sustainability practices. The aim was to conduct face-to-face interview case studies to compare findings to determine the level of sustainability gaps in Nigerian highway design and construction projects. This helped to identify knowledge gaps on sustainability implementations and missed best practices within these projects and to formulate a valid theory (Shakir, 2002). The achieved results from the case studies contributed to developing a highway sustainability framework see Figure 3.18.

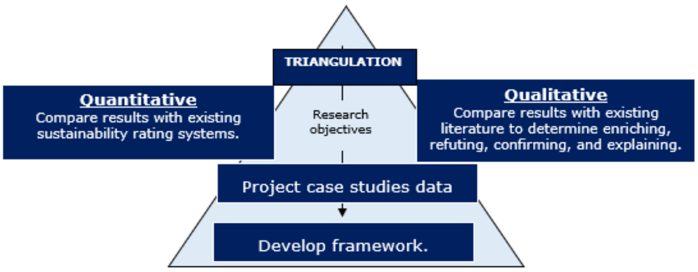


Figure 3.18 Triangulation concepts for current research

The benefit of multiple case studies is that first, it enables the investigation of individual cases, then later combines the results to find similarities and differences (Hunziker and Blankenagel, 2021:181). This comparison provided a robust outcome that might not have been achieved using a single research case study.

In brief, the justification for adopting to implementing multiple case studies is based on the following: — (1) The multiple case studies provided opportunities to examine the practical and theoretical underpinning of best practices leading to a comparison, (2) The case studies provided the opportunity to identify the usefulness of the created highway design and construction indicators required in answering research questions.

A case study arises systematically using a logical flowchart to portray the process of the project case studies under investigation. Figure 3.19 displayed case study investigation processes. Mills et al. (2010) suggest that the flow chart helps researchers to stay focused and alert to new possibilities. The use of saturation was utilised to determine when the data collection limit was achieved.

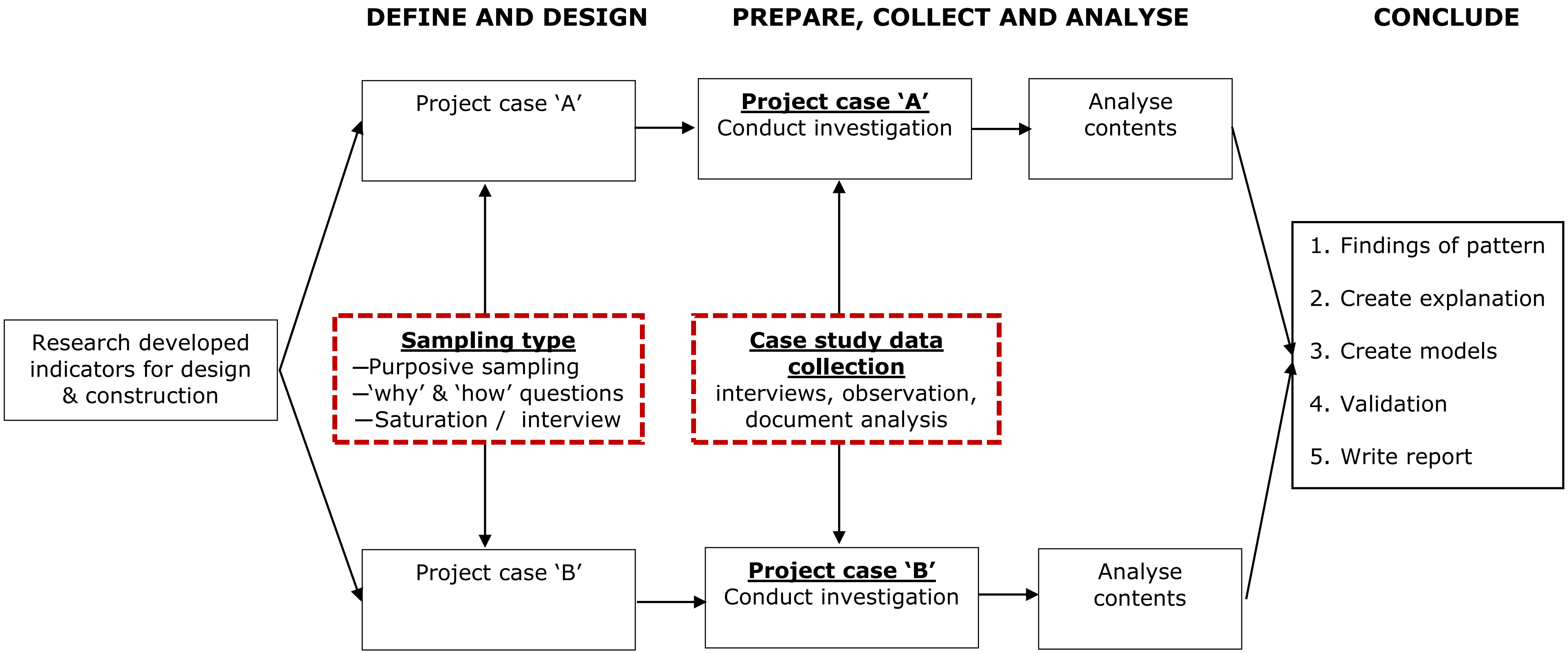


Figure 3.19 Multiple project case study process **Sources:** adapted from Mills et (2010), and Yin, (2009)

3.11 Ethical considerations

According to Saunders et al. (2019), the research process is approved and guided by the rules established by the research ethics committee's code of conduct. This research scope, purpose and implementation are guided by the 'Research Ethics Policy' of Robert Gordon University. The contents of the Research Ethics Policy are the various standards and requirements needed to protect the individuals, groups, and others whom the researcher will interact with during the research process.

Research ethics encouraged the researcher to adhere to best practices. The research ethics enabled the researcher to be aware of the law and due diligence needed to be undertaken during research to minimise risk. The contents of the ethical research consideration ensured all research undertaken at Robert Gordon University protected the rights of those who engaged or are linked to the research.

During the process of this research, the researcher took measures and steps before carrying out any research activities. The researcher considered evaluating if there are potential risks posed to the participants and how the identified risks will be removed or mitigated. Official consent letters from Robert Gordon University was sent to the participants seeking their permission to participate in the research survey, interview, and project case study. The contents of the consent letter outlined the role the participants played during the data collection, such as their expectation of data contributions and information to support the research.

Participants are made aware that they have the right to withdraw before or during the research interview or survey process in case they do not feel comfortable. Creswell (2014:132) stated that ethical considerations are very important to protect research participants from harm, ensure that trust is developed, promote integrity, guard against misconduct and cope with new challenges. During the research process, the researcher ensured that academic considerations focused on maintaining research quality and displayed competence to advance in the field of highway sustainability development. (See Appendix B for an extract of the ethical research information).

3.12 Chapter summary

This chapter describes the underlying principles supporting the research philosophy, method, methodology and the various stages of the research process. This research philosophy employed is based on axiology, epistemology, and ontology (within a mixed-method approach). The axiology focused on the moral belief of the researcher to be impartial, curious, and diligent in adopting legitimate knowledge, tools, and adequate research design in conducting this research. Epistemological research takes into consideration past pertinent knowledge across literature, methodologies, data collection approach and contributions made to knowledge in the past. Ontology shaped ways for the researcher to be objective in examining data within the context of true versus false and real versus imagined.

Positivism and constructivism are the branches of research philosophy considered. This gave rise to the use of mixed methods, comprising quantitative and qualitative, and consideration given to this method is that—it mitigated weakness in the use of a single research strategy. This is the justification for this research, considering that sustainability for highways is still evolving. Accordingly, the use of the mixed method helped to gain a blend of qualitative and quantitative data insight for analysis. The tools and techniques used in collecting data for this research are a questionnaire survey for quantitative and an interview for qualitative. The analytical tool for the data involved the use of SPSS to verify quantitative data reliability. The interview data analysis used NVivo and Maxqda software. Both result outcomes, qualitative and quantitative, are utilised to assess highway development practices in the form of a project case study in Nigeria.

The next, Chapter 4, is quantitative data analysis and results.

CHAPTER 4 – QUANTITATIVE ANALYSIS AND RESULTS

4.1 Introduction

This chapter builds upon research-established strategies outlined in Figure 3.3 of Chapter 3 to answer the research questions. This chapter presented;- (1) thematically categorised highway design and construction indicators that emerged from Chapter 2 literature review, (2) the opinion data survey collected from global respondents working on highway projects regarding sustainable construction strategies utilised on a global scale, (3) the opinion data survey collected from respondents working in Nigeria's highway design and construction sectors, and (4) the Likert scale results triangulation with AHP weighting results, (5) triangulation of results between AHP and Likert scale, and (6) Triangulation of 36 design and 53 construction indicator results with existing highway rating systems.

4.2 Preliminary target highway indicators

The identified preliminary indicators are classified into major areas determined to reduce the adverse impacts of unsustainable highway development in Nigeria. These indicators for design and construction are thematically presented in Tables 4.1 and 4.2. The preliminary target indicators are classified into distinct categories. For highway design, namely, technical, environmental, economic, and social factors. For highway construction, namely, social, environmental, economic, project management, engineering, and health safety factors. The classified categories of indicators for highway design and construction emerged from the literature.

Table 4.1 Primary category of initial target sustainability indicators for highway design

SN°	Category	Subcategory	Number of indicators
A	Technical	R1 – R11	11
B	Environmental	R12 – R27	16
C	Economic	R28 - R31	4
D	Social	R32 – R36	5
Total indicators for sustainable design			36

Table 4.2 Primary category of initial target sustainability indicators for highway construction

SN°	Category	Subcategory	Number of indicators
E	Social	S1 – S6	6
F	Environmental	S7 – S30	24
G	Economic	S31 – S33	3
H	Project management	S34 – S43	10
I	Engineering	S44 - S49	6
J	Health and Safety	S50 – S53	4
Total Indicators for sustainable construction			53

These identified preliminary target sustainability indicators are utilised to issue an online questionnaire survey to Nigerian project-level participants. Similarly, another online questionnaire survey was issued to project-level participants globally to elicit their inputs in assigning Likert scale values of 1-5 to determine preference for the indicators on sustainability strategies utilised in highway projects.

Tables 4.3 and 4.4 display the indicators and their reference codes for highway design and construction, respectively.

Table 4.3 Design sustainability target indicators

SNO	Preliminary highway sustainability design indicators	Code reference
	A: TECHNICAL INDICATORS	
1	Traffic volume count	R1
2	Speed limit	R2
3	Topographical terrain analysis	R3
4	Stopping sight distance	R4
5	The safe radius of the curve in the highway	R5
6	Safe superelevation	R6
7	Profile and vertical curve	R7
8	Safe cross-section and geometric elements	R8
9	Catchment basin for stormwater	R9
10	Sustainable, flexible pavement design	R10
11	Culverts, gull pots and stormwater	R11
	(Total 11 indicators for this category)	
	B: ENVIRONMENTAL INDICATORS	
12	Reduce habitat fragmentation due to alignment	R12
13	Impact on farmland and habitat	R13
14	Ecological connectivity	R14
15	Enhanced air quality	R15

16	Watershed restoration	R16
17	Climate preparedness and resilience	R17
18	Renewable energy use	R18
19	Avoid groundwater pollution	R19
20	Reduce greenhouse gas emission	R20
21	Material design reuse	R21
22	Highway sound barrier wall	R22
23	Eliminate environmental pollution	R23
24	Long-life design	R24
25	Runoff flow control	R25
26	Smart infrastructure	R26
27	Measurement and verification	R27
	(Total 16 indicators for this category)	
	C: ECONOMIC INDICATORS	
28	Lifecycle cost analysis	R28
29	Cost-benefit ratio	R29
30	Return on investment	R30
31	Innovative ideas	R31
	(Total 4 indicators for this category)	
	D: SOCIAL INDICATORS	
32	Community and stakeholders 'engagement	R32
33	Intermodal connectivity	R33
34	Travel time reduction	R34
35	Protect cultural & natural heritage	R35
36	Serviceability	R36
	(Total 5 indicators for this category)	

Table 4.4 Construction sustainability target indicators

SNO	Preliminary highway sustainability construction indicators	Code reference
	E. SOCIAL INDICATORS	
1	Community engagement and context-sensitive solution	S1
2	Travel time reduction	S2
3	Protect cultural and natural heritage	S3
4	Access to the cyclist and pedestrian / Equity accessibility	S4
5	Travel rest areas and recreational parks	S5
6	Scenic views	S6
	(Total 6 indicators for this category)	
	F: ENVIRONMENTAL INDICATORS	
7	Highway connectivity across communities	S7
8	Avoid contamination of the substrata	S8
9	Avoid climate catastrophe	S9
10	Ecological protection	S10
11	Erosion control	S11
12	Maintain vegetation cover	S12
13	Stormwater facility	S13
14	Protect wetland	S14

15	Environmental Impact Assessment	S15
16	Promote recycling from construction	S16
17	Reduction of GHG emissions due to construction	S17
18	Protection of flora and fauna habitat	S18
19	Protect biodiversity and landscape	S19
20	Site Remediation	S20
21	Restore site topography	S21
22	Reuse topsoil clearing and grubbing	S22
23	Avoid impact on agricultural land	S23
24	Noise control from equipment and tools	S24
25	Reduce use, and recycle wastewater	S25
26	Pollution prevention management	S26
27	Protect catchment environment	S27
28	Habitat protection	S28
29	Water run-off control	S29
30	Surface water run-off	S30
	(Total 24 indicators for this category)	
	G: ECONOMIC INDICATORS	
31	Life cycle cost analysis	S31
32	Return on investment	S32
33	Cost-benefit ratio analysis	S33
	(Total 3 indicators for this category)	
	H: PROJECT MANAGEMENT INDICATORS	
34	Material quality process and testing	S34
35	Engage with the supply chain	S35
36	Innovation implementation	S36
37	Value Engineering	S37
38	Construction project governance	S38
39	Early stakeholders' involvement	S39
40	Training and collaboration	S40
41	Use of BIM and new technological advance strategy	S41
42	Sustainability incentive in contract delivery	S42
43	Construction audit across development phases	S43
	(Total 10 indicators for this category)	
	I: ENGINEERING INDICATORS	
44	Design for long-life pavement	S44
45	Operational efficiency	S45
46	The durability of asphalt pavement construction	S46
47	Quality process and procedures	S47
48	Sustainable material sourcing and processing	S48
48	Resiliency	S49
	(Total 6 indicators for this category)	
	J: SAFETY AND HEALTH INDICATORS	
50	Manage hazardous construction materials	S50
51	Safe rideability pavement surface and alignment	S51
52	A sustainable safety management plan	S52
53	Safety training and auditing	S53
	(Total 4 indicators for this category)	

4.2.1 Sample population and questionnaire survey

Ahmad and Halim (2017) identified that sample population selection is important, both for economic reasons and adequate for data collection. For instance, an oversized sample population is a waste of resources. In contrast, an undersized sample population resulted in underachieved data. This research sample population for the questionnaire survey was established at a 5% margin of error and a 95% confidence level for the population. The sample population was accessed from the Nigerian Institution of Civil Engineers Membership website. To extend an invitation to all the registered Nigerian civil engineers is practically impossible and economically not viable.

A 5% margin of error with a 95% confidence level is applied using the below formula in equation 3.9 from Chapter 3. A total sample size population of 255 for highway construction was achieved, and 124 sample population for highway design was pre-determined, both from the website of the Nigerian Institution of Civil Engineers Membership website. To ensure the required level of work experience is considered, 5 years of experience and above is applied, and the final sample population selected were 100 respondents for highway construction and 33 respondents for highway design.

Sample size $'\boldsymbol{n}'$ is determined using the below formula: -

$\boldsymbol{n} = [z^2 * p(1-p)] / e^2 / 1+ [z^2 * p(1-p)] /e^2 * N]$ from Equation 3.9

The questionnaires were prepared using an online application called Google forms, which has a dashboard to examine incoming data in real-time. The data for the questionnaire survey were collected (see Appendix 'C') according to the below timeframe; —

1. Data regarding highway sustainability strategies received between July – August 2022.
2. Data for highway design indicators received between April – May 2021.
3. Data for highway construction indicators received between February – March 2022.
4. The analytical hierarchy process (AHP) pairwise comparison matrix was collected in 2022.

4.3 Results of highway sustainability strategies

To achieve this research objective 1, an online questionnaire survey was sent to project-level participants working on highway construction projects globally. The aim was for participants to express their opinions regarding the presented 17 sustainability strategies identified during the literature review in Chapter 2. Participants targeted for this survey were professionals, and specialists involved in the development of highway construction, both in contracting and governmental transportation agencies globally.

A total of thirty online questionnaire surveys were sent out to target participants in July 2022, and the cut-off date for the survey was August 2022. A total of 22 valid responses were received, making it a 73% response rate (22 responses / 30 issued questionnaires). Response rates are essential to improve the validity of the questionnaire survey (Phillips et al., 2016).

a) Results summary of the participants' job roles revealed civil engineers are 45.5%. Project directors and construction engineers are 4.55% each. Project managers and construction managers are 9.09% each. Others consisting of site supervisors, designers and site agents comprised 27.27% respectively. In summary, a total of 22 project-level participants offered different levels of opinion regarding the 17 presented highway construction sustainability strategies.
b) The participants' country of origin summaries are the United Kingdom (22.73%), Qatar (22.73%), Canada (4.55%), India (4.55%), United States (4.55%), Australia (4.55%), Nigeria (18.18%), and Ghana (18.18%).
c) To measure the total number of project-level participants involved in decision-making in sustainable highway projects. A total of 54.55% agree they are involved in decision-making related to sustainable highway development. While 40.91% selected 'No', and 4.55% are unsure if they have made decisions in sustainable highway projects.
d) Participants' years of experience in the development of highway projects revealed that 0 – 5 years are the highest, with 52.38%. The second highest is 11 – 20 years with 23.81%, and the lowest is 6 – 10 years with 9.52%.
e) To measure the project-level participants' awareness using sustainability concepts. Findings revealed that 40.91% are fully aware of sustainability concepts in the project. A total of 13.64% stated they are unaware of

sustainability concepts in a project. And 45.45% are moderately aware of sustainability concepts in highway construction projects.

Statement	1=Not significant	2=Low significant	3=Significant	4=High significance	5=Very high significance	Overall
Sustainable procurement	2 9.52%	1 4.76%	8 38.1%	3 14.29%	7 33.33%	21 100%
Sustainable design	1 5.56%	0 0%	4 22.22%	6 33.33%	7 38.89%	18 100%
Innovative construction processes	1 5.56%	1 5.56%	3 16.67%	4 22.22%	9 50%	18 100%
Continuous professional development	1 5.88%	2 11.76%	1 5.88%	5 29.41%	8 47.06%	17 100%
Climate change adaptation	1 5.26%	1 5.26%	4 21.05%	6 31.58%	7 36.84%	19 100%
Reduce consumption of resources	2 11.11%	0 0%	1 5.56%	7 38.89%	8 44.44%	18 100%
Protect biodiversity	1 5.26%	2 10.53%	3 15.79%	4 21.05%	9 47.37%	19 100%
Recycle waste and reuse	2 11.76%	0 0%	2 11.76%	4 23.53%	9 52.94%	17 100%
Use renewable energy	1 5.56%	3 16.67%	1 5.56%	5 27.78%	8 44.44%	18 100%
Avoid pollution/ground water and air	2 12.5%	0 0%	1 6.25%	3 18.75%	10 62.5%	16 100%
Life cost analysis	1 5.56%	0 0%	4 22.22%	6 33.33%	7 38.89%	18 100%
Context sensitive analysis	1 5.56%	1 5.56%	6 33.33%	5 27.78%	5 27.78%	18 100%
Governance in projects	2 11.11%	1 5.56%	4 22.22%	2 11.11%	9 50%	18 100%
Use of BIM and technological advancement	1 5.56%	2 11.11%	4 22.22%	3 16.67%	8 44.44%	18 100%
Sustainable safety management plan	1 5.88%	2 11.76%	0 0%	4 23.53%	10 58.82%	17 100%
Sustainable social considerations	1 5.88%	0 0%	5 29.41%	4 23.53%	7 41.18%	17 100%
Use of construction materials with least adverse impact on society	1 6.25%	1 6.25%	2 12.5%	5 31.25%	7 43.75%	16 100%

Min Max

Figure 4.1 Heatmap participants' level of opinion with sustainability strategy

f) Figure 4.1 is the heatmap, showing project participants' level of opinion for the 17 highway sustainability strategies assigned values using a 1–5 Likert scale. The Likert scale used to measure the 17 highway sustainability strategies are; - 1 = not significant, 2 = low significant, 3 = significant, 4 = high significance and 5 = very high significance.

What stands out in the heatmap display in Figure 4.1 is the dense blue colour between the Likert scale value 3 = significant to 5 = very high significant, which provided insight into the achieved results from average to high-ranking participant level of opinion for the presented 17 highway sustainability strategies.

In Figure 4.1, it is noted that between 1 = not significant and 2 = low significant, the participants that attempted these questions had a minimum of

1 and a maximum of 3, see the light blue colour across the heatmap, which revealed a low level of opinion among the participants.

Although this value is truly insignificant, the identified participants who expressed a low level of opinion towards the 17 sustainability strategies did not accept a universal standard version of sustainability strategies (Purvis et al., 2019).

Figure 4.2 is the graphical representation of the Likert scale results for the 17 highway sustainability strategies, which complements the heatmap in Figure 4.1 for a better illustration.

g) Given the presented 17 sustainability strategies, participants were asked if these strategies are useful for sustainable project development. Results revealed that 85% agree the strategies are useful, and 15% consider the strategies as un-useful.

h) A blank text box was provided for the participants to identify additional sustainability strategies. The identified strategies are stated below; —

1. Use of low-temperature asphalt materials/use of cheaper / sustainable raw materials/
2. Reduce afforestation during construction/
3. Recycle waste and reduction of virgin raw materials/
4. use of a rating system / and
5. use of reclaimed asphalt pavement.

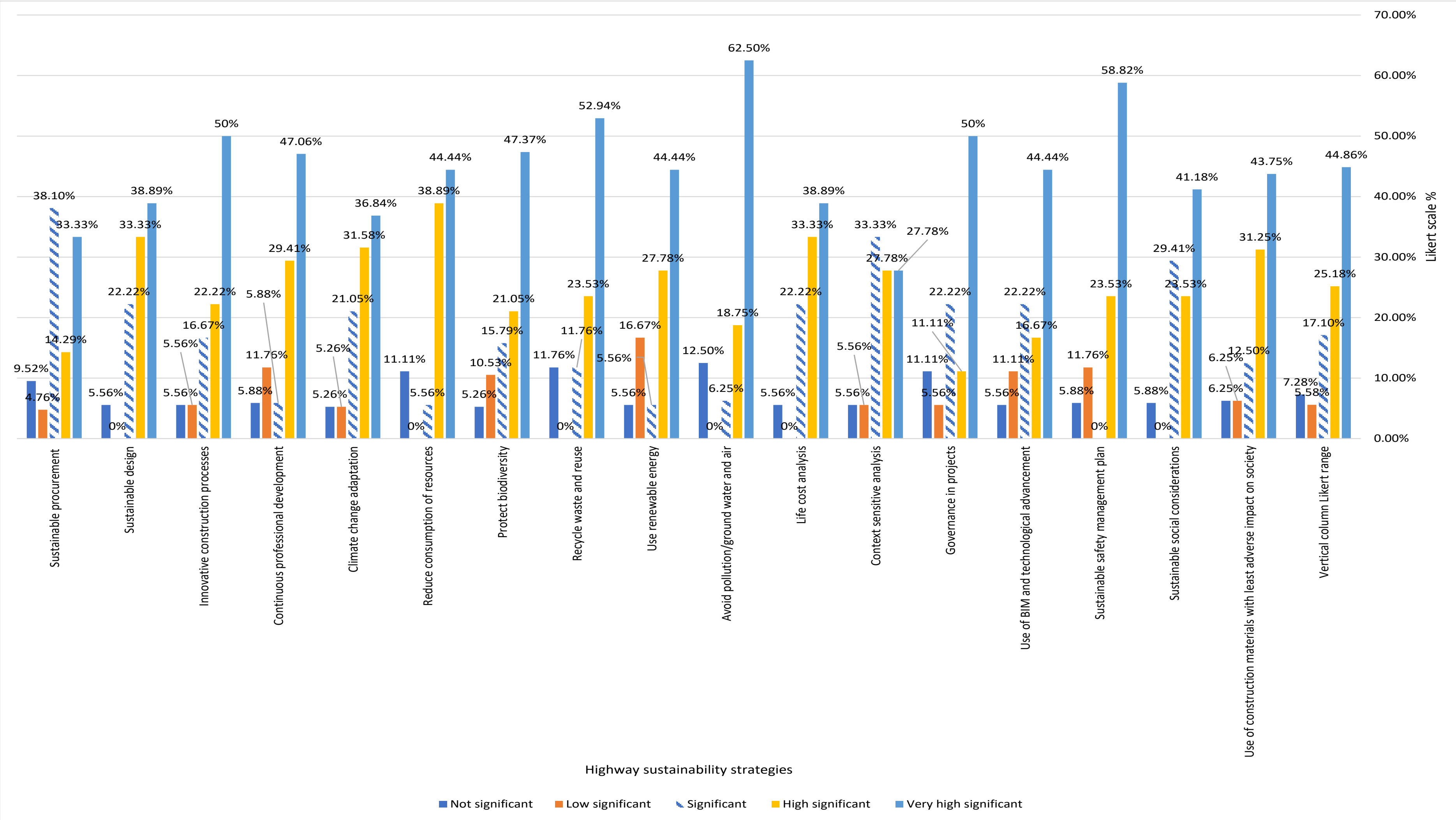
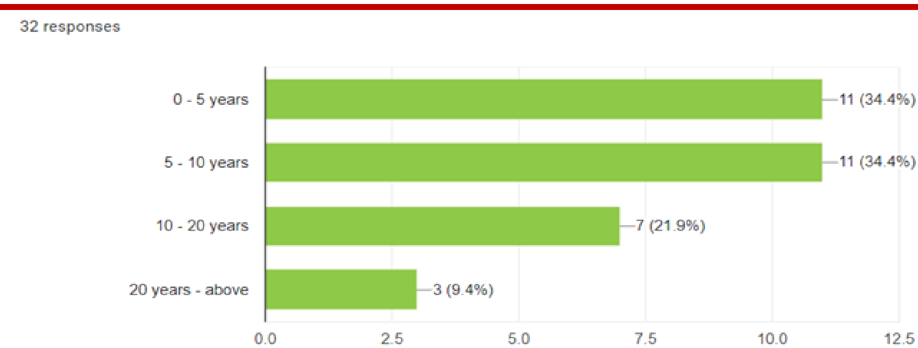


Figure 4.2 Graphical representation of the Likert scale for 17 highway sustainability strategies

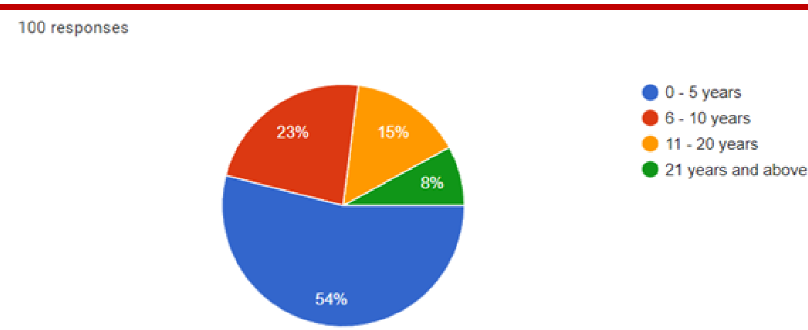
4.4 Survey results- (Design & construction)-PART A

The participants targeted were experts involved in highway development research at the universities located in Lagos, Anambra and Kaduna state, the Nigerian government transportation officials involved in highway development, and civil engineers, both in the private and public sectors across Nigeria. The highway design online questionnaire survey was sent out to the participants in April 2021. A questionnaire survey for highway construction was sent to participants in February 2022. A total of thirty-three valid responses were received from forty issued highway design questionnaire surveys, making it an 83% response rate (33 responses / 40 issued questionnaires). Similarly, for the highway construction questionnaire survey response rate is 80% (100 responses / 125 questionnaires). Figures 4.3 – 4.16 displayed quantitative data for the design and construction sustainability indicators questionnaire survey results.

Q.1 Please specify years of experience.



a. Highway design participants' years of experience

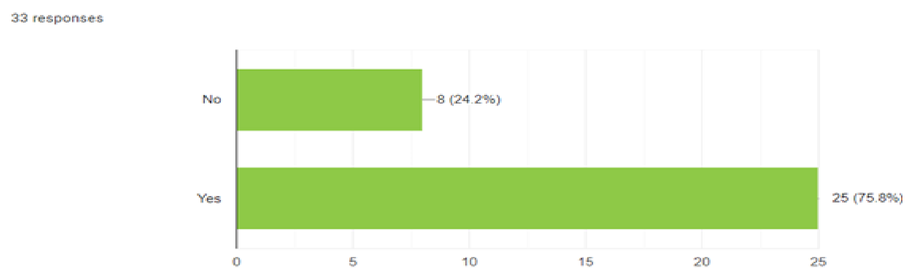


b. Highway construction participants' years of experience

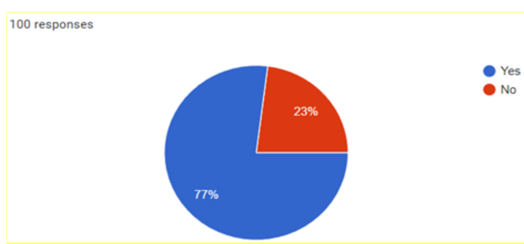
Figure 4.3 Participants' years of experience in design and construction

Figure 4.3 sections ‘a’ and ‘b’ displayed respectively, the participants' years of experience in highway design and construction. The purpose of using different forms of representations such as {‘a’ and ‘b’} is for a broad visual comparison of the respondents' years of experience in highway design and construction. In Figure 4.3, section 'a' for highway design, a total of 32 respondents completed the survey. The years of experience are from 0 – 5 years (34.4%), 6 – 10 years (34.4%), 10 – 20 years (21.9%), and 20 years and above (9.4%). Participants who contributed more to the survey are between 0 – 10 years, totalling (68.8%). While 10 – 20 years are within the medium range, and 20 years and above is the least with 9.4%. In Figure 4.3, section 'b' for highway construction. A total of 100 respondents completed the questionnaire survey. The results revealed 0 – 5 years of experience consist of (54%) which is the highest, 6 – 10 years (23%), 11 – 20 years (15%), and 21 years and above (9.4%). Comparatively, in both design and construction, 20 years of experience and above are within the same range, and other years of experience are noted to be variant.

Q.2 Respond if you are involved in project decision-making.



a. Participants involved in design decisions



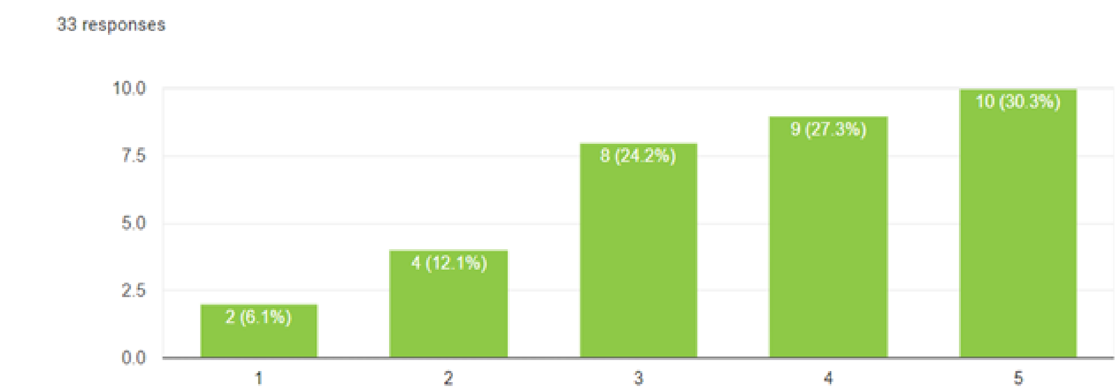
b. Participants involved in construction decisions

Figure 4.4 Participants involved in decision-making.

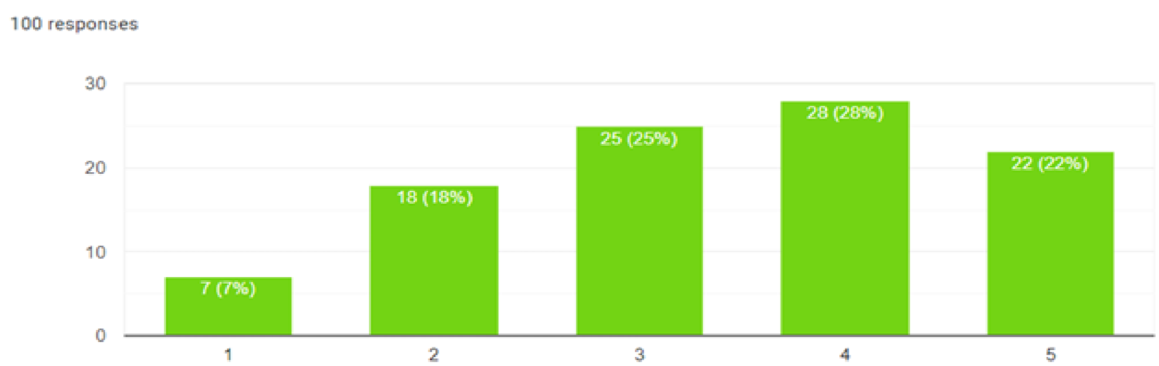
Figure 4.4 section 'a', the percentage of respondents involved in highway decision-making is 75.8% (25 respondents), and 24.2% (8 respondents) expressed they do not get involved during highway design decision-making.

Similarly, in section 'b' of Figure 4.4. A total of 77% (77 respondents) agreed they are involved in highway construction decision-making, and 23% (23 respondents) agreed they do not get involved in highway construction decision-making. A similar trend is noted between 4.4a and 4.4.b.

Q.3 Participants' awareness of sustainability concepts?



a. Participants' sustainability awareness in highway design



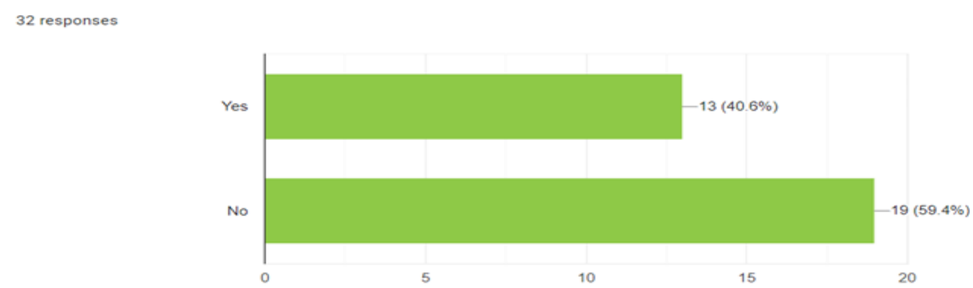
b. Participants' sustainability awareness in highway construction

Figure 4.5 Participants' awareness regarding sustainability concepts

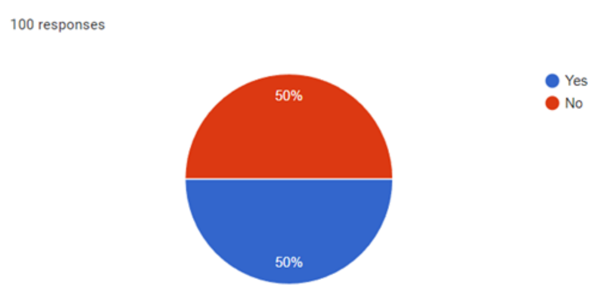
Figure 4.5 displays the responses from respondents when asked about their awareness of using sustainable design and construction tools. In section 'a' Figure 4.5, a total of 81.8% (27 respondents) agree they are aware of sustainability tools in design. This number of values was achieved from the summation of Likert scale values of 3 = significant (8 respondents; 24.2%), 4 = high significant (9 respondents; 27.3%), and 5 = very high significant (10 respondents; 30.3%). It was also noted that 6 respondents, roughly 18.2%, are unaware of sustainable design.

Section 'b' of Figure 4.5 displayed the level of respondents' opinions on sustainability awareness in highway construction. There is a noted high opinion due to the achieved Likert scale value of 75% (75 respondents). Comprising of 3 = significant (25 respondents; 25%), 4 = high significance (28 respondents; 28%), and 5 = very high significance (22 respondents; 22%). Some respondents are unaware of highway construction sustainability concepts, which is 25% (25 respondents). This value was achieved by adding up from 1 = not significant (7 respondents; 7%), 2 =low significant (18 respondents; 18%).

Q.4: Participants' confirmation of sustainability design protocol



a. Participants use of sustainable highway design protocol.



b. Participants use of sustainable highway construction protocol.

Figure 4.6 Participants' use of the sustainable protocol in the highway project

Figure 4.6a represents participants who have utilised a sustainable design protocol in highway projects (13 respondents, at 40.6%), and 4.6b represents participants who have used sustainable construction protocols (50 respondents, at 50%). Likewise, 19 respondents (59.4%) and 50 respondents (50%) have not used highway sustainable design and construction protocols, respectively.

Given the above responses, the respondents were asked to identify the names of the sustainability tools and protocols used during sustainable highway design and construction, respectively. Below are the various identified sustainability protocols by project-level respondents; —

Design

1. Project specification.
2. Design manual / Computer-aided design.
3. AASHTO Design Manual.
4. Nigeria Highway Design Manual.
5. Bridge / Highway / Road Maintenance.
6. Optimization of maintenance and materials.
7. Environmental Impact Assessment.

Construction

1. Environmental Impact Assessment.
2. Reclaimed Asphalt Pavement.
3. Use of recycling process.
4. Value Engineering.
5. Use of highway design standards.

After a careful examination of the above-suggested list by respondents, the majority of the listed items are not related to sustainability in highway development. Only reclaimed asphalt pavement and recycling are more inclined to sustainability considerations. These findings aligned with the study of Coker et al. (2021) that there is a stakeholders' knowledge gap concerning sustainability concepts in Nigeria.

4.4.1 Survey results- (design) – PART B indicators

The second part of the questionnaire survey consists of thirty-six (36) and fifty-three (53) indicators for highway design and highway construction, respectively. The respondents were asked to assign between 1 to 5 Likert scale values across each sustainability indicator.

The aim is to collect data to measure participants' opinions in selecting suitable highway design sustainability indicators needed to reduce unsustainable highway development across Nigeria.

Figure 4.7 displayed respondents' assigned Likert scale opinion for highway design technical indicators from (R1 – R11). What is outstanding in Figure 4.7 is the overall level of opinion, as shown. For instance, significant =3 (grey colour), 4= high significance (yellow colour) and 5 =very high significance (light blue colour). It is evident from Figure 4.7 that the highest level of respondents' opinion level is 66.7% for traffic volume count. A noted 'very high significant' level of opinion for R2, R3, R4, R5, R7, R9, R10, and R11. High significant levels of opinion Likert scale values are R7 (30.3%), R9 (36.4%), and R10 (30.3%), which are middle priority indicators, and R1-R6, R8, and R11 are considered lower priority indicators. The results align with these authors, that technical indicators along three pillars of sustainability are needed for resilient infrastructure development (Hill and Bowen, 1997; Arukala et al., 2019).

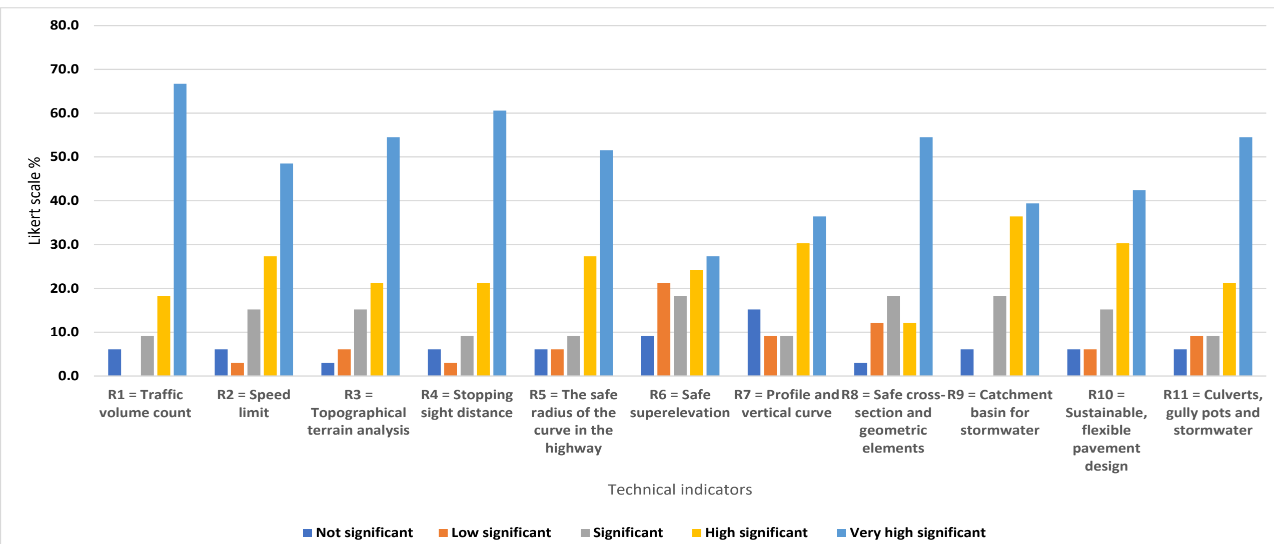


Figure 4.7 Graphical summary of technical indicator Likert scale values(design)

Figure 4.8 displayed environmental indicators for highway design, showing indicators represented with R12 – R27. There are noted responses for 'very high significant' assigned with the Likert scale across R17 (30.3), R19(36.4%), R20(39.4%), R23(39.4%), R24(42.4%), R25(42.4%), and R27(42.4%). There is a mid-range level of opinion both for significant and highly significant indicators, with a range between

(15.2% - 42.4%) and (18.2% - 36.4%) respectively. There are noted 'low' and 'not significant levels of opinion assigned among the respondents.

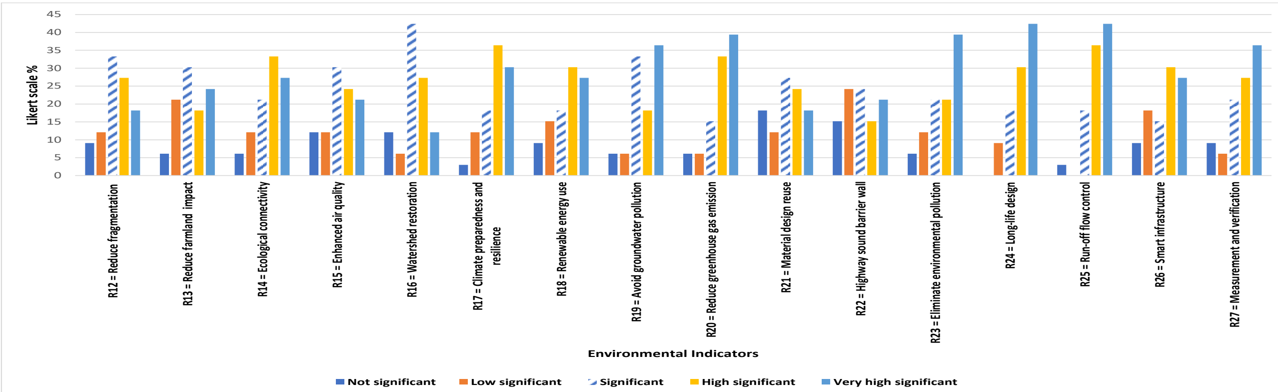


Figure 4.8 Graphical summary environmental indicator Likert scale values (design)

Figure 4.9 displays the economic sustainability indicators from R28 – R31. The blue histogram bar represents the R28 lifecycle cost analysis indicator. R28 was assigned very high significant and high significant values. The significant blue histogram bar is less at 9.1%. R28 is low significant. Also, R29 – R31 achieved a high to low level of opinion.

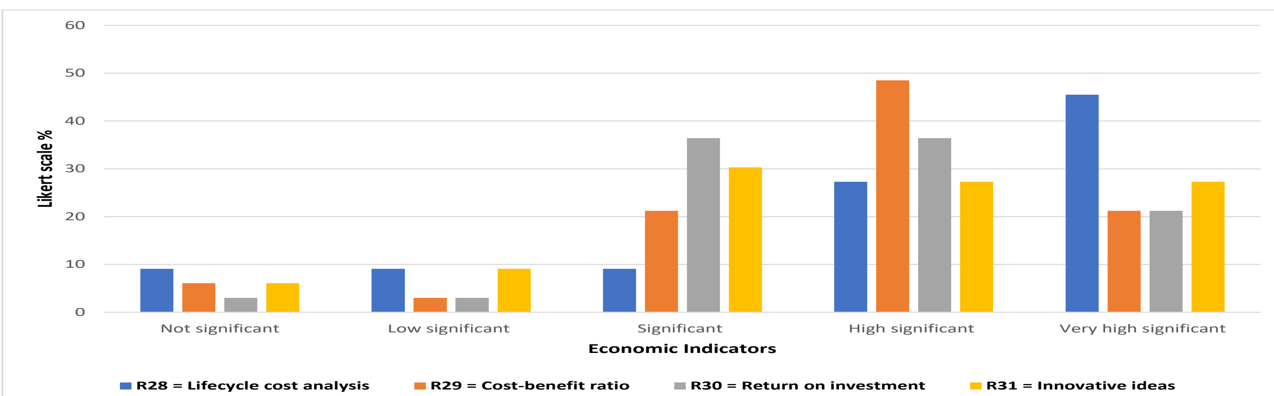


Figure 4.9 Graphical summary economic indicators Likert scale values (design)

Figure 4.10 displayed social sustainability indicators, represented from R32 – R36. Results from Figure 4.10 revealed a high level of assigned opinion for the indicators R32 – R35 across significant, highly significant, and very highly significant. There is also a low level of opinion from the respondents for R32 and R36, which is insignificant considering fewer participants contributed to the answer.

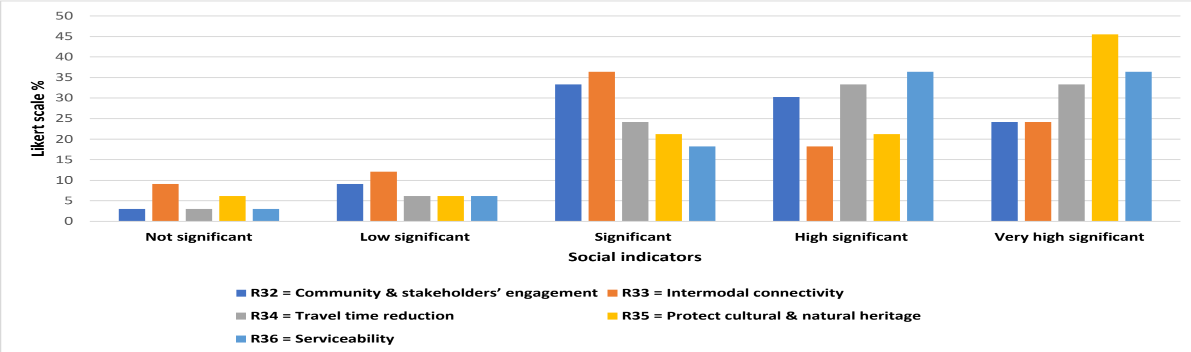


Figure 4.10 Graphical summary social indicator Likert scale values (design)

4.4.2 Results — Sustainability indicators (construction)

There are six different categories of highway construction indicators considered, — social, environmental, economic, project management, engineering and health and safety.

Figure 4.11 displayed the social sustainability indicators (S1 – S6); on average, there is a noted optimal level of opinion considering most indicators were assigned with "high significance", "very high significance", and "significant". Also, a low number of participants selected "not significant" and "low significant" across the entire social indicators, which is insignificant. Generally, within the social indicators, the range of participants' Likert scales can be viewed in the histogram bars in Figure 4.11, which gives an idea of the achieved range of satisfactory values across these indicators S1 - S6.

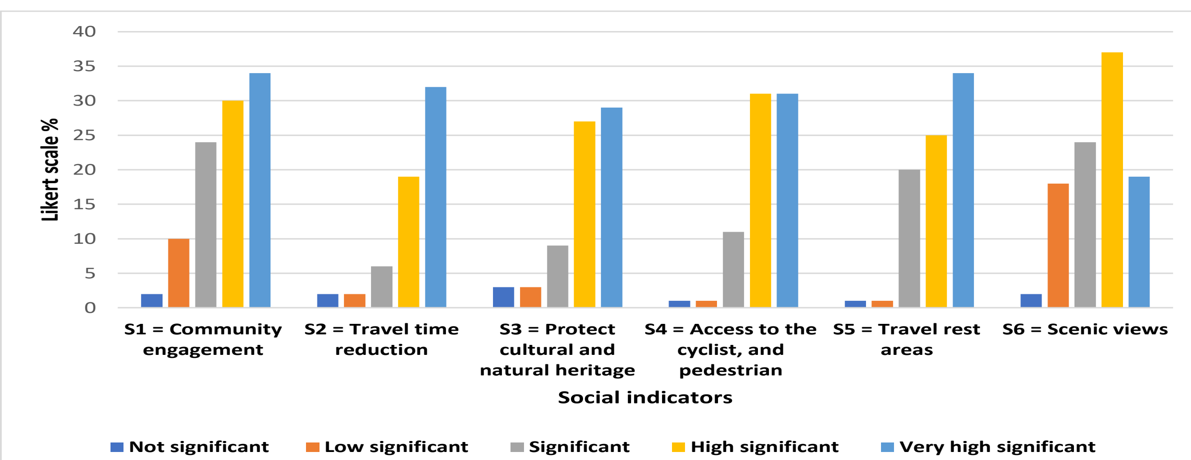


Figure 4.11 Graphical summary social indicator Likert scale values (construction)

Figure 4.12 is the environmental sustainability indicators, S7 – S30. The participants' level of opinion is evident across the "significant", "high significant", and "very high significant" Likert scale. The participants' level of opinion across "not significant" and "low significant" is noted to be minimal.

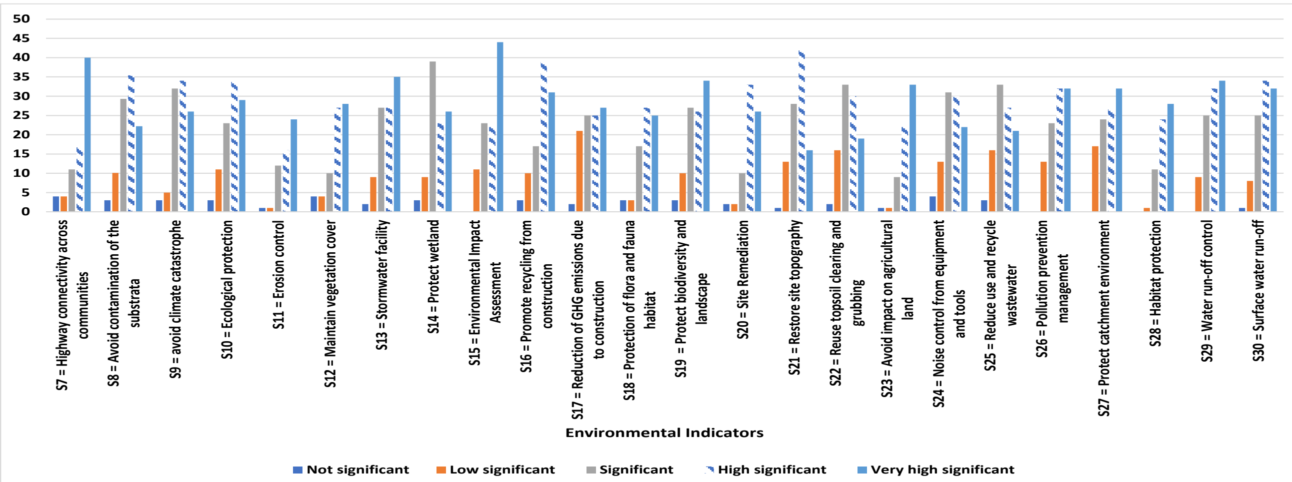


Figure 4.12 Graphical summary environmental indicator Likert scale values (construction)

Figure 4.13 displays the economic indicators from S31 – S33. The Results revealed there is a substantial level of respondents' high level of opinion across "significant", "high significant" and "very high significant" for the indicators. There is also a noted "low opinion" Likert scale value from the respondent, which is presented in below Figure 4.13.

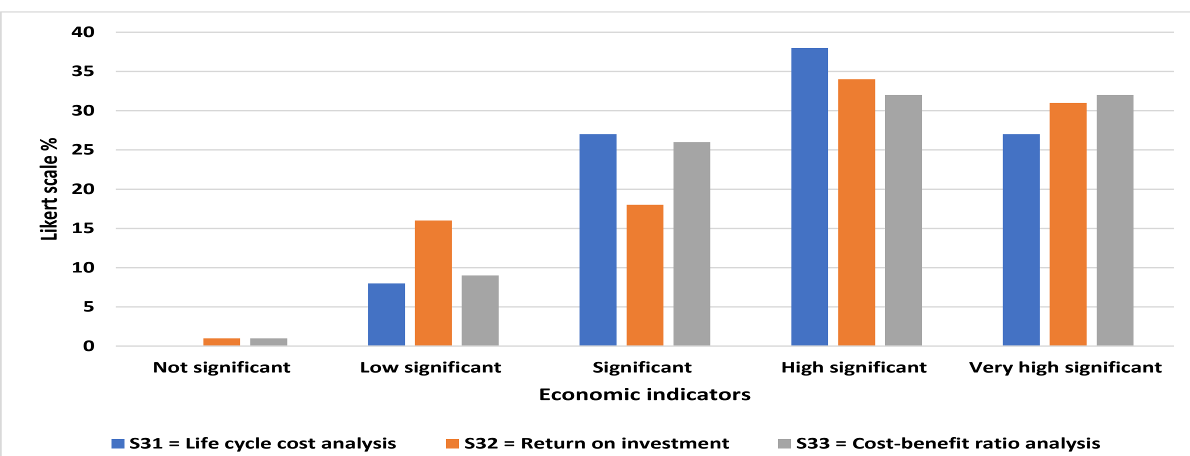


Figure 4.13 Graphical summary economic indicator Likert scale values (construction)

Figure 4.14 represents project management respondents' level of opinion for S34 – S34, S35 and S42. Also, results revealed there is a substantial level of respondents' positive opinions across "significant", "high significant" and "very high significant". Although there are noted "not significant" and "low significant" from the respondents, the most evident is S43, the construction audit, with a value close to 14.48%.

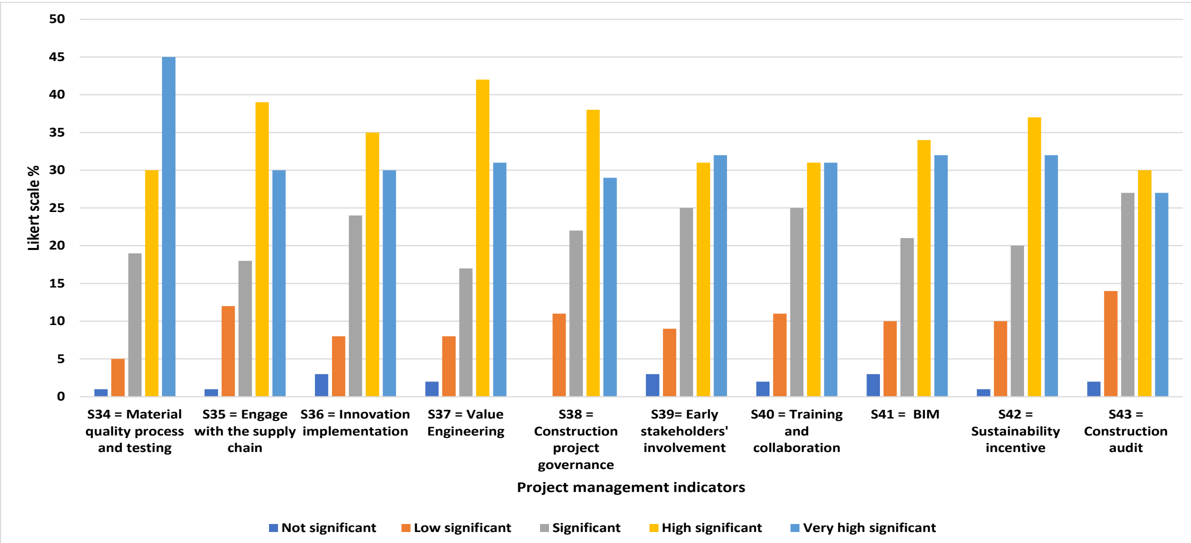


Figure 4.14 Graphical summary project management indicator Likert scale values (construction)

Figure 4.15 presents engineering indicators from S44 – S49. What stands out in the below histogram is the high level of respondents' opinions for the indicators.

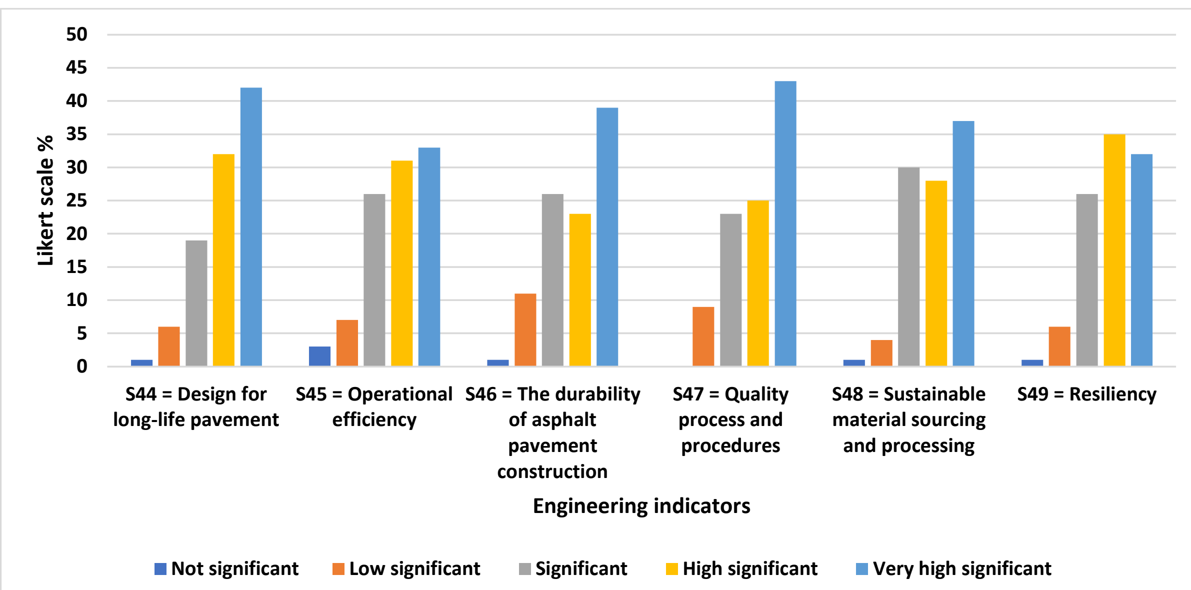


Figure 4.15 Graphical summary engineering indicator Likert scale values (construction)

These high levels of opinion in Figure 4.15 are noted across “significant”, “high significant” and “very high significant”. There is also a noted less significant number of low respondents’ level of opinion across S44 – S49 for “not significant” and “low significant” indicators.

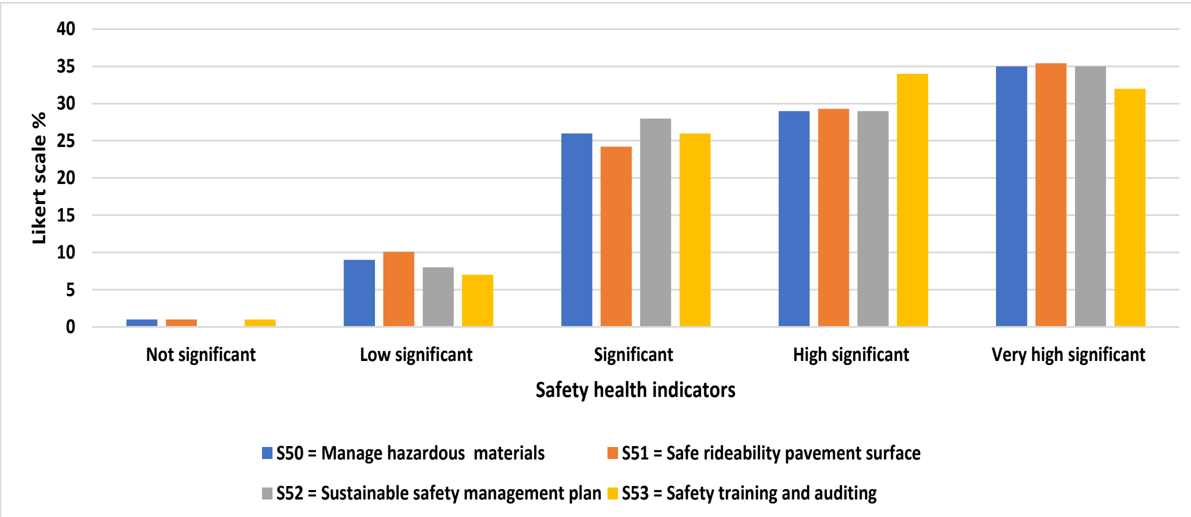


Figure 4.16 Graphical summary safety and health indicator Likert scale values (construction)

Figure 4.16 represents the safety and health indicators represented with S50 – S56. It is evident from the histogram there is a significant level of positive opinion from the respondents across “significant”, “high significant” and “very high significant” Likert scale values. It was also noted from the histogram bars that there is a low level of respondents’ opinion in assigning the Likert scale values to the safety health indicators.

4.4.3 Reliability of collected data.

The reliability analysis of a questionnaire survey represented a stability check against the occurrence of random error from the collected data (Strang, 2015). In quantitative statistical data analysis, Cronbach’s Alpha is used as a measure to determine the internal consistency of collected data sets. A minimum of .7 Cronbach alpha (α=alpha) is an acceptable criterion for measuring data sets’ internal consistency (Pallant, 2020; DeVellis, 2014). The achieved Cronbach alpha for the collected online data is α = .857 and .759, respectively. Therefore, the achieved data is reliable. Please refer to Tables 4.5 and 4.6 for the measured internal consistency quantitative data.

Table 4.5 Case Process Summary and Reliability Statistics (highway design data)

Case Process Summary			
		N	%
Cases	Valid	33	100.0
	Excluded [a]	0	0.0
	Total	33	100.0
a. Listwise deletion based on all variables in the procedure			
Reliability Statistics			
Cronbach's Alpha	Cronbach's Alpha Based on standardized items		N of Items
0.857	0.857		7

N= a Total number of measured samples.

Table 4.6 Case Process Summary and Reliability Statistics (highway construction data)

Case Process Summary			
		N	%
Cases	Valid	53	100.0
	Excluded [a]	0	0.0
	Total	53	100.0
a. Listwise deletion based on all variables in the procedure			
Reliability Statistics			
Cronbach's Alpha	Cronbach's Alpha Based on standardized items		N of Items
0.759	0.759		11

N= a Total number of measured samples.

4.5 Results for analysed pairwise comparison matrix

The aim is to determine sustainability weighting for the indicators using an expert opinion pairwise comparison matrix. Tables 4.7 to 4.8 are the AHP pairwise analysis results for the four participants involved in the survey for highway design and construction indicators, respectively. What is shown in Tables 4.7 and 4.8 are the indicator codes, the indicators, and each AHP indicator results between participants 1 and 2. Tables 4.7 and 4.8 display the consistency ratio (CR) results, and each category of indicators fulfilled the acceptance criteria by Thomas Saaty (1980).

Table 4.7 Aggregation of individual pairwise comparison for highway design AHP

			Priority weighting		
Categories	**Code**	**Indicators**	**Participant -1**	**Participant -2**	**Integrated weighting**
Technical	R1	Traffic volume count	0.092	0.149	0.121
	R2	Speed limit	0.058	0.062	0.060
	R3	Topographical terrain analysis	0.058	0.029	0.044
	R4	Stopping sight distance	0.028	0.041	0.035
	R5	The safe radius of the curve in the highway	0.068	0.086	0.077
	R6	Safe superelevation	0.066	0.078	0.072
	R7	Profile and vertical curve	0.085	0.109	0.097
	R8	Safe cross-section and geometric elements	0.123	0.187	0.155
	R9	Catchment basin for stormwater	0.156	0.122	0.139
	R10	Sustainable, flexible pavement design	0.166	0.068	0.117
	R11	Culverts, gull pots and stormwater	0.098	0.069	0.084
	CONSISTENCY RATIO		**0.085<0.1**	**0.099<0.1**	
Environmental	R12	Reduce habitat fragmentation due to alignment	0.038	0.073	0.056
	R13	Impact on farmland and habitat	0.037	0.081	0.059
	R14	Ecological connectivity	0.093	0.098	0.096
	R15	Enhanced air quality	0.029	0.144	0.087
	R16	Watershed restoration	0.023	0.041	0.032
	R17	Climate preparedness and resilience	0.073	0.035	0.054
	R18	Renewable energy use	0.100	0.051	0.076
	R19	Avoid groundwater pollution	0.113	0.084	0.099
	R20	Reduce greenhouse gas emission	0.090	0.081	0.086

	R21	Material design reuse	0.070	0.029	0.050
	R22	Highway sound barrier wall	0.012	0.029	0.021
	R23	Eliminate environmental pollution	0.096	0.091	0.094
	R24	Long-life design	0.068	0.042	0.055
	R25	Runoff flow control	0.062	0.043	0.053
	R26	Smart infrastructure	0.046	0.035	0.041
	R27	Measurement and verification	0.050	0.043	0.047
	CONSISTENCY RATIO		**0.086<0.1**	**0.081<0.1**	
Economic	R28	Lifecycle cost analysis	0.287	0.186	0.237
	R29	Cost-benefit ratio	0.318	0.245	0.282
	R30	Return on investment	0.241	0.323	0.282
	R31	Innovative ideas	0.154	0.245	0.200
	CONSISTENCY RATIO		**0.055<0.1**	**0.029<0.1**	
Social	R32	Community and stakeholders' engagement	0.224	0.360	0.292
	R33	Intermodal connectivity	0.279	0.162	0.221
	R34	Travel time reduction	0.170	0.120	0.145
	R35	Protect cultural & natural heritage	0.157	0.186	0.172
	R36	Serviceability	0.170	0.172	0.171
	CONSISTENCY RATIO		**0.028<0.1**	**0.083<0.1**	

Table 4.8 Aggregation of individual pairwise comparison for highway construction AHP

			Priority weighting		
Categories	**Code**	**Indicators**	**Participant -1**	**Participant -2**	**Integrated weighting**
Social indicators	S1	Community engagement and context-sensitive solution	0.183	0.121	0.152
	S2	Travel time reduction	0.254	0.187	0.221
	S3	Protect cultural and natural heritage	0.090	0.232	0.161
	S4	Access to the cyclist, and pedestrian / Equity accessibility	0.088	0.074	0.081

	S5	Travel rest areas and recreational parks	0.143	0.143	0.143
	S6	Scenic views	0.242	0.243	0.243
		CONSISTENCY RATIO	**0.088 < 0.1**	**0.085 < 0.1**	
Environmental	S7	Highway connectivity across communities	0.083	0.072	0.078
	S8	Avoid contamination of the substrata	0.097	0.062	0.080
	S9	Avoid climate catastrophe	0.066	0.057	0.062
	S10	Ecological protection	0.053	0.061	0.057
	S11	Erosion control	0.074	0.075	0.075
	S12	Maintain vegetation cover	0.046	0.046	0.046
	S13	Stormwater facility	0.054	0.050	0.052
	S14	Protect wetland	0.040	0.044	0.042
	S15	Environmental Impact Assessment	0.048	0.052	0.050
	S16	Promote recycling from construction	0.019	0.026	0.023
	S17	Reduction of GHG emissions due to construction	0.019	0.023	0.021
	S18	Protection of flora and fauna habitat	0.015	0.020	0.018
	S19	Protect biodiversity and landscape	0.020	0.026	0.023
	S20	Site Remediation	0.042	0.062	0.052
	S21	Restore site topography	0.063	0.080	0.072
	S22	Reuse topsoil clearing and grubbing	0.032	0.035	0.034
	S23	Avoid impact on agricultural land	0.013	0.015	0.014
	S24	Noise control from equipment and tools	0.018	0.019	0.019
	S25	Reduce use, and recycle wastewater	0.039	0.041	0.040
	S26	Pollution prevention management	0.048	0.051	0.050
	S27	Protect catchment environment	0.038	0.039	0.039
	S28	Habitat protection	0.027	0.024	0.026
	S29	Water run-off control	0.021	0.020	0.021
	S30	Surface water run-off	0.025	0.072	0.049
		CONSISTENCY RATIO	**0.1 $\leq$ 0.1**	**0.075 < 0.1**	
Economic	S31	Life cycle cost analysis	0.413	0.260	0.337
	S32	Return on investment	0.327	0.413	0.370

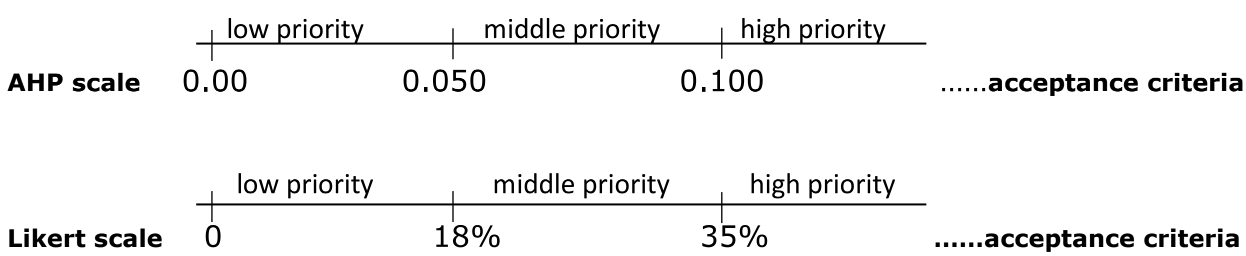
	S33	Cost-benefit ratio analysis	0.260	0.327	0.294
	CONSISTENCY RATIO		**0.051 < 0.1**	**0.051 < 0.1**	
Project management	S34	Material quality process and testing	0.236	0.180	0.208
	S35	Engage with the supply chain	0.154	0.154	0.154
	S36	Innovation implementation	0.112	0.139	0.126
	S37	Value Engineering	0.076	0.079	0.078
	S38	Construction project governance	0.091	0.089	0.090
	S39	Early stakeholders' involvement	0.099	0.081	0.090
	S40	Training and collaboration	0.051	0.065	0.058
	S41	Use of BIM and new technological advance strategy	0.060	0.097	0.079
	S42	Sustainability incentive in contract delivery	0.054	0.059	0.057
	S43	Construction audit across development phases	0.066	0.058	0.062
	CONSISTENCY RATIO		**0.093 < 0.1**	**0.059 < 0.1**	
Engineering	S44	Construct for long-life pavement	0.217	0.126	0.172
	S45	Operational efficiency	0.266	0.282	0.274
	S46	The durability of asphalt pavement construction	0.122	0.178	0.150
	S47	Quality process and procedures	0.193	0.170	0.182
	S48	Sustainable material sourcing and processing	0.075	0.132	0.104
	S49	Resiliency	0.128	0.112	0.120
	CONSISTENCY RATIO		**0.094 < 0.1**	**0.055 < 0.1**	
Safety and health	S50	Manage hazardous construction materials	0.387	0.314	0.351
	S51	Safe rideability pavement surface and alignment	0.238	0.337	0.288
	S52	A sustainable safety management plan	0.174	0.181	0.178
	S53	Safety training and auditing	0.200	0.168	0.184
	CONSISTENCY RATIO		**0.075 < 0.1**	**0.075 < 0.1**	

4.6 Correlation of results between AHP and Likert scale

Presented in this section are the various correlations achieved between quantitative AHP weighting results and Likert scale results. The purpose is to seek to ascertain if the AHP results mutually collaborate with the findings of the Likert scale method. According to Saunders et al. (2019), such measures using triangulation facilitate determining the reliability of the results in answering the research questions. Below are AHP and Likert scale acceptance criteria using a comparison from both techniques to categorise results using low, middle, and high priority ranking.

a) AHP priority criteria; High priority (0.100 and above); Middle priority (0.050 – 0.099); Low priority (0.0 - 0.049).

b) Likert scale priority criteria (High 35% – above), Middle priority (34% – 19%); Low priority (18% – 0%).



Considering the above acceptance criteria listed in (a) and (b), the integrated AHP values and the Likert scale values achieved for each indicator are presented as high-priority, middle-priority, and low-priority indicator ranking. A similar analysis is applied to achieve results across Tables 4.9 – 4.19 for design and construction indicators.

Table 4.9 Technical indicators priority ranking for AHP and Likert scale (design)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	R8, R9, R10	R1, R7, R8, R9		High-priority indicators from the Likert scale	R1, R8, R9, R10	-
middle priority indicators from AHP	R1, R2, R3, R5, R6, R7, R11	R2, R5, R6, R10, R11		Middle priority indicators from the Likert scale	R2, R5, R6, R7, R11	R1-R11
Low-priority indicators from AHP	R4,	R3, R4,		Low-priority indicators from the Likert scale	R3, R4	-

Table 4.9 is technical indicator weighting. In the vertical columns, the blue rectangle contains AHP pairwise comparison values for participants 1 and 2 indicators weighting results, categorised as high, middle, and low priority ranking. The red rectangle in the horizontal row displayed "integrated" AHP participants 1 and 2 high, middle, and low indicators weighting results.

Comparing the AHP results of PA-1 and PA-2, there is no clear correlation. Although both PA-1 and PA-2 have common indicators, which are; - R1, R8, R9, and R10 are high priority, R2, R5, R6, R7, and R11 are the medium priority and R4, and R3 are low priority; therefore, removed as non-essential.

Table 4.9, when AHP integrated results are compared with Likert scale indicators results for technical sustainability, scattered findings are noted. For instance, integrated AHP top priority results for R1, R8, R9, and R10 do not correlate with the Likert scale results of R1 – R11 with middle priority ranking.

The AHP results cannot be relied upon due to the low number of participants taking the survey. The Likert scale results are more promising considering the significant number of participants that contributed to the data (100 for construction and 33 for design).

Table 4.10 Environmental indicators priority ranking for AHP and Likert scale(design)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	R18, R19	R15,		High-priority indicators from the Likert scale	-	-
Middle priority indicators from AHP	R14, R17, R20, R21, R23, R24, R25, R26, R27	R12, R13, R14, R18, R19, R20, R23,		Middle priority indicators from the Likert scale	R12, R13, R14, R15, R17, R18, R19, R20, R21, R23, R24, R25	R12 - R27
Low-priority indicators from AHP	R12, R13, R15, R16 R22,	R17, R21, R22, R24, R25, R26, R27		Low-priority indicators from the Likert scale	R16, R22, R26, R27	-

In Table 4.10, there is no notable result correlation between participants' PA-1 and PA-2. There are a few noted high-priority indicators, such as R18, R19, and R15, for both participants. There is a noted large number of indicators within the middle priorities and low priorities for both participants PA-1 and PA-2.

A few similarities were noted for both participants, PA-1, and PA-2; for instance, within the low priorities is R22, which is common for both.

On the same Table 4.10 is the classification and comparison of integrated AHP weighting values with Likert scale results to determine indicators (e.g., high priority, middle priority, and low priority). It is noted that both integrated AHP values have no high priority and low priority. For the Likert scale, there are no high and low priority indicators, only the middle priority, which has 16 indicators.

Table 4.11 Economic indicators priority ranking for AHP and Likert scale (design)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	R28, R29, R30, R31	R28, R29, R30, R31		High-priority indicators from the Likert scale	R28, R29, R30, R31	-
Medium priority indicators from AHP	-	-		Middle priority indicators from the Likert scale	-	R28, R29, R30, R31
Low-priority indicators from AHP	-	-		Low-priority indicators from the Likert scale	-	-

Table 4.11 there is a noted correlation between AHP weighting for both participants, which is high-priority ranking, namely, R28, R29, R30, and R31. There are no middle or low-priority indicators for both participants, PA-1, and PA-2. Although this is an acceptable result but cannot be utilized considering the low number of participants contributing to the data for PA-1 and PA-2.

Table 4.11 displayed a comparison of integrated AHP weighting values with Likert scale results to determine indicators' high, middle, and low priority ranking. The AHP weighting integrated results achieved top priority indicators, for instance, R28, R29, R30, and R31. In contrast, Likert scale values achieved only middle priority indicators R28, R29, R30, and R31 and low priority indicators for the Likert scale.

Table 4.12 Social indicators priority ranking for AHP and Likert scale (design)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	R32, R33, R34, R35, R36	R32, R33, R34, R35, R36		High-priority indicators from the Likert scale	R32, R33, R34, R35, R36	-
Middle priority indicators from AHP	-	-		Middle priority indicators from the Likert scale	-	R32, R33, R34, R35, R36
Low-priority indicators from AHP	-	-		Low-priority indicators from the Likert scale	-	-

In Table 4.12, there is a noted correlation between AHP weighting for both participants, which are considered top high priorities R32, R33, R34, R35, and R36. There is no middle or low priority for both participants.

Table 4.12 is the comparison of integrated AHP weighting values with Likert scale results to determine indicators of high, middle, and low priority ranking. The AHP weighting achieved top high priority only, with no indicators within the middle and low priority indicators. The Likert scale achieved only middle-priority indicators and non for high and low-priority indicators.

Table 4.13 Social indicators priority ranking for AHP and Likert scale(construction)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	S1 – S6	S1 – S6		High-priority indicators from the Likert scale	S1 – S6	
Middle priority indicators from AHP	-	-		Middle priority indicators from the Likert scale	-	S1 – S6
Low-priority indicators from AHP	-	-		Low-priority indicators from the Likert scale	-	-

Tables 4.13 to 4.19 display the highway construction indicators. Similar trends are noted across Tables 4.13 to 4.19, considering AHP weighting comparisons with participant PA-1 and PA-2, and the outcome displayed no correlation when results are evaluated using high, middle, and low priority level ranking.

Besides, the lack of correlation in the results has been attributed to the low number of participants, which constitutes a limitation for the AHP results. The comparison of AHP-integrated weighing results with the Likert scale showed there is no correlation. The result considered for inclusion is the Likert scale values displayed in Table 4.19.

Table 4.14 Environmental indicators priority ranking for AHP and Likert scale(construction)

Priority values	**PA-1**	**PA-2**		**Priority values**	**Integrated**	**LS**
High-priority indicators from AHP	-	-		High-priority indicators from the Likert scale	-	-
Middle priority indicators from AHP	S7-S11 S13, S21,	S7-S11, S13, S15, S20, S21,		Middle priority indicators from the Likert scale	S7-S11, S13, S15, S20, S21, S26,	S7-S30
Low-priority indicators from AHP	S12, S14-S20, S22-S30	S12, S14, S16-S19, S22-S25, S27-S30		Low-priority indicators from the Likert scale	S12, S14, S16-S19, S22-S25, S27-S30.	-

Table 4.15 Economics indicators priority ranking for AHP and Likert scale(construction)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	S31, S32, S33	S31, S32, S33		High-priority indicators from the Likert scale	S31, S32, S33	-
Middle priority indicators from AHP	-	-		Middle priority indicators from the Likert scale	-	S31, S32, S33
Low-priority indicators from AHP	-	-		Low-priority indicators from the Likert scale	-	-

Table 4.16 Project management indicators priority ranking and Likert scale (construction)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	S34-S36	S34-S36		High-priority indicators from the Likert scale	S34-S36	-
Middle priority indicators from AHP	S37–S43	S37–S43		Middle priority indicators from the Likert scale	S37–S43	S34–S43
Low-priority indicators from AHP	-	-		Low-priority indicators from the Likert scale	-	-

Table 4.17 Engineering indicators priority ranking for AHP and Likert scale(construction)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	S44–S49	S44–S49		High-priority indicators from the Likert scale	S44–S49	-
Middle priority indicators from AHP	-	-		Middle priority indicators from the Likert scale	-	S44-S49
Low-priority indicators from AHP	-	-		Low-priority indicators from the Likert scale	-	-

Table 4.18 Health and safety indicators priority ranking for AHP and Likert scale(construction)

Priority values	PA-1	PA-2		Priority values	Integrated	LS
High-priority indicators from AHP	S50-S53	S50-S53		High-priority indicators from the Likert scale	S50 – S53	-
Middle priority indicators from AHP	-	-		Middle priority indicators from the Likert scale	-	S50-S53
Low-priority indicators from AHP	-	-		Low-priority indicators from the Likert scale	-	-

4.7 Inclusion and exclusion of final indicators

Table 4.19 displayed the final indicators categorized for consideration using acceptance criteria high and middle priority ranking.

Table 4.19 Collective achieved Likert scale ranking for highway design and construction.

Categories	Indicators		Total
	High priority	Middle priority	
Technical indicators (design)	-	R1- R11	11
Environmental (design)	-	R12 – R17	16
Economic (design)	-	R28; R29; R30; R31	4
Social (design)	-	R32 – R36	5
		Total indicators for highway design	**36**
Social (construction)		S1 – S6	6
Environmental (construction)	-	S7- S30	24
Economic (construction)	-	S31 – S33	3
Project management (construction	-	S34 – S43	10
Engineering	-	S44 – S49	6
Health and Safety	-	S50 – S53	4
		Total indicators for highway construction	**53**

****Indicators in above Table 4.19 are utilized for triangulation*

4.8 Triangulation with existing sustainability indicators

Triangulation of the achieved results is tabulated in (Table 4.20), in comparison with existing highway rating systems, namely, BE^{2}ST-in-Highways, Envision, CEEQUAL, GreenLITES, Greenroads, Greenpave and INVEST.

The information displayed in Table 4.20 is the various phases of the existing sustainability rating systems that can be utilised across the highway project lifecycle development. As stated in the literature review (chapter 2), the benefits of the existing rating systems are in a wide range. It is noted that each of the existing sustainability rating systems is engaged in achieving a different method of sustainability across the highway project lifecycle (refer to Table 2.5).

Current research developed a rating system that is useful for the design and construction of highways only. Other rating systems are used at different phases of the highway project lifecycle; see Table 4.20.

Table 4.20 Comparison of highway infrastructure sustainability rating systems

Rating system	Planning & Design	Construction	Operations & Maintenance	Total points	Assessment type
INVEST	X	X	X	631	Voluntary
Green-roads	X	X	-	130	3rd party
Envision	X	X	X	1000	3rd party
Green-LITES	X	X	X	281	Self-certification program
BE^{2}ST-in-Highways	X	-	-	18	Internal / Research
CEEQUAL now BREEAM	X	X	X	5,050	Self-assessment
Current research	X	X	-	89	Proposed as 3rd party

Source; Adapted from Mattinzioli et al., (2020); and Clevenger et al., (2013)

Table 4.21 Structure of highway sustainable rating systems

System	Indicator Categories across primary	Indicators summary	Mandatory indicators	Credits as per total indicator group
CEEQUAL v6	Management	29		550
	Resilience	16		600
	Communication & stakeholders	23		550
	Land use & ecology Landscape & historic	38	Yes	600
	Environment	30		450
	Pollution	20		400
	Resources	73		1451
	Transport	19	Yes	400
	Innovation	2		500
	Total = 9	**250**		**5,050**
ENVISION V3	Quality of life	14		200
	Leadership	12		182
	Resources allocation	14		196
	Natural world	14		232
	Climate & resilience	10		190
	Total = 5	**64**		**1,000**
BE²ST-in-Highways	Pre-requisites	Indicators same as categories	Yes	2
	GHG emission			2
	Energy use			2
	Waste reduction (Ex situ) Waste reduction (In situ)			2
	Water consumption			2
	Hazardous waste			2
	Life cycle cost			2
	Traffic noise			2
	Social carbon cost-saving			2
	Total = 9			**18**
GreenLITES V2.1	Sustainable cities	55		93
	Water quality	12		19
	Material & resources	39		65
	Energy & atmosphere	69		104
	Innovation/Unlisted	3		17
	Total = 5	**178**		**281**
Greenroads v2	Project requirement	12	Yes	
	Environment & water	10		30
	Construction activities	11		20
	Material and design	6		24
	Utility & control	8		20
	Access & Liveability	10		21
	Creativity & effort	4		15
	Total = 5	**61**		**130**
INVEST V_1.3	System planning state	17		250
	Sustainable planning	17		250
	Project, and operation	33		171
	Total = 3	**64**		**631**
GreenPave v2.1	Pavement technology	4		9
	Material & resources	4		11
	Energy & atmosphere	4		8
	Innovation & design	2		4
	Total = 4	**14**		**32**

System	Indicator Categories	Indicators summary	Mandatory indicators	Credits as per total indicator group
	Design			
Current research	Technical	11	Yes	11
	Environmental	16	Yes	16
	Economic	4	Yes	4
	Social	5	Yes	5
	Total = 4	**36**		**36**
	Construction			
	Social	6	Yes	6
	Environmental	24	Yes	24
	Economic	3	Yes	3
	Project management	10	Yes	10
	Engineering	6	Yes	6
	Safety and health	4	Yes	4
		53		**53**

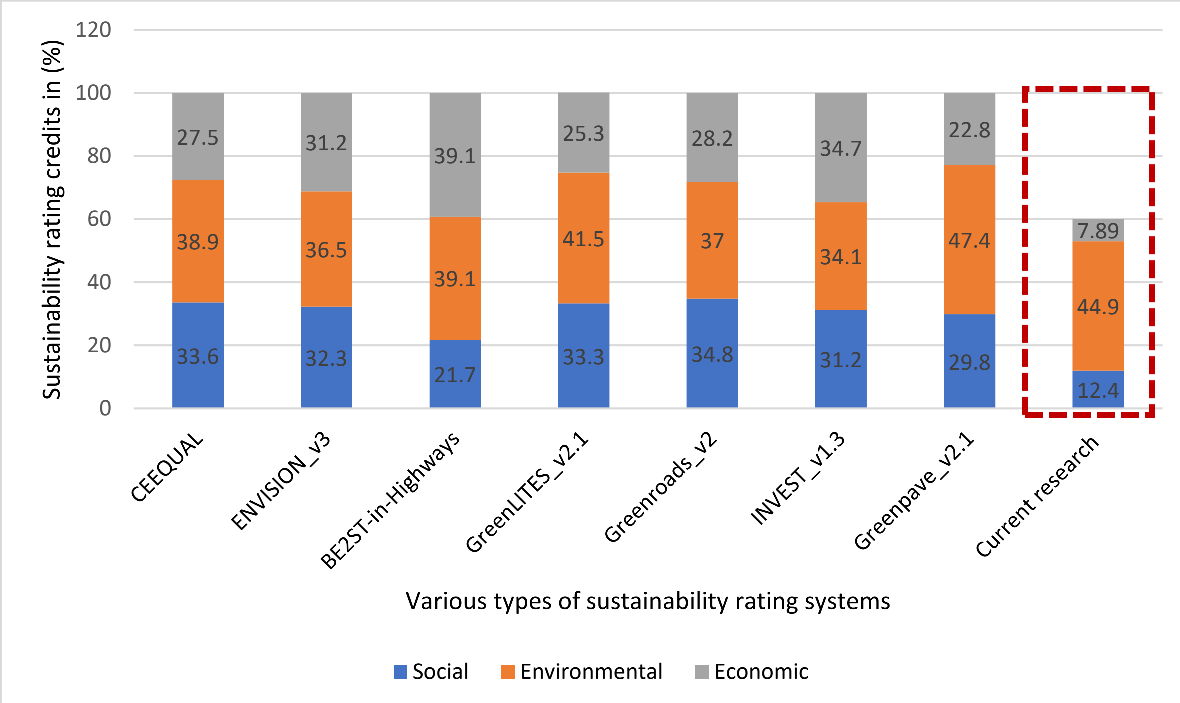
Source: Adapted from Mattinzioli et al., (2020)

Table 4.21 displayed classifications associated with each sustainability rating system. The CEEQUAL rating system has 5050 sustainability credit points. Credit points are best practices required for assessment across different project lifecycles. The reason CEEQUAL sustainability credit has a high number of indicators because it is used to measure sustainability practices across different types of infrastructure development, which is not limited to; - sewers, dams, canals, coastal defence, ports, pipelines, windfarm, and pump stations.

Similarly, other sustainability rating systems, such as ENVISION, INVEST, and GreenLITES, consist of integrated infrastructure facility development alongside highway development. The existing sustainability rating systems assigned each of their indicators between 1-5 credit points. These credit points are awarded based on achieved best practices at the project site. For this research, the indicators are assigned only one credit point per each indicator as a baseline.

Table 4.21 (the red highlighted rectangle) shows credit points for this research-developed sustainability indicator for highway design and construction.

Figure 4.17 Distribution of credits according to three pillars of sustainability

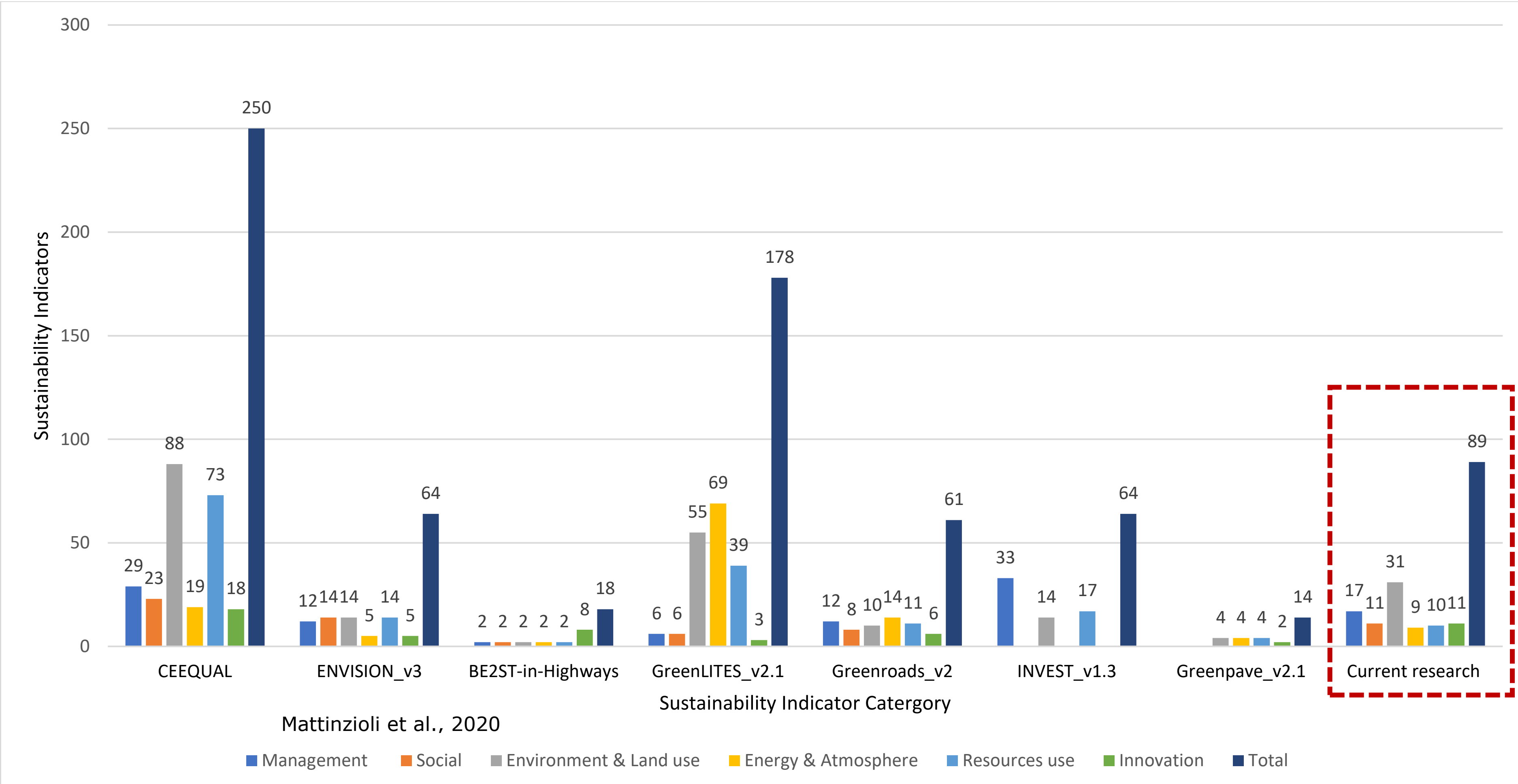


Source: Adapted from Mattinzioli et al., 2020

Figure 4.17 displays three pillars of sustainability, namely social, environmental, and economic, for each of the existing highway sustainability rating systems. Overall, the environmental sustainability consideration is higher across rating systems such as Greenpave, GreenLITES, and this research-developed environmental indicator contributed 44.9 sustainability credit points in reducing unsustainable highway development across Nigeria. It is evident from Figure 4.17 that current research developed economic and social sustainability is fewer in the number of indicators than the other rating systems. The current research developed rating system is what is considered by the project level participants as adequate in reducing the adverse impacts of highway development across Nigeria using three pillars of sustainability, namely social, environmental, and economic (plus technical, engineering, and project management).

To further evaluate highway sustainability indicator results presented in Table 4.21 (refer to the rectangle highlighted in red colour), a comparison is achieved using credit points with other global sustainability rating systems across six major categories.

Figure 4.18 Triangulation graph of existing highway rating systems with current research indicators



4.9 Chapter summary

This chapter discussed the preliminary target indicators achieved for developing a sustainability rating system for Nigeria using a back-casting model. The preliminary sustainability indicators emerged from the back-casting model, which was utilised for online questionnaire survey preparation. These 36 design and 53 construction indicators were selected through the lens of environmental impact due to unsustainable highway development across Nigeria.

Sustainability concepts in highway projects are multi-dimensional and complex. AHP results and Likert scale results were used to determine indicators' high, middle, and low priority ranking. The AHP weighting results displayed fewer correlations considering limitation due to the low number of respondents that participated in the pairwise comparison data collection. The Likert scale results were more consistent with a better correlation considering data contributions from 33 participants for highway design and 100 participants for highway construction. In contrast, the AHP pairwise comparison had only four participants that contributed to the data.

The accepted Likert scale results were categorized into high, middle, and low-priority rating systems, which further was utilized for triangulation using existing highway rating systems to determine the level of contribution in reducing unsustainable highway development when compared with other rating systems globally.

The achieved results revealed that current research indicators are outstanding in sustainability categories based on project-level participant-assigned values. The sustainability rating system acceptability in one country is different in another country. These indicators created for Nigerian highways 36 design and 53 construction indicators are unique in resolving current research-identified problems, as stated in section 1.3 and across the literature review.

CHAPTER 5 – QUALITATIVE ANALYSIS

5.1 Chapter Introduction

This chapter consolidates the outcome of the quantitative results from the previous chapter 4. It is essential to validate the findings from the quantitative results using a qualitative approach (concept of inclusion and exclusion from the interviewees). The qualitative approach is utilised to refine the findings of the indicator results from the quantitative method. And to gain insight into the awareness of sustainability concepts to identify factors influencing the implementation of sustainable highway design and construction across Nigeria.

5.2 Interviewees profile

As earlier outlined in (Section 3.9 and Table 3.10), a purposive sampling approach is adopted in selecting interviewees from Nigeria's highway projects. A total of eleven interviewees for the highway construction sector and four for the highway design were collectively selected. Consent letters were sent to selected interviewees' (refer to Appendix 'A' for a sample consent letter).

Table 5 displays a summary of the interviewees' characteristics. All the interviewees played different roles during highway project development, from the feasibility studies, design phase to the construction and handover of projects. The wide range of interviewees' roles and responsibilities and active participation from past projects across Nigeria contributed to enriching the collected data. This assisted in diving deep into the aspect of gaining information to enable answering the research questions and for the exclusion and inclusion of the indicators. The interview duration ranged from 40 minutes minimum to a maximum of 1 hour.

Table 5 Interviewees lists and characteristics from Nigeria.

SN°	Interviewees designation	Type	Sector	Area
IP-1	Highway Roads Engineer	Client	Designer	Roads/highway
IP-2	Highway Roads Engineer	Client	Construction	Roads/highway
IP-3	Highway Planning Officer	Client	Construction	Roads/highway
IP-4	Emeritus Professor (Roads)	Academic	Research	Roads/highway
IP-5	Project Manager	Private sector	Construction	Roads/highway
IP-6	Construction Manager	Private sector	Construction	Roads/highway
IP-7	Emeritus Professor (Roads)	Academic	Research	Roads/highway
IP-8	Materials Roads Engineer	Private sector	Construction	Roads/highway
IP-9	Senior Environmentalist	Private sector	Designer	Roads/highway
IP-10	Project Director	Private sector	Construction	Roads/highway
IP-11	Stakeholder representative	Community	Construction	Infrastructures
DE-1	Road Design Engineer	Client	Design Unit	Roads/highway
DE-2	Road Design Team Leader	Client	Design Unit	Roads/highway
DE-3	Road Design Engineer	Private	Design Unit	Roads/highway
DE-4	Road Design Engineer	Private	Design Unit	Roads/highway

5.2.1 Interview question and format

The interviews were conducted in May 2022, and this was after the quantitative questionnaire survey data collection and analysis in section 4.4 in Chapter 4. Before each interview, consent letters from Robert Gordon University were sent out to the interviewees in Nigeria. The contents of the letter are a request to participate in the interview to capture expert opinions from relevant sectors of highway developers.

The interview was held remotely using a telephone device. Before the start of each interview, the researcher outlined the purpose of the interview, the objective of the research and the need to collect the data from participants in contributing to knowledge and answering research questions about the highway infrastructure development for Nigeria. The interview questions consist of three areas of focus, see Table 5.1, which gave rise to follow-up questions during the interview (refer to Appendix 'E').

Table 5.1 Interview Questions

Main questions
• Are you aware of the sustainability concept and its application at the project level?
• What are the factors negatively influencing the implementation of sustainability practices in highway design and construction in Nigeria?
• What are the local contents in the form of sustainability indicators needed to reduce the adverse impact of unsustainable development (validation process for the presented quantitative results)?

5.3 Structure of data analysis

Braun and Clark (2006) identify six steps of data analysis, which was adopted for this research.

a. **Steps utilised for qualitative analysis using NVivo —**

Step 1 includes interview data recorded and collected by the researcher from the interviewees using a digital voice recording device. The primary objective at this stage is gathering data and familiarisation with the data collected.

The other focus is to evaluate data collected using thematic analysis to reduce the data for better evaluation. This was achieved with NVivo software. The setup in NVivo enabled the researcher to develop a mind map visualisation, as illustrated in Figures 5.0 and 5.1. This facilitates data visualisation to present a connection between the nodes and the codes across the data considered for analysis. A code within NVivo software is the process of categorizing different data collected from the originator of the information. In this case, the interviewee is assigned a different identification code, such as IP-1 to IP-11, respectively. The node held the coded information. What is created in the mind map in Figure 5 are the various questions raised during the interview, which form part of the epistemology inputs.

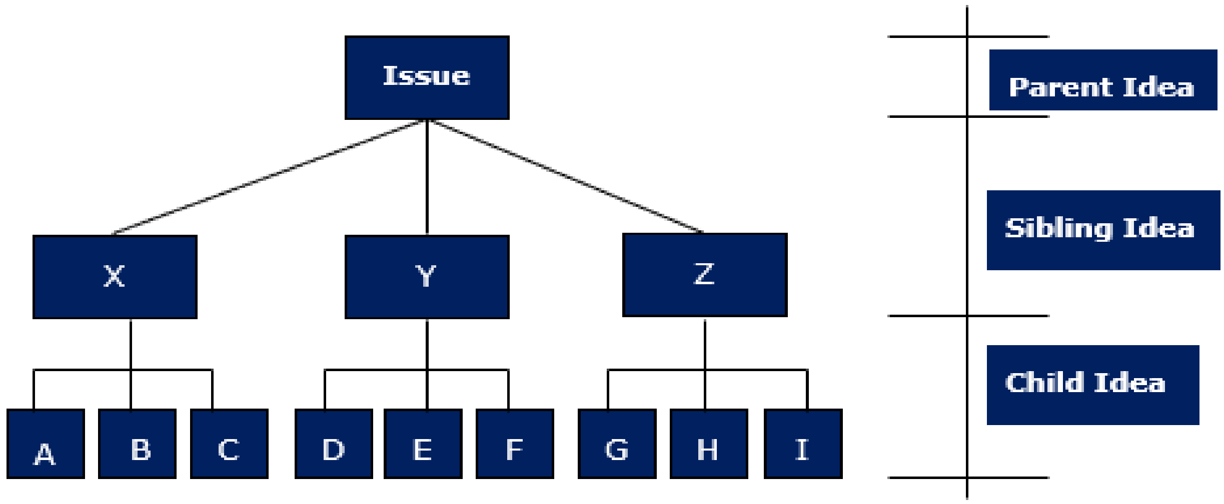


Figure 5 NVivo logical mind map visualisation schematic method

The NVivo mind map is primarily a brainstorming tool that helps to break down the main idea under investigation.

The mind map is achieved using different colours and shapes connected to represent the main category and subcategories of qualitative interview questions (see Figure 5.1).

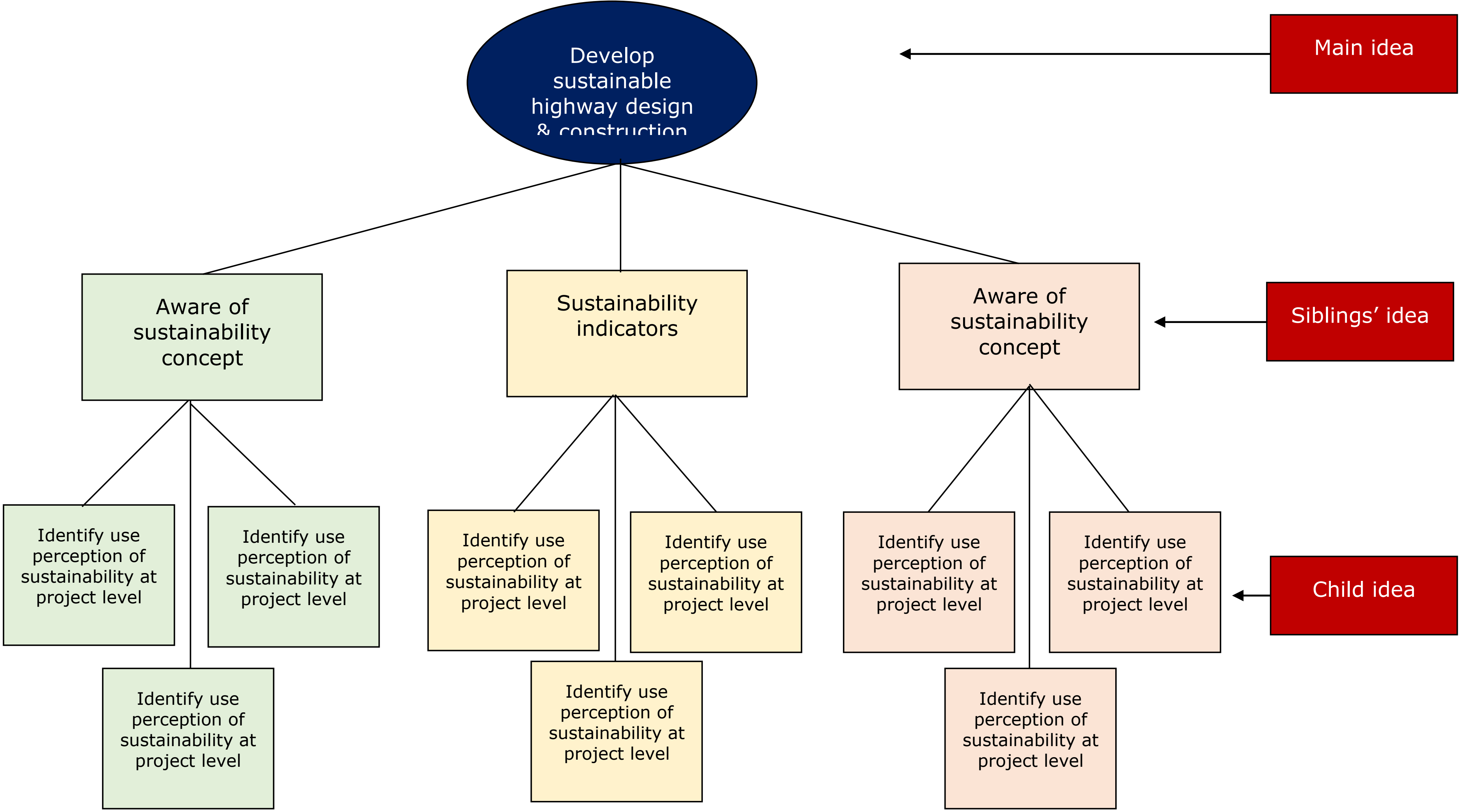


Figure 5.1 NVivo visualization mind ma

Step 2 involves the coding process of the primary categories of the themes identified in Figure 5.1, which is mind map visualisation. Figure 5.2 is a screenshot of the coding process, which emerged through the NVivo mind map.

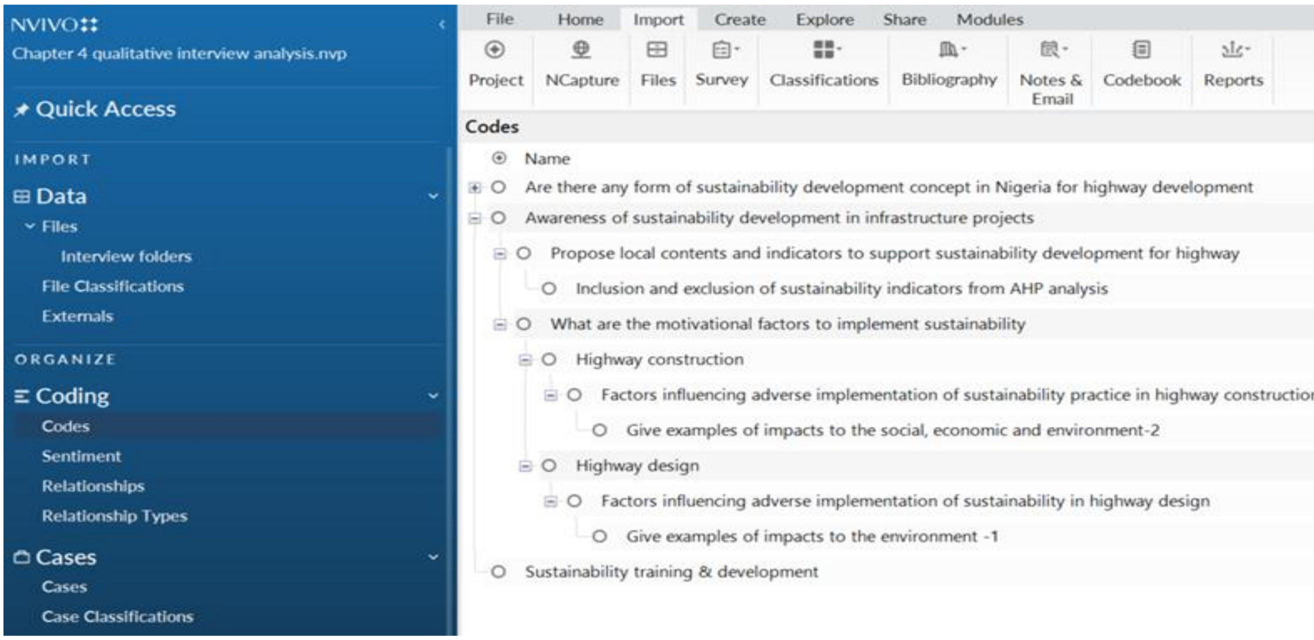


Figure 5.2 NVivo Coding

In step 3, the data are assigned against each interviewee's coding and categorisation system created in NVivo, see Figure 5.3. Here the researcher matched each of the collected interview data against each categorisation set up in the previous NVivo mind map in Figure 5.1.

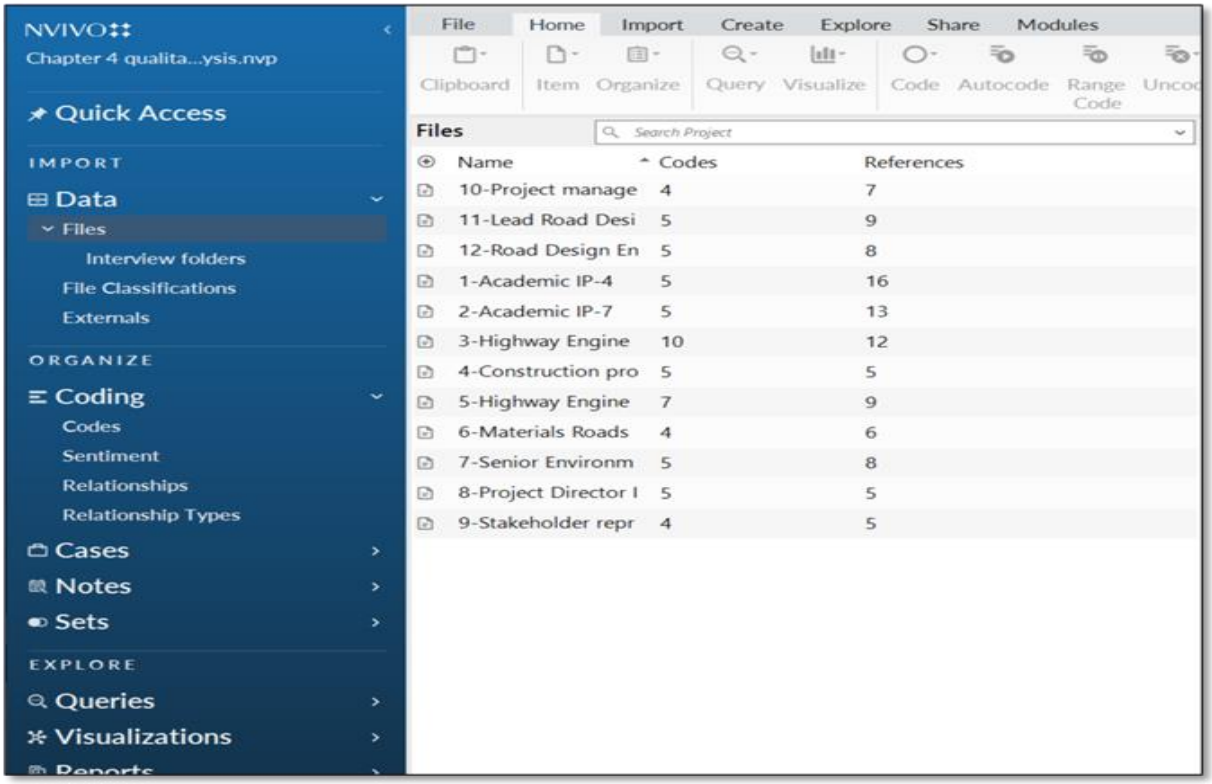


Figure 5.3 Data reconstruction of each interviewee in NVivo.

Step 4, it is important to review how well each of the coded data fits in with the assigned code categorisation to ensure all the data are categorized. During this stage, the researcher endeavoured to identify what was not coded or missed and thereafter fill in any noted gaps by reviewing the data bank information in NVivo.

Step 5, during this stage, analysis was carried out in the form of visualisation, and the query output from NVivo software helped to gain insight into the pattern and themes that emerged from the interview.

Step 6, the visualization called the word tree cloud, comprises the various themes identified for analysis towards gaining insight from the dataset.

5.3.1 Run search query in NVivo

In this research, query analysis within the NVivo software assisted in providing output in the form of a word occurrence and frequency word cluster. This is an exploratory technique that helped to visualise the pattern from the interview data collected. The word cluster helped the researcher to focus on the area of discussion to gain insight into information, themes, and concepts relevant to answering the research questions.

Similarly, Figure 5.4 is the output of the word frequency trends for the interview data analysed using MAXQDA software. According to Chandra and Shang (2019), qualitative findings are based on coding, analysing, and finding the theme evolving through the dataset. The theme considered here is the frequency of words often mentioned during the interview data collection, and that assisted the researcher in focusing on the identified theme in developing knowledge from insight gained (Micheltree, 2021).

Figure 5.4 MAXQDA word trend analysis outcome

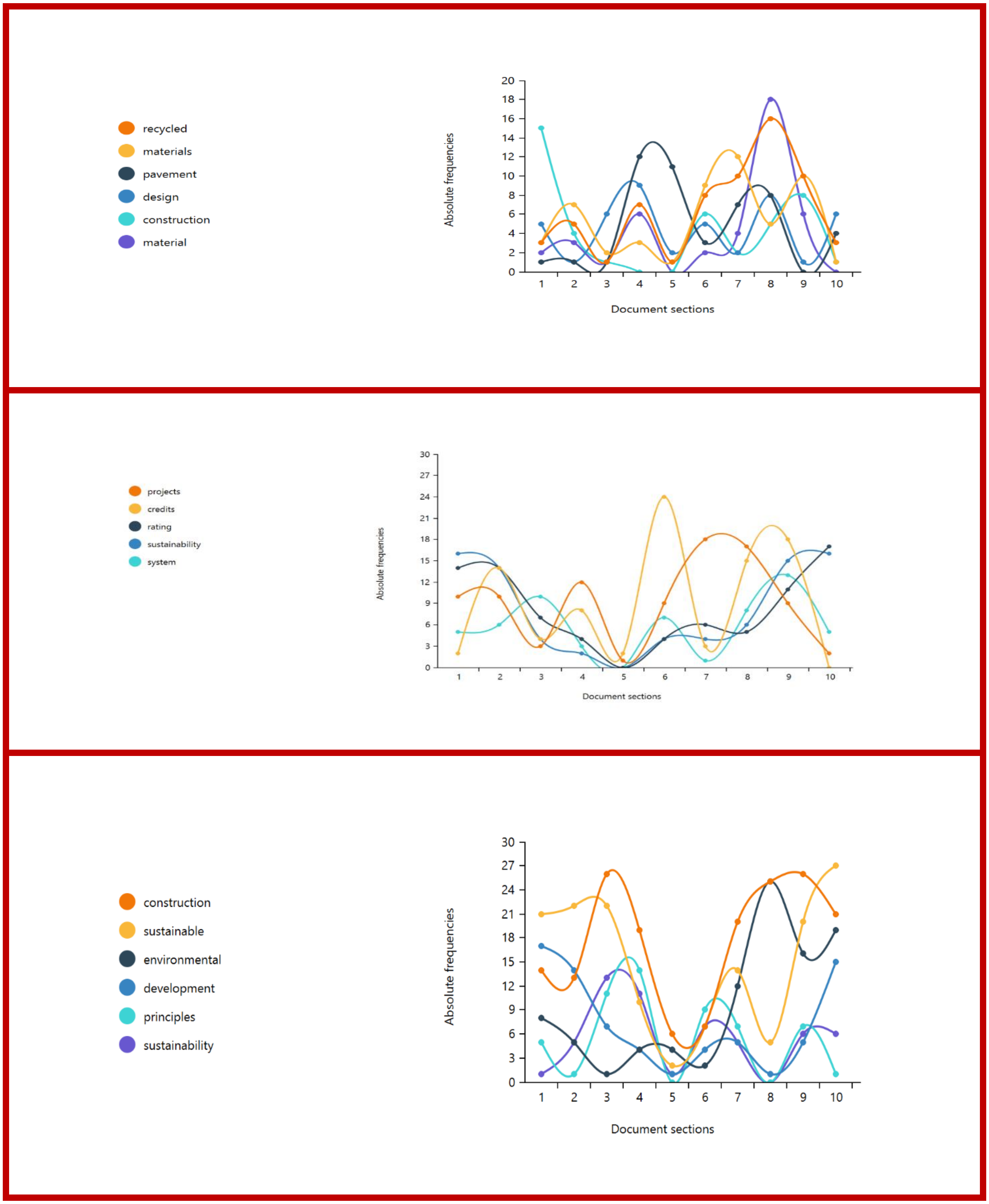


Table 5.2 Interview findings of theme on sustainability in the highway projects

Interviewee Code	Remark	Emerging theme(s)
What is your perception of sustainability at the highway project level?		
Academic IP-4	[….] **sustainability** is a focus of a worldview; the construction of projects should ensure that the impact does not affect this generation and future development. **Sustainability** in projects should consider the benefits of the **society**, **environment**, and **economic** aspects. Infrastructure project development in Nigeria provides economic benefits, but due to capital-intensive resources required during development result in affecting the natural resources and depletion of resources.	There are adverse impacts of development on the environment. Worldview sustainability is essential.
Academic IP-7	[…] little is known about **sustainability** across Nigeria's **project infrastructure** development. There is no mathematical model to support **projects** developing sustainably. **Sustainability** is essential but remains **vague** in developing nations like Nigeria.	Sustainability knowledge gap in project development.
Highway Engineer IP-1	**Sustainability** is not in existence at the **project** level, I attended a workshop held during an engineering conference to understand that **sustainability** is essential to avoid **pollution** during development. [….]. There is a lot of **pollution** during **project development** in Nigeria, so **environmental engineering sustainability** is necessary.	Sustainability learning in projects is lacking. Reduce pollution due to project development.
Construction Manager IP-6	[..] there is no portfolio for **sustainability**, nor a driving policy for **sustainability** implementation in **projects**. **Sustainability** supports human existence and the **environment**.	Sustainability guidance is required because of the knowledge gaps
Highway Engineers IP 2 & 3	[..]…[..].. the responsible approach is managing resources is **sustainability**, although **sustainability** is better positioned for big projects considering the **resources** used and the **impact exerted** on society. The primary focus of development in Nigeria focused on quality, scope, time, cost, and project management.	The focus of development has been the use of traditional measures
Material Road Engineer	The **Nigerian government** do not implement **sustainability** in their projects. […]. The	Recycling is encouraged

IP-8	**development** impact of the project should avoid damage to the **environment**. **Recycling** should be encouraged to preserve the environment, through waste reduction and preserving natural raw materials.	
Interviewee Code	**Remark**	**Emerging theme(s)**
What is your awareness of sustainability at the project level?		
Senior Environmentalist IP-9	…[..] the careless way **projects** are delivered is what creates problems for the **environment**. The existing **environmental policy** can only do little to stop the impact of development. […] tougher **environmental policies** are required in achieving **sustainability practices**.	Lack of sustainability policy.
Project Director IP-10	…[..] **sustainability** is somehow implemented in some projects across Nigeria, the only issue is that no documentation to share from the practice…. […] there is no common **specification** guiding the client on the **sustainability** agenda. [..].	A guiding principle is required for sustainability
Project Manager IP-5	**Sustainability** is not a regular term used in **project development** across Nigeria. [..].client and government do not understand the **pattern**, nor the impact of omitting **sustainability** in **projects**.	Routine terms like sustainability are lacking at the project level
Road Designers DE-1 & DE-2	…. […]…in **design, sustainability** is new and it is not implemented during our daily work. We replicate our **design** and only make a few changes depending on the survey data. Some of the **designs** utilised in some of our **projects** are contracted out to contractors who are mostly foreigners. I can agree that the **design** sometimes conflicts with the requirements of our **environment** leading to variation and delay in the project.	A sustainable design strategy is essential for projects
Road Designers DE-3 & DE-4	.we do not understand **sustainability** during **design**, rather our organisation ensures our **design** conforms with **highway design** manual, geotechnical soil investigation reports, **environmental impact** assessment reports…[..]	The focus of design has been through the use of highway design manual

Interviewee Code	Remark	Emerging theme(s)
How are the factors affecting sustainability in highway projects be resolved?		
Academic IP-4	..[..] the adoption and use of **standards** to enforce **environmental control policy** will be adequate...[..] **sustainability standards** will also add to achieving this common goal of **sustainability**. The primary concern is the lack of a **sustainability policy** to add to project **development**.	Absence of sustainability policy and standard
Academic IP-7	..[..] there is no data, policy, and learning pattern on **sustainability** required for the **development** of **projects**. **Nigeria** is a long way behind in **sustainability practice** and the **government** interest is low.	Lack of data, policy, and learning practice on project sustainability
Highway Engineer IP-1	..[..] hindering factor towards achieving **sustainability** is **finance, technology, policies,** and documented practices on **sustainability.**	Lack of finance, technology, and practice to foster the adoption of sustainability
Construction Manager IP-6	There is no buy-in from the stakeholders on the **sustainability** agenda. The status quo is the use of **traditional methods** of construction by the government.[…]…the use of **sustainability** has **uncertainties** for fear of being unable to complete the project within the original scope and on time, we have no idea of the **impact** of **sustainability** on the project timeline. There are **technological** gaps….[…]	Lack of stakeholders' buy-in to adopt sustainability. Uncertainties on the cost of sustainability
Highway Engineers IP-2 & 3	..[..] a proper **investigation** is needed to understand how **sustainability** can fit into our society and projects.	To view sustainability impact through the lens of the Nigerian environment
Materials Roads Engineer IP-8	..[..] different arms of the **government** undertake **road project construction** as a priority shaped by their **design concept**, rather than access development impact on the environment.	Isolated decision-making during project development
Project Director IP-10	..[..] type of **procurement** affects **sustainability** and the focus is on timely delivery and not **sustainability**	Inconsistent plan in projects

Stakeholders representative IP-11	..[..] there is a **negative influence** of **road development** across my **community**, which **affects** our **daily source** of income.	Lack of stakeholder involvement

Interviewee Code	Remark	Emerging theme(s)
What is the proposed sustainability indicator and to validate presented 36 design and 53 construction indicators?		
Academics IP-4	"sustainability indicators need to measure;- **empowerment** and **participation of all stakeholders** during project development cycle..." ..other considerations are infrastructure assessment, **measure funding and budget**…[..] **engineering design** and **specification**…" sustainability indicators can help to **manage the cost of project** and **reduction material extraction** from its source"	Validates 36 design and 53 construction indicators with comments.
Academic IP-7	"With the increasing population, there is a need to **reduce energy use**, **promote renewable energy**, also **balance earthwork materials".** …most asphalt pavements fail after construction….so a **long-life pavement indicator** should be encouraged".	Validates 36 design and 53 construction indicators with comments.
Highway Engineer IP-1	it is highly encouraged to use an indicator to measure the use of **regional materials, rather than importation**". …" indicators should **measure raw material waste to save money and time in projects**"…" indicators encouraging the greater use of **recycled materials** should be encouraged.	Validates 36 design and 53 construction indicators with comments.
Construction Manager IP-6	.. should be an indicator to measure compliance to transparency in sustainability because corruption impacts the progress of these projects...	Validates 36 design and 53 construction indicators with comments.
Highway Engineers IP-2 &3	"the **indicator** should be able to measure the **consistency** and **expectation** of the **project**"	Validates 36 design and 53 construction indicators with comments.
Materials Roads	"…there is evidence to believe **materials** for **highway** development are scarce, so there is a demand to use the	Validates 36

Engineer IP-8	indicator in **promoting recycling**..".	design and 53 construction indicators with comments.
Senior Environmentalist IP-9	there is a lot of campaign in the media due to **environmental pollution**…" indicators to control, **emissions, prevent pollution, protect land use**.."	Validates 36 design and 53 construction indicators with comments.
Project Director IP-10	…indicators worthy to be considered is to **educate the people, without innovation sustainability will not have a track record, sharing ideas then sustainability** performance cannot be achieved, sustainability cannot occur in isolation, local values can be achieved…"	Validates 36 design and 53 construction indicators with comments.
Stakeholder Representative IP-11	.." **sustainability indicator** should **measure community outreach**, this is how the government can perform in reaching out to the communities affected by the project development..".	indicators with comments only
Project Manager IP-5	"….progress in projects helps to **reduce the impact on time, cost and scope, accelerated construction** can be measured to ensure savings on cost and time on the project…".	indicators with comments only
Road Designer DE1- and 2	.." using **a sustainability model in design framework** to achieve international standards will be very good.." "a major **concern is to ensure design, sustainability and construction implementation** achieve the required benefits"…	Validates 36 design and 53 construction indicators with comments.
Road Designer DE3- and 4	…" the indicators should cover negative design impact, this will help to identify lapses during design.."	indicators with comments only

5.3.2 Interview summarised findings; -

—Result regarding awareness of sustainability in highway projects

a) Sustainability is essential during infrastructure project development considering the use of large resources, which subsequently affects the environment.
b) The term sustainability is vague within the Nigerian project context, and no existing mathematical model supports how sustainability should be implemented in projects.
c) Sustainability is non-existence at the project level; it is vague to understand, when compared with the traditional method of construction which is established.

Summary: —

A few of the participants with academic backgrounds were able to point out what sustainability is all about,. These participants are aware that traditional development created opportunities as well as an adverse impact. Consequently, little is known of sustainability at the project level; the focus of participants is primarily on time, quality, and cost of project delivery.

—Result regarding factors affecting sustainability in projects

a) There is a lack of sustainability standards to enforce environmental control.
b) A lack of data to support practical sustainability learning.
c) There is low interest from the Nigerian transportation authorities to adopt sustainability.
d) Absence of technology and lack of stakeholders' buy-in.
e) Sustainable procurement in highway projects is lacking.

Summary: —

It was noted that hindering factors are in a wide range, but these factors are collectively identified as lack of sustainability standards, no technology, lack of research knowledge and the Nigerian government's inaction towards adopting a sustainability agenda for highway development.

—Result of proposed sustainability indicators

a) Suggestions given by interviewees for the intended indicators to help in resolving issues such as:— (1) empowerment of stakeholders affected by project development to provide solutions towards highway development, (2) an indicator to analyse project funding, (3) monitoring engineering design and specifications, (4) reduction of material extractions, (5) reduce the use of energy, (6) promotion of renewable energy, (7) reduce earthwork usage, (8) designing long-life pavement asphalt, (9) utilise local material made from recycled by-products, (10) measure compliance of sustainability in projects, (11) measures the impact of corruption towards sustainability implementation, and (12) indicator to measure pollution and land use.

Summary: -

A total of 12 participants validated transcribed interview text using member checking (see Section 3.9.2).

5.4 Triangulation of qualitative and quantitative result findings

Triangulation, according to Creswell and Creswell (2018), is a technique used for multi-mixed methods. It helps to ascertain findings from one method to another to see if both collaborated. Since no single research method of inquiry provides a flawless result, comparing findings helped to view the convergence or divergence of results (Saunders et al., 2019). As discussed in Section 3.9.4, the research design is a sequential explanatory quantitative and qualitative approach, so triangulation at this stage is essential.

Table 5.3 Synthesized quantitative and qualitative results

Quantitative factors		**Qualitative factors validated**	
Social factors		**Social factors**	
Community & stakeholder (R32) ;(S39)	✓	Stakeholders' involvement	✓
Protect natural heritage (R35)	✓	Land use	✓
Environmental factors		**Environmental factors**	
Material reuse (R21); (S25)	✓	Material extractions	✓
Sustainable material processing	✓	Reduce the use of earthworks	✓
Reuse and recycle waste (S25)	✓	Utilise local materials	✓
Pollution management prevention (S26)	✓	Reduce pollution	✓
Additional indicator	X	Use low energy	✓
Economic factors		**Economic factors**	
No required	X	Project funding	✓
Lifecycle costing (S31)	✓	Cost management model	✓
Others (Engineering/Project management		**Others (Engineering/Project management**	

Sustainability framework & sub-logic	✓	Specification	✓
Technical design (R1 – R11)	✓	Sustainable designs	✓
Engineering (S44 – S49)	✓	Engineering innovation	✓
Additional indicator	X	Renewable energy source	✓
Not required	X	Corruption	✓

The highlighted indicators in Table 5.3 with green background and (X) marked red colour are indicators identified from the interview results, which are considered beneficial for sustainable development in highway projects. These indicators are the use of low-energy and renewable energy sources. The items marked 'X' with red and white backgrounds are deleted because it is out of the scope of this research. The comparison in Table 5.3 presented a similarity of identified indicators during the interview, which is within the same range as the indicator that emerged from quantitative data. In Table 5.3, the checkmarks (✓) are the noted similarities of indicators between quantitative and qualitative data.

5.5 Chapter summary

The interview questions are primarily in three main categories, and the aim is to gain insight from the collected qualitative data. An analytical approach called 'thematic analysis', is utilised because it helped interpret qualitative data to determine patterns and themes formed within the interview data collected. For accuracy and to avoid error, a thematic analytical tool supported by the NVivo software package and MAXQDA is used in organising and analysing the open-ended and unstructured interview dataset. The steps and concepts utilised for the NVivo analysis are based on the earlier works of Braun and Clark, 2006.

The steps involved in transcribing the data and developing a visualization mind map for the interview questions using a model within NVivo. The mind map concept helped in systematic coding. Coding helped to assign each interviewee's comments, answers, and oral contributions to enable theme and pattern analysis. The technique within NVivo is used to visualize word occurrences and the frequency of word clusters. These assisted in identifying similarities, patterns, and differences in the interview data collected. The results outcome is presented. Finally, a triangulation of qualitative and quantitative results was conducted to ascertain findings in terms of convergence and divergence, and two new additional indicators were identified for the construction, and the majority of indicators proposed during the interview were rejected because it is out of the scope of this research.

The next chapter 6 is the project case study conducted using face-to-face interviews at the highway project level in Nigeria. This is to assess the effectiveness of the sustainability indicators that emerged from quantitative results in Chapter 4 and interview results from Chapter 5.

CHAPTER 6 – PROJECT CASE STUDY

6.1 Chapter introduction

In Chapter six, the previous chapter developed 36 design and 53 construction sustainability indicators are utilized to measure the extent of sustainability application at the highway project level in Nigeria.

The project case studies are Project A (case study A) and B (case study B). Case study A is the Rehabilitation, Reconstruction and Expansion of Lagos-Ibadan Dual Carriageway Section II in Nigeria, called the Shagamu-Ibadan project.

Project B is the Highway Dualization of the Federal Capital Territory of Nigeria, called the Southern Parkway Project. Discussed are the overall project background, milestones, and project requirements assessed alongside current research-developed sustainability rating indicators. The objectives are to assess the extent current research-developed indicators contributed to measuring the design and construction of highway project practices in Nigeria.

6.2 Project selection criteria for case studies

Below are the reasons for selecting the project case studies A and B; —

1. Contributed to achieving the aim of current research regarding "how to develop a sustainability assessment framework and indicator decision sub logic for Nigerian highway projects". The selected project case study design and construction phases are measured across the social, environmental, and economical plus technical aspects to determine what was achieved at the project level.
2. The selected project case studies 'A' and 'B' provided new insights for this research to determine the practical course of action on how to develop highway design and construction sustainability strategy in answering research questions.

6.3 Case study project 'A' – Shagamu-Ibadan project

Discussed within this section are the project case studies' background, key milestones, events, and a measure of the project 'A' development strategy using this research-developed sustainability rating indicators.

6.3.1 Project 'A' background

Project A is the Rehabilitation, Reconstruction and Expansion of Lagos-Ibadan Dual Carriageway Section II in Nigeria, called Shagamu-Ibadan, which is 127.6 km of highway connecting Ibadan. Ibadan city is connected to a commercial city of Lagos state, which is the largest megacity in Nigeria, see Figure 6. The Lagos-Ibadan dual carriageway section II is a major route connecting the eastern, northern, western, and southern parts of Nigeria. This route has a long history, dating to 1978 when it was commissioned. Then the population of Nigeria was 69.2 million. Figure 6 illustrates the Project 'A' map plan.

Figure 6 Layout drawing plan, Lagos-Ibadan Section I and II Highway

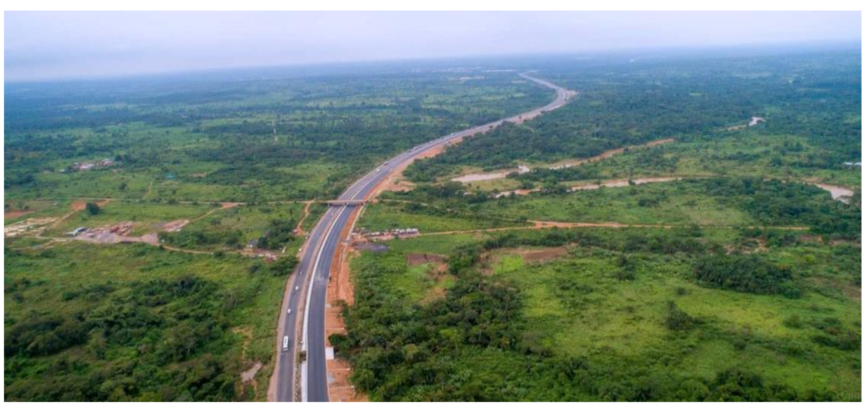
In the past years, due to the increased population and urban development, the congestion of traffic experienced along the Ibadan-Lagos route released a large volume of carbon, also the existing road inclined to accidents and other socioeconomic difficulties within this road section (refer to Figure 6.1). In 2013, the Federal Government of Nigeria (FGON) commissioned the Lagos-Ibadan highway for reconstruction, expansion, and modernization of a 127.6km section. Figure 6.1 shows the Lagos-Ibadan Road before Project 'A' construction and rehabilitation began.

Figure 6.1 Lagos-Ibadan Road before construction. Source: RCC Nigeria (2013)

The consultant for the project is WSP Global, a global company that specialises in infrastructure development. In Project 'A', there were proposals for alternative route construction, which was the subject of debate and discussions across the project host communities (Ibrahim et al., 2022). These proposals for alternative routes suggested planned and justified solutions for solving transportation issues between the Lagos to Ibadan highways. The Federal Ministry of Power and Housing, in conjunction with the client-consultant, carried out a detailed feasibility study to recommend the adoption of the Lagos-Ibadan existing route alignment, and expansion of the right of ways for the rehabilitation, reconstruction and dualization purposes (Lamai, 2020).

According to the pre-planning traffic studies and feasibility report, the Lagos-Ibadan highway project development is anticipated to reduce 74% of the traffic congestion due to carbon emissions from vehicles. A current study revealed there are fewer carbon fumes along the Ibadan-Lagos way (Ayinde et al., 2021). Figures 6.2 and 6.3 display various progress site pictures.

Aerial view of one of the completed Toll Plaza. Source: RCC (2022)



Drone aerial view of Lagos-Ibadan Section II highway project Source: RCC (2022)

Figure 6.2 Complete project progress pictures. Source: RCC Nigeria (2013)

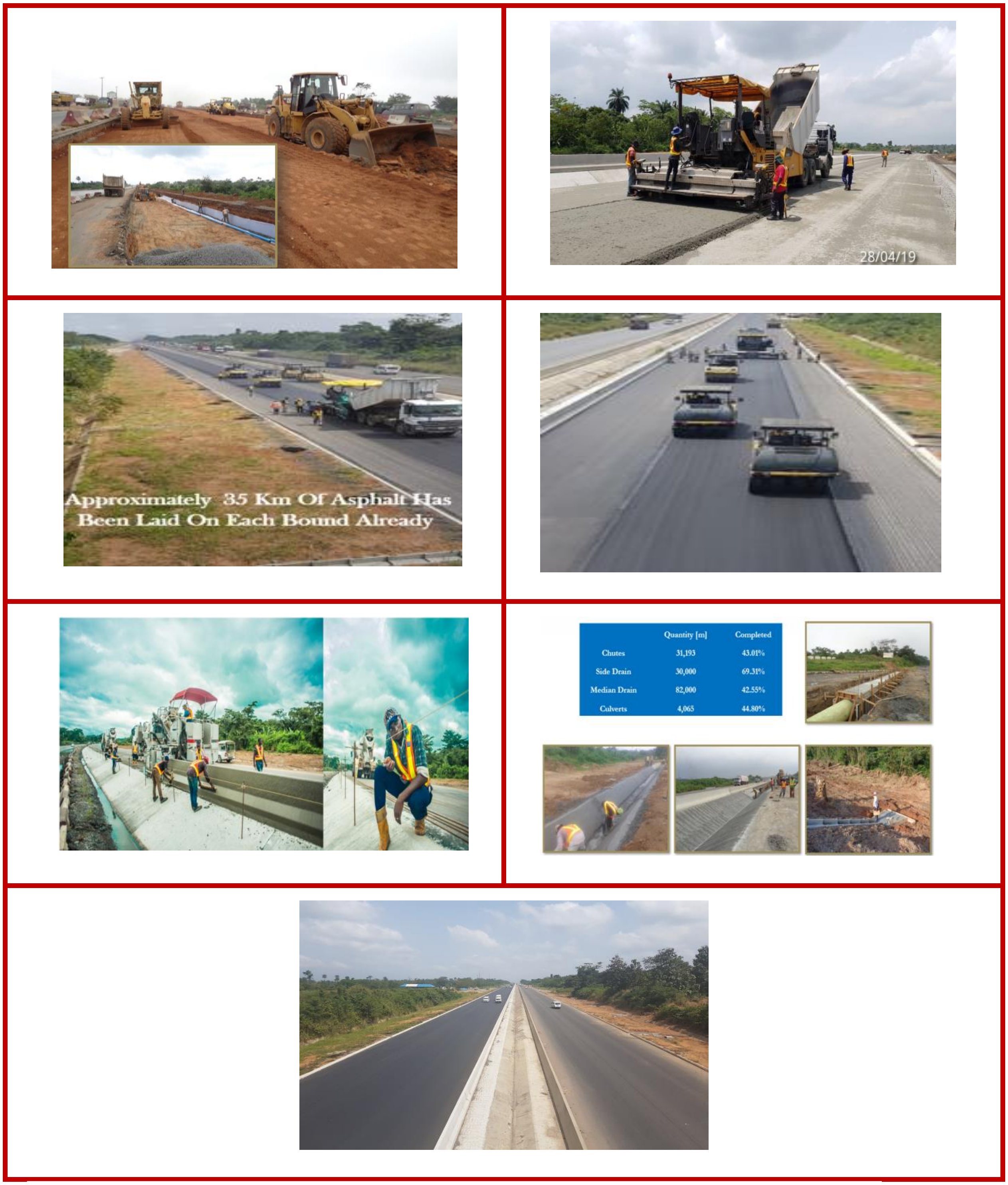


Figure 6.3 Progress pictures of some achieved best practice. Source: RCC Nigeria (2022)

6.4 Case study project B background

Discussed in this section are the project background, design and construction development practices implemented, major events, and challenges. The project was commissioned by the Nigerian Federal Capital Territory (FCT) to bring solutions to solving traffic challenges within the Nigerian Federal Capital Territory of Abuja, see Figure 6.4.

Figure 6.4 Traffic congestion in Abuja Federal Capital City Source: Federal Capital Territory, 2019

The Federal Capital Development Authority (FCDA) is the client with the responsibility for developing the Abuja master plan in Nigeria. The Southern Parkway project is a highway that runs across four phases in Abuja, including the Central Business District. The Southern Parkway section of the road forms a critical part of a larger system, supporting the movement of goods, people, and services from the North and South of the Federal Capital Territory (FCT).

Setraco, a multi-national construction company based in Nigeria is contracted to reconstruct the 21km Dual Southern Parkway highway Project Abuja, which is called Project Case study 'B', see Figure 6.5.

Figure 6.5 Layout drawing plan, Southern Parkway Project, Abuja, Nigeria.

According to the documentary evidence viewed from the project site, one of the aims of the project is to deliver value-driven transportation solutions. It was stated during the project case study interview that sections of the highway facility had been pioneered using innovative sustainability methods. There is evidence of community engagement, which is the act of communicating with the community affected by the development impact of the highway. Another noted best practice across the project is the effective alignment of route connectivity, which enabled communities demarcated due to highway alignment to be integrated using a connecting path route for better social cohesion and economic growth.

Below are milestones and events; -

- The total project length is 21 km of dual carriageway.
- 300,000 m^3 of earthworks
- Pavement section with asphalt of 600,000 tons
- Recreational areas
- Café, underpass, street lighting, and other electromechanical equipment.

The primary aim of developing project ‘B’ is to establish an urban public system that is key in supporting the various socioeconomic systems in Abuja-Nigeria, with the need to enhance reliable travel time distance for the traffic and to reduce congestion and exhaust pollution from traffic.

6.5 Interviewees' profiles

Table 6 displayed interviewees who participated in the project case studies interviews. The roles and responsibilities of the interviewees were confirmed during the interview at the project sites and the various project and corporate offices. They include the area manager, project manager, construction manager, design representative from the client-side, construction engineers, and environmental manager. All the interviewees were project-site and office-based across Nigeria, with a total of 14 interviewees. These interviewees were selected because of their involvement in project management, such as design and construction, across the project lifecycle.

The decision-making approach considered here included the ability of the interviewees to plan, execute and manage a project. Both project case studies are designed and built types of procurement projects, using varying bespoke Standard Forms of Contracts. In this project case study, the wide range of interviewees' roles and responsibilities, in addition to their experience and active participation in both projects, enriched the collected information to support the case study data collection.

The interviewee's experience is observed to be across Nigeria with regards to projects executed in the past, and their experiences were brought forward in suggesting the likelihood of potential issues that needed to be addressed for sustainability implementation across Nigerian highway development projects.

The recorded interview range per participant is between 25 minutes to 2 hours maximum. The researcher visited the project sites and offices in Nigeria, both in Enugu and Abuja, respectively, which are 8 hours' journey apart.

Table 6 list of interviewees in the two project case studies

Interviewee designation	Interview date	Project interview location	Interview duration
Project case study A: Lagos-Ibadan Dual Carriageway Section II in Nigeria			
Area Manager	03/07/2022	Abuja Head Office	25 minutes
Chief Engineer	03/07/2022	Abuja Head Office	1 hour
Assistant Chief Engineer	03/07/2022	Abuja Head Office	1 hour
Quantity surveyor	03/07/2022	Abuja Head Office	1 hour
Project Manager	07/05/2022	Enugu project site	1 hour
Construction site Agent	07/05/2022	Enugu project site	1 hour
Project Engineer	07/05/2022	Enugu project site	1 hour
Project case study B - Federal Capital Territory Southern Parkway Project			
Deputy Director	04/05/2022	FCDA - Abuja	45 minutes
Highway Designer 1	04/05/2022	FCDA - Abuja	2 hours
Highway Designer 2	04/05/2022	FCDA - Abuja	1 hour
Project Manager	04/05/2022	Abuja project site	1 hour
Construction manager	04/05/2022	Abuja project site	1 hour
Client representatives	04/05/2022	Abuja project site	1 hour
Environmental manager	04/05/2022	Abuja project site	1 hour

Table 6.1 displayed a summary of the project case study interview. The aim was to utilise the 36 design and 53 construction indicators developed in this research to measure sustainability practices, identify knowledge gaps, and develop a decision-making sub-logic framework to enable project-level participants in Nigeria to adopt and implement sustainability. The project case study questions focused on measuring project lifecycle practices across social,

environmental, and economic development factors. Some sample project case study interview questions and responses are in Table 6.1.

Table 6.1 Project case study interview findings on highway sustainability in Nigeria

Interviewee	Remark	Findings
Traffic volume count indicator		
Designers/Project manager/Project Engineer	**According to an interviewee**, "the project feasibility study, traffic study and prediction are systematically carried out in determining highway classification, and cross-sections needed to accommodate the flow of traffic". Therefore, the volume count and the flow of traffic facilitate in determining vehicle axle loading, which further helped to determine the capacity of the highway pavement and life cycle span. **An interviewee stated that** "traffic volume count from adjoining communities and towns are considered in adjusting the data while taking into consideration the seasonal variation of traffic to represent adequate annual average daily traffic (AADT) across the project". ***S1: Interview and findings:*** *— the inability to establish before the highway design phase, an effective annual, average daily traffic (AADT) or average daily traffic ADT) —volume count will result in congestion and limited highway carrying capacity during peak hours. Besides, when recent traffic data are not considered a critical factor in determining the required level of road services and furniture, that will likely have an adverse impact on the proposed highway geometrics.* ***The identified issue is, how is consideration given to the use of digitalised traffic volume count in making decisions for the monthly, yearly, and seasonal traffic flow and volume count.*** *Also, has the traffic volume count been considered as a baseline for determining design speed and assigning highway functional classifications?*	Findings revealed that **manual** traffic volume count was the main consideration during the feasibility studies, which has a drawback in achieving sustainable design
Intermodal and multimodal transport connectivity indicator		
Designers/Project manager/Project Engineer	**One of the interviewees** stated that "the inability to have an integrated transport facility will discourage the frequent use by the commuters". For instance, connecting bus commuters towards a train line and airport facility will not only save the cost of the travellers but encourage first-hand sustainable quality	The design of intermodal and multimodal transportation was omitted from the design.

	travelling experience. Besides, the unsustainable transportation system is the largest end-use of energy in developing countries and one of the highest emitters of Green House Gases (GHG). Sustainable transport can be achieved using an integrated public transport system to deliver goods and services, which should be affordable, improve accessibility, efficient and convenient. The benefits of intermodal and multimodal transport are unique, with consideration concerning the natural environment in terms of reduction in GHG emission and less energy consumption. **The design approach to the intermodal and multimodal transport system in the project case study**: According to the future design within Project case study B, the Federal Capital Territory Southern Parkway Project will form an integral part of a future highway alignment supporting the "city centre" which will be integrated with a wide range of different modes of transportations, such as pedestrian, bicycle, transit, rapid/mass/rail transit, high-occupancy vehicle (HOV) carpool, freight, and single-occupancy vehicle (SOV). However, the current design for the Lagos-Ibadan Dual Carriageway Section II and the Federal Capital Territory Southern Parkway Project in Nigeria was designed to mitigate traffic congestion due to the growing population in Lagos commercial state and the increasingly high level of congestion in the Federal Capital City Nigeria.	
	S2: Interview and findings*: — Due to the need for urgent delivery of goods and services. The public anticipates having critical highway infrastructure upgraded for efficiency and maximum use. One of the future anticipations is the development of Intermodal transport connectivity, which involves the integration of trucks, rail, and ships. It involves the transfer of goods for easy handling across the supply chains and logistics. It involves the delivery of goods from origin to destination and vice versa. It reduces service time of delivery, lowers cost, increases carrying capacity, and is eco-friendly. Another type of sustainable transportation is the Multimodal type of transport, which integrates a wide range of different modes of transportation, such as pedestrian, bicycle, transit, rapid/mass/rail transit, and high-occupancy vehicle (HOV) carpool, freight, and single-occupancy vehicle (SOV). Given the need to incorporate intermodal and multimodal transport to manage to deliver community expectations, - this is part of the Sustainable Development Goal.*	

Innovative ideas indicator		
Designers/Project manager/Project Engineer	**An interviewee pointed** out that "in projects, innovative approach and value engineering are considered necessary only when the client hopes to achieve benefits in terms of cost savings". However, the interviewee buttressed that "at the project level, the contractor cannot stray away in trying innovative sustainability solutions across key project raw materials", such will incur sunk costs, and the company can run out of business". One of the interviewees gave an account of an innovative solution in a project design phase, "in the bill of quantity, and the Issue For Construction drawing, and the paid item suggests laying 200 mm sub-base thickness, to compact to 150mm in two different layers, the contractor proposed an innovative solution of paving the same highway pavement using proposed Cement Base Material (CBM) of thickness 250mm, which is durable with a better stable functionality". The interviewee concurred that, "innovative solutions will not occur except if the item is payable within the contract bill of quantities". **One of the interviewees pointed** out that "*even when a contractor is poised to develop an innovative solution, which is new, only if the client will not benefit much in terms of cost, then it is considered out of scope and a delay to the project*". **Besides, the interviewee stated that**, "*in previous highway design project, which involved a Design and Build procurement, the project design and construction overlapped, and that encouraged a fruitful and innovative solution*". "*In contracts with measurable items using traditional procurement, both the contractor and the client in most cases do not see the need to implement innovative solutions during the project development*". **Another interviewee shed light that** "*prescriptive specification from the client hinders innovative highway design because no one can verify acceptance of generic standard if contractor deviates from the norm".* Also, it is suggested by the interviewee that the "*client does not want to be associated with the cost of such innovative ideas in highway design*". In view of the collected data, innovative solutions need to be deep-rooted during highway design phases for a sustainable future.	
	S3: Interview and findings: — *Innovative ideas in highway design are different viable ways of achieving sustainable development while keeping the same*	Innovative ideas and solutions are not a consistent

	functionality of the highway design scopes. Innovative ways in highway design result in using aggregates to reduce noise in asphalt, which is more economical than building a sound barrier wall to prevent noise from moving traffic. Because of reducing GHG emission from hot mixed asphalt, a warm mix asphalt with less carbon footprint of 20%, which equally achieves— a lower temperature during manufacturing and laying, has less odour and consumes less fuel. Another good practice during highway design innovation is the use of recycled materials, which Project A, provided evidence of the use in asphalt pavement. — this is part of the Sustainable Development Goal (SDG 9.4) Highway design development in the past focused primarily on achieving socio-economic benefits. After the Brundtland Commission report of 1987 on sustainable development. The innovative approach has become essential in fulfilling the needs of the present generation without affecting the needs of the future generation in fulfilling their own needs.	practice in the projects. However, recycling of earthworks was a good practice identified.
Travel time reduction indicator		
Designers/Project manager/Project Engineer	**An interviewee stated** that "with regards to the initial feasibility study and adoption of road existing alignment, the data and simulation models revealed travel time reduction can be achieved because the width of the highway is widened, with a better rideability design surface". Another interviewee pointed out that "regardless of the effective route alignment with wide cross-sections, that commuters and road users will still experience one form of delay travel time due to weather conditions". "Some other bottleneck is the horizontal curves, such changes in road alignment affects travel time experience of the commuters, inadequate speed limits-such as a flat road with adequate sight distance using low-speed running limit, lack of informative traffic signboards, and inadequate provisions of the alternative routes to avoid traffic congestion ahead". Another significant area pointed out by the interviewee is the "lack of installation of traffic control signal devices, which could have helped to guide and inform the flow of traffic". However, in the Federal Capital Territory, the interviewee agreed that "there are provisions for traffic signals at every intersection to enhance traffic travel reliability". Another valid point from an interviewee hinted that "travel time reduction can be hindered due to temporary changes to the highway environment". **The primary noted issue is the lack of a database or website to inform commuters about anticipated delays across the highway travel distance.**	

	One of the interviewees stated that "with the new highway alignment within the FCT, the travel time, which is the time taken to move from point X to Y of the project, divided by the average operational speed of the vehicle, which gives reliability time in minutes while taking into considerations mandatory stationary delays, such as traffic control redlight signals, and weather effects, which may result to speed reduction of the vehicle".	
	S4: Interview and findings: — *Travel time reduction is a measure of the dependability in time for a trip to be made across a section of road segment called origin and destination. It is a measure of reliability time for commuters to convey goods and services from one point to another.* ***The success of commuters' time reduction travel is a function of an effective intermodal and multimodal transport system****. The lack of travel time reliability increases the cost of travel due to delays and its impacts across society when there is a need to attend to an emergency. Although, this is a relatively new concept in transportation planning and management. Reliable travel time reduction supports integrated business, while delays incur severe economic implications.*	There is evidence of good practice which contributes to three pillars of sustainability in the projects.
Design speed limit indicator		
Designers/Project Manager/Project Engineer	With regards to the design speed, evidence collected from the client designers suggests a fixed geometric road design standard for the assigned Design speed limits specified in kilometres per hour against the road width. It is assumed from the 85th percentile distribution that the operating speed, is the speed at which the drivers are observed to be operating at free-flow conditions. This signifies that 80km/hr, 60 km/hr, 50 km/hr, 40 km/hr and 30 km/hr are the required 85th percentile distribution at which the majority of travellers are operating below it. This is assumed to be the safe speed design for particular road types. According to case study evidence from the project site, "*the design speed assisted in selecting various highway geometric features". "An interviewee stressed that at "the horizontal curve alignment, design speed should be lower to overcome crash frequencies*". In addition, "*design speed is verified against the travel sight distance and the radius of the curve*". It is stated during the interview that within "*the Federal Capital Territory of Nigeria, the topography and terrain are flat and that has influenced the assigned design speed which tends to be uniform across areas of the road type*".	

	S5: Interview and findings: — *Speed limits are the target speed of a driver, which is critical to safety. The activities within the right of way of the highway pavement section, such as walking, cycling and other activities, result in the behaviour change of a speed limit. Reducing the speed limit could change the design options to local street roads rather than a highway. The speed limit is one of the important factors car travellers consider in selecting alternative transportation routes. The speed limit is a matter of convenience and economics, and these factors are weighed against saving money and operation costs. The design objective of a speed limit is to focus on safety and low crash frequency under any severe or extreme traffic conditions.*	Findings revealed 85^{th} percentile speed limits are not determined to identify the free flow of travel paths in a particular section of the highway design.

During the case study, below are some examples of good practices and challenges experienced and how it was overcome.

- *The good practices noted during the project case data collection is the opportunity to gather in-depth information and context using interview, observing the construction of the highway and the level of environmental interaction and considering the in-depth information gathered during the case study, which was effective because only a few participants (<14) were utilised, and that provided an opportunity to discuss and explain issues, best practices and suggestions.*
- *The identified core challenges during the project case study; participants attempted to cover a wide range of issues, which was time-consuming and the researcher had to politely rephrase the question to enable direct feedback without offending the participants.*

6.6 Project case studies results

Tables 6.2 and 6.3 present the Project case 'A' results. According to Figure 3.15, multiple project case studies are selected. The data collection instrument utilised open-ended interview questions, observation of activities at the project sites, and review of project site documents. The open-ended interview session was used to collect verbal data from individuals based on their experience and perspective of highway project lifecycle design and construction strategies. The observation session was carried out during the project site visits to view how the project participants interact with the development of their environment in terms of highway development. The documents reviewed, such as reports, working drawings, management plans and specifications.

The approach utilised for the project case study is to measure practices using this research developed 36 design and 53 construction indicators across the highway project lifecycle in Nigeria. This supported in probing the project-level participants on the actions taken in achieving design and construction within the context of three pillars of sustainability, namely social, environmental, and economic aspects, plus technical.

Tables 6.2 and 6.3 consist of three levels of asterisk for the representation of practices identified using the 36 design and 53 construction indicators. According to the legend in Table 6.2, a single black colour asterisk (**x**) depicts there is a noted good practice across the three pillars of sustainability plus technical. A double red asterisk (**xx**) and triple asterisk (**xxx**) revealed there is a gap towards the implementation of the triple bottom line concept.

The project case studies, interviews, observation, and project document reviewed took place at the project sites and offices in Nigeria.

Table 6.2 Sustainability rating system versus project requirements Project Case 'A'-design

Project requirements & Characteristics	Sustainability design rating system	Noted gaps
• Highway design analysis framework	—(R_1)—Traffic volume count	xx
	—(R_{33})—Intermodal connectivity	xxx
	—(R_{31})—Innovative ideas	xxx
	—(R_{34})—Travel time reduction	x
	—(R_2)—Speed limit design	x
	—(R_5)—Safe radius of a curve	x
	—(R_4)—Stopping sight distance	x
	—(R_6)—Safe superelevation	x
	—(R_8)—Safe cross-sections	x
	—(R_3)—Terrain analysis	xxx
	—(R_7)—Profile and vertical curves	x
• Cost-benefit of the project	—(R_{28})—Lifecycle cost analysis	xxx
	—(R_{29})—Cost-benefit ratio	xxx
	—(R_{30})—Return on investment	xxx
	—(R_{26})—Measurement and verification	xxx
• Design strategy and environmental issues	—(R_{12})—Reduce habitat fragmentation	xxx
	—(R_{13})—Reduce impact on farmland	xx
	—(R_{14})—Enhance ecology connectivity	xxx
	—(R_{16})—Watershed restoration	x
	—(R_{17})—Climate resilience	xxx
	—(R_{19})—Avoid groundwater pollution	xxx
	—(R_{21})—Material reuse	xxx
	—(R_{23})—Eliminate environmental pollution	xxx
	—(R_{11})—Culverts and gully pots	xxx
	—(R_2)—Runoff flow	xxx
	—(R_9)—Catchment basic for stormwater	xxx
	—(R_{15})— Air quality	xx
	—(R_{18})—Renewable energy	xxx
	—(R_{20})—Greenhouse gas emission	xxx
	—(R_{26})—Smart infrastructure	xxx
• Stakeholders' involvement	—(R_{32})—Community & stakeholders	x
	—(R_{33})—Intermodal	xxx
• Structural pavement design elements	—Highway sound barrier wall	xxx
	—(R_{10})— Sustainable flexible pavement	xxx
	—(R_{24})—Long-life design	x
	—(R_{31})—Innovative ideas	xxx

xxx = extremely poor; xx = poor; x = good practice

Table 6.3 Sustainability construction rating system versus project requirements-Project case 'A'-construction

Project requirements & Characteristics	Sustainability construction rating system	Noted gaps
• Pre-construction strategy and project benefit	—(S_1)—Community engagement and context-sensitive solution	xxx xx
	—(S_2)—Travel time reduction measurement	xx
	—(S_3)—Protect cultural and natural heritage	x
	—(S_4)—Access to the cyclist, and pedestrian / Equity accessibility	 xxx
	—(S_5)—Travel rest areas and recreational parks	xx
	—(S_6)—Scenic views	
• Construction phase environmental management control	—(S_7)—Highway connectivity across communities	x
	—(S_8)—Avoid contamination of the substrata	xxx
	—(S_9)—Avoid climate catastrophe	xxx
	—(S_{10})—Ecological protection	xxx
	—(S_{12})—Maintain vegetation cover	xxx
	—(S_{13})—Stormwater facility	xx
	—(S_{14})—Protect wetland	xx
	—(S_{15})—Environmental Impact Assessment	x
	—(S_{16})—Promote recycling from construction	xxx
	—(S_{17})—Reduction of GHG emissions due to construction	xxx xx
	—(S_{18})—Protection of flora and fauna habitat	xx
	—(S_{19})—Protect biodiversity and landscape	x
	—(S_{20})—Site Remediation	x
	—(S_{21})—Restore site topography	xxx
	—(S_{22})—Reuse topsoil clearing and grubbing	xxx
	—(S_{23})—Avoid impact on agricultural land	xxx
	—(S_{24})—Noise control from equipment and tools	xxx
	—(S_{25})—Reduce use, and recycle wastewater	xxx
	—(S_{26})—Pollution prevention management	xxx
	—(S_{27})—Protect the catchment environment	xxx
	—(S_{28})—Habitat protection	xx
	—(S_{29})—Water run-off control	x
	—(S_{30})—Surface water run-off	xxx
• Cost and project control mechanism	—(S_{31})—Life cycle cost analysis	xx
	—(S_{32})—Return on investment	x
	—(S_{33})—Cost-benefit ratio analysis	x
• Project management, quality, governance, and technological advancement.	—(S_{34})—Material quality process and testing	xx
	—(S_{35})—Engage with the supply chain	x
	—(S_{36})—Innovation implementation	xx
	—(S_{37})—Value Engineering	x
	—(S_{38})—Construction project governance	x
	—(S_{39})—Early stakeholders' involvement	xxx
	—(S_{40})—Training and collaboration	x
	—(S_{41})—Use of BIM and new technological advanced strategy	xxx xxx

	—(S_{42})—Sustainability incentive in contract delivery	xx
	—(S_{43})—Construction audit across development phases	
• Effectiveness of engineering properties.	—(S_{44})—Design for long-life pavement	xx
	—(S_{45})—Operational efficiency	x
	—(S_{46})—Durability of asphalt pavement construction	x
	—(S_{47})—Quality process and procedures	xx
	—(S_{48})—Sustainable material sourcing and processing	xxx
	—(S_{49})—Resiliency	xx
• Health and Safety mechanism.	—(S_{50})—Manage hazardous construction materials	xxx
	—(S_{51})—Safe rideability pavement surface and alignment	xx
	—(S_{52})—Sustainable safety management plan	xx
	—(S_{53})—Safety training and auditing	x

xxx = extremely poor; xx = poor; x = good practice

6.6.1 Matrix tabulation for case study findings

Table 6.4 displayed a matrix comprising of Project case 'A' and 'B' result outcomes, which was measured in phases across three pillars of sustainability. Figures 6.6 and 6.7 are histograms that complement each other to present the analysis of measured best practices and noted sustainability gaps for highway design project case studies 'A' and 'B', using 36 highway design indicators and 53 construction indicators.

The objective is to provide a real context upon which to identify project-level practices for a meaningful understanding of the project scenarios and measures taken to achieve best practices in sustainability. Each of the best practices achieved is issued a credit point across the triple bottom line. The awarded credit points are noted as good practices within the three pillars of sustainability. Table 6.4 displayed project case studies 'A' and 'B' sustainability design measurements. A similar approach was taken for 53 highway construction indicators across the project planning stage, execution stage, monitoring and control and project close-out stage. The results are presented in Figures 6.6 and 6.7, respectively.

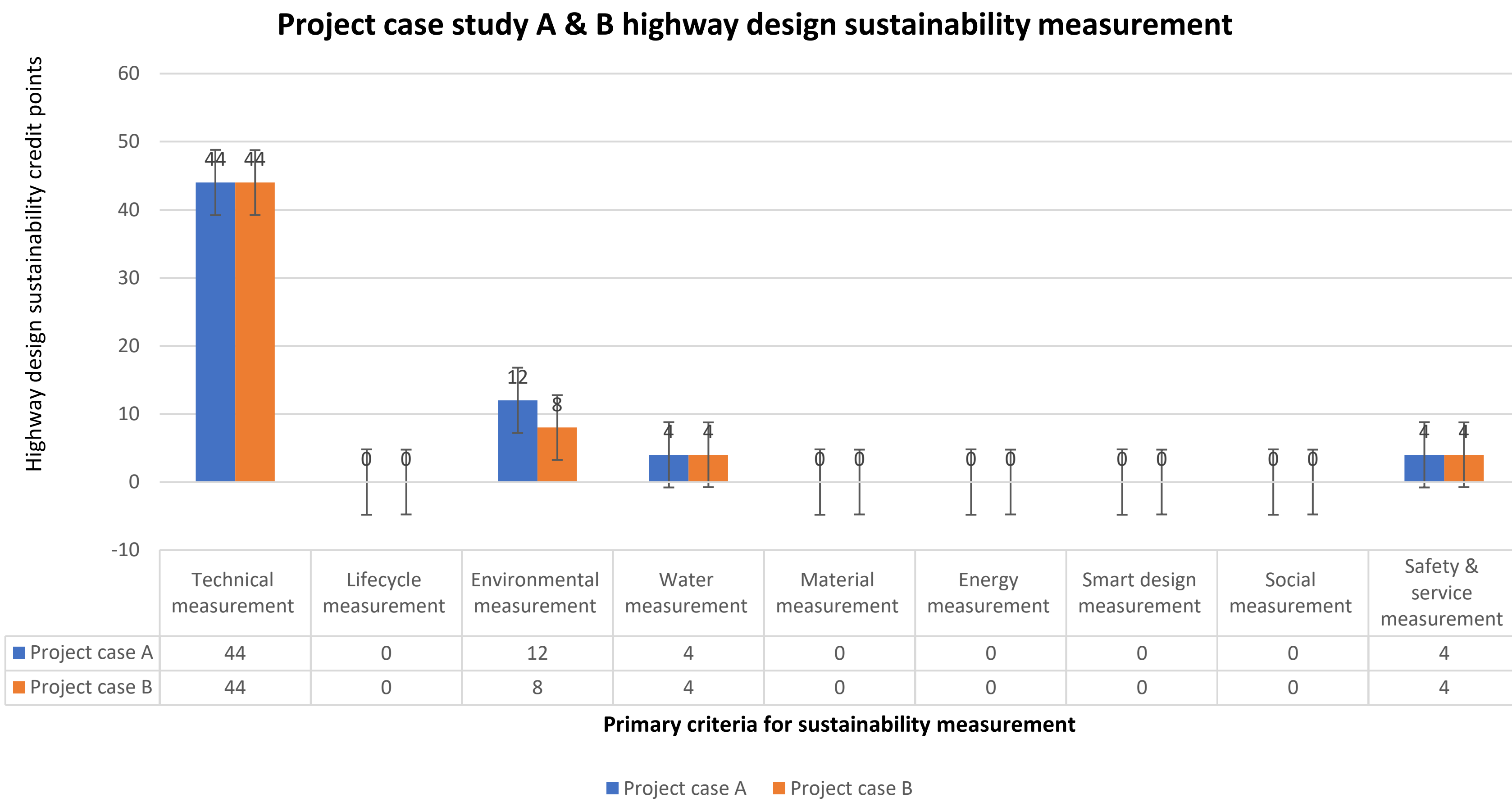
Table 6.4 Project case study matrix for design cycle – Project case 'A' and 'B'

Category	**Criteria**	**Planning design**			**Preliminary design**			**Final design**			**Develop design stage**			**System metrics**				**Project A Outcome**			**Project B Outcome**		
Category	Sustainability measurement performance factors	Social	Economical	Environmental	Social	Economical	Environmental	Social	Economical	Environmental	Social	Economical	Environmental	Tracking performance	Showing impact	Green growth / Communication	Improvement	Credit points	Percentage achieved		Credit Points	Percentage achieved	Tracking performance
Technical measurement	Traffic volume count	xq	xq	-	xq	xq	-	xq	xq	-	xq	xq	-	-	-	-	-	8	67%		8	67%	-
	Intermodal connectivity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Innovation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-		-	-	-
	Travel time reduction	xq	xq	xq	xq	xq	xq	xq	xq	xq	xq	xq	xq	✓	-	-	-	12	100%		12	100%	-
	Speed limit design	-	xq	-	-	xq	-	-	xq	-	-	xq	-	✓	-	-	-	4	33.3%		4	33.3%	-
	The radius of a curve	-	xq	-	-	xq	-	-	xq	-	-	xq	-	-	-	-	-	4	33.3%		4	33.3%	-
	Stopping sight distance	-	xq	-	-	xq	-	-	xq	-	-	xq	-	-	-	-	-	4	33.3%		4	33.3%	-
	Safe superelevation	-	xq	-	-	xq	-	-	xq	-	-	xq	-	-	-	-	-	4	33.3%		4	33.3%	-
	Safe cross-sections	-	xq	-	-	xq	-	-	xq	-	-	xq	-	-	-	-	-	4	33.3%		4	33.3%	-
	Terrain analysis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Profile and vertical curves	-	xq	-	-	xq	-	-	xq	-	-	xq	-		-	-	-	4	33.3%		4	33.3%	-
	Total credit points to the summary																	**44**			**44**		
Lifecycle measurement	Lifecycle cost analysis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Cost-benefit ratio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Return on investment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-

	Measurement and verification	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Total credit points to the summary																	**00**			**00**		
Environmental measurement	Reduce habitat fragmentation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Reduce impact on farmland	**x-**	-	-	**x-**	-	-	**x-**	-	-	**x-**	-	-	-	-	-	-	4	33.3%		-	33.3%	-
	Ecology connectivity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Climate resilience	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Eliminate environmental pollution	**x-**	-	-	**x-**	-	-	**x-**	-	-	**x-**	-	-	-	-	-	-	4	33.3%		-	-	-
	Air quality	-	**xq**	-	-	**xq**	-	-	**xq**	-	-	**xq**	-	-	-	-	-	4	33.3%		4	33.3%	-
	Greenhouse gas emission	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-		-
	Total credit points to the summary																	**12**			**4**		
Water measurement	Watershed restoration	-	**xq**	-	-	**xq**	-	-	**xq**	-	-	**xq**	-		-	-	-	4	33.3%		4	33.3%	-
	Avoid groundwater pollution	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Runoff flow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Catchment basin for stormwater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Culverts and gully pots	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	4	33.3%		4	33.3%	-
	Total credit points to the summary																	4			4		
Material measurement	Material reuse	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Total credit points to the summary																	00			00		
Energy measurement	Renewable energy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Total credit points to the summary																	**00**			**00**		
Smart design measurement	Smart infrastructure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	-
	Total credit points to the summary																	00			00		

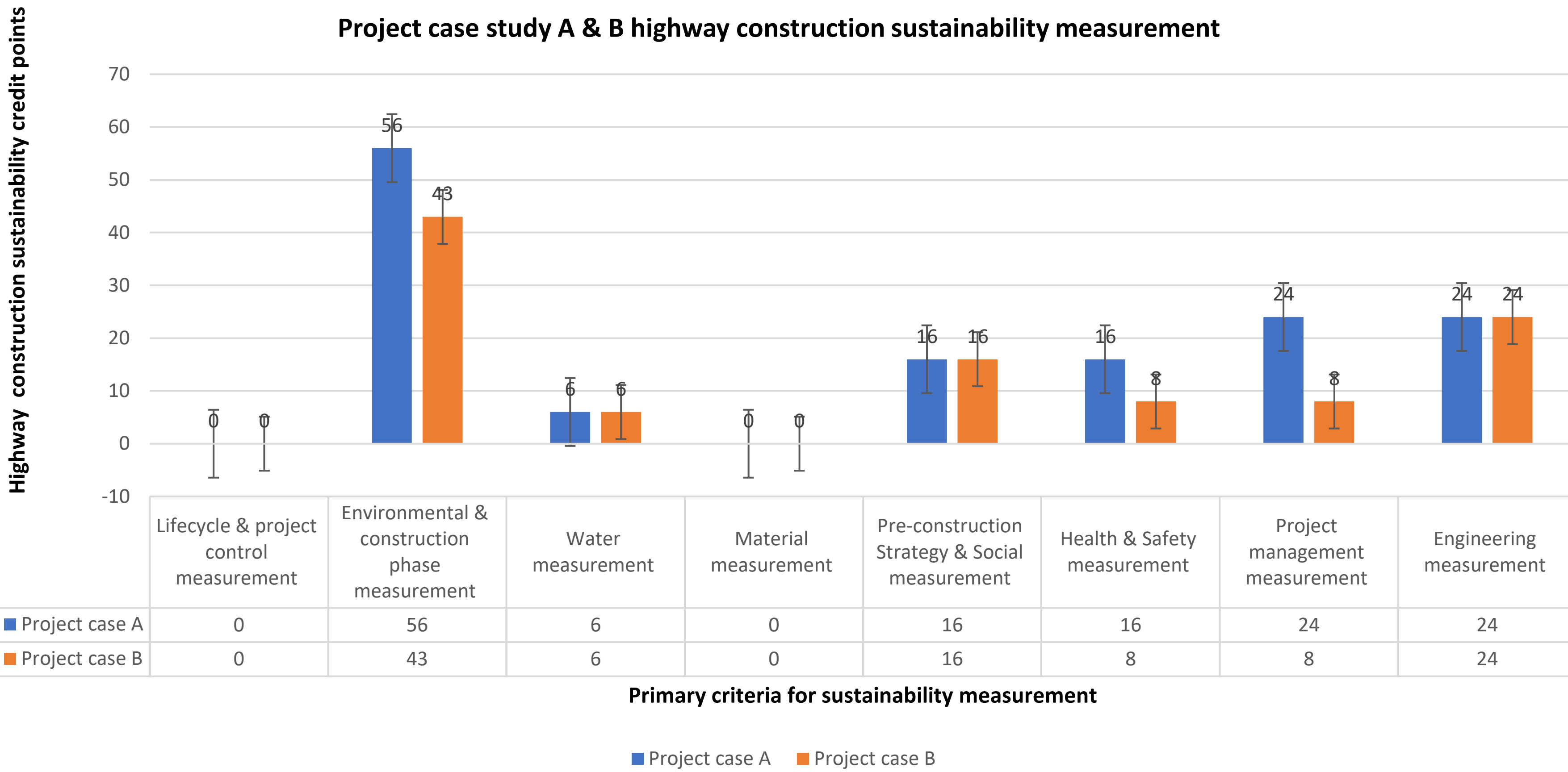
Social measurement	Community & Stakeholders	-	**xq**	-	-	**xq**	-	-	**xq**	-	-	**xq**	-		-	-	-	4	33.3%	-	4	33.3%	-
	Protect cultural and natural heritage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Highway sound barrier wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total credit points to the summary																	4			4		
Safety and service measurement	Sustainable flexible pavement	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-		-	-	-
	Long-life design	-	-	**xq**	-	-	**xq**	-	-	**xq**	-	-	**xq**	-	-	-	-	4	33.3%	-	4	33.3%	-
	Innovative ideas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total credit points to the summary																	4			4		
	Legend				**Point**																		
	X = Project A				**1 per cell**																		
	q = Project B				**1 per cell**																		

Figure 6.6 Measured sustainability design practice



	Technical measurement	Lifecycle measurement	Environmental measurement	Water measurement	Material measurement	Energy measurement	Smart design measurement	Social measurement	Safety & service measurement
Project case A	44	0	12	4	0	0	0	0	4
Project case B	44	0	8	4	0	0	0	0	4

Figure 6.7 Measured sustainability construction practice



	Lifecycle & project control measurement	Environmental & construction phase measurement	Water measurement	Material measurement	Pre-construction Strategy & Social measurement	Health & Safety measurement	Project management measurement	Engineering measurement
Project case A	0	56	6	0	16	16	24	24
Project case B	0	43	6	0	16	8	8	24

6.6.2 Noted sustainability practice gaps.

Findings from project case studies A and B (refer to Tables 6.1 and 6.2 and Figures 6.6 and 6.7) revealed best practices and sustainability opportunities were not considered from the inception of the highway project development. The noted best practices in some phases and non-existing across the majority of the phases. The partially achieved best practices are in two categories: —

1. The contractor's partial best practices are those implemented through good faith and accountability in performing contractual duties in the projects.
2. The contractor in correcting defects noted because of poor workmanship in the projects resulted in developing a one-off unique sustainability concept in solving the noted challenges.

Figure 6.8 Sustainability gaps in the project case study A and B.

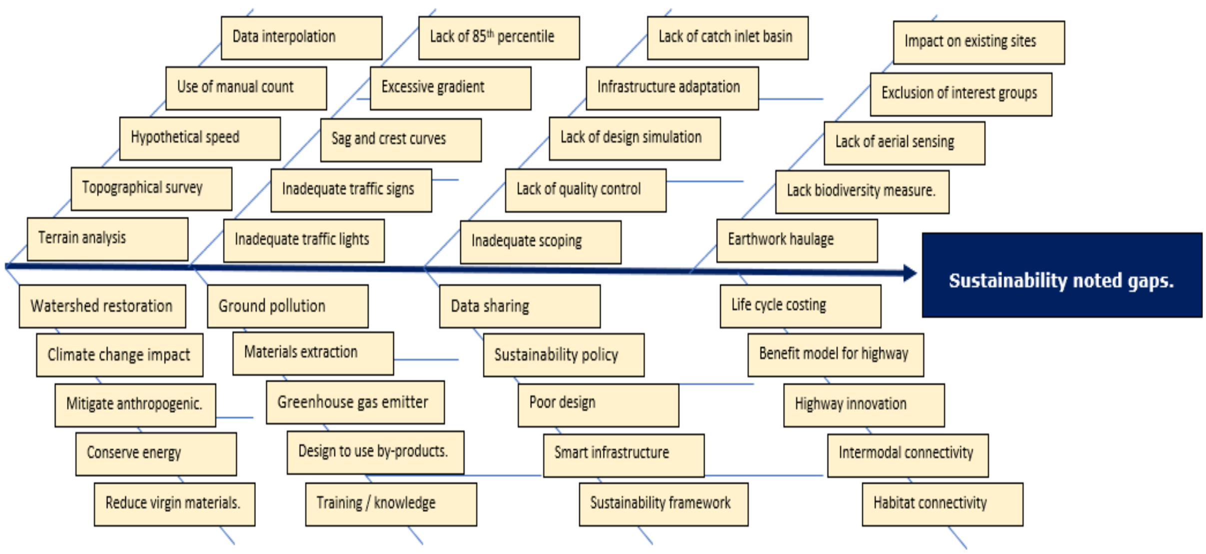


Figure 6.8 shows the summarised noted sustainability gaps from the project case studies 'A' and 'B'. What is noted is that the projects was executed with the same contract documents and client but with different foreign contractors. There are noted similarities in practices across design and construction. This is evident because both projects are using a similar highway design manual for Nigeria.

The Nigerian highway design manual focused primarily on the use of time, cost, and scope concepts.

According to Green Road manual v1.5(2011), highway projects should use sustainability indicators and credit points to challenge the teams to be proactive beyond the minimum environmental practices. A sustainability rating system facilitates how best practices can be achieved in contributing to reducing adverse development impacts on the ecology. The rating system should be implemented in a project from the onset during the "preparation phase" to develop a strategy for sustainability implementation. The current noted gaps assisted in developing highway sustainability framework and indicator decision sub-logics and attributes (refer to Chapter 7 and Appendix 'F').

6.7 Chapter summary

From Nigeria, two highway design and construction project case studies were conducted to determine the best practices implemented and the noted sustainability knowledge gaps. The procedure adopted in collecting information comprises document data, semi-structured interviews, and project site observations to gain insight into highway development.

Multiple case studies were adopted, considering that no previous study in this area has been carried out within the Nigerian context. The multiple case studies aided in gaining a broad understanding of sustainability accomplishment and noted gaps in practices at the Nigerian highway project level.

Findings from project case studies A and B revealed sustainability agenda and goals were not considered from the inception of the highway project level. According to the literature, the sustainability gap is a result of highway project design and construction in Nigeria being handled by foreign organisations, which deprives local engineers of the ability to develop sustainability agendas in projects (Yusuf et al., 2022). The much-noted sustainability practice that occurred was a result of the contractor's partial sustainability implementation through good faith and accountability in performing contractual duties across the projects.

The next, Chapter 7, is a discussion of achieved results to aid in the development of a framework and sustainability indicator decision sub-logics for Nigerian highway development.

CHAPTER 7 DISCUSSION AND RESEARCH FINDINGS

7.1 Introduction

This research aimed to investigate the challenges associated with unsustainable highway development in Nigeria. Chapter 7 presented the research findings from Chapter 4 (quantitative), Chapter 5 (qualitative), and Chapter 6 (project case studies). These findings are compared with the literature reviewed in Chapter 2 in contributing to knowledge. The literature review considered within this context provided the background for the interpretation of findings and, in comparison, with the existing knowledge to determine what was planned and how this research contributed to what has not been achieved in the literature. The results, findings and discussions are presented in subdivisions of research questions; —

a) **Quantitative**

- What are the highway sustainability strategies utilized globally [Question.1].
- What are the highway design and sustainability rating systems for Nigeria [Question.4].

b) **Qualitative**

- How will the benefits and disbenefits associated with sustainable highway design and construction development be identified [Question 2].
- What factors influenced the implementation of sustainable highway development in Nigeria [Question.3].
- Inclusion and exclusion of indicators that emerged from the quantitative approach [Question 4].

c). Project case studies

- project case studies for current research accessed the extent of sustainability application and noted gaps at the Nigeria highway project level [Question.5].

7.1.1 Quantitative results discussions and findings

This section is divided into three distinct parts. The first is (Section 7.1.2) which focuses on the result discussion and findings of the Likert scale questionnaire opinion survey issued to global project participants. This is to gain data on the type of highway sustainability strategies utilised globally. The second section (Section 7.1.3) is the project-level participant opinion survey, utilised in assigning Likert scale values to the highway design and construction indicators within Nigeria. The third section (Section 7.1.4) is the AHP comparative analysis with Likert scale results in selecting sustainability indicators based on using high, middle, and low priority ranking to answer research questions.

7.1.2. Survey results for 17 highway sustainability strategies

This research identified through literature a total of 17 sustainability strategies utilised globally for the development of highway projects. These highway sustainability strategies are stated within Sections 2.6.1 and 2.6.5 in Chapter 2. The online questionnaire survey was issued to participants using the 17 sustainability strategies for highway development. A questionnaire survey provides a platform to build knowledge from data in making deductive conclusions (Strang, 2015). The primary objective of the online questionnaire survey was to identify concepts utilised globally in reducing adverse impacts of unsustainable highway development.

The most noticeable finding to emerge from the result analysis is the consistent level of opinion among respondents acknowledging that all the 17 highway sustainability strategies presented are most favourable in reducing the adverse impact of highway development. A total of 85% (19) respondents agreed through the survey that the presented 17 highway sustainability strategies are useful. In contrast, 15% (3) of respondents consider these strategies as un-useful. Factors contributing to variance in the opinion of the participants suggested that some project-level practitioners do not accept universal standard versions of sustainability solutions from others (Purvis et al., 2019).

Overall, the above-discussed results and findings are consistent with the study of Huang and Hsu (2011) that emulating and keeping track of sustainable development strategies utilised, both regionally and globally, will enhance the growth of sustainable construction.

Furthermore, comparing findings with the literature also confirmed that it is practically and theoretically reassuring that developing countries should take pragmatic steps towards the implementation of sustainable construction strategies (Otaibi et al., 2022). These findings suggested a need to adopt strategies for developing countries like Nigeria to achieve a robust sustainability development strategy for highway construction.

7.1.3 Survey results for highway design and construction indicators

This research questionnaire survey set out with the aim of assessing the Nigerian project-level participants' opinions in assigning a 5-point psychometric Likert scale to 36 design and 53 construction sustainability indicators. Chapter 2 identified relevant sustainability indicators considering the adverse impacts of highway project development in Nigeria. These indicators were selected through the lens of the Nigerian environment using a concept called the back-casting model (refer to Section 3.6.1 Table 3.6). These preliminary indicators are sourced from relevant literature, highway manuals and existing sustainability rating systems (refer to Table 2.10 and Chapter 2). A total of 36 design and 53 construction indicators were proposed to reduce unsustainable highway development practices in Nigeria (refer to Tables 4.3 and 4.4).

These highway design sustainability indicators are categorised into four distinct parts, namely, technical, social, environmental, and economic. The construction indicators are categorised into six distinct parts, namely, social, environmental, economic, project management, safety and health and engineering. The identified supplementary categorised indicator groups supporting the triple bottom line concepts are necessary because it provide overall needed efforts through the back-casting model in reducing the impacts of unsustainable development practices in Nigeria.

The identified categories of indicators agreed with the assertions made by Arukala et al. (2019) that multi-dimensional pillars for achieving sustainability in construction are required. These additional categories of inclusions into the three pillars of sustainability helped to widen other traditional development construction methods into sustainable practice. Another advantage in selecting these indicators from the literature is that it emerged completely from highway project-related efforts needed for sustainable development. One of the early pioneers in sustainable construction research, Hill, and Bowen (1997) encouraged the use of additional pillars of sustainability for sustainable construction within the developing countries of Africa, which is technical alongside social, environmental, and economic concepts.

The tabulated results for highway design sustainability indicators in Figures 4.7 to 4.10 revealed optimal opinion among the project-level participants in assigning Likert scale values to technical, social, environmental, and economic sustainability indicators. This level of opinion can be viewed by looking at the assigned Likert scale scores for 'significant', 'high significant' and 'very high significant'. Approximately 81.8% (27 respondents') are aware of sustainable design concepts. There was a noted reduction in opinion when participants were asked to confirm if they had utilised sustainability design protocol. A total of 40.6% (13 respondents') agreed yes, while 59.4% (19 respondents) responded no, which is a noted knowledge gap at the project level. The next response from the participant provided clear evidence of the sustainability knowledge gap in highway development in Nigeria. An open-ended question in the survey asked participants to identify types of sustainable highway design protocols used in projects. The listed responses from the participants were in the range of specification, highway design manual, which is not within the range of highway design sustainability rating systems indicators.

A similar trend of opinion was noted for 53 highway construction sustainability indicators presented to the 100 project-level respondents (refer to Figures 4.13 to 4.18). Across the six categories of highway construction indicators, namely, social, environmental, economic, engineering, project management and safety-health. There is a noted consistency of opinion among respondents, which suggested the desire to support the reduction of unsustainability impact due to highway construction in Nigeria using survey data.

The noted optimal opinion is evident across Likert scale values from 'significant', 'high significant' and 'very high significant''. A total of 77% (77 respondents') agreed they are involved in project decision-making during construction, and 75% (75 respondents) replied yes to awareness of sustainability concepts used in highway construction. Only 50% (50 respondents) confirmed they had utilised sustainable highway construction protocols.

In generalising, the result findings with regards to assigning opinion values to the indicators were optimal, as the participant opinion level is consistent across the board for design and construction. These achieved optimal results was because of participant's perceptions in contributing to this survey data to resolve adverse impacts of unsustainable highway development across the Nigerian society (Olayeni et al., 2018; Eja and Ramegowda, 2019; Ifije and Aigbavboa, 2020).

There was a well-noted sustainability knowledge gap from the results because all the respondents, both from the design and construction sectors, were unable to identify any existing highway sustainability protocols such as Greenroads, GreenLITES, and I-LAST. Although these rating indicators are not in existence within Nigeria, industry and global knowledge of construction practices should have enabled the participant to identify existing sustainability rating systems. These findings aligned with the study of Opoku and Fortune (2011), that organisational learning aligned with sustainability assisted in gaining insight on how to develop sustainably.

7.1.4 Results of analytical hierarchy process (AHP)

AHP is a tool utilised in this research to determine the relative degree of sustainability weighting for the indicators using pairwise comparison matrix data. The AHP weighting results and the Likert scale project level participants' opinion results for the 36 design and 53 construction indicators are comparatively assessed using high, middle, and low priority ranking (refer to Table 4.9 – 4.18 in Chapter 4).

The primary findings revealed there is no clear correlation between AHP weighting values for the participants. The noted AHP results achieved scattered findings, which suggested unsatisfactory findings due to the low number of participants selected for the pairwise comparison matrix (PCM). Furthermore, the integrated AHP weighting results for both participants involved in the survey were correlated and compared with the Likert scale results (see Tables 4.9 to 4.18). It was noted no correlation was achieved when the indicators were ranked using high, middle, and low priority ranking. This is considered a variance because of the low number of participants that contributed to the AHP pairwise comparison matrix survey.

Given the noted limitation for the AHP weighting results for the indicators, the Likert scale values are adopted considering that the results achieved are not scattered; there was a noted cluster of 36 design indicators within the middle priority ranking, which is optimal and consistent (See Table 4.19).

For the construction indicators, there is a cluster of 53 indicators for the middle priority ranking. The positive findings for the Likert scale values was as a result of the number of participants that contributed to the survey data, which is 33 design and 100 construction participants. The achieved Likert scale priority ranking values for high, middle, and low indicators are presented in Table 4.19 in Chapter 4, and lastly, 36 design and 53 construction indicators were achieved.

7.1.5 Triangulation of indicator results

Triangulation in this research is used to verify different data sources to build a coherent insight in contributing to knowledge (Strang, 2015).

The existing highway sustainability indicators and indicators developed in this research are compared (refer to Tables 4.20 and 4.21, Figures 4.17 and 4.18 in Chapter 4).

The results from the triangulation showed that this research developed indicators aligned with the Greenroads rating system for the development of highway design and construction phases only (see Table 4.20). Other existing rating systems for highway development, such as INVEST, ENVISION, and CEEQUAL, covered a wider highway project lifecycle, such as planning, design, construction, operation, and maintenance (see Table 4.20).

BE^2ST-in-Highways is a rating system that can only be implemented during the planning and design phases of highway project development (see Table 4.20). All the benefits associated with the rating systems are summarised in Table 2.5, literature review Chapter 2. A noted theme is that some of the rating systems are voluntary, third-party certification, internal research, and self-certification (see Table 4.20).

In Chapter 4, Table 4.20 displayed the structure of the existing highway rating systems in comparison with the indicators developed in this research. CEEQUAL has 250 indicators and 5,050 credit units, which is the highest among all the rating systems. The identified large number of rating systems and credit units is because CEEQUAL is used in the United Kingdom to develop a wide range of infrastructure and building projects.

ENVISION rating system is utilised in the United States for sustainable infrastructure development, to increase public awareness of sustainability, it enhances sustainable design. ENVISION has 5 primary categories, 64 indicators and 1000 credit units. Current research has a total of 89 indicators and 89 credit units.

Figure 4.17 displayed three pillars of sustainability, namely, (social, economic, and environmental) of the existing highway sustainability rating systems compared with indicators developed in this research. The finding suggested that CEEQUAL, ENVISION, GreenLITES, Greenroads, and INVEST are in the same category of social sustainability contribution during highway development. Social sustainability indicators developed for this research are considered minimal, with only 12.4%, and Greenpave with 29.8%. The implication is that different stakeholders consider their sustainability goals to be unique, and this research achieved social sustainability indicators is considered adequate; this is based on data collected and analysed for the Nigerian highway project sites.

For environmental indicators, this research, Greenpave and GreenLITES have the highest score with 44.9% and 47.4% and GreenLITES has 41.5%. There is another category of sustainability indicators developed in this research, namely, engineering, project management, technical, and safety health, which are measured across other rating systems, which is presented in Table 4.21.

Figure 4.18 presents six project lifecycle categories, namely, management, social, environmental & land use, energy & atmosphere, resources use, and innovation. The information displayed in Figure 4.18 showed the total credit units per each highway indicator and the application across the six identified categories,— to gain insight into what each rating system achieved in terms of sustainability agenda.

Besides, sustainability indicators are unique in solving environmental impact due to development. Also, these indicators may not be compatible when utilized in other regions to reduce the impact of unsustainable construction (Mattinzioli et al.,2020).

7.2 Qualitative results discussions and findings

The interview discussion is categorized into three (Section 7.2.1) to understand the level of awareness of sustainability practices at the project level. (Section 7.2.2) is the interviewees' exclusion and inclusion of presented sustainability indicators. (Section 7.2.3) is to gain insight into factors influencing sustainability implementation in Nigeria, the benefits and disbenefits of sustainability, and the impact of sustainability gaps in a project.

7.2.1 Awareness of sustainability concepts

The summary of interview results in Table 5.2 in Chapter 5, indicates sustainability concepts are understood in three different contexts with varying interpretations and usage. These are the views and thoughts of the sustainability concepts by the respondents; - (1) sustainability is a target to be achieved within the worldview requirements, (2) others pointed out that sustainability is required for infrastructure development, and (3) some considered sustainability as a platform for human survival. This finding aligned with the views of Klarin (2018) that sustainable development aids in preserving the limits of the planet's environment while meeting the diverse needs of the people.

Therefore, the identified categories of sustainability interpretations at the project level for Nigeria should be harmonised for robust sustainability initiatives at a highway project level. In addition, sustainability has diverse interpretations, which can only be consolidated for implementation through the minds, experience and understanding of the project-level participants.

The insight gained from the project-level participants on sustainability perception revealed that sustainability knowledge can only be implemented through organisational learning and personal development using continuous professional development offered by commercial third parties and through engineering conferences held in Nigeria.

The participants critiqued that since there is no agenda at the project level to practice sustainability, the little knowledge gathered through training and conference are unlikely to provide any meaningful platform to practice sustainability in projects.

It was noted that engineers working as research scholars within the Nigerian university stated that sustainability insight is mostly gained through mainstream media publicity, that is, promotion through sponsored commercial advertisements on pollution reduction and climate change catastrophe, which is a campaign by the United Nations, and related non-governmental agencies. At the highway project level, participants acknowledged that the term sustainability is not common within the Nigerian project context, and there is no mathematical model to assist in determining the implementation.

Participants were asked to identify and differentiate sustainable development models. Some responses suggested sustainability comprises society, the environment, and the economy. Others pointed out that sustainability helped preserve the human environment. To some, the pattern of sustainability is vague, uncertain, and practically impossible to understand at the project level. Insight gathered from the interview suggested that the terms and usage of sustainability are unclear to the client and the performing contractors. Therefore, it is difficult to give a meaningful effect and interpretation of something that is not in place for use. Some project participants are unable to define categories of sustainability models within the context of social, environmental, and economic factors. Their primary knowledge focused on protecting the environment using recycling of earthwork materials based on project contract, cut and fill criteria.

To gain insight from the project-level practitioners on awareness of sustainability tools utilised at the site, they identified highway design manuals, geotechnical reports, and environmental impact assessment protocols. A significant finding revealed that sustainability is considered only suitable for major highway projects and should not be applied to medium to small-scale highway projects. These result findings confirmed findings from the earlier work of Du Plessis (2005) that Africa lacks suitable frameworks needed to fulfil social needs cultural and biophysical assessment of development impact across society.

7.2.2 Sustainability indicators for design and construction

Participants were presented with all the listed indicators for exclusion, inclusion, and validation (36 design and 53 construction indicators). Findings revealed that a total of 87% of the interviewees accepted the sustainability indicators presented. However, suggestions and inputs was given by participants for this research to consider adding a few more indicators (refer to Table 5.3 for miscellaneous indicators, which are triangulated using quantitative data from Chapter 4). It is noted that in cross-checking the miscellaneous indicators with the 36 design and 53 construction indicators, some duplication was noted and removed (Table 5.3). It is evident from the current research results that these sustainability indicators required an attribute to enable project-level participants to understand how to use and implement sustainability in highway projects.

The above findings aligned with the assertion made by Luczak and Just (2021) that sustainable development is not a process that can be measured directly. It is only feasible to characterize measurement using certain quantitative variables and tools.

Figure 7 displayed a summary of key points gathered from the interview for a contribution towards sustainability practices for the Nigerian highway design and construction sector.

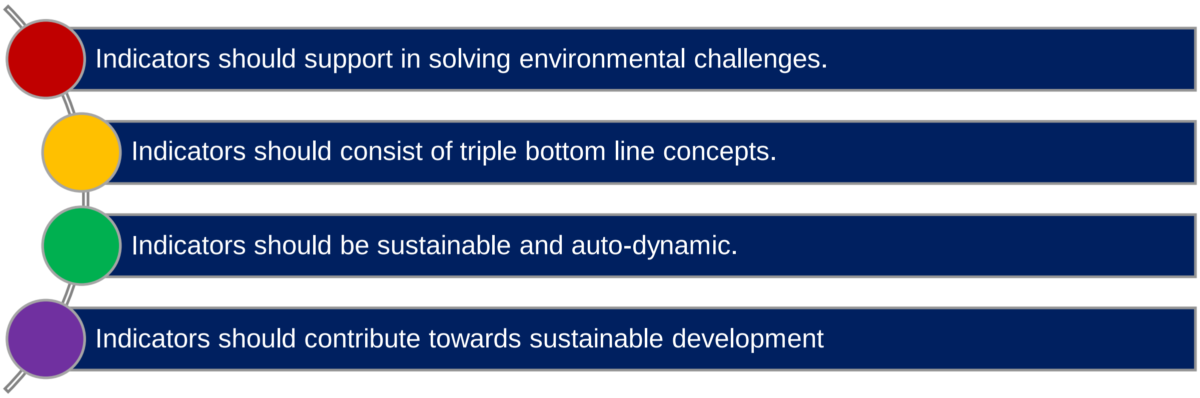


Figure 7 Project-level goals to be achieved using sustainability indicators.

7.2.3 Factors influencing sustainability implementation.

According to the project-level participants' interview insight, factors influencing the implementation of sustainability during highway development are lack of sustainability standards, no existing data to support sustainability practices, and low interest among government officials involved in highway development. The findings from the interview demonstrated that some organisations, for instance, foreign multi-nationals companies developing infrastructure projects for the Nigerian government, recognized the benefits associated with sustainability projects. However, there is no portfolio enforcing policies or driving force to implement sustainability at the highway project level in Nigeria.

It was pointed out during the interview that benefits associated with sustainability cannot be determined because there is no practice of any kind or knowledge base point of reference. The identified significant disbenefits, for instance, are the non-sustainability implementation, which resulted in a release of GHG emissions and depletion of natural resources (Espinoza et al., 2019).

According to the project-level participants, hindering factors in achieving a sustainability agenda are finance, technology, knowledge, and policies.

It was noted from the interviewees that a common factor influencing sustainability implementation during highway development is the type of procurement strategy adopted by the client, which focused on the project management cost approach rather than the use of sustainability concepts.

Given the above, the reason for no demand for sustainable construction is because of vague and imprecise understanding of the theory and practical implications (Coker et al., 2021). To address the low level of understanding of sustainability practices, ambitious targets have to be proposed for administering principles of sustainable construction strategies for the Nigerian highway sector.

The participants stated that there is dissatisfaction among stakeholders concerning project delivery style in Nigeria, and there is hesitation in adopting green construction among stakeholders because of uncertainties in completing the projects within the original scope.

A notable finding from the interview revealed that government parastatals within Nigeria undertake road and highway construction using developed bespoke contracts, and they perceive development as their organisational priority using their development preferences rather than sustainability concepts to prevent adverse impacts on the environment.

7.3 Research Findings from project case studies

As stated in Chapter 6, project case studies for this research aimed to measure the extent of sustainability application at the highway development project level. To quantify sustainability, a rating system must be used as a measuring tool to determine best practices (Suprayoga et al., 2020). Earlier discussions in Chapter 6 found out that the sustainability agenda and goals was not considered from the inception of the highway project level development for Nigeria (see Figure 6.8 page 211 for displayed noted sustainability gaps in Nigerian highway projects). The limited achieved sustainability best practices are in two categories: —

1. Foremost, the contractor's partial sustainability implementation through good faith and accountability in performing contractual duties in the project.
2. Secondly, the contractor develops a unique sustainability concept in solving identified defects in their project.

7.3.1 Sustainability framework and sub-logic

Considering findings from the questionnaire survey level of opinion, interview and project case studies interviews, observation and site visit observation, an integrated highway design and sustainability framework is developed for this research, see Figure 7.1, and indicator decision sub-logic for highway design and construction, see sample in Figure 7.2 and please refer to (Appendix F) for the 36 design and 53 construction sustainability indicator decision sub-logics.

The established sustainability framework was validated at the highway project level by the participants for inclusion using a 'review'. The primary review is to verify the logical links of sub-elements, such as the drivers and motivation for project-level sustainability strategies, the project-level goals to be achieved using sustainability indicators, factors to counter sustainability influence at the project level, and the overall motives of the indicators across the highway project lifecycle. All the factors identified within Figure 7.1 are considered a baseline for sustainability implementation. The created sustainability indicator decision sub-logic and attributes will enable project-level participants to implement sustainability practices during highway development (refer to Appendix 'F').

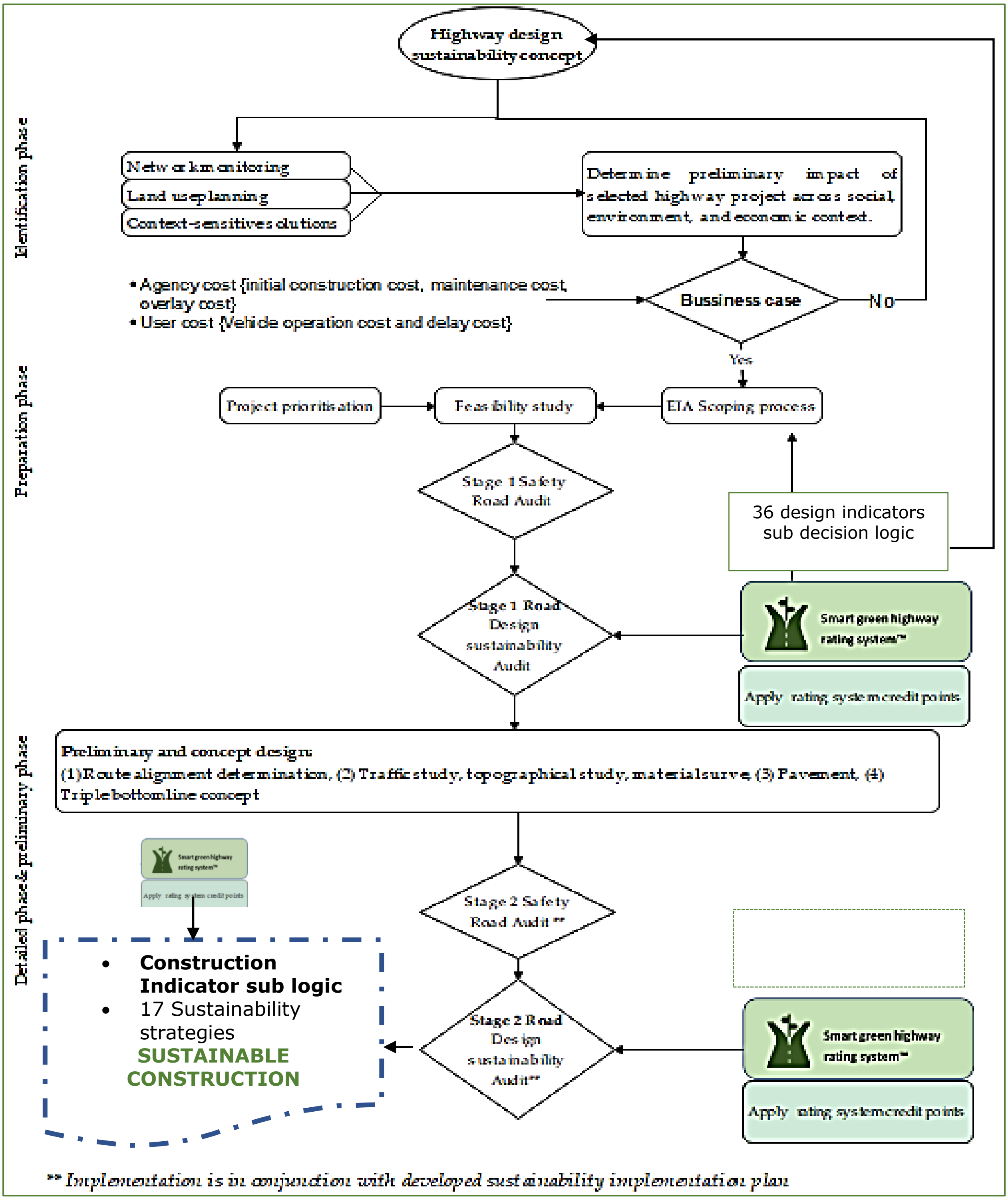
Figure 7.1, the sustainability framework clearly defines interdependencies between sustainable design concepts and the various stages of a checkpoint on the level of sustainable design and construction. Another significant feature within Figure 7.1 is the retained statutory requirements, such as environmental impact assessment (EIA) scoping. In addition, the EIA must be subject to assessment using sustainability indicators.

Figure 7.1 includes the integrated sustainability development strategy across highway project requirements and how it can be utilised for human survival in Nigeria. The aim of fulfilling project participants' motives enabled the project to achieve unique best practices given the identified framework for sustainable highway development; this research advances in establishing the decision sub-logic for each indicator attribute (refer to Appendix F and Figure 7.2). It facilitates project participants to understand what is likely to occur when sustainability opportunities are missed. And the likely benefits when sustainability is implemented.

7.3.1.1 Connection between the discussion and analysis

The aim of the quantitative data collection approach in this research was to determine the highway design and construction sustainability strategy utilised within the global context and to add such identified best practices in developing the Nigerian sustainability highway design and construction. Findings achieved, as stated in items 7.1.2 and 7.1.3, revealed the 17 highway sustainability strategies and the 36 design and 53 construction indicators are considered optimal. This consideration of best practices was added to the development of the sustainability framework in Figures 7.1 and 7.2. The qualitative data collection and analysis revealed the level of sustainability awareness and expectation of sustainability practices required for highway design and construction within the Nigerian context. The focus of the findings suggested that participants propose the use of pertinent indicators to support reducing adverse impacts of unsustainable highway development in Nigeria. These findings above are added as input into developing Figure 7.1. The indicators that emerged from quantitative and qualitative were utilised to measure highway projects in Nigeria as a case study, which revealed sustainability knowledge gaps and few identified best practices. The result findings contributed to the development of the framework and indicator decision sublogic.

Figure 7.1 Highway Design and sustainable construction framework



INTEGRATED PROJECT-LEVEL PERCEPTION OF SUSTAINABILITY

PROJECT LEVEL GOALS TO BE ACHIEVED USING SUSTAINABILITY INDICATORS.

7.3.2 Developed decision logic sub-framework for highway development

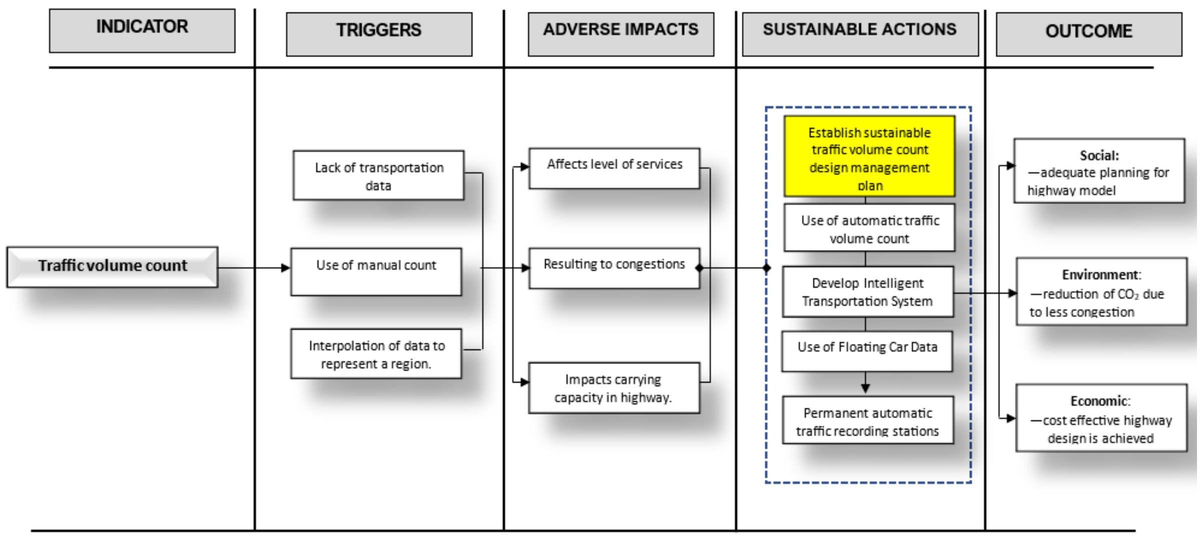
Figure 7.2 displays the decision sub-logic, which is a system that represents a process towards achieving a set of sustainability strategies. The process within the framework is considered an overall opportunity to solve a problem as identified during the project case study. The key aim of the decision logic is to explain processes involved towards the implementation of sustainability indicators. This concept was adapted from the earlier work of Yang and Lim (2007), which was utilised to resolve integrated retrofitting in commercial buildings. This research developed a sustainability indicator decision sublogic to represent the implementation of sustainability concepts in highway development in Nigeria. The decision sublogic helped to integrate the best practical guide and logical knowledge for project-level participants in Nigeria, who are not knowledgeable on sustainability development. The subheading of the process decision sublogic is organised according to the following: —

1. INDICATOR— the source of sustainability practice developed in this research.
2. TRIGGERS— which implies causes of unsustainability issues in a project.
3. ADVERSE IMPACTS— due to unsustainable project practices.
4. SUSTAINABLE ACTIONS—steps identified to address triggers and impacts.
5. OUTCOME—the results and measurable objectives across triple constraints of social, environmental, and economic benefits.
6. SUSTAINABLE RECOMMENDATIONS- these are key recommended actions to be considered by project participants while utilising the processes within the sustainable indicator decision logic to achieve highway sustainability.

The INDICATORS are the 36 design and 53 construction sustainability indicators developed in this research. The TRIGGERS are the causes of unsustainability practices, as identified through the project case studies conducted through this research. The ADVERSE IMPACTS are the direct negative effects on the projects and environment when the sustainability concept is unimplemented. The SUSTAINABLE ACTIONS are good sustainability practices, which is a requirement to achieve sustainability in a highway project. The OUTCOME is the measurable benefit of sustainability. The overall sustainability indicator decision logic sub-framework was validated at the highway project level in Nigeria. See appendix 'F' for a detailed decision sub-logic for the 36 design and 53 construction sustainability indicators. The contents of the logic are the project participants agree upon best practices suitable for sustainability practices.

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R1: Traffic Volume Count (Technical Category)



INDICATOR R1: Traffic Volume Count

TRIGGERS	ADVERSE IMPACTS
• Lack of sustainable transportation data • The use of obsolete traffic manual count • Interpolation of data to make decisions.	• Inadequate design of required service level for the highway project. • Inadequate design results in congestion. • The highway carrying capacity and space is under-utilised.

SUSTAINABLE RECOMMENDATIONS
• The use of a sustainability action plan for traffic volume count management, helps to establish the needed sustainability goals over time, and the best practices needed for improvements. Determined within the sustainability action plan are the notable gaps in the use of dated traffic volume count, and the impact across the social, environmental, and economic fabric of the designed project, versus the society and environment. • The use of the traditional traffic road sensor, for instance, inductive loops for traffic volume count detection can be utilised in the collecting of data across highways passing through remote areas in Nigeria. • The Floating Car Data (FCD) is a highway-quality source of data reliable in developing an Intelligent Transportation System (ITS). The ITS helps provide a mode of various types of transportation management systems, which is called "smart network". For instance, traffic speed, traffic congestions, and travel time of a car can be calculated. • The use of Floating Car Data (FCD) is effective in collecting robust traffic volume data using mobile GPS and a fixed detector across a region. • To determine average annual daily traffic (AADT), establish permanent automatic traffic recording stations for the continuous counting of traffic volume for 365 days or as desired by standard. The data are taken at intervals of 15 minutes or hourly in principle.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Within the social context, sustainable traffic volume count provides a better understanding of the level of services of planning required and determines types of collision rates. A traffic volume survey helps determine the level of road users' satisfaction with the perception of noise, and air pollution. • Within the environmental context, the use of Floating Car Data supports the development of an Intelligent Transportation System, which is an integrated approach to achieving an eco-driving experience in reducing carbon emissions resulting from traffic congestion. • Within the economic context, cost-effective highway design is achieved.
Credit point awarded to implement best practices = 1

Figure 7.2 Sample sub-logic for sustainability highway development

7.4 Chapter Summary

This chapter discussed the outcomes of the questionnaire survey, analytical hierarchy process, interview, and project case study findings in chapters 4, 5 and 6, respectively. First, findings from the quantitative dataset approach included global project-level participants expressing their opinions in accepting the presented 17 sustainability strategies utilised in highway development.

Similarly, the 36 design indicators presented in four distinct categories and 53 construction indicators presented with six distinct categories are acknowledged by the Nigerian project level participant as being sustainable in serving as the baseline to resolve unsustainable adverse impacts across the society due to highway development. The results of the Likert scale indicator values were categorized into high, middle, and low priority ranking. The results achieved contribute to knowledge; for instance, these indicators are relevant towards reducing the impact of unsustainable highway development. It supports developing resilient infrastructure, thereby giving recognition for making sustainable contributions.

The next phase of the results and discussion is the qualitative interview, and discussions involved awareness of sustainability concepts and findings which revealed there is a sustainability knowledge gap at the Nigerian project level. The indicators that emerged from the questionnaire survey were presented to project participants to determine further inclusion and exclusion to the set of 36 design and 53 construction indicators. Suggestions were made for inclusions, and findings revealed these newly added indicators are repetitions and have no additional benefits.

The final phase is the project case study utilised to measure the developed sustainability rating system with ongoing highway design and construction projects in Nigeria. The aim is to understand how best practices are achieved and the noted gaps. The results and findings from the quantitative, qualitative and project case studies assisted in developing a highway design and construction framework and indicator decision sub-logic for Nigeria.

CHAPTER 8 CONCLUSIONS

8.1 Introduction

This research presented an appraisal of sustainability strategies utilised globally in highway construction, factors influencing the implementation of sustainable highway development in Nigeria, and the adverse impact that evolves from the use of unsustainable highway development practices. As a result of the identified knowledge gap. A mixed method and project case studies was used to develop sustainability indicators and indicator decision sub-logics to reduce adverse impacts during unsustainable highway development and to create sustainability awareness among the Nigerian highway project level participants.

The purpose of this chapter focus on the conclusion of this research, recommendations, and considerations for conducting future research in this field. To achieve afore stated, this chapter reiterates the research aim, objectives, and questions of this research to indicate how these have been met in contributing to the existing body of knowledge and the limitations summarised.

8.1.1 Reiteration of research aim and objectives

Conducting this research is inspired by the adverse impact of unsustainable highway development practices and the adverse impact on society, as noted in the literature for Nigeria. The factors influencing the adoption and implementation of sustainability in Nigeria was evaluated. This research identified there had been past research efforts recommending the use of recycled industry by-products to implement sustainability during highway construction across Nigeria. Previous studies have not investigated unsustainable highway development impacts through the lens of the Nigerian environment. As noted, the use of mixed-method and project case study was utilised in collecting data in arguing to achieve the research aim, objectives, and research questions.

This research developed a sustainability rating framework and indicator decision sub-logic for highway design and construction for Nigeria, which was achieved using the below objectives; —

1. Identified and critically explored highway sustainability development concepts utilised globally.
2. Appraised benefits and disbenefits associated with sustainable highway design and construction.

3. Examined factors affecting the implementation of sustainable highway development in Nigeria.
4. Identified local sustainability indicators for reducing adverse impacts due to highway development in Nigeria.
5. Developed a sustainability framework and indicator decision sub-logic for Nigeria's highway development.

8.1.2 Research objective 1

This research reviewed critical highway construction sustainability development strategies utilised globally (refer to Section 2.6.1). Based on literature review findings and results of data collected using a questionnaire survey, the sustainability strategies utilised globally during highway development are summarised; —

1. There are identified benefits in the use and implementation of a sustainable procurement strategy. A green procurement strategy is a contract-based system of encouraging and guaranteeing the use of sustainability during road construction (Garbarino et al., 2016). Due to the adverse impact of highway development. There are benefits associated with using and implementing sustainable green procurement (Butt et al., 2015). Sustainable green procurement determines project requirements and expected contractors' sustainable technical abilities to foster innovative design solutions with different ambitions in reducing the adverse impact of development.
2. Organisational learning aligned with the concept of sustainability helped to support sustainable project delivery (Opoku and Fortune, 2011). Organisational learning is achieved using continuous professional development (CPD). Especially when the CPD is positioned towards delivering sustainability learning objectives. Sustainability in highway development is new and evolving. The use of CPD concepts enables project-level practitioners to acquire knowledge and improve their skills in reducing impacts resulting from environmental climate change (Ajayi, 2022).
3. The implementation of low carbon footprint materials and the use of a carbon management approach at the project site (Shi et al., 2012; Karlsson et al., 2020; Uchehara et al., 2020; Peng et al., 2020) helped in

reducing carbon emission. The Intergovernmental Panel on Climate Change has pointed out that efforts should be made globally to prevent the earth from a temperature rise of more than 1.5^{O}C. To achieve this target, the construction industry is encouraged to adopt and implement the use of recycled materials for road and highway construction (Ojuri et al., 2022).

4. Adopting and implementing context-sensitive solutions (CSS) as an avenue in engaging with the communities to gather inputs towards developing sustainable highway projects (Weiner, 2016). The use of context-sensitive solutions is primarily a collaborative measure using an interdisciplinary approach to involve relevant stakeholders in providing solutions for the development of transportation facilities. The use of context-sensitive solutions aims to develop the physical settings in the development of highway facilities. These physical highway settings are the use and control of environmental resources, safety, mobility and route connection between the communities and the highways to be developed. During context-sensitive solutions, inputs are required from stakeholders on the level of aesthetics required, the type of scenic views, the land use, and how to preserve areas with cultural significance.
5. Sustainable project governance manages green thinking in design, ensuring that sustainable, innovative ideas implemented do not affect the overall project timeline in meeting sustainability goals (Art and Faith-Ell, 2012; Zhang et al., 2023). Sustainability development is new in highway projects. Therefore, the use of sustainable governance is essential to manage the main and subcategories of sustainability strategies (Mohandes et al., 2023). The use of sustainable governance helped to accomplish stability in managing the sustainability agenda, which requires a longer time to plan to deliver innovative solutions. The need to maintain consistency in the delivery of sustainable solutions throughout the highway project lifecycle requires sustainable project governance. This consistency required in sustainable governance is the use of procurement in achieving the implementation of renewable materials, and holding meetings and discussions on risk mitigation in the adoption and implementation of sustainability strategies.

Within the Nigerian context, sustainability strategies are lacking (Coker et al., 2021). Through literature review, a list of 17 highway sustainability strategies was identified and presented through an online questionnaire survey to gain the opinion of project-level participants globally. These identified sustainable highway strategies are; sustainable procurement, sustainable design, innovative construction processes, continuous professional development, climate change adaptation design, reducing consumption of resources, protecting biodiversity, recycling waste and reuse, using renewable energy, avoiding pollution, using lifecycle cost analysis, context-sensitive solution, governance in projects, use of advance technology for smart design, sustainable safety management, social consideration and use of law carbon footprint materials. The opinion results achieved from the online questionnaire were optimal for the sustainable development of highway projects (refer to Chapter 4 Section 4.3).

Research objective 1 assisted in gaining insight from the literature and data collected on the benefits associated with the highway sustainability strategies utilised globally. This contributed to building a sustainability framework for Nigerian highway development. Therefore objective 1 is achieved.

8.1.3 Research objective 2

The benefits and disbenefits associated with sustainable highway design and construction are reviewed within the context of three pillars of sustainability, namely, social, environmental, economic, and technical aspects (refer to Section 2.4.3 and Table 2.5). The benefits and disbenefits of highway sustainability are summarised; —

1. The benefits of sustainability include reduced use of natural resources, elimination of carbon emissions, use of renewable energy, and creation of a healthy non-toxic environment (Purvis et al., 2019; Gardoni and Murphy, 2020). Sustainability benefits are vital goals that need to be achieved to enable the co-existence of human development and the environment. The benefits of sustainability in highways support social demand and encourage economic growth while reducing adverse negative impacts across the natural environment. The associated benefits of highway sustainability are embedded in the concepts of sustainability rating systems. These associated benefits are the ability to develop and

build resilient infrastructure projects, improve quality of life, and encourage the use of modern innovation in sustainable design.

2. The multidimensional characteristics of highway projects desire the use of four pillars of sustainability to enhance benefits across social, economic, biophysical, and technical factors (Hill and Bowen,1997; Arukala et al., 2019). The social dimension of sustainability implemented in highway projects resulted in a liveable society with a good quality of life. Social sustainability in highways is utilised to measure traffic tyre noise with different asphalt pavement alternatives to determine the health and safety of road users (Inti and Tandon, 2021). This social sustainability evolution in highway development is achieved using the traffic noise model (TNM). The social benefits of sustainability assisted in improving human life, seeking an equal distribution of social benefits, and protecting human health (Raheem and Ramsbottom, 2016). The summary of this is that social sustainability in highway project development included— caring and respecting communities, ensuring an improved quality living standard as a result of highway development, — ensuring diversity in empowering the communities through employment, guaranteeing social equality among diversities, change in attitude towards the use of sustainable development practices, and showing accountability during the development of highway projects.
3. The economic sustainability dimension focused on providing highways with minimal cost of development. The common approach identified in the literature is using lifecycle cost analysis, which is a model utilised to compare and contrast the agency cost and user cost of highway projects. The lifecycle cost analysis is also a subset of benefit-cost analysis, and this tool is used to determine the cost and benefits of selecting an alternative highway design. Other benefits of lifecycle cost analysis in sustainable highway development are to determine the initial construction cost, the user cost, and the rehabilitation cost. This model provides a structured approach to address cost-related issues in developing sustainable highway projects. Within the Nigerian concept, there is review evidence of failed projects due to a lack of economic sustainability models (Anigbogu et al., 2019; Eja and Ramegowda, 2020).

4. The benefits of the technical dimension of sustainability are required for the performance of the infrastructure in terms of resilience (Gardoni and Murphy, 2020). Within the Nigerian context, there are knowledge gap in developing highway projects using sustainability technical knowledge. The emphasis considered here is that each of the technical elements in highway design should be measured using three pillars of sustainability.
5. Sustainability benefits identified from advanced countries like the United Kingdom and Australia established pragmatic steps in building resilient and sustainable projects (Geissdoerfer et al., 2020; Magbool et al., 2023). The United Kingdom Construction 2025 aimed to achieve a 50% reduction in greenhouse gas by 2030 and net-zero emissions by 2045. It is estimated that using the Construction 2025 sustainability agenda, project delivery will increase by 50% with a 33% reduction in whole lifecycle cost, and UK companies are estimated to participate in 70% growth in global sustainable construction projects before 2025. This innovative approach and the achievements using Construction Strategy 2025 are ascertained to be progressing according to this study (Maqbool et al., 2023). The benefits of sustainability identified from the literature suggested that investing in people to have digital knowledge of carbon technology helped in reducing climate change impacts (Giest, 2017). The benefits of sustainability in construction include the use of smart design and construction to develop infrastructure worthy of reducing the impact of the climate change catastrophe (Chen et al., 2015; Montgomery et al., 2015; Haider, 2019).

This research used qualitative data collected to gain insight into the perceived sustainability benefits from the Nigerian project-level participants. The received response revealed that the benefit of sustainability is the reduction of adverse impacts of highway development across the Nigerian environment.

It was noted that the associated disbenefits of sustainability are the adverse impact faced when unsustainability practice is implemented (Espinoza et al., 2019). Objective 2 contributed to developing the sustainability indicator sub-logic for this research because it outlined designated benefits and disbenefits when sustainability is implemented and when it is not. Therefore objective 2 is achieved.

8.1.4 Research objective 3

Research objective 3 focused on identifying the issues affecting the implementation of sustainability highway design and construction in Nigeria. Through literature, these factors affecting sustainability adoption are categorised into distinct groups, namely, societal challenges, technical challenges, environmental challenges, economic challenges, engineering challenges, project management challenges and safety and health challenges (refer to Table 2.8, and 2.7.4.1 to 2.7.4.4); -

1. societal challenges, which is the exclusion of affected communities and stakeholders in providing inputs using context-sensitive solutions (CSS) in highway project planning,
2. technical challenges, which is the knowledge gap in developing resilient infrastructure and innovative highway design,
3. lack of economic model and deficient use of lifecycle cost analysis.

Identified through literature is the lack of sustainability measurement standards, and practices in Nigeria, which are part of the major issues affecting sustainability implementation (Olowosile et al., 2019; Coker et al., 2021).

Interview data collected from Nigeria's project-level participants on the challenges facing sustainability implementation— identified impeding factors, which are the non-existence of data to support sustainability learning, the absence of technology, the use of traditional procurement strategies that do not promote sustainability concepts, and the general lack of stakeholders' buy-in.

A major finding in objective 3 is the absence of a sustainability framework, which could have aided in attaining standard sustainability practices during highway development. Therefore, objective 3 is achieved.

8.1.5 Research objective 4

This stage involved data collection and results from Chapters 4, 5 and 6. The result findings and triangulation assisted in determining answers to the research questions. All the research results and findings are summarised in Chapter 7; therefore, objective 4 is achieved.

8.1.6 Research objective 5

Discussion and findings established in (Chapter 7) enabled the development of an integrated highway design and construction sustainability rating framework and indicator decision sub-logic for design and construction (please refer to Figure 7.1; Figure 7.2 and see Appendix 'F').

8.2 Assessment of research questions

The research questions guided this research to focus on solving the various identified problems, which are researchable and relevant. The research questions are clearly connected, which is established around the central research problem statement in section 1.3. The type of questions asked in this research is derived from the research objectives. Therefore, the questions are listed below; -

1. What are the current sustainability strategies utilised for highway development globally?
2. How will the benefits and disbenefits of sustainable highway development be identified?
3. What are the critical issues influencing the implementation of sustainable highway development in Nigeria?
4. What are the appropriate sustainability indicators that can resolve unsustainable highway development practices across Nigeria?
5. What is the sustainable framework adequate to reduce the impact of highway development in Nigeria?

Table 8 is a summary of what was achieved in answering research questions.

Table 8 Research questions and answers

Research questions	Research achieved answers/ Findings	Measurement type
1. What are the current sustainability strategies utilised for highway development globally?	The presented 17 highway sustainability strategies achieved through quantitative survey, the achieved results are optimal in reducing the impact of unsustainable highway construction (chapter 4)	Findings aligned with literature.
2. What are the benefits and disbenefits of sustainable highway development?	Through literature, the benefits are identified across the three pillars of sustainability. Using qualitative data collected at the project level, the benefits reduce the adverse impacts of highway development in Nigeria (Chapter 5). Disbenefits are when sustainability is not implemented at the project level.	Findings aligned with literature.
3. What are the critical issues influencing the implementation of sustainable highway development in Nigeria?	Critical issues influencing sustainability implementation in highway development in Nigeria were identified through the literature and qualitative interviews held with practitioners from Nigeria (Chapter 5). These critical issues are the lack of knowledge, data, and stakeholders' buy-in.	Findings aligned with literature.
4. What are the appropriate sustainability indicators that can resolve unsustainable highway development practices across Nigeria?	The use of quantitative, qualitative and project case studies to determine 36 design and 53 construction indicators (Chapter 4, Chapter 5, and Chapter 6). This identified the basis for developing a solution for the sustainability agenda for Nigeria's highway development.	Correlation of Likert scale results achieved. Triangulation of quantitative data with existing rating systems. Triangulation of quantitative and qualitative data.
5. What is the sustainable framework adequate to reduce the impact of highway development in Nigeria?	An integrated sustainability framework and indicator decision sub-logic is developed for highway design and construction in Nigeria (Chapter 7).	The framework is endorsed by experts' practitioners in Nigeria.

8.2.1 Research contribution to academic knowledge

According to Phillips et al. (2022), originality in research is, setting down new information in writing for the first time, such as carrying out empirical work that has not been done before. Originality in research contributes to knowledge (Gill and Dolan, 2015). Originality is the application of existing knowledge using methods, methodology, data, and techniques to develop new interpretations and findings in contributing to the existing body of knowledge. This research contributed to academic knowledge by using research methods to fill the noted gap in the literature in these key areas: —

1. This research used a sustainability back-casting model and quantitative data approach to identify 36 relevant designs and 53 construction indicators for highway sustainability development. The triangulation of these indicators using existing rating systems assisted in consolidating the indicators' contribution to the three pillars of sustainability. Previous literature only focused on the use of recycled by-products for sustainable asphalt pavement construction in Nigeria (Oluwatuyi et al., 2018; Bamiaboye et al.,2021; Ojuri et al., 2022).
2. A qualitative approach is used to gain insight from highway design and construction participants on the key expectation of what sustainability should look like within the context of Nigerian highway development. This included developing a framework adequate for reducing adverse impacts of highway development. Gaining insight using qualitative methods revealed factors impeding sustainability, such as the lack of sustainability standards.
3. The project case studies conducted in Nigeria highway projects gave insight into the gap in practice. The collected evidence suggested sustainability was not considered from the inception of the highway project development in Nigeria. This resulted in the development of an integrated design and construction sustainability framework for Nigeria. The developed framework contributed to existing knowledge on how sustainable design and construction be achieved.
4. The developed 36 design decision sub-logics and 6 group decision sub-logics for sustainable highway construction consisted of what should be done to achieve sustainability best practices (refer to Appendix 'F'). Likewise, when sustainability is not carried out for a particular indicator or

groups of indicators, the likelihood of the adverse impact is identified within the decision sub-logic. The decision sub-logic consists of actions needed at the project site to achieve sustainability across the three pillars of social, environmental, economic, and technical aspects. The decision sub-logic had descriptive information on the sustainability implementation agenda in highway development.

8.2.2 Contribution to industry sphere knowledge

As noted earlier in Chapter 1 (refer to 1.1 and 1.3), traditional highway infrastructure development across Nigeria is associated with adverse environmental impacts. The sustainability knowledge gaps are considered a drawback, which is a hindrance due to project-level practitioners' lack of knowledge.

This research established and developed 36 design and 53 construction indicators, with the indicator decision sub-logic to guide project-level participants on how to implement sustainability. These developed best practices are suitable for reducing unsustainable development practices during highway development in Nigeria.

The current research developed a sustainability framework that can improve performance in achieving sustainable practices across highway projects in Nigeria. For instance, in developing resilient highways with recognition for making sustainability contributions, the framework fosters a modern method of innovative development and design of smart infrastructure. The research-developed indicators serve as a benchmark for developing African countries to emulate practical approaches in creating a sustainability framework.

This research-developed framework assists the Nigerian transportation agencies, project-level practitioners, stakeholders, contractors, consultants, and client representatives in achieving the following for the industry; —

1. Act as a baseline in measuring highway sustainability practices in projects.
2. It serves as a collaborative tool for project-level practitioners in achieving sustainability best practices across the highway project lifecycle.
3. Created sustainability awareness for stakeholders using organisational learning and continuous professional development.

8.2.3 Research limitations

The limitation considered has an impact on the quantitative research finding.

1. The limitation of this study is associated with the choice of sampling in the AHP pairwise comparison matrix. Given the participants' level of opinion in assigning pairwise comparison matrix across 36 design and 53 construction indicators. A total of 4 experts' opinions from Nigeria were selected to participate in the design and construction of pairwise comparison matrix data collection. This limited AHP sampling population affected the level of quantitative research results (due to the lack of noted correlation within AHP results). In this case, the decision taken by the researcher was to adopt results achieved only using Likert scale values to determine indicators top, middle, and low priority ranking for the 36 design and 53 construction indicators (refer to Table 4.19).

In this research, the design population sampling choice for the AHP was conducted based on the literature review recommendation that a single experienced participant or a maximum of a group of seven people can aid in determining the AHP pairwise comparison matrix (Saaty and ÖZdemir, 2014).

8.2.4 Recommendation for Future research

This section brings the research to a conclusion with the below recommendations.

1. Future research within this field should consider conducting both qualitative (interview) and quantitative (questionnaire survey) globally to determine sustainability strategies utilised in highway development. This helps to gain deeper insight into current sustainability frameworks in developed countries and to determine where it will benefit developing countries.
2. Future research should consider using between 6 - 7 participants for the AHP pairwise comparison data collection.
3. This research did not venture into the cost of sustainability. Future research should determine the impact of the cost associated with sustainability in highway projects.

4. Other sub-Saharan African regions should expand sustainability knowledge using the knowledge contributions from this research to develop a sustainability rating system for building highways and roads.
5. Future research should consider measuring to determine additional credit points for each indicator developed in this research, which is based on best practices implemented at the highway project sites.

8.2.5 SWOT analysis on research and personal reflection

STRENGTH +	WEAKNESSES -
1. Academically valuable to researchers and project practitioners in highway projects. 2. Beneficial as educational material for developing countries considering how to commence sustainability development.	1. The developed framework applies only to the Nigerian highway sector. 2. Policy recognition is required from the Nigerian government to boost sustainability implementations in highway development.
OPPORTUNITIES +	**THREAT -**
1. Transform the highway sector from a traditional to a sustainable sector using innovative methods of development. 2. Join global advanced countries in contributing to sustainable development and advancement in knowledge. 3. Contribute to transforming obsolete environmental policies into sustainability policies.	1. The cost is yet undefined for a sustainable development strategy. 2. Requires training of personnel through a new certification programme and CPD, change in the learning curriculum, which alters the status quo. 3. There may be a lack of buy-in by some stakeholders threatened by this new paradigm (along with supply chains).

A strength, weaknesses, opportunities, and threats (SWOT) analysis is used to evaluate the situational assessment of a strategic position (Benzaghta et al., 2021). The SWOT opportunities for this research are summarised in the above table.

APPENDIX 'A'

Sample consent letter

Ref / UI / Research / XX / XXX

TO WHOM IT MAY CONCERN

Dear Sir

Request to conduct project site research interview on Sustainable "Highway Design and Construction for Nigeria."

I am the Principal Supervisor for Mr. Ikechukwu Uchehara, a Nigerian citizen currently conducting his PhD research at the Scott Sutherland School of Architecture and Built Environment, the Robert Gordon University Aberdeen, Scotland. His research project is focused on the "possibility of developing a sustainability assessment rating system for highway design and construction in Nigeria", in which context he is currently seeking to identify issues with regards to implementing sustainable highway design and construction in Nigeria.

To identify critical issues impeding sustainability initiatives, the involvement of expert teams of engineers is crucially important. I, therefore, request Mr. Ikechukwu Uchehara be permitted to access appropriate road and highway construction project sites in the Abuja, Nigeria environment and to conduct academic interviews with project team members. The value of the data collected from the project site will provide insight into factors to be considered when developing a sustainability framework relevant to successful highway design and construction. Mr. Ikechukwu Uchehara plans to commence onsite research.

Following the Robert Gordon University data protection and management policy, all responses will be kept confidential, and no reference shall be made to a specific individual within the PhD research thesis. All data/information collected will be anonymized. After the completion of the studies, all data will be destroyed.

If you have any queries at any time, please do not hesitate to contact either myself.

Dr David Moore (PhD) – Principal Supervisor (d.moore2@rgu.ac.uk), or

Mr Ikechukwu Uchehara (MNSE, COREN) – PhD research student (i.uchehara@rgu.ac.uk)

Thank you in anticipation of your support for this research.

Yours sincerely

David Moore ***(Principal Supervisor)***

APPENDIX 'B'

Robert Gordon University

RESEARCH ETHICS: RESEARCH STUDENT AND SUPERVISOR ASSESSMENT (RESSA) FORM (**Extract**)

PART 2: Impact of the research		
In the process of doing the research, is there any potential for harm to be done to, or costs to be imposed on	**Yes**	**No**
(a) research participants?		
(b) research subjects?		
(c) you, as the researcher?		
(d) third parties?		
When the research is complete, could negative consequences follow:	**Yes**	**No**
(a) for research subjects		
(b) or elsewhere?		
Does the research require informed consent or approval from	**Yes**	**No**
(a) research participants?		
(b) research subjects?		
(c) external bodies?		

APPENDIX 'C'

Table C1 Likert Scale questionnaire prototype **(Highway Design)**

Developing a sustainability rating system for the Nigerian highway design
PART A: (Demography information of participants) **Q.1: Please specify your profession** □ Civil Engineer □ Construction Engineer □ Construction Manager □ Project Manager □ Project Director □ Quality Engineer □ Quality Manager □ Others **Q.2 Have you been involved in highway construction decision-making** □ 0 – 5 years □ 5 – 10 years □ 10 – 20 years □ 21 years and above
Part A: Q.1: Awareness of the concept of sustainable highway design? Q.2: Have you made use of the existing sustainable design protocol? Q.3: Identify the sustainable highway design protocol used? Q.4: Rank the usefulness of the sustainability tools and design protocol used? Q.5: Have you been involved in decision-making in sustainable highway design?
Part B: Assign the Likert scale to a range of indicators (1= not significant to 5= very high significant)
Q.6: Technical sustainability indicators (R1 – R11)? Q.7: Environmental sustainability indicators (R12 – R27)? Q.8: Economic sustainability indicators (R28 – R31)? Q.9: Social sustainability indicators (R32 – R33)?

**Please provide good quality information to the best of expert knowledge during the survey participation.

Table C2: Likert Scale questionnaire prototype **(Highway construction)**

Developing a sustainability rating system for the Nigerian highway construction
PART A: (Demography information of participants) **Q.1: Please specify your profession** □ Civil Engineer □ Construction Engineer □ Construction Manager □ Project Manager □ Project Director □ Quality Engineer □ Quality Manager □ Others **Q.2 Have you been involved in highway construction decision-making** □ 0 – 5 years □ 6 – 10 years □ 11 – 20 years □ 21 years and above
Part A: Q.1: Awareness of the concept of sustainable highway construction? Q.2: Have you made use of the existing sustainable construction protocol? Q.3: Identify the sustainable highway construction protocol used? Q.4: Rank the usefulness of the sustainability tools and construction protocol used? Q.5: Have you been involved in decision-making in sustainable highway construction?
Part B: Assign the Likert scale to a range of indicators (1= not significant to 5= very high significant)
Q.6: Social sustainability indicators (R1 – R6)? Q.7: Environmental sustainability indicators (R7 – R30)? Q.8: Economic sustainability indicators (R31 – R33)? Q.9: Project management sustainability indicators (R34 – R43)? Q.10: Engineering sustainability indicators (R44 – R49)? Q.11: Health and safety sustainability indicators (R50 – R53)?

**Please provide good quality information to the best of expert knowledge during the survey participation.

Table C3: Likert Scale questionnaire prototype **(Sustainability strategies)**

Current global sustainability strategies for highway development
PART A: (Demography information of participants) **Q.1: Please specify your profession** □ Civil Engineer □ Construction Engineer □ Construction Manager □ Project Manager □ Project Director □ Quality Engineer □ Quality Manager □ Others **Q.2 What part of the continent is your project located** □ North America □ South America □ Europe □ Africa □ Asia □ Australia and Oceania
Q.3 Have you been involved in highway design and construction decision-making? (Yes / No / Others) **Q.4: How many years have you worked in highway design and construction projects?** (0 – 5 years / 6 – 10 years / 11 – 20 years / 21 years and above **Q.2: What is your awareness level with regards to the use of concept of sustainability during highway development ?** (Unaware of sustainability / Moderately aware of sustainability / fully aware of sustainability) **Q.3: Please specify current sustainable highway construction strategies utilised in projects?............................** **Q.4: Considering the above question, is sustainability strategies utilised in projects useful? (**Yes / No) Q.5:
Part B: Assign the Likert scale to a range of indicators (1= not significant to 5= very high significant)
1. Sustainable procurement 2. Sustainable design 3. Innovative construction processes

4. Continuous professional development
5. Climate change adaptation
6. Reduce consumption of resources
7. Protect biodiversity
8. Recycle waste and reuse
9. Use renewable energy
10. Avoid/pollution/ground water
11. Lifecycle cost analysis
12. Context sensitive analysis
13. Governance in projects
14. Sustainable safety management plan
15. Sustainable social considerations
16. Use of least raw materials with carbon footprint
17. Use of BIM technology

**Please provide good quality information to the best of expert knowledge during the survey participation.

GROUP QUESTIONNIARE SURVEY

Figure 1, AHP structure to develop indicators for sustainable highway design

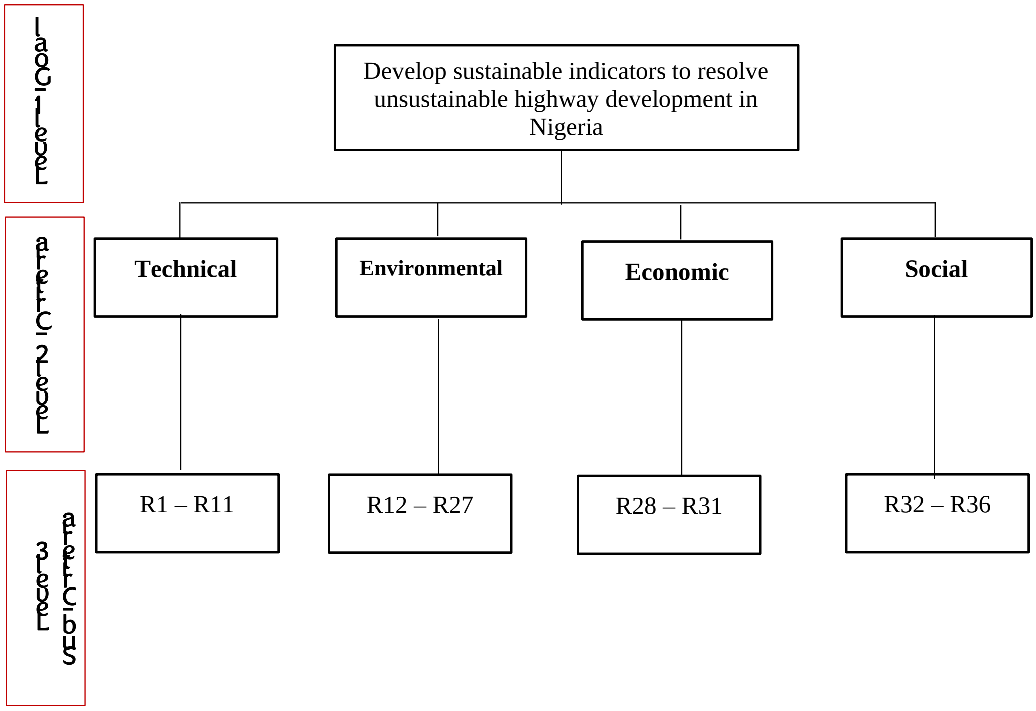


Figure 1 level 1, the goal of the model is to develop indicators needed to achieve sustainable highway development through the reduction of unsustainable development practices in Nigeria.

Level 2 is the main criteria for the various categories called multi-dimensional pillars for achieving sustainable development for highways in Nigeria. Level 2, for highway design, consists of four categories namely, social, environmental, economic, and technical.

Level 3 consists of sub-criteria contributing to clusters per each main criterion in level 2. These listed sub-criteria are the indicators selected from the literature; it consists of 36 indicators for highway design.

You as a group of expert participants, are requested to conduct a pairwise comparison for the clusters of the 36 indicators across matrices using tables A and 1-4.

AHP Pairwise comparison matrix -questionnaire

QUESTIONNAIRE SURVEY TO DETERMINE PAIRWISE COMPARISON (PCM) FOR HIGHWAY DESIGN INDICATORS

Appendix 1

Dear Participant,

This questionnaire is part of ongoing (PhD) research to identify indicators suitable for developing sustainable highway design indicators. I would very much appreciate your group participation in this survey; adding your expertise will contribute to knowledge about this subject and the value of the resultant protocol proposal.

Note: Details of all participants, along with any data and information provided, are kept anonymous. No individuals will be identified in any products or outcomes of this research. Kindly answer the questions with checkboxes and assign a score range provided.

“Please endeavour to be ethical in assigning the pairwise comparison values to the best of your professional ability”

Part A (Demography information of participants)

Q.1: Please specify ALL professions within the group.

□ Highway design

□ Highway construction

Q.2: How many years of experience in highway design projects, please specify.

	0 – 5 years	6 – 10 years	11 – 20 years	21 years & above
Participant 1				
Participant 2				
Participant 3				
Participant 4				
Participant 5				
Participant 6				
Participant 7				

PART B Scoring of sustainability assessment indicators using pairwise

This section lists optional highway design sustainability assessment indicators obtained from current standards, literature, etc. Please, complete the pairwise comparison survey by assigning a score from the psychometric MATRIX table 1-4. Table 'A' is the scale of judgement.

Table A — Scale of judgement

Intensity of importance	Definition	Explanation
1	Equal Importance	Two elements contribute equally to indicator assessment
3 or 3*	Moderate Importance	An element is lightly favoured over another
5 or 5*	Strong Importance	An element is strongly favoured over another
7 or 7*	Demonstrated Importance	Dominance of an element is demonstrated in practice
9 or 9*	Absolute Importance	Absolute dominance of an element is affirmed at the highest level
2,4,6,8	Intermediate values	Used to compromise between judgement in data analysis

The purpose of the survey is to determine the relative importance across indicators denoted using R1 – R11, see page 7. Please consider the relative importance of each indicator versus another, using— 'equal importance', 'moderate importance', 'strong importance' 'demonstrated importance', and 'absolute importance. Please see tables 1, and A. Assign pairwise comparison values to the matrix – 1.

Technical Indicators Pairwise Comparison Matrix- 1

(*inverse of the rating is given)

Factor	More importance than								Equal	Less importance than*								Factor
R1																		R2
R1																		R3
R1																		R4
R1																		R5
R1																		R6
R1																		R7
R1																		R8
R1																		R9
R1																		R10
R1																		R11
Factor	More importance than								Equal	Less importance than*								Factor
R2																		R3
R2																		R4
R2																		R5
R2																		R6
R2																		R7
R2																		R8

R2																		R9
R2																		R10
R2																		R11
Factor	More importance than								Equal	Less importance than*								Factor
R3																		R4
R3																		R5
R3																		R6
R3																		R7
R3																		R8
R3																		R9
R3																		R10
R3																		R11
Factor	More importance than								Equal	Less importance than*								Factor
R4																		R5
R4																		R6
R4																		R7
R4																		R8
R4																		R9
R4																		R10
R4																		R11
Factor	More importance than								Equal	Less importance than*								Factor

R5																		R6
R5																		R7
R5																		R8
R5																		R9
R5																		R10
R5																		R11
Factor	More importance than								Equal	Less importance than*								Factor
R6																		R7
R6																		R8
R6																		R9
R6																		R10
R6																		R11
Factor																		Factor
R7																		R8
R7																		R9
R7																		R10
R7																		R11
Factor	More importance than								Equal	Less importance than*								Factor
R8																		R9
R8																		R10
R8																		R11

Factor	More importance than								Equal	Less importance than*								Factor
R9																		R10
R9																		R11
Factor	More importance than								Equal	Less importance than*								Factor
R10																		R11

Table 1 – Technical indicators
R1 = Traffic volume count
R2 = Speed limit
R3 = Topographical terrain analysis
R4 = Stopping sight distance
R5 = The safe radius of the curve in, the highway
R6 = Safe superelevation
R7 = Profile and vertical curve
R8 = Safe cross-section and geometric elements
R9 = Catchment basin for stormwater
R10 = Sustainable, flexible pavement design
R11 = Culverts, gully pots and stormwater

Table A — Scale of judgement

Intensity of importance	Definition	Explanation
1	Equal Importance	Two elements contribute equally to indicator assessment
3 or 3*	Moderate Importance	An element is lightly favoured over another
5 or 5*	Strong Importance	An element is strongly favoured over another
7 or 7*	Demonstrated Importance	Dominance of an element is demonstrated in practice
9 or 9*	Absolute Importance	Absolute dominance of an element is affirmed at the highest level
2,4,6,8	Intermediate values	Used to compromise between judgement in data analysis

Note: When comparing (X with Y), '9', for example, indicates X is 'Extremely Important' compared with Y, while '9*' indicates Y is 'Extremely Important' compared with X

APPENDIX 'D'

n	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.523	0.882	1.109	1.248	1.342	1.406	1.450	1.485	1.514	1.537	1.555	1.571	1.584
n	16	17	18	19	20	21	22	23	24	25	26	27	28
RI	1.598	1.609	1.618	1.627	1.634	1.641	1.647	1.653	1.658	1.662	1.667	1.671	1.674
n	29	30	31	32	33	34	35	36	37	38	39		
RI	1.678	1.681	1.684	1.687	1.689	1.692	1.694	1.696	1.698	1.700	1.702		

Random Index

Random Index utilized for AHP analysis.

Source: Alonso and Lamata (2006)

APPENDIX 'E'

Interview semi structured interview questions qualitative method.

Main Questions	Sub-questions
Are you aware of the sustainability concept and its application at the project level in the development of highway infrastructure projects?	• Identify sustainability in the design and construction of highway projects. • What are the benefits, and disbenefits of sustainability in highway projects?
What are the factors negatively influencing the implementation of sustainability practices in highway design and construction in Nigeria?	• What are the issues hindering sustainability implementation?
To help ascertain if the sustainability indicators development from the previous chapter requires an exclusion or exclusion.	• Identify exclusion and inclusion of indicators presented

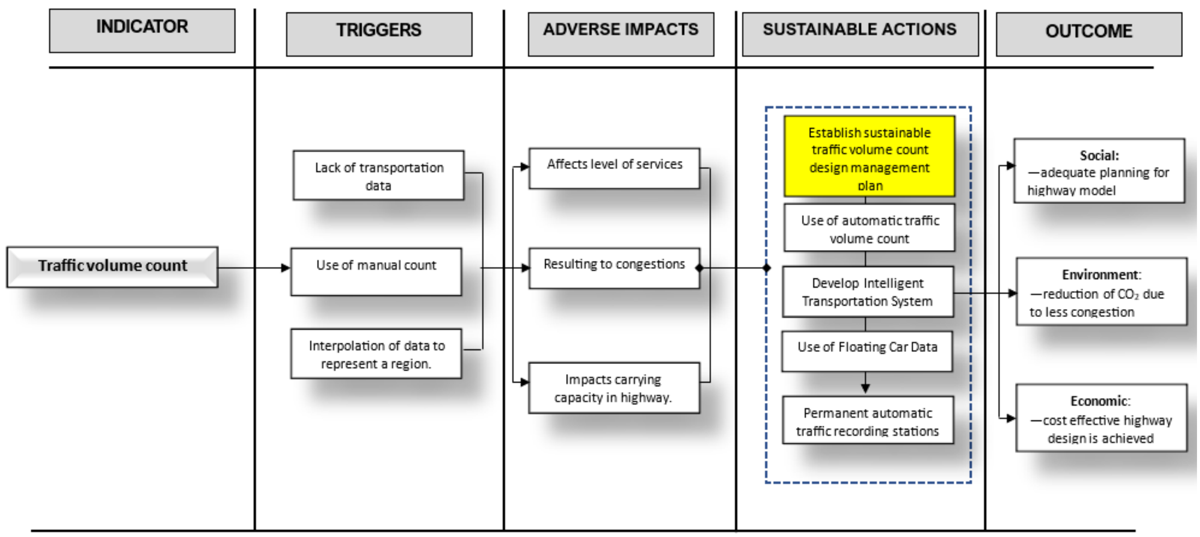
Project case study questions

TECHNICAL INDICATORS CATERGORY	
Main Questions	Sub-questions
<u>TRAFFIC VOLUME COUNT</u> How did you implement traffic volume count within the social considerations' context?	• Why did you use manual traffic volume count? • Why did you rely on data interpolation of traffic volume count?
<u>DESIGN SPEED</u> For social consideration, how was the hypothetical speed of the travel pathway of the vehicle determined from the main highway to local roads, any survey?	• Any consideration for smart highway having variable speed limits? • Any considerations in the design to save road users economic cost towards delay of traffic?
<u>TOPOGRAPHICAL TERRAIN</u> For social development of highway, how was factors considered using terrain modelling to determine ecological features, contours, slops, elevations during alignment design?	• Any decision during feasibility study to catalogue natural habitat and impacts on its ecosystem? • What are the mitigation design plan?
<u>STOPPING SIGHT DISTANCE</u> To enhance travellers experience, how was 85^{th} percentile speed considered for social/economic and environmental benefits?	• How was the 85^{th} percentile design speed correlated with the design speed sign?

APPENDIX 'F'

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R1: Traffic Volume Count (Technical Category)



INDICATOR R1: Traffic Volume Count	
TRIGGERS	**ADVERSE IMPACTS**
• Lack of sustainable transportation data • The use of obsolete traffic manual count • Interpolation of data to make decisions.	• Inadequate design of required service level for the highway project. • Inadequate design results in congestion. • The highway carrying capacity and space is under-utilised.

SUSTAINABLE RECOMMENDATIONS

- The use of a sustainability action plan for traffic volume count management, helps to establish the needed sustainability goals over time, and the best practices needed for improvements. Determined within the sustainability action plan are the notable gaps in the use of dated traffic volume count, and the impact across the social, environmental, and economic fabric of the designed project, versus the society and environment.

- The use of the traditional traffic road sensor, for instance, inductive loops for traffic volume count detection can be utilised in the collecting of data across highways passing through remote areas in Nigeria.

- The Floating Car Data (FCD) is a highway-quality source of data reliable in developing an intelligent Transportation System (ITS). The ITS helps provide a mode of various types of transportation management systems, which is called "smart network". For instance, traffic speed, traffic congestions, and travel time of a car can be calculated.

- The use of Floating Car Data (FCD) is effective in collecting robust traffic volume data using mobile GPS and a fixed detector across a region.

- To determine average annual daily traffic (AADT), establish permanent automatic traffic recording stations for the continuous counting of traffic volume for 365 days or as desired by standard. The data are taken at intervals of 15 minutes or hourly in principle.

REQUIRED BEST PRACTICES AND RESULTS OUTCOME

- Within the social context, sustainable traffic volume count provides a better understanding of the level of services of planning required and determines types of collision rates. A traffic volume survey helps determine the level of road users' satisfaction with the perception of noise, and air pollution.

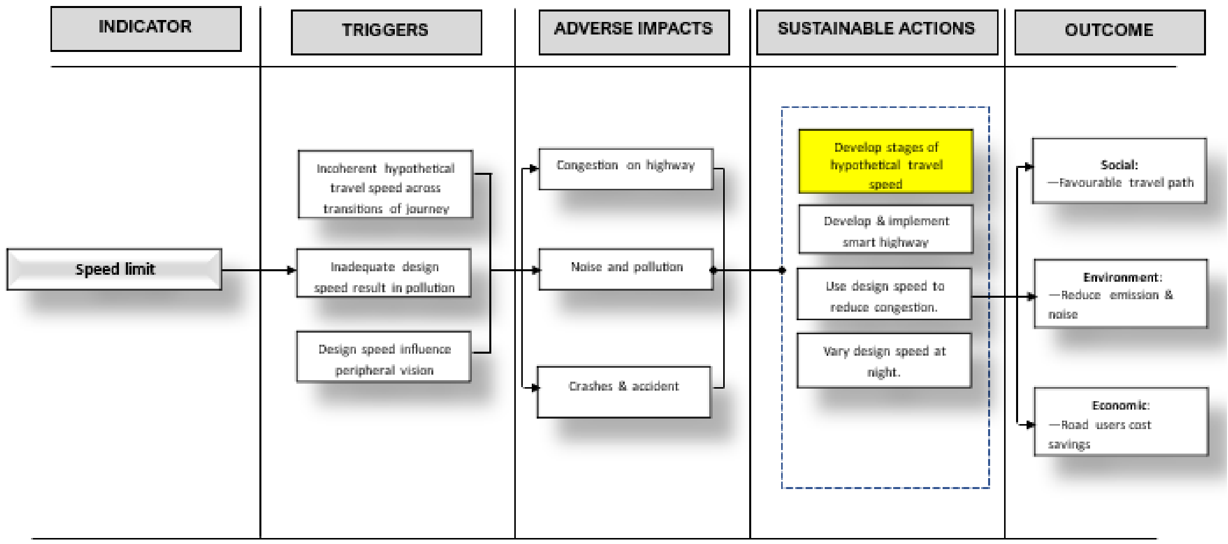
- Within the environmental context, the use of Floating Car Data supports the development of an Intelligent Transportation System, which is an integrated approach to achieving an eco-driving experience in reducing carbon emissions resulting from traffic congestion.

- Within the economic context, cost-effective highway design is achieved.

Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R2: Speed limit (Technical Category)



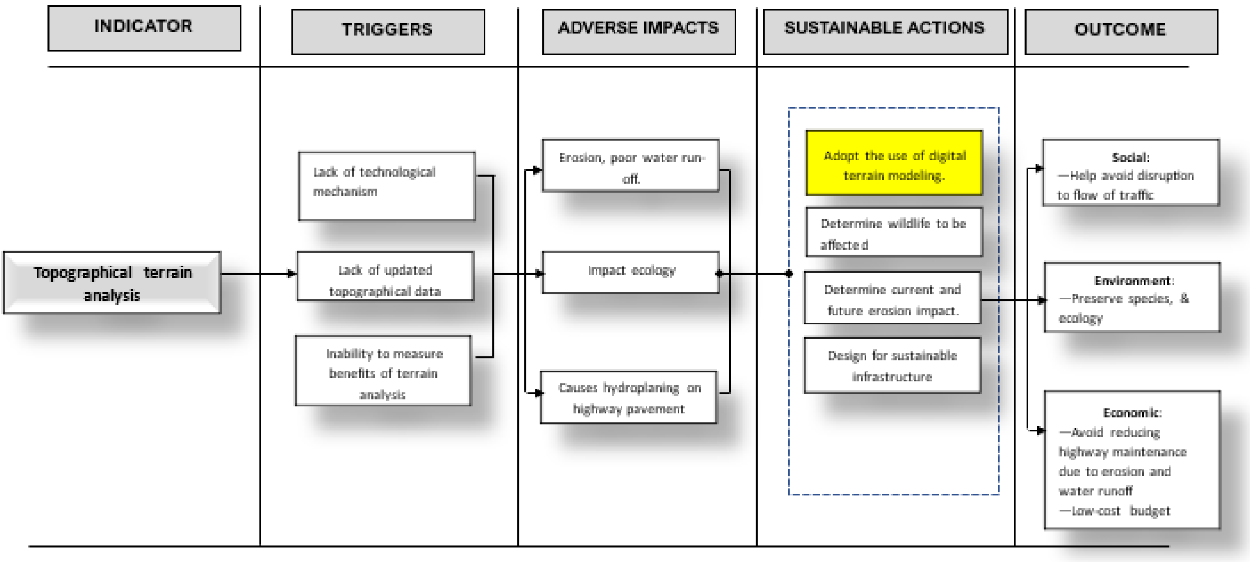
INDICATOR R2: SPEED LIMIT	
TRIGGERS	**ADVERSE IMPACTS**
• Lack of highway design speed between highway to other transient roads. • Poor speed influence, safety, pollution & noise	• This result in congestion across the highway alignment. • Noise, pollution, and crashes.

SUSTAINABLE RECOMMENDATIONS
• The design speed involves six different stages of a hypothetical trip consideration for vehicular manoeuvres coming from the highway, such as the main movement, transition, distribution, collection, access, and termination. • The aim of the above is to eliminate the gradual generation of traffic congestion building up on the highway (main movement) due to inadequate speed limit design for the transition, distribution, collection, access, and termination of a moving vehicle[1]. • The mechanical operation and movement of cars and trucks impacts, lands, and adjacent properties along the highway should be carefully considered during design phase. This results in the emission of pollution and tyre noise generated due to movement on the pavements and aerodynamics resulting in wind noise. The use of the alternative route, mixed design speed and noise barrier walls, can form as a mitigation factor. • Highway design speed reduces the peripheral vision of the moving vehicle considering the limited time available for a driver to receive and process information. Efforts should be made by the designer to mitigate and compensate for the speed design, by using an enhanced cone of clear vision, and eliminating peripheral vision using spacing to decrease information processing demands. • To avoid the likelihood of crashing especially, where there is high design speed, the use of smart highways should be used at night to reduce speed due to poor vision and the inability of the vehicle to illuminate objects along the driver's paths, and at a sufficient time to respond.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Within the social context, the design speed limit ought to be favourable for the road users to select alternative routes, this is based on convenience and economic decision-making in conveying goods, and services. The road users in selecting the most favourable pathway to travel, consider measure moving along the highway in terms of time, cost saving and convenience. • Design speed must complement the statutory law to satisfy public demands for public services economically, efficient traffic operations and low crash frequency. • It should be indicated using the smart highway, that design speed cannot apply under unfavourable conditions, such as inclement weather and accidents occurrence.
Credit point awarded to implement best practices = 1

[1] Different speed design needs to be initiated for all six stages of vehicular transition considering variation of the traffic generated per category.

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R3: Topographical terrain analysis (Technical Category)



INDICATOR R3: TOPOGRAHICAL TERRAIN ANALYSIS

TRIGGERS	ADVERSE IMPACTS
• Lack of technological devices to help curb unsustainable highway development process. • Lack of updated topographical terrain data.	• Vulnerable highway facilities and ecological environments, for instance, are prone to erosion, and the impact of endangered species. • High level of hydroplaning on highway pavement due to water runoff from natural slopes.

SUSTAINABLE RECOMMENDATIONS

- The use of sustainable topographical terrain analysis measures the relationships between anticipated physical features of a highway with the ecological process. These key features are the contour lines, slopes, elevation, viewshed, and downslope lines. Slopes and elevations are significant in assessing the suitability of highway alignment.
- The topographical terrain analysis is used in the identification of wildlife habitats within specific elevations. It helps in the classification of vegetation and to determine types of species that might be associated with terrain habitat sensitivity. This involves the use of a data polygon used in form of a Global Positioning System (GPS).
- The use of topographical terrain analysis helps to determine long terms and short-term erosion control monitoring, based on the elevation and existing contour lines. It helps in the mitigations of future highway design. This helps dictate changes over time due to constant highway design.
- Terrain analysis helps to determine overall project site erosion control, and water runoff processes, for instance, to determine adequate curvatures, and slopes, and to protect natural habitats from destructions during highway development.

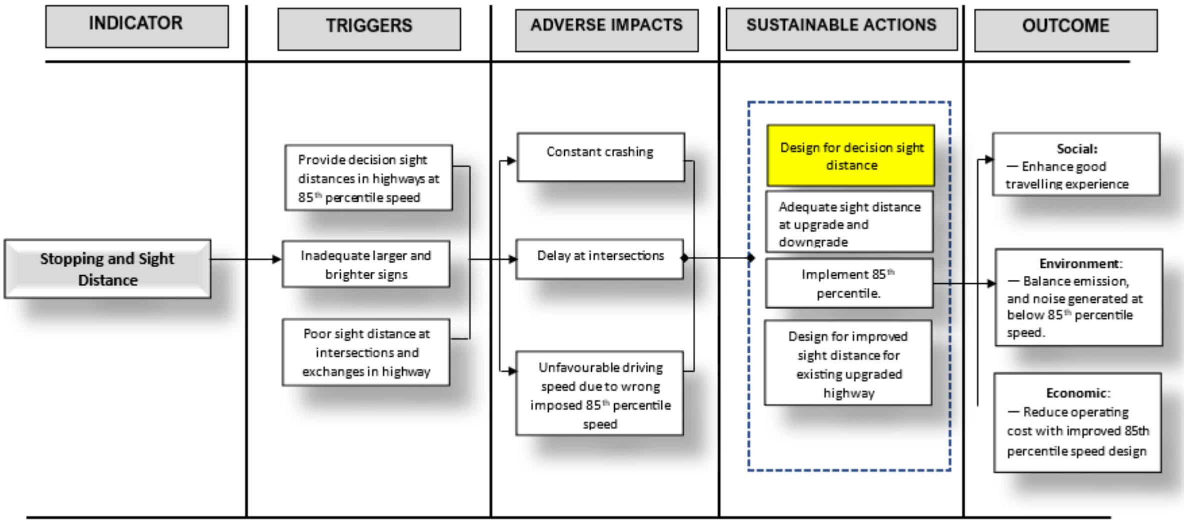
REQUIRED BEST PRACTICES AND RESULTS OUTCOME

- To adopt the use of the Digital Terrain Model (DTM), to measure terrain characteristics in the spatial topographical distribution, by measuring XY horizontal, and vertical coordinates, and the terrain elevation represented with a, Z. This helps to improve the flow of traffic, preserve species across ecology and reduces maintenance cost due to flooding and erosion.
- During the design phase, using DTM to establish sustainable estimation of the volumetric determination of borrow pits for earthworks and how it impacts the ecology is essential. This provides in reducing the project cost budget.

Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R4: Stopping and Sight Distance (Technical Category)



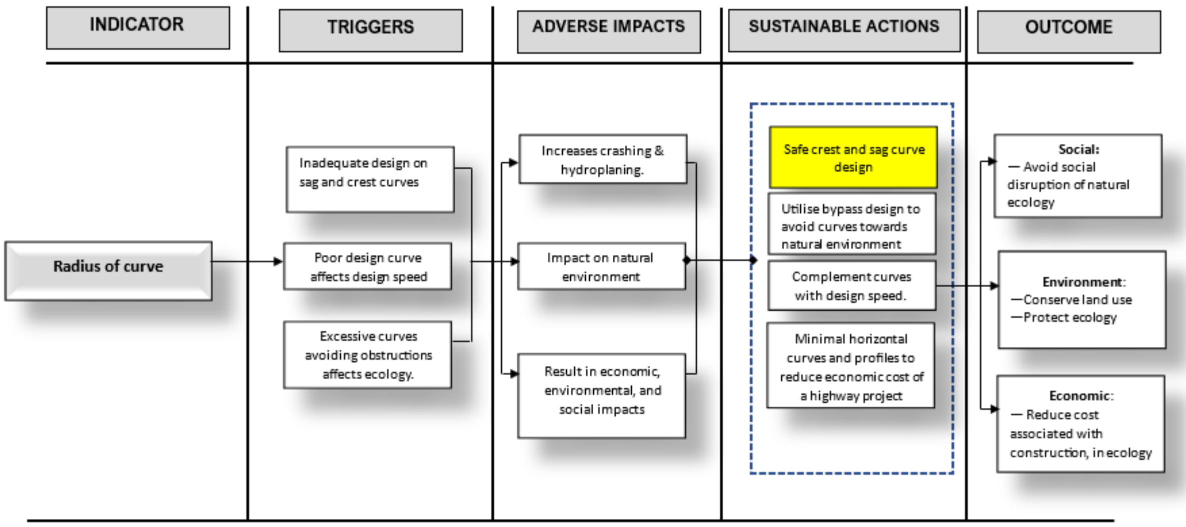
INDICATOR R4: STOPPING AND SIGHT DISTANCE

TRIGGERS	ADVERSE IMPACTS
• Inadequate 85th percentile speed design • Inadequate larger and brighter speed limits • Poor harmonic visibility along the highway curve alignments	• Increased frequencies of crashing • Unfavourable travelling path • Emissions and increase in vehicular cost

SUSTAINABLE RECOMMENDATIONS
• Highway design should consider the inclusion of decision sight distance as a measure to better accommodate ageing and older drivers, which is a practical measure needed to reduce future crash frequencies. This is especially at the intersection with no possibility of traffic signals, which are loaded with likely information that cannot be processed at the same time. • Highway designers should consider establishing in highway sight distance required for the driver to stop his vehicle, the sight distances for the overtaken purpose, and the sight distance needed for making decisions at complex locations. • The sight distance between upgrade and downgrade on highways must be counterbalanced to ensure a proper view of obstructions ahead. • Separate 85th percentile speed of drivers operating in Nigeria should be determined. This is the speed at which many of the drivers will operate which is perceived to be safe and under favourable conditions. Highway design speed created above or below the 85th percentile speed will create unsafe conditions due to varying speeds of drivers within a certain geographical zone and operating under certain environmental conditions. • Where an improved section of the highway with adequate sight distance is connected to re-join an unimproved section of an existing highway, the designer provides pertinent stopping sight distance and a safe profile. • At the curve highway alignment, sight distance must be available outside the highway boundaries to reveal the verge width, and the harmonic visibility along the highway.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Collect data to establish the 85th percentile speed of Nigerian road users, measured under different environmental conditions. This helps to enhance adequate design speed at the bend curves. It reduces the operating cost of a vehicle, enhances a good travelling experience and balances noise and emissions generated.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R5: Radius of the curve (Technical Category)

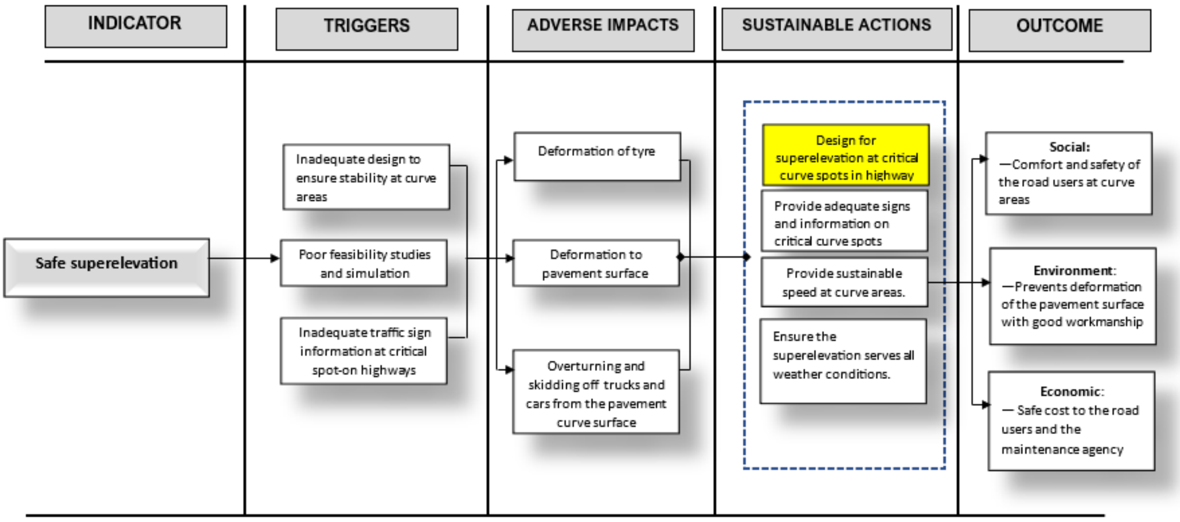


INDICATOR R5: RADIUS OF THE CURVE	
TRIGGERS	**ADVERSE IMPACTS**
• Use of excessive and unreasonable design of highway sag and crest in curve areas. • Inadequate speed design on the curve section of the highway results in crashing. • Excessive destruction of natural habitat results adds to global warming	• Consistent crashing at critical bend spots with unreasonable speed is not considered under the 85th percentile decision within Nigeria's local conditions. • The continuous destruction of natural habitats thereby increases carbon emissions in the atmosphere. • The causes of the trigger consist of cost and economic implications. This is due to crashing, and removal of natural habitats associated with cost impact, across the socioeconomic fabric of the society.

SUSTAINABLE RECOMMENDATIONS
• Implement considerable design for highway horizontal and vertical curves, while avoiding obstruction to reduce excessive cut and fill, —thereby maintaining minimal economic construction and maintenance costs for the highway. • The use of bypass can be utilised to protect endangered ecology due to introduced highway curves in avoiding obstructions. • The curves should also complement the speed design and superelevation to avoid centrifugal force and gravity pulling off the vehicle vertically down, and away from the road. • Sag curves form a concave in uphill highway alignment, thereby obstructing vehicle headlight sight distance. Therefore, safe sag curve should be designed. • Crest curves should be designed for a safe stopping sight distance, as vehicles descending a crest with no clear view of the alignment of the highway, might be stalled due to animals or other moving objects.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Safe design of crest and sag at curve areas of highway helps eliminate hydroplaning phenomena and increases sight distance of vehicles. • The use of a bypass is essential to eliminate the destruction of natural habitat, as this helps save the social imbalance of communities living close to the project, and the impact caused by the destruction of natural habitat, which is a natural asset base.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R6: Safe superelevation (Technical Category)



INDICATOR R6: SAFE SUPERELEVATION

TRIGGERS	ADVERSE IMPACTS
• Poor design strategy and feasibility study • Inadequate traffic signs • Lack of simulation to measure safe curves	• Increases operational cost of road users. • Results in deformation to the existing asphalt pavement at the curve areas.

SUSTAINABLE RECOMMENDATIONS

- Curved highway paths used by cars and heavy trucks are affected by centrifugal forces acting at the right angle to the direction of vehicle motion, and the weight of the car due to the centre of gravity, thereby causing deformation and pressure on the tyre, which increases less contact with the pavement surface. The centre of gravity of trucks is higher than a passenger car, which increases the overturning tendency for the former. For this reason, maximum superelevation should be introduced at curves and sharp bends in highway paths.

- Superelevation increases the stability of the fast-moving vehicles at the curve, and it decreases the tendency to overturn.

- Due to vehicular movement on a curve, the centrifugal turning effect acts at a right angle, and the centre of gravity weight on the tyre pressure is evenly distributed on both wheels which reduces wear and tear, these mechanics is achieved with the introduction of superelevation at the curves.

- The intensity of deformation across pavement surface curves in highways is reduced, thereby saving from the economic aspect of the maintenance budget.

- Reduces overturning and skidding off trucks and vehicles.

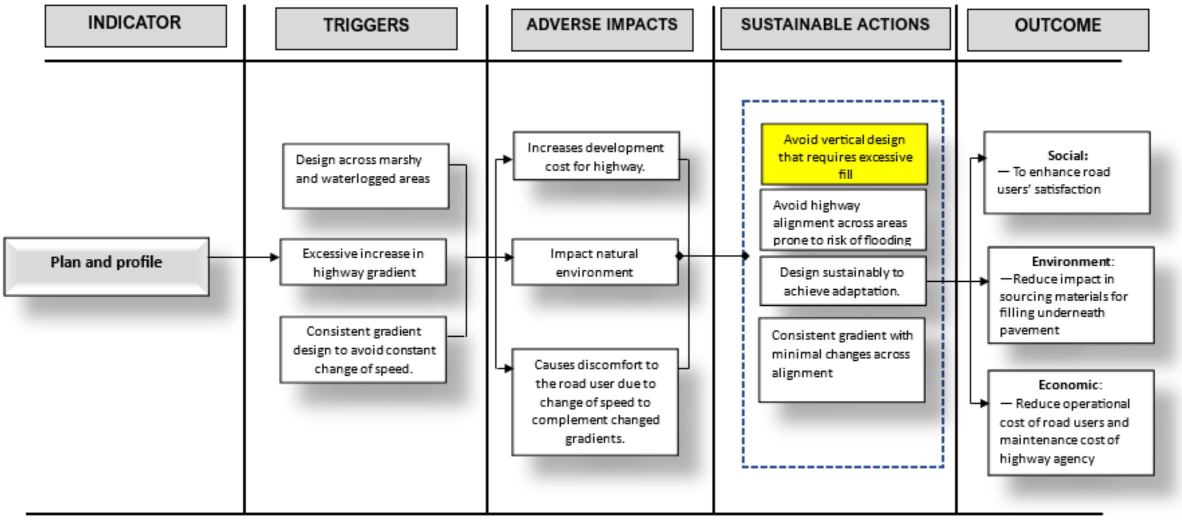
REQUIRED BEST PRACTICES AND RESULTS OUTCOME

- Superelevation helps maintain safe and optimum highway design speed at the curve areas, such as during various weather conditions. This provides social comfort for road users.
- During design and construction, the superelevation should be achieved where the outer section of the pavement is raised in a definite grade to the inner edge of the pavement. This helps protect the pavement surfaces and prevent maintenance and sourcing of materials from the environment, thereby saving costs.

Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R7: Plan and profile (Technical Category)

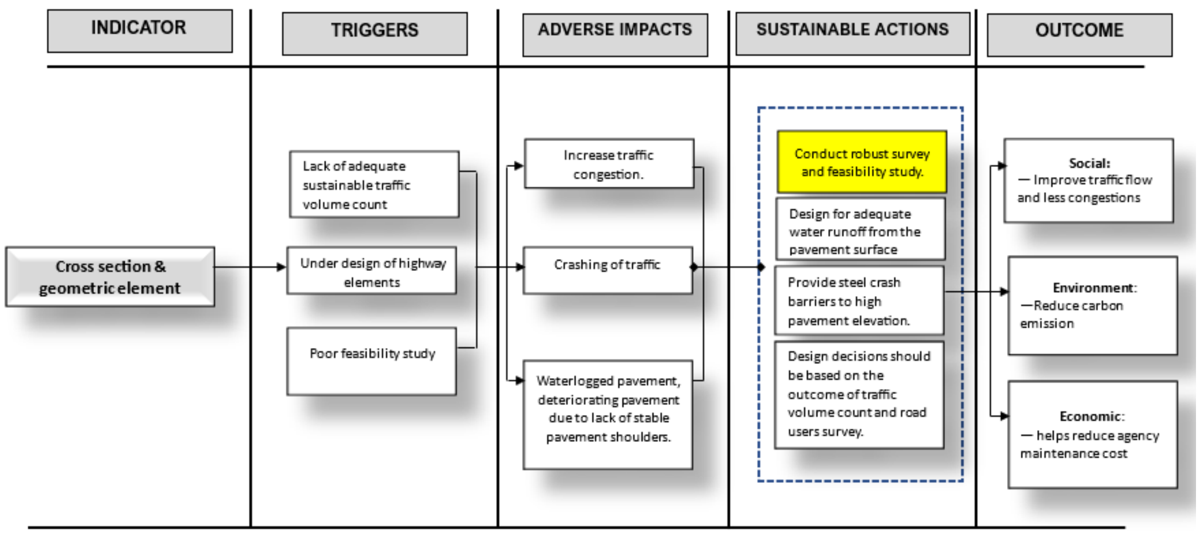


INDICATOR R7: PLAN AND PROFILE	
TRIGGERS	**ADVERSE IMPACTS**
• Highway design across critical terrain like waterlogged, marshy areas and densely populated communities. • When the design does not achieve infrastructure adaptation	• Result in flooding • Increase in cost. • Social discomfort

SUSTAINABLE RECOMMENDATIONS
• Minimize vertical alignment, which is the height and depth to reduce fill materials, this is to achieve economical construction and maintenance. • Design and construction should be avoided across marshy land, waterlogged areas, historical and archaeological areas, and densely populated areas. • Consistent vertical alignment is recommended to be designed to avoid trucks and vehicle change of speed due to constant undulating of vertical gradients.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Avoiding design and development of excessive vertical gradient reduces the impact of sourcing materials from the natural environment. It reduces the cost of project development and less carbon emission into the atmosphere. • The use of consistent gradient helps enhance road user travel satisfaction and it reduces vehicular operation costs.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R8: Safe Cross Section and geometric elements (Technical Category)

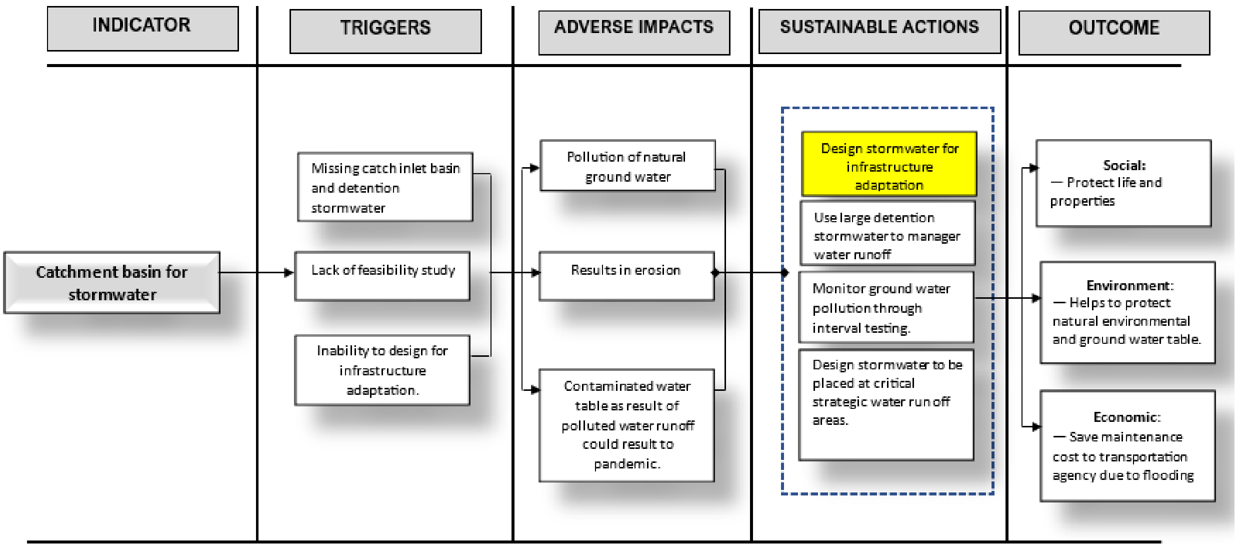


INDICATOR R8: CROSS SECTION AND GEOMETRIC ELEMENT	
TRIGGERS	**ADVERSE IMPACTS**
• Lack of feasibility study • The cost-cutting result in a design	• Under-designed pavement lane results in traffic congestion and the release of carbon emissions. • Inadequate safety measures such as crash cushions and barriers can result in the vehicle over-skidding away from the pavement.

SUSTAINABLE RECOMMENDATIONS
• In developing a functional sustainable highway cross-sectional element, such as the width of the road should be considered during traffic volume count, the classifications, and road users survey to determine adequate numbers of road width. • Another sustainable element in the highway is the central reservation, which is called the median, it helps provide separation between directional traffic flow. On the highway, it helps prevent headlight glare from opposite oncoming traffic. • The shoulders in the highway cross-section are required to provide space for vehicular emergency parking, it also acts as a lateral support to the pavement structure. The width of the shoulders must be designed to be minimal to reduce land use and cost. The shoulders should be sustainably stable to bear the weights of the vehicles parked at the sections even during wet conditions. • Where there is high embankment along the highway, guardrails should be provided to prevent vehicles from skidding off the highway pavement. • Adequate cross-slope camber should be provided in the transverse direction of the highway pavement to drain surface water.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Conduct feasibility studies to make highway design decisions based on factual surveys data, to improve traffic flow and less congestion, reduce carbon emissions and reduce transportation agency maintenance costs.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R9: Catchment basin for stormwater (Technical Category)

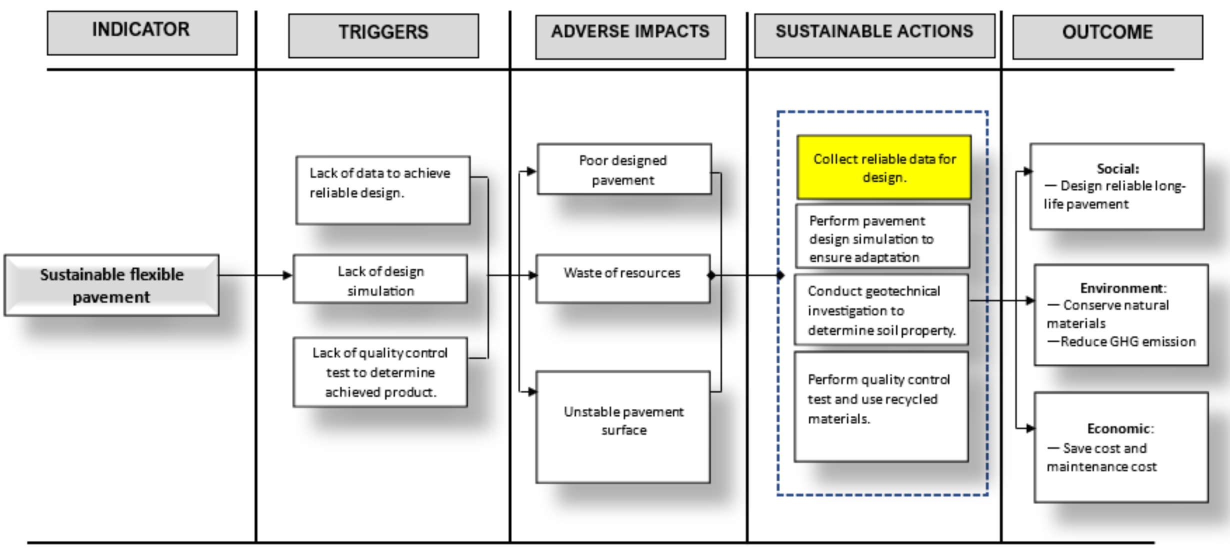


INDICATOR R9: CATCHMENT BASIN FOR STORWATER	
TRIGGERS	**ADVERSE IMPACTS**
• Inadequate measures to determine the right amount of infrastructure adaption required to counter excessive climate change impact on highway facilities.	• Groundwater pollution, and erosion of properties.

SUSTAINABLE RECOMMENDATIONS
• Design for catch basin inlet stormwater with grate cover, constructed strategically at critical locations to enable water runoff inlet. The catch basin is designed to capture sediments, debris and pollutant from the pavement surface using an infiltration mechanism. The catch basin consists of a sump which needs to be maintained regularly using a sewer vacuum.   • Another type of large detention stormwater basin is required to store water runoff along highway pavement surface which is a sieve and disallows percolation of polluted water into the natural water aquifer. The aim of collecting the water in strategic detention basins is because the water contains dissolved solvents which affect groundwater quality.   • Water-stable soil tests are to be carried out at intervals to determine the amount of groundwater table pollution because of surface water runoff, from the highway pavement surface.   • Channelling and control of stormwater runoff from the pavement surface has an impact on the existing natural stream and results in erosion.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• For highway design, a need to provide stormwater, both for the catch basin and detention basin   • A need to monitor groundwater to determine pollution because of surface pavement water runoff.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R10: Sustainable Flexible Pavement (Technical Category)



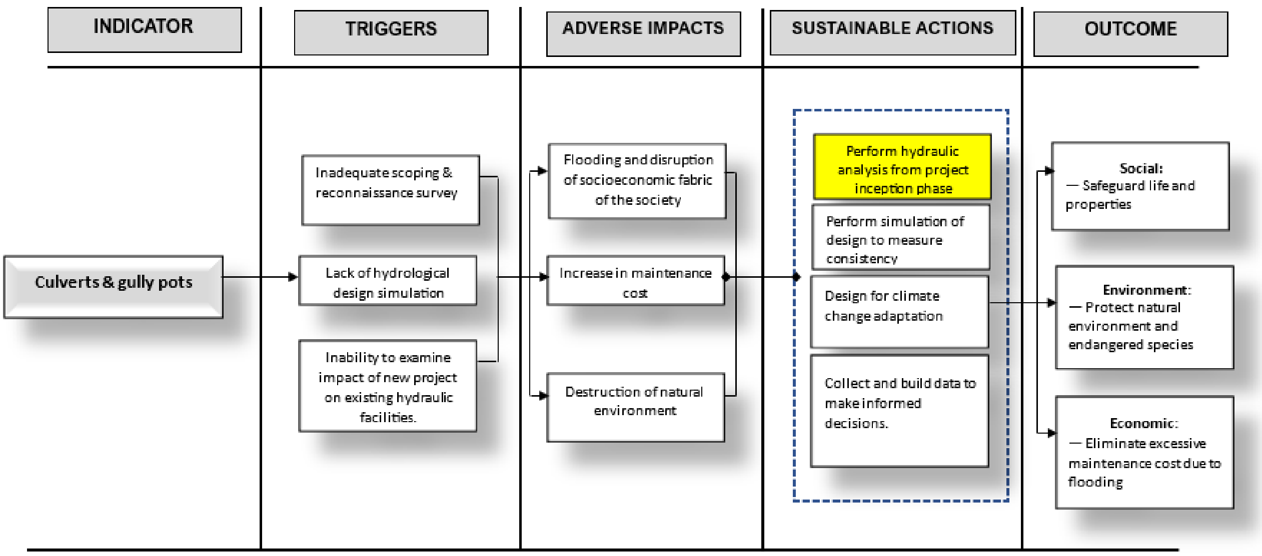
INDICATOR R10: SUSTAINABLE FLEXIBLE PAVEMENT

TRIGGERS	ADVERSE IMPACTS
• The inadequate data information and lack of design simulation. • Poor quality control measures.	• Results in poor design outcomes, waste of resources and unsustainable pavement surface

SUSTAINABLE RECOMMENDATIONS
• Develop design a long life sustainable flexible pavement required to reduce maintenance needs and lifecycle costs (using recycled materials). • Collect data on the subgrade, subbase and loading to determine the sustainable structural layer needed to achieve long-life pavement design. Also, to determine and take into consideration future growth of the wheel configuration and axle loading of trucks and cars proposed for the highway. • Design for resilience and highway pavement adaptation towards climate change, such as flooding and excessive heat. • Perform simulation to ensure pavement design will adapt to climate change impact. • Ensure seasonal variation of the water table does not affect the pavement properties. Design to ensure adaptation to frost and heat action. • Measure the International Roughness Index of the pavement surface yearly and carry out a non-destructive test to measure pavement defectives. • Visual rating, to assess the magnitude of ravelling, patching, alligator cracking and rutting
REQUIRED BEST PRACTICES AND RESULTS OUTCOME • There is a need to perform highway design using reliable data collected from the project site, rather than using generic standards in making an informed decision.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R11: Culvert, gully pots and stormwater (Technical Category)

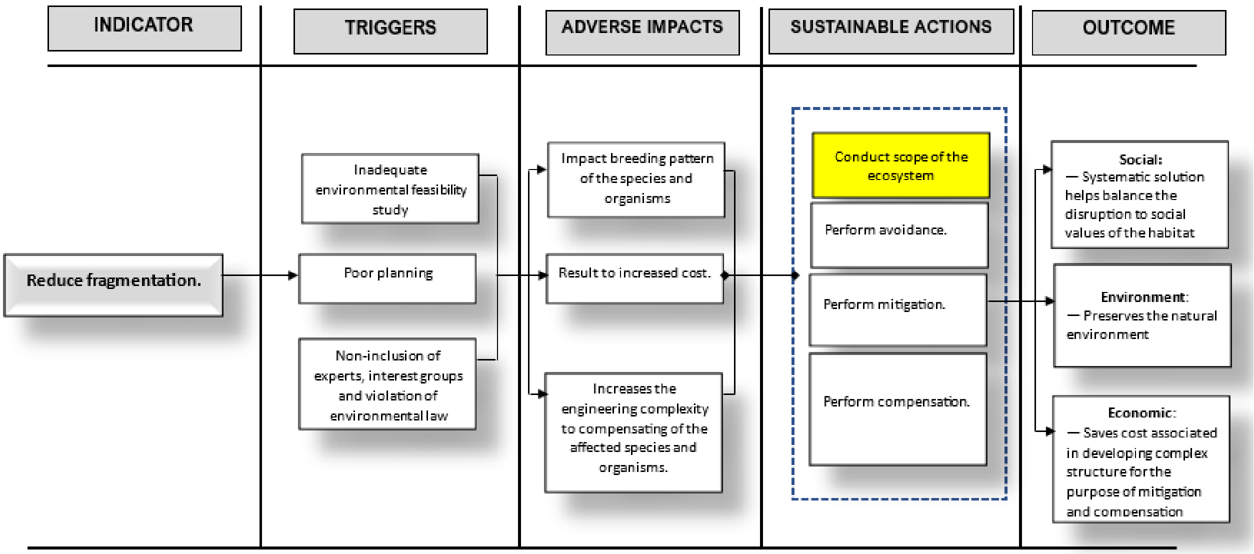


INDICATOR R11: CULVERT, GULLY POTS, AND STORMWATER	
TRIGGERS	**ADVERSE IMPACTS**
• Inadequate scoping and reconnaissance hydraulic survey • Lack of simulation to determine the impact of flooding on infrastructure and adaptation. • Inability to examine the impact of a new project on the existing hydraulic facilities and stormwater basins.	• Excessive flooding and socioeconomic impact. • Increases cost of the project • Undue destruction to the natural environment.

SUSTAINABLE RECOMMENDATIONS
• Sustainable hydraulic analysis should be planned and executed at the inception of the project. • Simulation is required to verify existing culverts and drainage systems to determine if they are hydraulically inadequate to support new inlet flow from a new project. This will result to determine the cost and environmental impact of either replacing or expanding the existing culverts to complement the new ones. • To design for infrastructure adaption to excessive flooding due to global warming. This can only be achieved using hydraulic scoping and reconnaissance survey to determine issues to be addressed. These are rainfall data, flood history, site and aerial mapping and photography, soil information, and existing bridge inspection reports. • Collect data survey of existing culvert facilities, estimate future characteristics, estimate discharge, and structural requirements and determine how to mitigate constraints in case there is flooding.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The implementation of hydraulic analysis for highway projects will result in safeguarding life and properties. That includes the measure of the consistency of the design through simulation to ensure the effectiveness of the developed infrastructure. The collected survey data will support making informed design solutions, first in protecting the environment and secondly to eliminate excessive costs incurred due to under-designed highways.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R12: Reduce habitat fragmentation (Environmental Category)



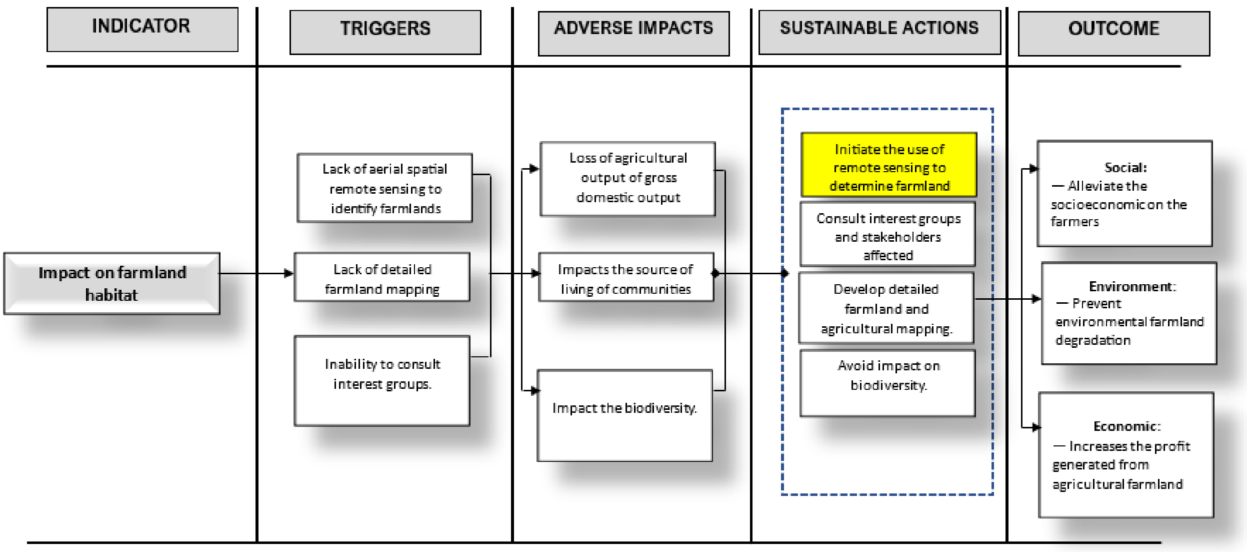
INDICATOR R12: REDUCE HABITAT FRAGEMENTATION

TRIGGERS	ADVERSE IMPACTS
• When optimal alignment considerations are neglected during the feasibility stage of a highway project. • When expert ecological experts and interest groups are not duly consulted.	• Habitat fragmentation impacts the existence and the extinction of many species due to isolation, which is less suitable for the species and organisms due to competitiveness. It affects their breeding pattern. • The inability to conduct preliminary scoping on habitat fragmentation could result in constraints, impact the cultural heritage, agriculture, and nature and it has cost impacts and implications.

SUSTAINABLE RECOMMENDATIONS
• Highway alignment can be utilised to reduce the threat of fragmentation of the natural habitat, which includes the use of sustainable strategies such as avoidance, mitigation, and compensation approaches. • Scoping at the inception of project development should determine to measure species diversity, the amount of rarity of the habitants and the amount of conservation status required. This includes the: — a) The avoidance of environmental impact due to the development of highway alignment, will prevent impact on vulnerable habitats. So during feasibility studies and planning phase, wide inclusion of interest groups, environmentalists, and survey data is required to determine the level of avoidance needed to be achieved. b) The next sustainable approach is using mitigation, which involves the use of eco-passage structures— (these are over and underpasses for different species and organisms). It involves a detailed systematic understanding of each species affected and the structure needed to mitigate their fragmentation impact. c) In situations where the fragmentation of the natural ecosystem is inevitable, then the compensation approach should be considered. This consideration is to ensure that there is no net loss of the species, that involves, creating another similar ecosystem to relocate each of the identified impacted species and organisms.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The best practice is to adopt systematic measures such as the use of avoidance, mitigation, or compensation for the purpose to reduce fragmentation of the natural ecosystem due to highway development
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R13: Impact on farmland and habitat (Environmental Category)



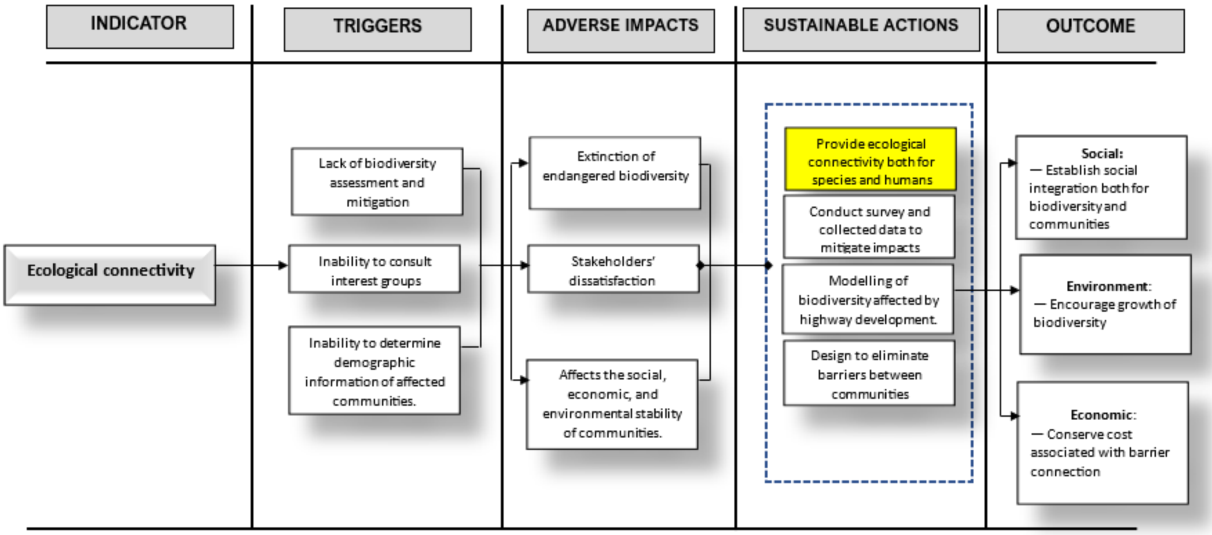
INDICATOR R13: IMPACT ON FARMLAND AND HABITAT

TRIGGERS	ADVERSE IMPACTS
• Lack of remote sensing and aerial spatial analysis to determine accurate agricultural mapping needed to be excluded from future or current development of highway	• Impact on the social, environmental, and economic status of the local community inhabitation. • Alters the natural biodiversity struggling to survive.

SUSTAINABLE RECOMMENDATIONS
• Urbanisation and highway design development should avoid displacement of agricultural land mass, which affects the devolution of social community and biodiversity restructuring. • Use of remote sensing and aerial spatial analysis to analyse farmland loss due to potential highway development.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Establish agricultural mapping for both small, medium, and commercial farming to exclude both current and future urban and highway development.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R14: Ecological connectivity (Environmental Category)



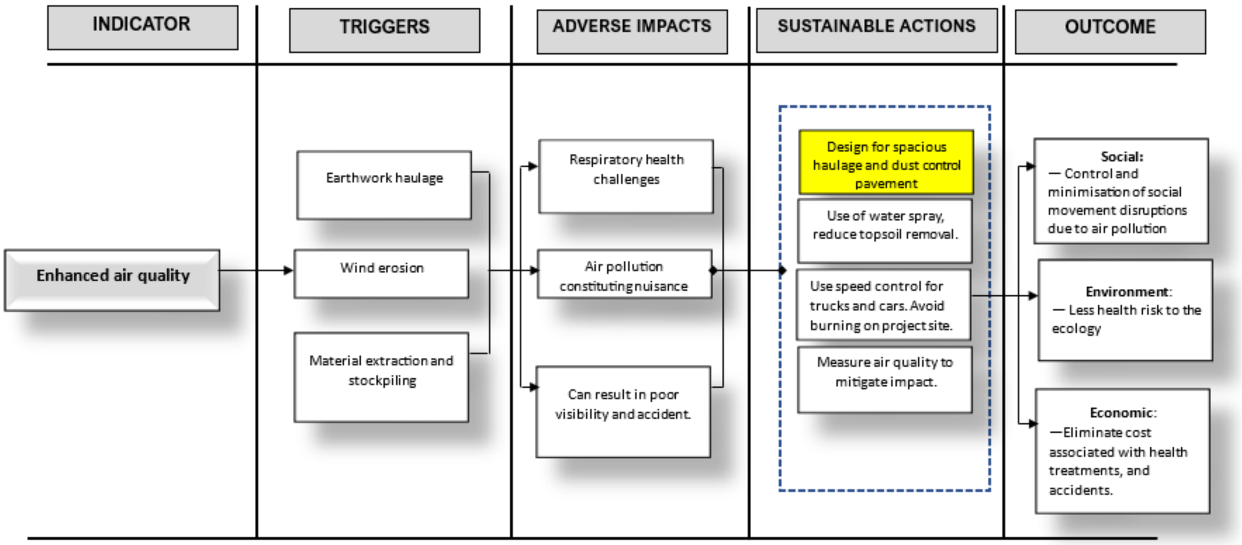
INDICATOR R14: ECOLOGICAL CONNECTIVITY

TRIGGERS	ADVERSE IMPACTS
• Lack of biodiversity assessment and mitigation strategy both for biodiversity and community	• Loss of species and biodiversity • Alters social, environmental, and economic stability of the community

SUSTAINABLE RECOMMENDATIONS
• Where highway alignment is inevitable resulting in ecology fragmentation, ecological connectivity is essential for the functionality of the ecosystem. There is a need to improve wildlife access and mobility across the highways. • Conduct during the feasibility study biodiversity assessment impacted by highway development to propose wildlife fencing, wildlife-dedicated crossing structures, and an overpass. • Modelling of biodiversity impact to provide solutions and mitigations, for instance in providing aquatic connectivity and access and mobility for wildlife. • Design to eliminate barriers to mobility, and to provide a consistent connection between communities to access jobs, essential services, and education. • Collect data to determine demographic information towards communities affected by highway development, which includes collecting data on job areas, marketplace, churches, and recreational areas. • Determine to collect data on commuters' cost of travel, and key employment areas,
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Conduct a feasibility study on the biodiversity likely to be affected by highway development. • To design wild fencing and dedicated structures for each affected species and organism due to highway development. • Ensure access to the human population to the workplace, market, and recreational areas.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R15: Enhanced air quality (Environmental Category)



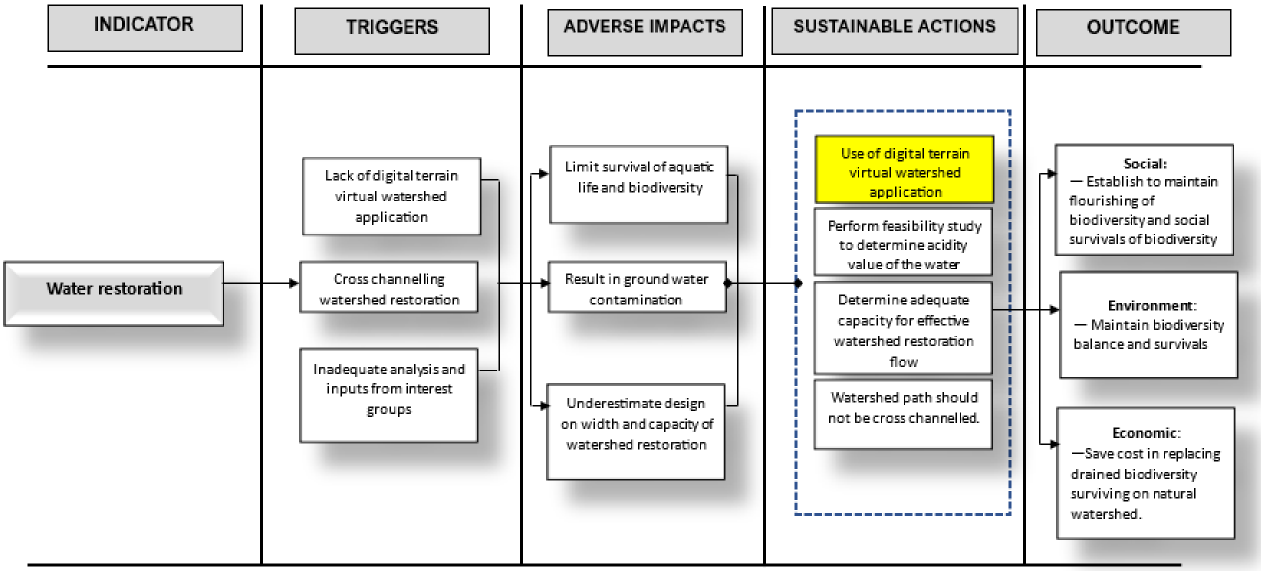
INDICATOR R15: ENHANCED AIR QUALITY

TRIGGERS	ADVERSE IMPACTS
• Earthwork haulage equipment • Expose topsoil resulting in wind erosion. • Material extractions and stockpiling • Use of chemicals in the highway project sites	• Health-related respiratory illness • Dust and poor visibility can result in an accident.

SUSTAINABLE RECOMMENDATIONS
• Design and recommend for dust and air quality control across construction activities, mitigation measures include using water sprays to control dust, and eliminate removal of topsoil. • Keep speed to a minimum within the project site, train operators and drivers on the benefits associated with reducing speed. • Inform through notices and integrate interest groups and communities about construction activities that might generate dust. • Monitor weather forecasts such as wind speed to provide mitigation. • Provide health and safety surveillance to reduce any adverse dust generation. • Monitor and measure air quality to determine mitigation and determine peak and off-peak pollution hours.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Develop dust control measures such as water spray, reduce the speed of the truck and offer training to the operators. • Monitor and measure the quality of dust and communicate to the affected communities, on the likelihood of impacts and mitigation procedures.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R16: Watershed restoration (Environmental Category)



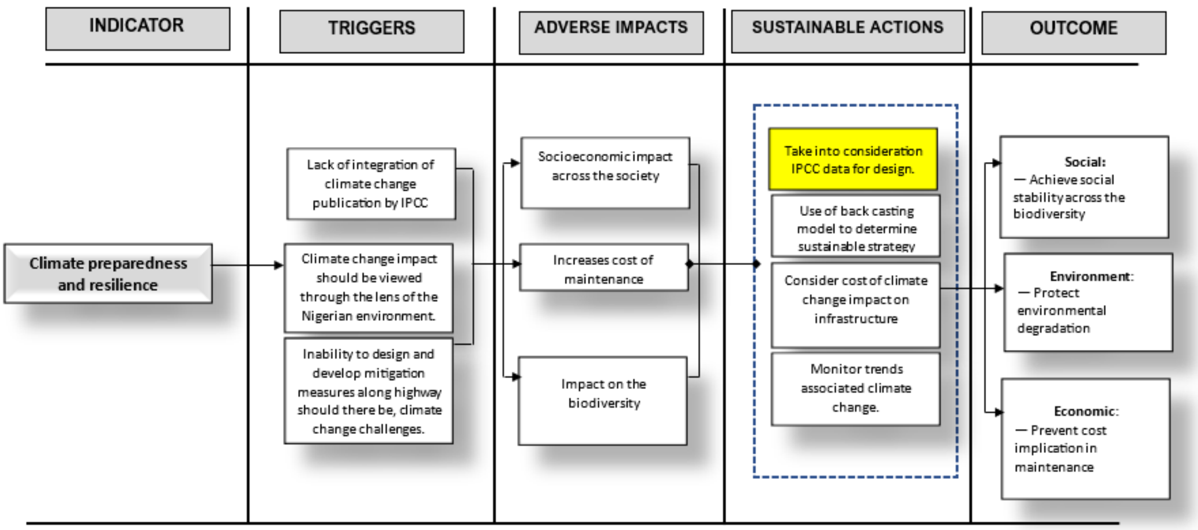
INDICATOR R16: WATERSHED RESTORATION

TRIGGERS	ADVERSE IMPACTS
• Inability to determine during the feasibility phase, terrain virtual watershed to determine aquatic life impacted due to highway development. • Design of water restoration channelled from polluted water to unpolluted watershed.	• Affects the survival of aquatic life

SUSTAINABLE RECOMMENDATIONS
• The use of terrain virtual watershed database support in the design for conduits and restorations of habitats within the stream layers. Terrain virtual watershed reveals digital elevation of attributes within stream segments, and it identifies habitats within stream plain and which helps in making informed decisions on the type of restoration to protect biodiversity. • Feasibility study and data should be collected to avoid the design of conduits connecting the flow of high PH value stream flowing, into lower PH value stream to avoid contamination and endangering of organisms and aquatic animals. • The design consideration should ensure the flow of water within the natural tributaries to ensure the sustainability of the biodiversity along the flow pathway.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Adopt the use of a watershed database to make an informed decision on how to channel watershed restorations. • The watershed path should not be altered or redirected to another flow path to avoid contamination
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R17: Climate preparedness and resilience (Environmental Category)



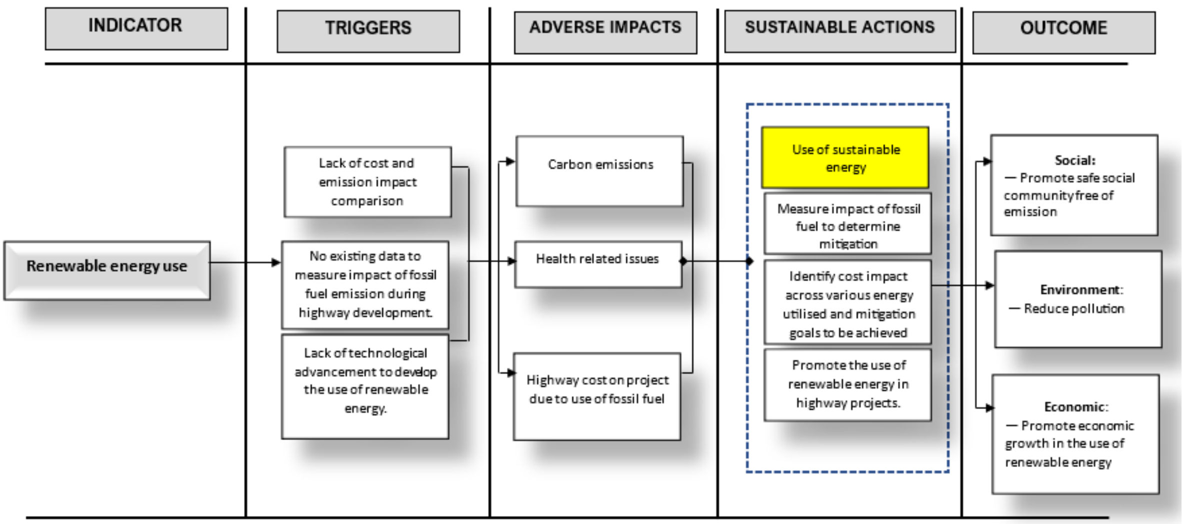
INDICATOR R17: CLIMATE PREPARADNESS AND RESILIENCE

TRIGGERS	ADVERSE IMPACTS
• Lack of integration of data publications from the Intergovernmental Panel on Climate Change (IPCC) for the design of highway projects • • The inability to view climate change's impact through the lens of the Nigerian environment to develop robust solutions for highway projects. • • Inability to provide mitigation measures in case of climate change catastrophe.	• Impact on the socioeconomic status of the society. • Increase the cost of maintenance due to under-design.

SUSTAINABLE RECOMMENDATIONS
• Design resilient highway infrastructure to measure up to climate change variability and extreme weather effects. • The Use of the back-casting model to estimate the level of service required for the highway towards mitigation against flooding, sea level rise impact, extreme precipitation, and heat waves. • Determine cost and impact and mitigation against unexpected climate change impact and need for adaptation.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The integration of climate change impact during highway design will reduce damage to the infrastructure and save lives and properties across biodiversity.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R18: Renewable energy use (Environmental Category)



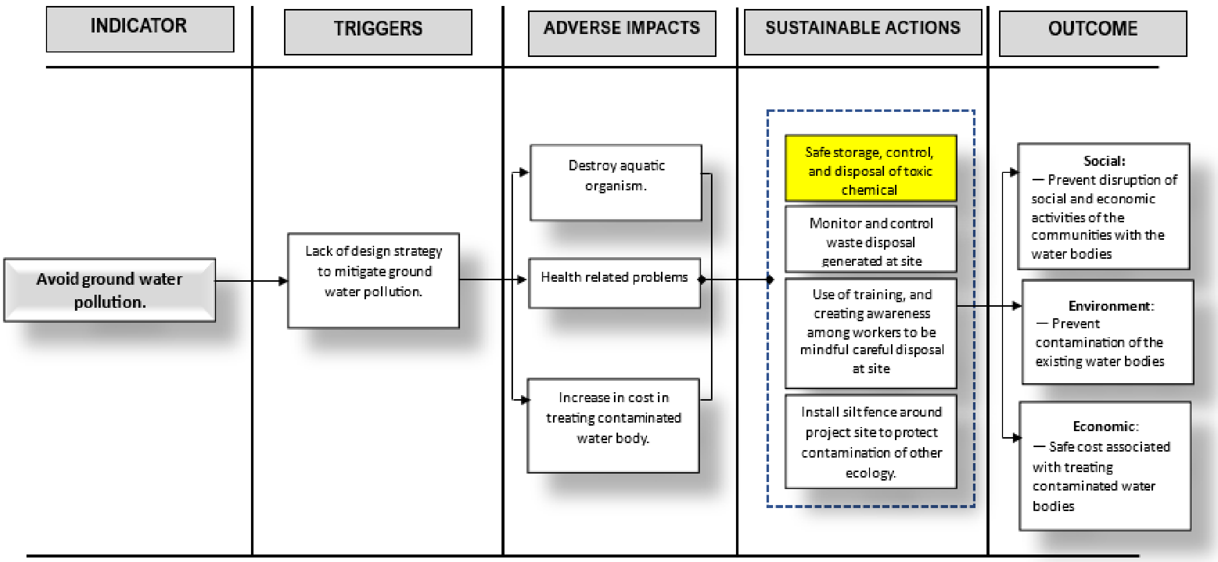
INDICATOR R18: RENEWABLE ENERGY USE

TRIGGERS	ADVERSE IMPACTS
• Lack of measures to adopt renewable energy. • Lack of technological advancement in the use of renewable energy	• Carbon emissions • Cost implications

SUSTAINABLE RECOMMENDATIONS
• Use of solar energy power to energies, such as photovoltaic frames for highway infrastructure facilities. • Determine lifecycle sustainable energy cost with the cost associated with fossil fuel to determine mitigation measures and the impact of carbon emission from the project. • Determine peak and off-peak associated with the energy use and mitigation optimisation and cost savings.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Reduce emissions associated with fossil fuels. • Reduce energy cost. • Use of wind energy
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R19: Avoid groundwater pollution (Environmental Category)



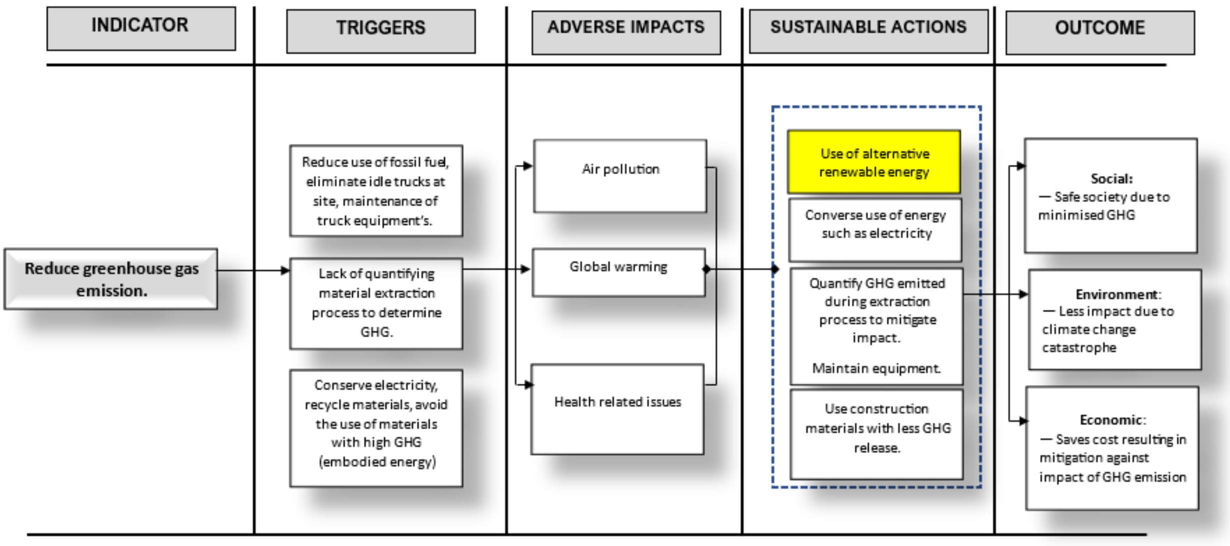
INDICATOR R19: AVOID GROUND WATER POLLUTION

TRIGGERS	ADVERSE IMPACTS
• Lack of design for control of groundwater management strategy. • Lack of data to determine the impact of groundwater pollution due to highway construction projects.	• Destroys aquatic life. • Resulting in complex related illnesses.

SUSTAINABLE RECOMMENDATIONS
• Toxic substances such as cement, oil, glue, and other chemicals from the construction site must not end up in the water bodies (safe storage, control, and disposal). • Educate the workers on the challenges and dangers of releasing toxic chemicals into the ground and water bodies. • Monitor and manage waste disposals. • Secure toxic materials in proper storage with specific policies and procedures on management • Install a silt fence around the site to avoid contamination of the adjoining properties or communities.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The design and use of safe storage, control measures and disposal of toxic materials generated from the construction site will help to keep society safe from encountering hazardous materials.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R20: Reduce greenhouse gas emission (Environmental Category)



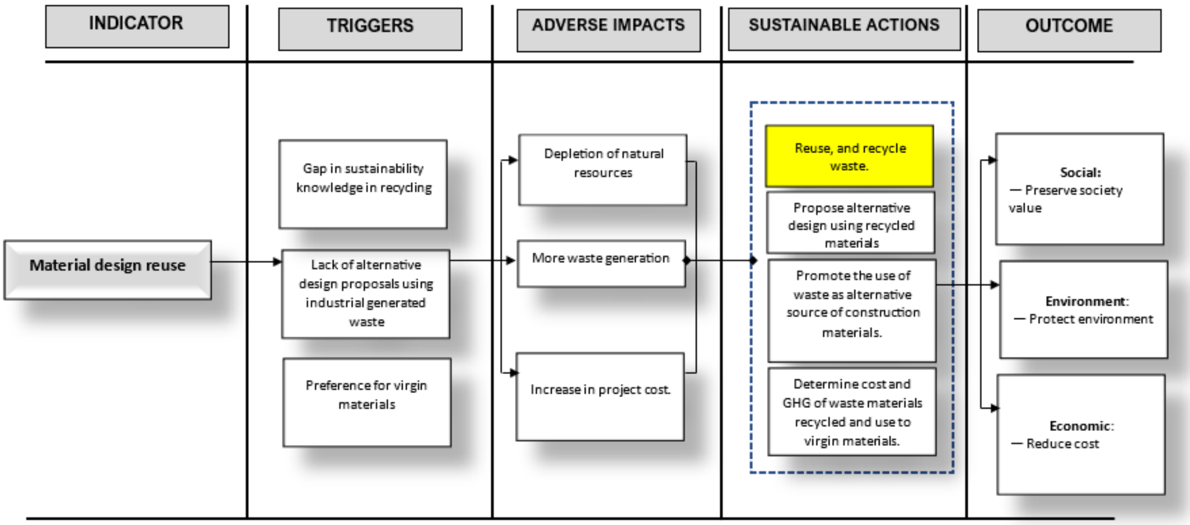
INDICATOR R20: REDUCE GREENHOUSE GAS EMISSION

TRIGGERS	ADVERSE IMPACTS
• Use of fossil fuel, and electricity (direct sources), and indirect sources (embodied energy), such as construction materials. • Lack of quantifying GHG of construction materials	• Air pollution • Health-related illness • Climate change impact

SUSTAINABLE RECOMMENDATIONS
• Quantify emissions from the extractions and production of asphalts to determine mitigation on the reduction of carbon released into the atmosphere. • Examine the benefits of using Warm Mix Asphalt as against Hot Mix Asphalt to reduce carbon emissions. • Reduce the use of fossil fuels and encourage the use of hydrogen biofuel and other renewable energy. • Eliminate the idling time of trucks, when not in use to reduce the amount of greenhouse gas (GHG) released into the atmosphere. • Proper maintenance of equipment reduces fuel consumption, thereby reduce the amount of GHG emitted into the atmosphere. • Conserving electricity • Reducing the use of construction materials that releases GHG emissions. • Recycling and reuse to avoid extraction of new raw materials. • Determine each activity GHG emission released to mitigate the reduction in the release of GHG
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The quantification to determine GHG will help to reduce material extraction and production processes. • The use of materials with less release of GHG emission for construction.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R21: Material design reuse (Environmental Category)



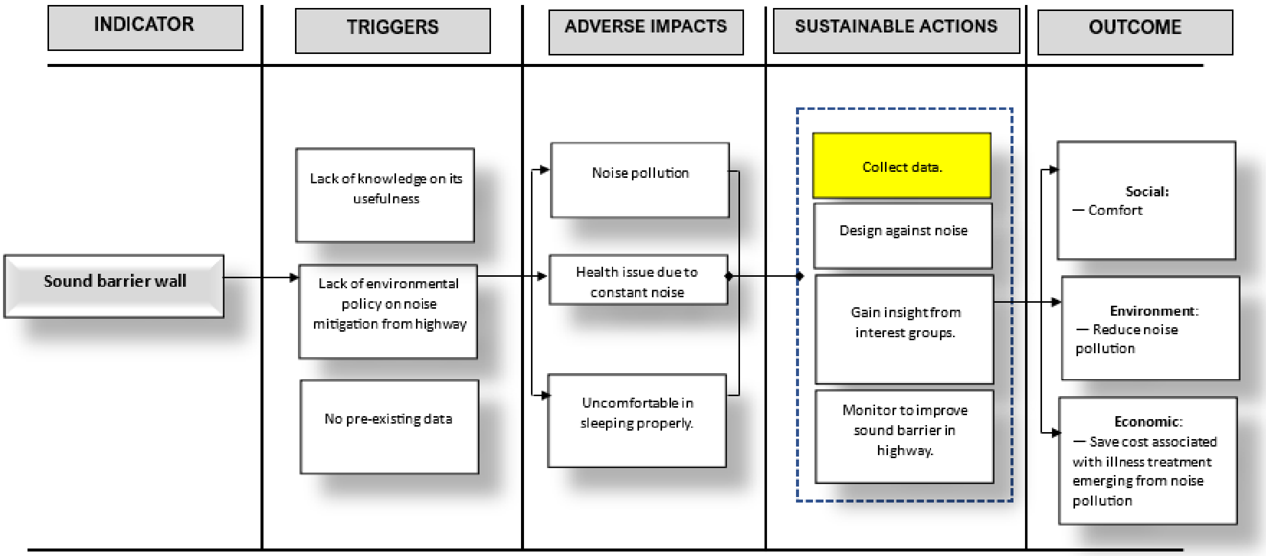
INDICATOR R21: MATERIAL DESIGN REUSE

TRIGGERS	ADVERSE IMPACTS
• Inability to design reuse of waste materials generated across industry and construction site. • Lack of sustainability knowledge	• Depletion of natural raw materials • Release of GHG

SUSTAINABLE RECOMMENDATIONS
• Preserve and reuse waste and materials generated from the project site to reduce material extraction from the environment. • Establish the documented material use, the amount recycled by content and weight. • Design to experiment with the use of material waste such as (blast furnace slag, coal fly ash reclaimed concrete pavement, reclaimed asphalt pavement, and scrap tires) in developing new asphalt pavement.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The reuse, and recycling of waste and to preserve of virgin materials
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R22: Sound barrier wall (Environmental Category)



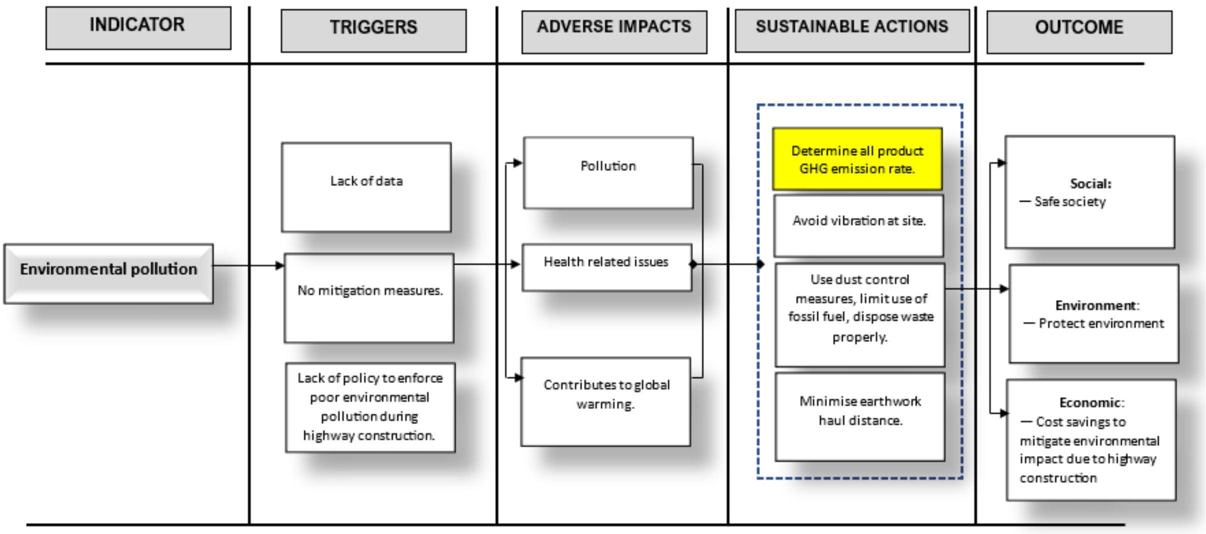
INDICATOR R22: SOUND BARRIER WALL

TRIGGERS	ADVERSE IMPACTS
• The lack of design mitigating how to reduce noise pollution is a result of automobile aerodynamics.	• Noise pollution • Discomfort due to noise

SUSTAINABLE RECOMMENDATIONS
• Design use of reflective and absorptive sound barrier walls using concrete slabs or trees • Helps mitigate noise which causes health-related issues due to automobile aerodynamics. • Conduct computer modelling to measure the impact of noise across communities and mitigate factors using a sound barrier.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Health-effective and noise control • Safety barrier • Soundproofing
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R23: Eliminate environmental pollution (Environmental Category)



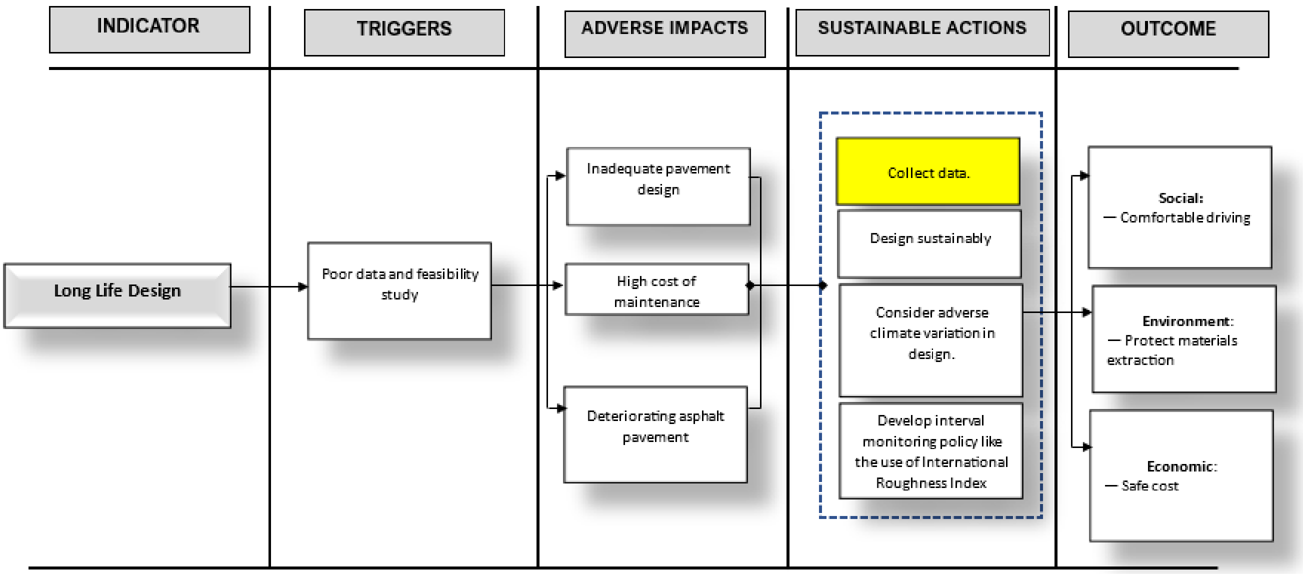
INDICATOR R23: ELIMINATE ENVIRONMENTAL POLLUTION

TRIGGERS	ADVERSE IMPACTS
• Inability to collect data to determine environmental pollution impact. • Keep records to manage mitigation	• Environmental pollution • Increase in global warming

SUSTAINABLE RECOMMENDATIONS
• Design to determine all materials and products used in the project site and the pollution impact and mitigation approach. • Avoid unnecessary vibration. • Use dust control measures. • Avoid unnecessary waste generation. • Limit fuel usage • Dispose properly. • Reduce noise. • Utilise reusable energy. • Decrease environmental impact. • Minimise earthwork haul distance
REQUIRED BEST PRACTICES AND RESULTS OUTCOME • Increase the use of a sustainability approach across the development of highway project
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R24: Long Life design (Environmental Category)



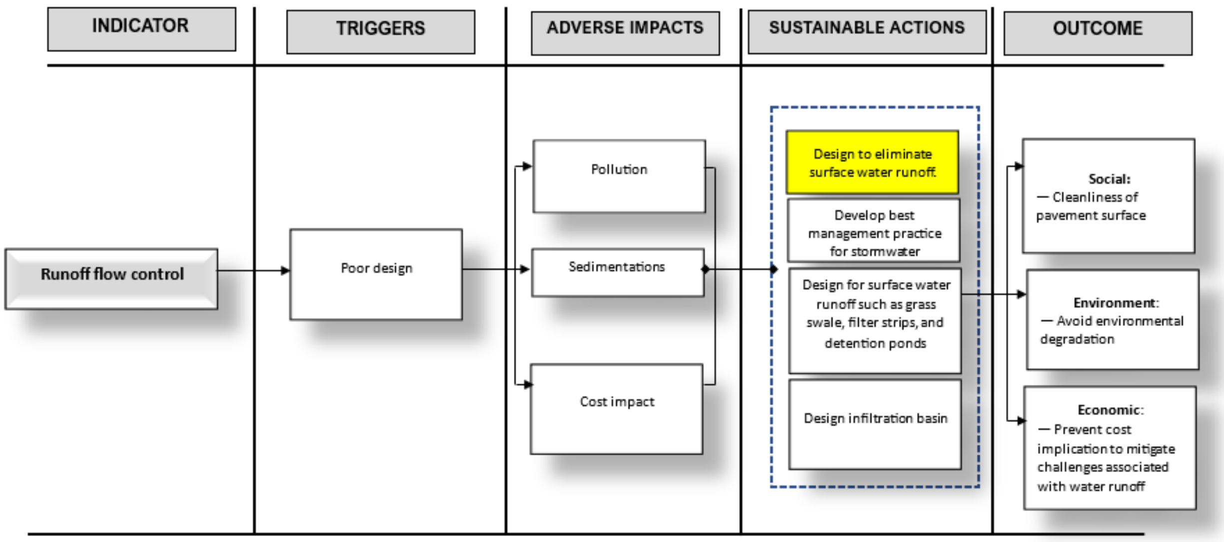
INDICATOR R24: LONG LIFE DESIGN

TRIGGERS	ADVERSE IMPACTS
• Inability to determine robust information and data needed to make informed decisions to achieve.	• Inadequate pavement design resulting in road users' discomfort. • High cost of maintenance • Deteriorating asphalt pavement

SUSTAINABLE RECOMMENDATIONS
• Highway pavement long-life design should consider factors such as robust traffic volume count data, the axle wheel configuration, the various tyre contact pressure, and the rainfall and drainage system required. • Take into consideration the design of pavement against frost action and atmospheric temperature variations. • Others are economic considerations and material characteristics.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Collect data on materials, and take into consideration environmental, social, and economic factors to determine asphalt long life pavement design
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R25: Runoff flow control (Environmental Category)



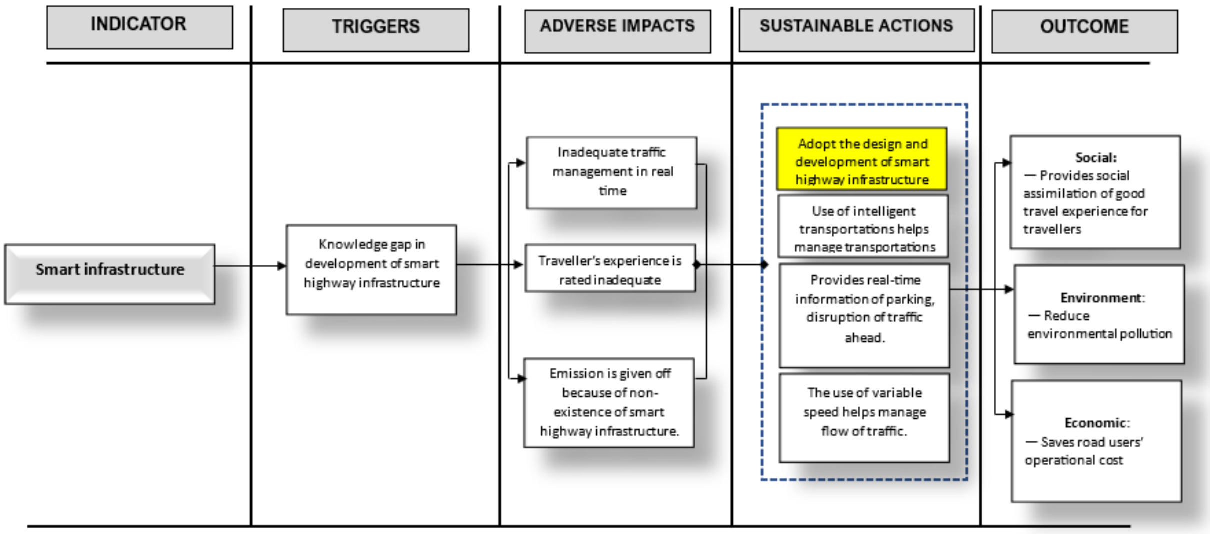
INDICATOR R25: RUNOFF FLOW CONTROL

TRIGGERS	ADVERSE IMPACTS
• Poor design to eliminate surface water runoff from polluting the riverbed	• Polluted groundwater • Sediments of materials across the environment

SUSTAINABLE RECOMMENDATIONS
• Reduce and eliminate surface water runoff to avoid polluting water bodies. • Design to address control of stormwater during normal times and flooding. • Develop a robust detailed map indicating the inlet and outlet of the stormwater showing best management practice (BMP). • Design for grass swales • Design for filter strips • Detention ponds or basins • Infiltration basins and constructed wetlands
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• To control asphalt pavements surface runoff from polluting existing river water beds
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R26: Smart Infrastructure (Environmental Category)



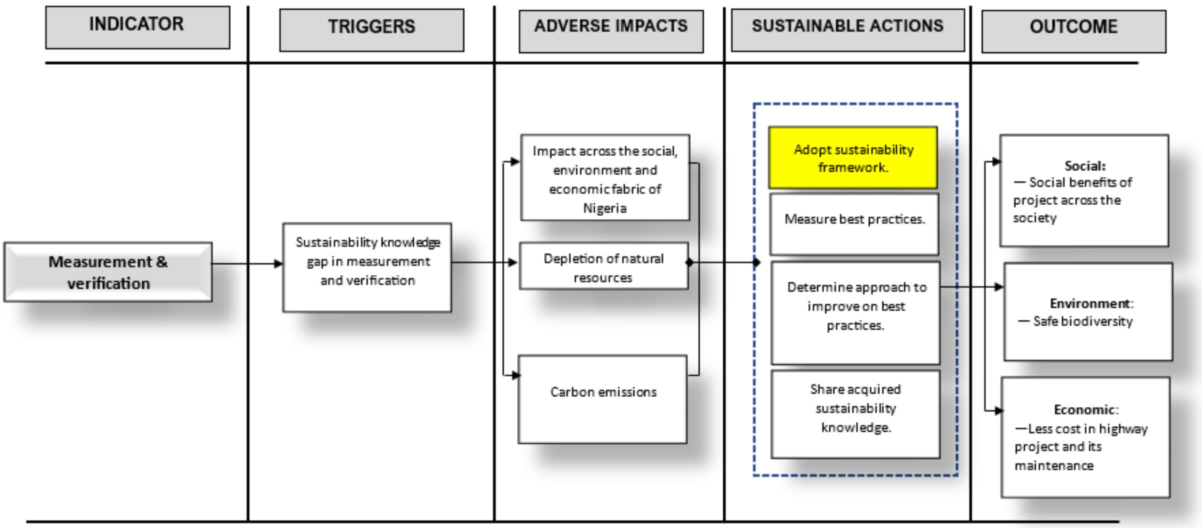
INDICATOR R26: SMART INFRASTRUCTURE

TRIGGERS	ADVERSE IMPACTS
• Lack of technology to establish smart highway infrastructure	• Inadequate traffic management, resulting in the unsatisfaction of road users and high rate of emission due to congestion

SUSTAINABLE RECOMMENDATIONS
• Smart highway infrastructure such as a flashing in-pavement cat eye indicates different types of warning road users of potential traffic disruption ahead. • The inclusion of an intelligent transportation system helps to manage different modes of transportation. • Smart highway uses real-time video traffic detection to resolve real-time traffic conditions. • Support advanced travellers' information systems. • It provides parking guidance
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The adoption of best practices of smart highway infrastructure enhances the effective flow of traffic in real time.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R27: Measurement and verification (Environmental Category)



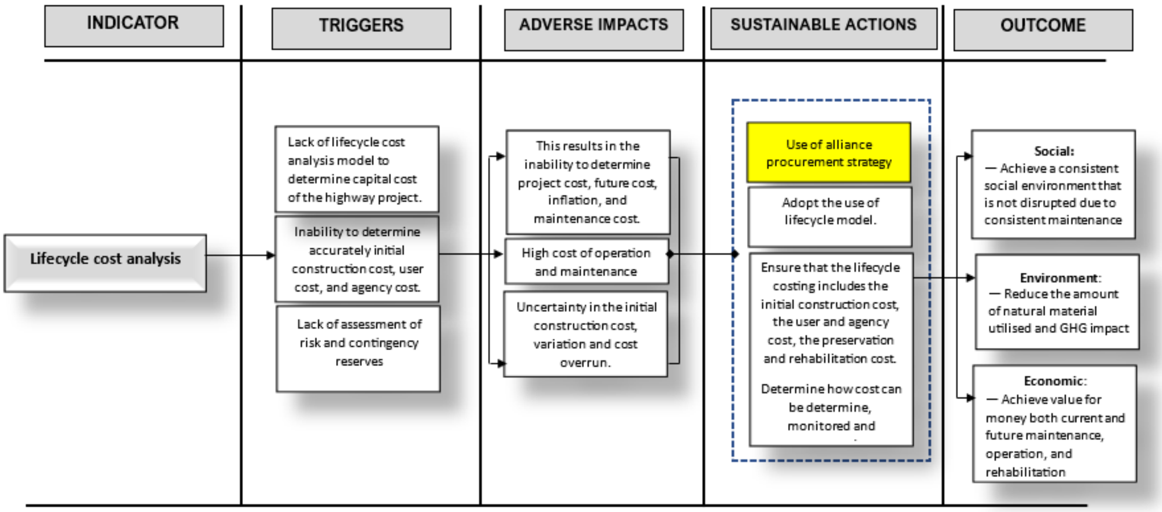
INDICATOR R27: MEASUREMENT AND VERIFICATION

TRIGGERS	ADVERSE IMPACTS
• Knowledge gap in developing sustainability rating framework for highway design and construction.	• Unsustainable adverse impact across society due to highway development.

SUSTAINABLE RECOMMENDATIONS
• Develop specifications and procedures to measure sustainability accountability using the adopted sustainability rating system and decision logic framework per each indicator. • Determine how the sustainability credit award level is issued to determine the level of sustainability indicator achieved in a project. • Document sustainability best practices and determine what was done wrong to achieve improvement in a future project. • Compare achieved best practices with other projects to determine how to increase the benchmark. • At the end of a project, issue a sustainability close-out report for future learning curves.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• To design a specification for sustainability practice and to issue a sustainability completion report
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R28: (lifecycle cost analysis) Economic Categories



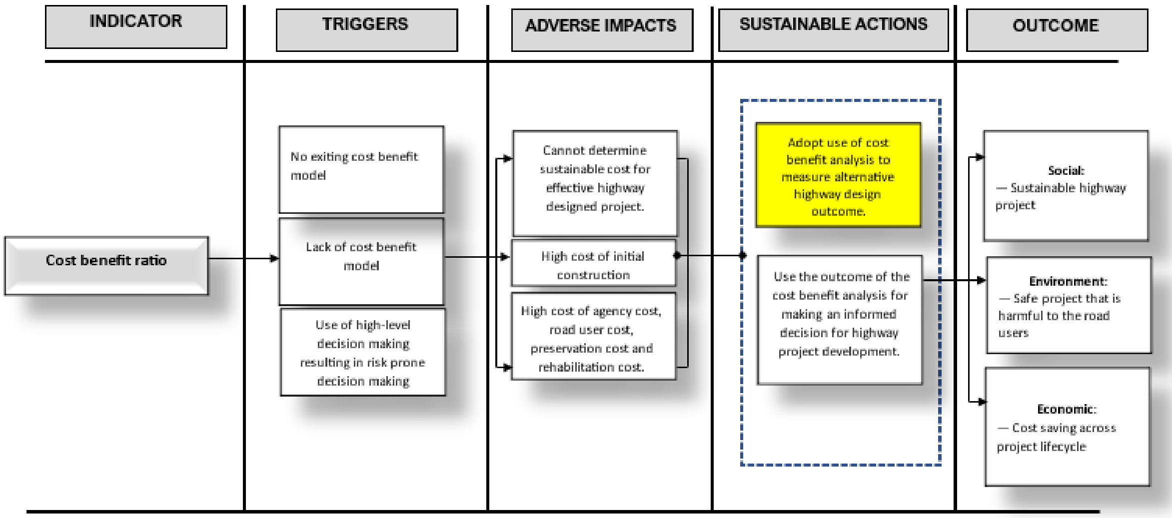
INDICATOR R28: LIFECYCLE COST ANALYSIS

TRIGGERS	**ADVERSE IMPACTS**
• Lack of a lifecycle model to determine the effectiveness of a different type of design. • Lack of analysis to determine accurately the initial construction cost, the agency cost, and the road user cost.	• It results in the highway cost of the project which will take a longer time to complete. • It is challenging to determine maintenance cost, unforeseen cost

SUSTAINABLE RECOMMENDATIONS
• Determine at the procurement stages the entire lifecycle, and whole lifecycle cost analysis of the highway project. This includes the cost of the initial investment, the operating cost, the maintenance cost, and the cost of upgrading and removal of the facility when not required. • The lifecycle costing analysis supports determining benefits such as estimates incurred on an asset life span, it helps in making the best decision which is accurate and realistic. • Determine User Costs, which are costs associated with maintenance of a road section that affects the road user, such as delay, vehicle operating costs, and costs associated with crashing due to the highway. Lane closure due to maintenance affects the road user cost, so overall different design alternatives' lifecycle cost is analysed properly. • Agency Cost analysis are costs incurred in four categories which are (1) the initial construction cost, which is called capital cost, (2) the maintenance cost, and (3) the preservation cost needed to preserve the life of the services within the highway facilities, preservation cost differs from maintenance and rehabilitation because preservation cost is a preventive type of cost, the last is the (4) rehabilitation cost. The difference between maintenance cost and rehabilitation cost is that the former is a less routine cost, while the former is a huge cost for the overhauling of s highway facility. • Develop a highway transportation agency lifecycle analysis model, to help in determining the selection of the best alternative design outcome. • Determine how to minimise cost in the use of a sustainability approach across the whole and lifecycle analysis of a highway project facility.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Achieve the best cost-effective highway design facility. • It is an opportunity to integrate sustainable development to reduce costs across the project lifecycle. • It helps to determine fit for purpose highway project facility.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R29: (Cost-benefit ratio) Economic Categories



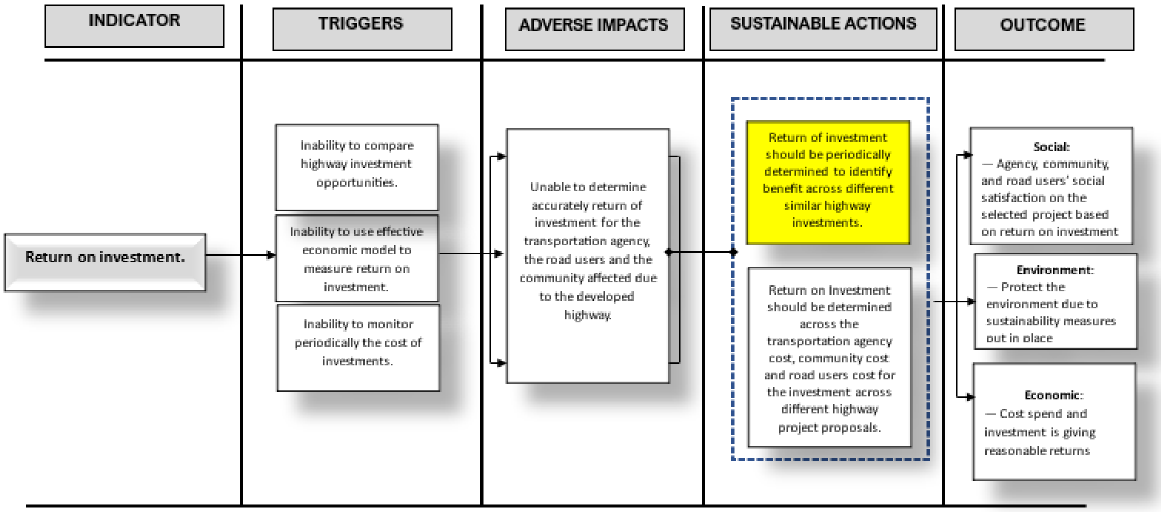
INDICATOR R29: COST BENEFIT RATIO

TRIGGERS	ADVERSE IMPACTS
• Lack of cost-benefit analysis model • Lack of knowledge on the benefits of the use of cost-benefit analysis	• The inability to make an informed economically sound decision in selecting the best-designed highway facility for development involves giving a false cost-benefit and lifecycle analysis.

SUSTAINABLE RECOMMENDATIONS
• The cost-benefit analysis (CBA) should be utilised to determine systematically the weakness and strengths of alternative design under the lifecycle cost analysis. The CBA help identify, benefits in terms of the sustainability approach considered and achieved. • The cost-benefit analysis measures a wide range of factors to determine if the investment decisions are sound, ascertaining in terms of cost and benefits, it provides the basis for comparison of investments in coming to a final decision making.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The CBA measures the positive and negative consequences of different alternative designs, for instance, to conclude the investment decisions. • It helps identify a project that can achieve the best potential long-term objective performance.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R30: (Return on investment) Economic Categories

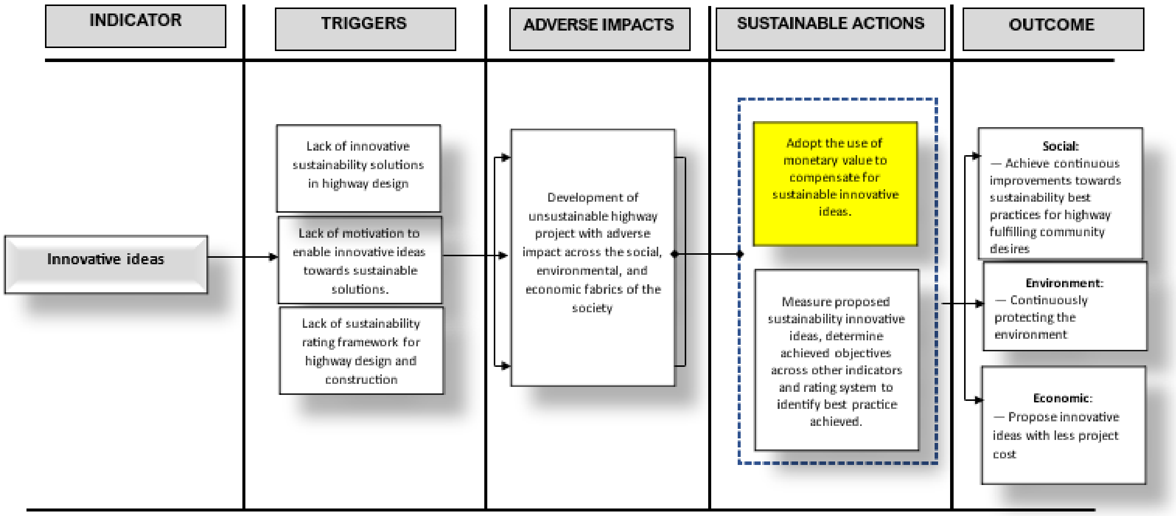


INDICATOR R30: RETURN ON INVESTMENT

TRIGGERS	ADVERSE IMPACTS
• Inability to determine the return-on-investment model for the analysis of highway projects	• This will result in the inability of the agency to determine accurately highway investment opportunities that are most attractive.
SUSTAINABLE RECOMMENDATIONS	
• Return on investment (ROI) measures the performance profitability of an investment with other similar types of investments. In this case, for the selected highway design project, after construction what is the intended profitability measured within the context of sustainability, and socioeconomic benefits towards the road users, agency and communities measured in terms of cost, before and after the highway investment. • The return on investment should be measured over a given agreed period for the transportation agency, the community and road users.	
REQUIRED BEST PRACTICES AND RESULTS OUTCOME	
• Return on investment for the highway project measures within a period incremental return on highway investments to determine benefits across other investments. This will be accessed within the context of social, economic, and environmental.	
Credit point awarded to implement best practices = 1	

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R31: (Innovative ideas) Economic Categories



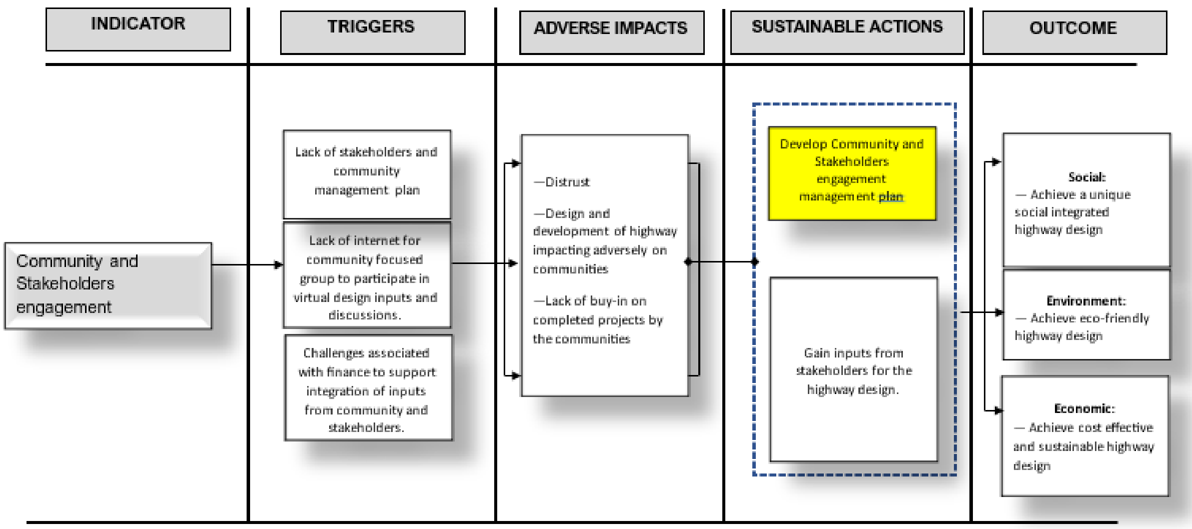
INDICATOR R31: INNOVATIVE IDEAS

TRIGGERS	ADVERSE IMPACTS
• Lack of innovative solutions to determine best practices and sustainable development approach, which requires monetary compensation	• Unsustainable highway development, with adverse impacts across the socioeconomic of the society.

SUSTAINABLE RECOMMENDATIONS
• Reward and compensate with monetary value, new and innovative sustainable design for highway construction. • Determine and propose best practices to enhance highway design and construction sustainability. This should not be limited to the triple bottom line of social, environmental, and economic sustainability. • Measure the proposed innovative approach to determine improvements. • Compare the best practices, and the credit rating system across other existing sustainability rating systems to determine the achieved level and criteria of best practice implemented.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The intended purpose is to continually determine how to maximise highway low carbon emissions such as the use of warm mix asphalt, the design of safer sustainable pavement, the use of recycled materials in greater percentage, the effective ecosystem management of highways with the environment, the use of energy reduction during the operation of highway and the stormwater management.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R32: (Community and Stakeholders engagement) Social Categories



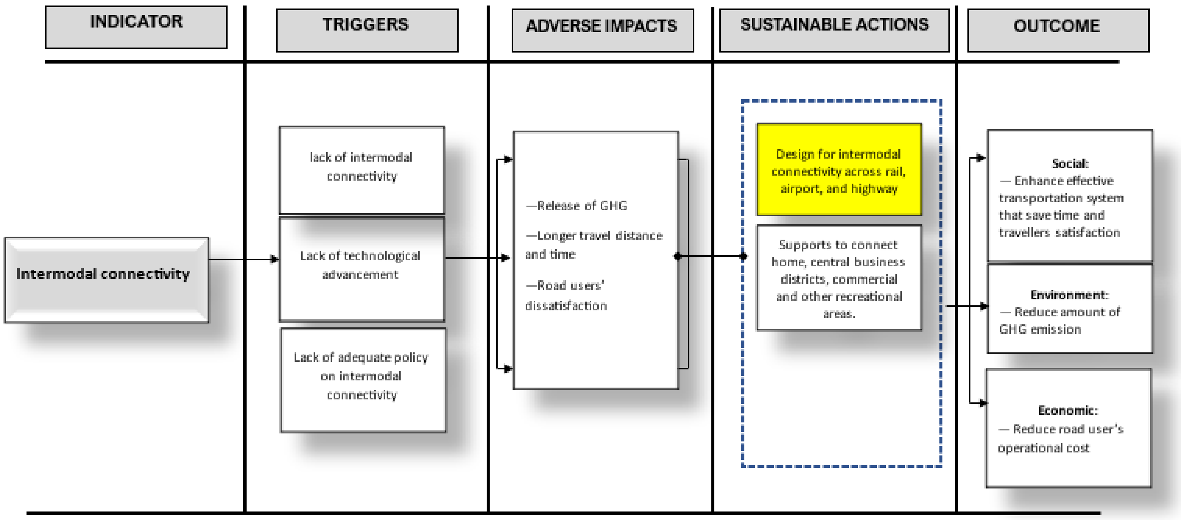
INDICATOR R32: COMMUNITY AND STAKEHOLDERS ENGAGEMENT

TRIGGERS	ADVERSE IMPACTS
• Lack of internet to access information electronically. • Lack of stakeholders and community consultation during design phases. • Lack of finance to support active engagement. • Non-existence of Community and Stakeholders engagement plan	• Distrust • Project design and construction impacting adversely on the community. • Lack of buy-in from the community due to neglect.

SUSTAINABLE RECOMMENDATIONS
• Develop Community Engagement Management Plan to enable consultation at the level of sustainability needed to be achieved. • The engagement management plan should identify, how to reach out to the various communities affected by the highway projects, ensuring a non-discriminatory process in collecting inputs across communities to design the highway project. • Another consideration is how to facilitate communication, maximise creativity and innovation of the design, and ensure diverse inputs are gathered, to foster inclusiveness. • Inform the stakeholders, community and public of the challenges, assumptions and realistic design that can be achieved and the areas in which their inputs are required. • Document all communication, inputs for continuous management and updates towards achieving the goals of the project. • Categories the community and stakeholders focused groups to analyse the impact of the project and expectations.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• To establish a plan to gain input from stakeholders and communities for the development of highway design.
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R33: (Intermodal connectivity) Social Categories



INDICATOR R33: INTERMODAL CONNECTIVITY

TRIGGERS	ADVERSE IMPACTS
• The lack of intermodal connectivity • Inadequate intermodal design • Lack of technological advancement/policy	• Release of excessive GHG due to an increased number of the vehicle. • Longer travel time for road users

SUSTAINABLE RECOMMENDATIONS

- Intermodal connectivity of rail tram, ship freight and highway should be designed to foster an inclusive transportation system.
- Conduct feasibility studies to determine sustainability gain, and the alleviation in the design of intermodal connectivity to enhance the public transportation experience.
- To encourage the use of rail and roads integrated public transportation systems connecting the home to office and other public places like hospitals, recreational facilities, worship places and educational institutions.
- Integrated roads and railways reduce travel distance and save operational road user costs.

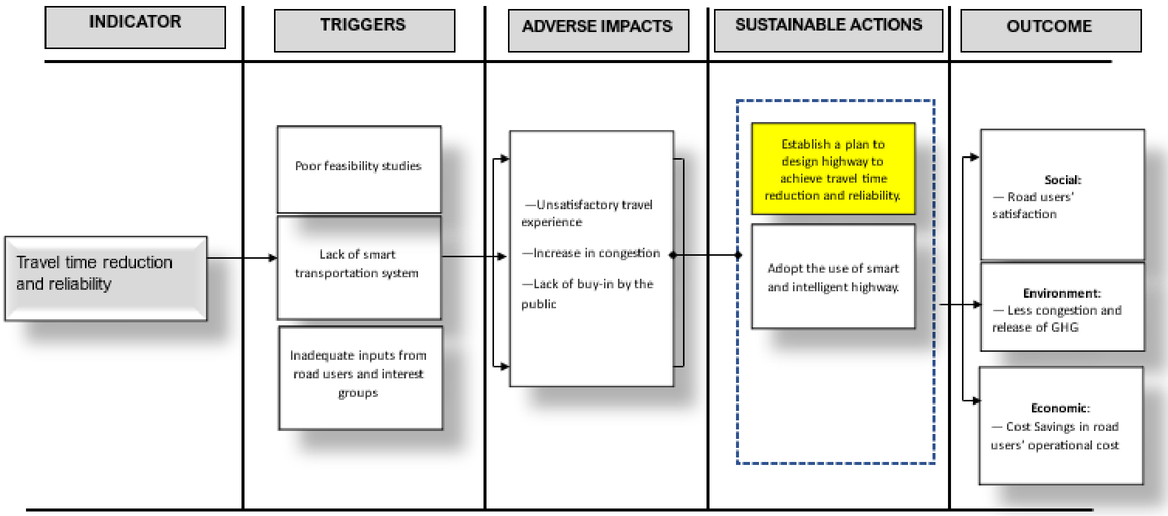
REQUIRED BEST PRACTICES AND RESULTS OUTCOME

- Intermodal transportation helps reduces traffic congestion and GHG emissions.
- Reduces the road users' operation cost.
- Increase transportation efficiency.

Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R34: (Travel time reduction and reliability) Social Categories



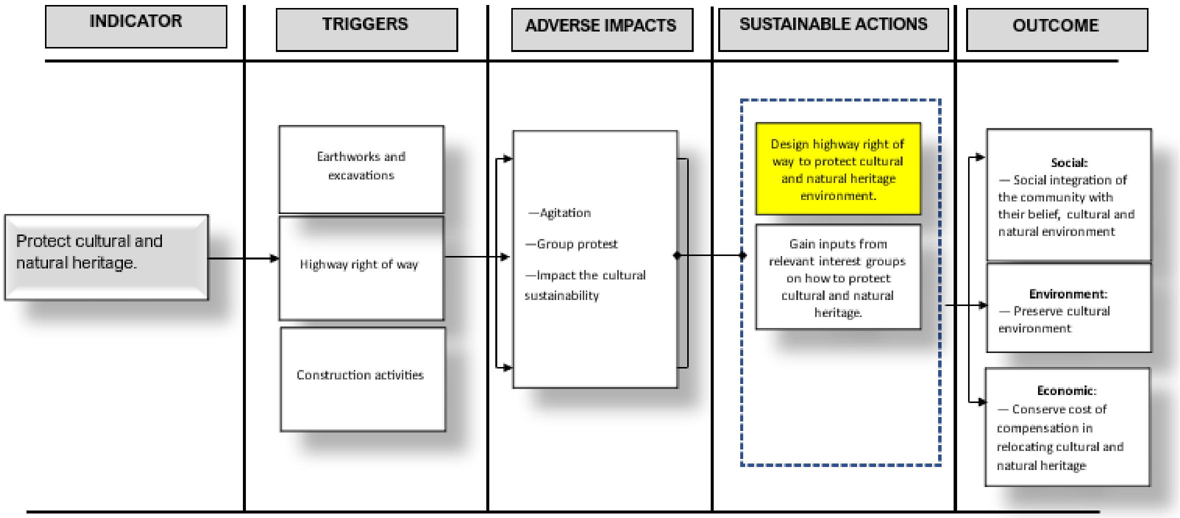
INDICATOR R34: TRAVEL TIME REDUCTION & RELIABILITY

TRIGGERS	ADVERSE IMPACTS
• Poor feasibility study • Lack of smart transportation system • Inadequate inputs for interest groups	• Unsatisfactory travel experience

SUSTAINABLE RECOMMENDATIONS
• To design and develop highway routes for road users to monitor congestions head, change in weather conditions, road closures, and some delays which are expected and unexpected in terms of reliability and variability of the travel path. • Sustainable travel time reliability along a highway path reflects the number of travel values and costs willingly to be paid by a traveller.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Achieve travel time and good value for money. • Increase road travellers' satisfaction. • Helps to avoid overcrowding of traffic on the highway
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R35: (Protect cultural and natural heritage) Social Categories



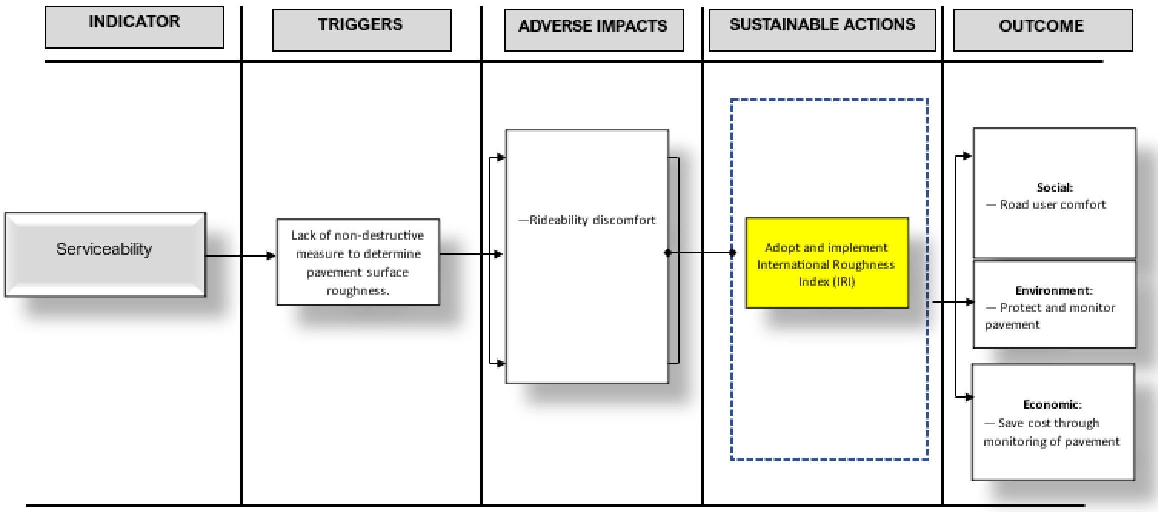
INDICATOR R35: PROTECT CULTURAL AND NATURAL HERITAGE

TRIGGERS	**ADVERSE IMPACTS**
• Highway earthworks and excavation • Right of way for highway alignment	• Resulting in protest and agitation • Impact cultural sustainability

SUSTAINABLE RECOMMENDATIONS
• During design, establish a plan to ensure the protection of cultural heritage and natural heritage. • The protection of cultural and natural heritage should include during design, the site assessment, and the identification of artefacts. • Protection of the indigenous environment, ensuring buffer distance from the proposed project alignment site. • Gain interest group inputs on how to protect the cultural and indigenous environment.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• Protect the heritage and cultural environment during highway design
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR DECISION LOGIC SUB-FRAMEWORK

Indicator R36: (Serviceability) Social Categories



INDICATOR R36: SERVICEABILITY

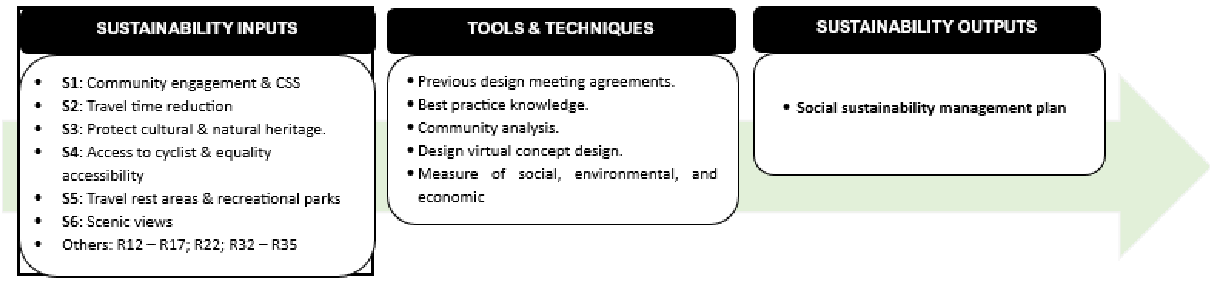
TRIGGERS	ADVERSE IMPACTS
• Design of non-destructive test measure to determine the roughness index of the highway pavement structure	• Rideability discomfort by the road users

SUSTAINABLE RECOMMENDATIONS
• The highway pavement surface “Present Serviceability Index” (PSI) or “International Roughness Index” (IRI) is a measure of ride quality rating. These non-destructive techniques measure slope variance across pavement profiles to determine the acceptability and unacceptability of the pavement surface. • The PSI and IRI measure the longitudinal road profiles and the roughness or smoothness of the pavement surface.
REQUIRED BEST PRACTICES AND RESULTS OUTCOME
• The PSI and IRI help to determine the roughness or severity of pavement classification to determine the response to fatigue damages that might occur in highway pavement. • The PSI and IRI establish ride comfort of the road users
Credit point awarded to implement best practices = 1

SUSTAINABILITY INDICATOR PROCESS LOGIC SUB-FRAMEWORK FOR CONSTRUCTION

SUSTAINABILITY INDICATOR PROCESS LOGIC SUB-FRAMEWORK

Indicators S1 – S6: Social Sustainability process group



INDICATORS S1 – S6: SOCIAL SUSTAINABILITY PROCESS GROUP

Aim	Goal
• The social sustainability process group is considered the foremost in engaging with the community and project stakeholders to align their expectations as agreed upon during the highway construction processes. • The emphasis under the social sustainability process group is on the implementation, monitoring and delivery of the sustainability concept developed during the design phase. • It involves guiding the sustainability visions of the community, road users and interest groups to be achieved during the development of the highway project.	• Development of social sustainability management plan with the communities and the contractor, to ensure the development of the highway facilities does not hinder the society's health, accessibility, and ecological, political, economic, and cultural sustainability.

SUSTAINABILITY INPUTS

- Social Sustainability consideration inputs during the construction phase are the measure of human welfare, to ensure intergenerational equity to increase the standard of living, through the participation of communities to add inputs towards the development of highway facilities. The various inputs are: —

1. To gain insight into the triggers and sustainable recommendations from the communities on details required for the Community Management Plan for highway construction.
2. The active participation of the community, stakeholders, and interest groups in communicating execution and progress and determining and influencing necessary changes made earlier during the sustainability design phases.
3. Inputs are made during highway design processes.

TOOLS AND TECHNIQUES

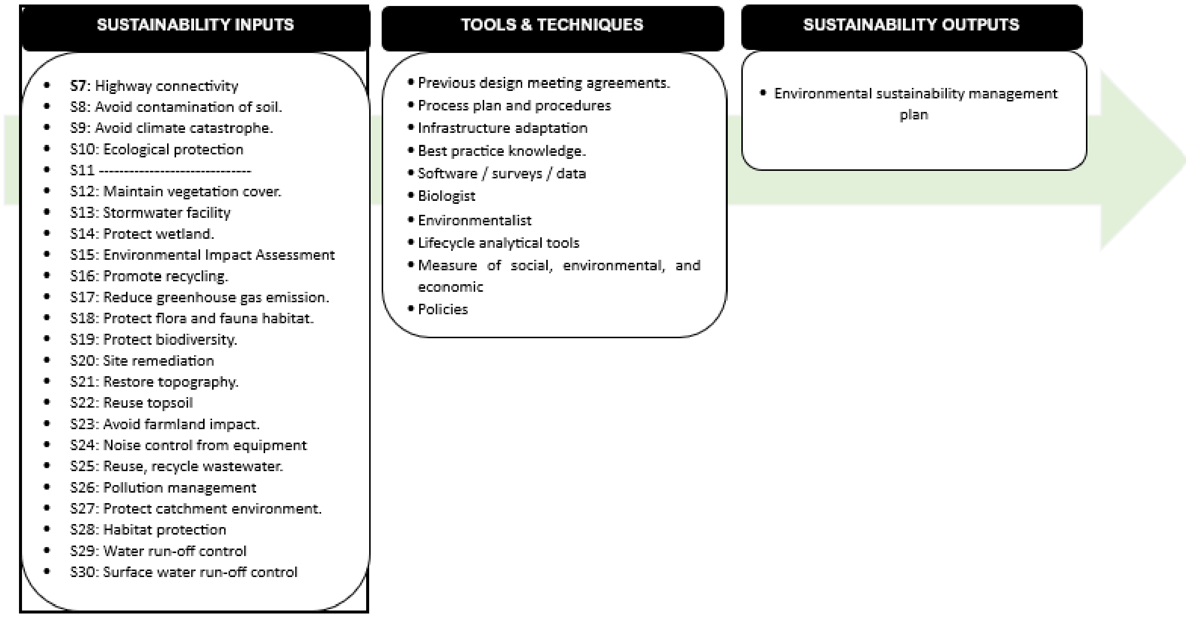
1. The tools and techniques are in varying degrees, for instance using the various matrix of agreement held during the design phase, best practice, analysis of community needs and virtual video of the ongoing project and maps to view the highway path, the protection of cultural and natural heritage, rest areas and scenic view to promoting culture.

SUSTAINABILITY OUTPUTS

1. A social sustainability management plan
2. **Credit point awarded to implement best practices = 1 per each indicator**

SUSTAINABILITY INDICATOR PROCESS LOGIC SUB-FRAMEWORK

Indicators S7-S10, and S12 – S30: Environmental Sustainability Process Group



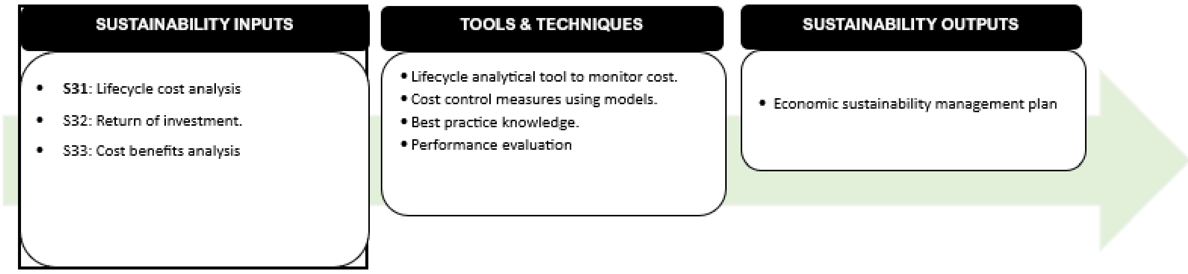
INDICATORS S7 -S10, and S12 – S30: ENVIRONMENTAL SUSTAINABILITY PROCESS GROUP

Aim	Goal
• To achieve connectivity of biodiversity and to avoid pollution, contamination, erosion, noise or the misuse of natural resources or generated materials within the project environment.	• Development of an environmental sustainability management plan to reduce any negative impacts such as consumption of natural resources, noise, pollution, and emission due to highway facility development. • To contribute to reducing climate change catastrophe.

SUSTAINABILITY INPUTS
• Inputs of environmental sustainability during the construction phase assure to determine the implementation of best practices to achieve: — 1. Consistent connectivity across biodiversity is affected due to highway development. 2. To develop plans and procedures on how to avoid soil contamination, and adverse impacts on the climate, ensure to protect of ecology, erosion control, stormwater control and wetland. 3. Determine effective environmental impact assessment through scoping, ensure site remediation, restore topography, and avoid impact on sensitive ecology. 4. Promote recycling to reduce greenhouse gas, maintain equipment, and protect flora and fauna. 5. Provide and control surface and water runoff. 6. Inputs of agreements made during the sustainable highway design process
TOOLS AND TECHNIQUES
The tools and techniques are in varying degrees, for instance, previous design agreements, use of best practices, software, survey, data, expert opinion, and policies.
SUSTAINABILITY OUTPUTS
An environmental sustainability management plan
Credit point awarded to implement best practices = 1 per each indicator

SUSTAINABILITY INDICATOR PROCESS LOGIC SUB-FRAMEWORK

Indicators S31 – S33: Economic Sustainability Process Group



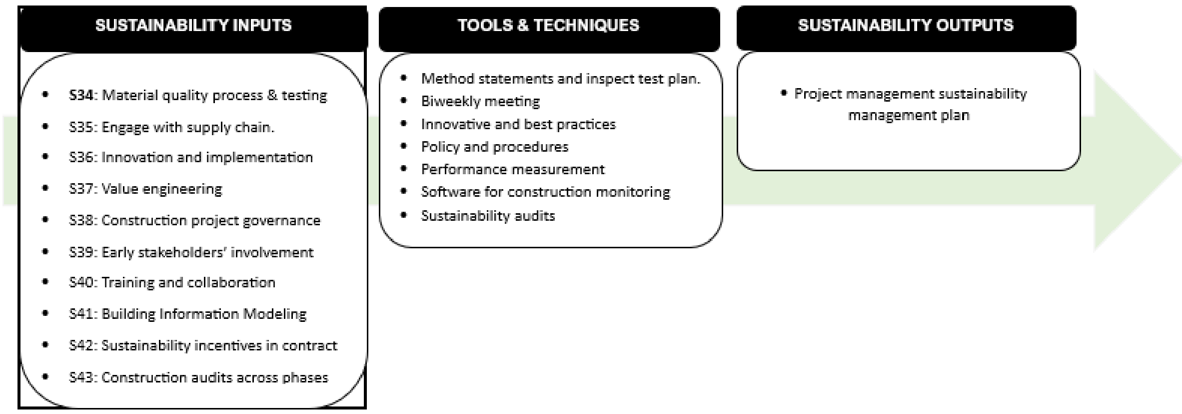
INDICATORS S31 – S33: ECONOMIC SUSTAINABILITY PROCESS GROUP

Aim	Goal
• To achieve cost-effective monitoring of the highway project to ensure the cost-benefit ratio is achieved, alongside, overall lifecycle costing.	• Development of an economic sustainability management plan to help foster economic growth while preserving the quality of the environment for future generations.

SUSTAINABILITY INPUTS
• Inputs of economic sustainability during the construction phase assure to determine the implementation of best practices to achieve: — 1. To ensure the selected alternative design is delivered within the cost with no impact on the environment, user operational cost, and agency cost. 2. To safeguard the cost-benefit analysis agreed upon during the highway design stage. 3. To ensure return on investment for the highway project is achieved.
TOOLS AND TECHNIQUES
The tools and techniques are in varying degrees, such as the use of performance evaluation tools to monitor and control the cost associated with the execution of the project.
SUSTAINABILITY OUTPUTS
An economic sustainability management plan
Credit point awarded to implement best practices = 1 per each indicator

SUSTAINABILITY INDICATOR PROCESS LOGIC SUB-FRAMEWORK

Indicators S34 – S43: Project management Sustainability Process Group



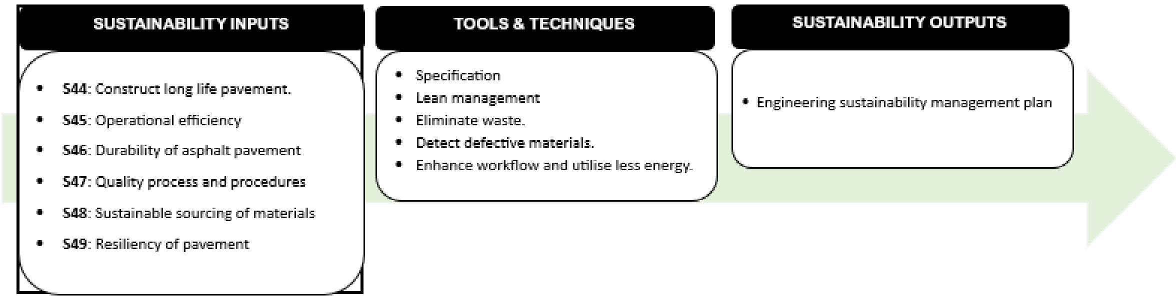
INDICATORS S34 – S43: PROJECT MANAGEMENT SUSTAINABILITY PROCESS GROUP

Aim	Goal
• To achieve delivery of sustainable highway projects to achieve quality, within the context of value engineering, inputs from the supply chain, stakeholders, the use of sustainable governance, training, and audits to manage the projects. Use of modern technology such as BIM and adding contract incentives for best sustainability practices.	• Development of sustainable project management efforts is to plan, monitor, controlling of highway project delivery with the consideration of achieving economic, social, and environmental aspects of lifecycle project resources and deliverables.

SUSTAINABILITY INPUTS
• Inputs of project management sustainability during the construction phase assure to determine the implementation of best practices to achieve: — 1. Manage to ensure materials used are low carbon emission, gain insight from the supply chain of best materials to use. 2. Innovation to foster sustainability best practices, perform value engineering. 3. Adopt the use of sustainable governance, training, collaboration, and modern method of building and add incentives to contracts for innovative best practices. 4. Perform an audit to measure sustainability practices.
TOOLS AND TECHNIQUES
1. The tools and techniques are in varying degrees, such as: — 2. Method statements and inspection test plan to measure and control work activities. 3. Conduct meetings to measure sustainability progress. 4. Document best practices implemented in the project. 5. Use of sustainable policy and procedures to control activities. 6. Measure performance 7. Conduct sustainability audits
SUSTAINABILITY OUTPUTS
Project management sustainability management plan
Credit point awarded to implement best practices = 1 per each indicator

SUSTAINABILITY INDICATOR PROCESS LOGIC SUB-FRAMEWORK

Indicators S44 – S49: Engineering Sustainability Process Group



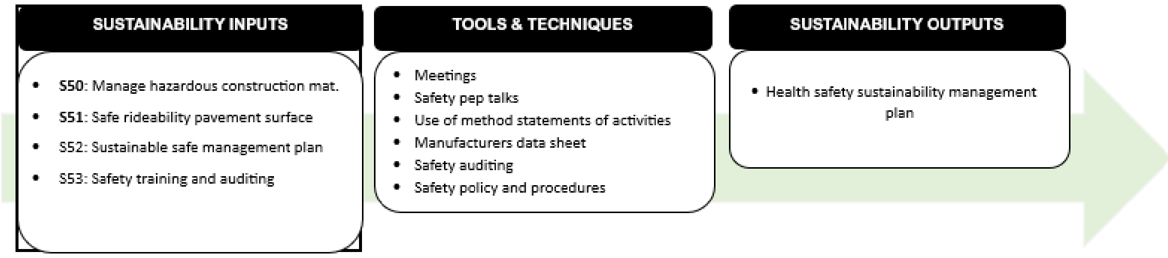
INDICATORS S44 – S49: ENGINEERING SUSTAINABILITY PROCESS GROUP

Aim	Goal
• To achieve sustainable engineering deliverables for the highway	• Development of an engineering sustainability management plan to help to enhance less use of energy, and resources that do not compromise the environment due to highway construction.

SUSTAINABILITY INPUTS
• Inputs of engineering sustainability during the construction phase assure to determine the implementation of best practices to achieve: — 1. Construction of long-life asphalt pavement involves the use of recycled materials, raw material management, pollution prevention, production enhancement and energy conservation. 2. Operational efficiency includes continuous best practice improvement, embracing the use of lean construction, and driving change during construction.
TOOLS AND TECHNIQUES
1. The use of sustainable specification 2. Use of lean measures and management 3. Eliminate waste. 4. Identify defective materials for isolation. 5. Enhance effective workflow and eliminate the use of excessive energy.
SUSTAINABILITY OUTPUTS
Engineering sustainability management plan
Credit point awarded to implement best practices = 1 per each indicator

SUSTAINABILITY INDICATOR PROCESS LOGIC SUB-FRAMEWORK

Indicators S50 – S53: Health and Safety Sustainability Process Group



INDICATORS S50 – S53: HEALTH SAFETY SUSTAINABILITY PROCESS GROUP

Aim	Goal
• To achieve sustainable health and safety deliverables for the highway project	• Development of a health sustainability management plan to manage hazards and perils associated with highway development.

SUSTAINABILITY INPUTS
• Inputs of health and safety sustainability during the construction phase assure to determine the implementation of safe and best practices to achieve: —   1. Manage any identified hazardous materials used for construction, for instance, asphalt materials. 2. Ensure the surface roughness index of highway pavement is safe for rod users. 3. Use of training and auditing to monitor and manage health safety management plan.
TOOLS AND TECHNIQUES
1. Using safety daily meetings, and pep talks before the start of activities. 2. Measure and verify that the methods stated in the method statements are sufficient to achieve sustainable safety management. 3. Review suppliers' and manufacturers' data sheets to incorporate guidance for the safe management of product activities.
SUSTAINABILITY OUTPUTS
Engineering sustainability management plan
Credit point awarded to implement best practices = 1 per each indicator

APPENDIX 'G'

Authors publications and co-authors

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Sustainability rating system for highway design:—A key focus for developing sustainable cities and societies in Nigeria

Ikechukwu Uchehara [a,*], David Moore [a], Naeimeh Jafarifar [a], Temitope Omotayo [b]

[a] Scott Sutherland School of Architecture and Built Environment, Robert Gordon University, Aberdeen, AB10 7AQ, Scotland, UK
[b] School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds LS1 3HE, UK

A R T I C L E I N F O

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Analytical hierarchy process
Carbon-emission
Highway design
Sustainability
System thinking
Smart-green-rating-system
Sustainable cities

A B S T R A C T

A growing body of evidence suggests that continuous increases in global population and urbanisation wield pressure across biodiversity. Nigeria and a few other Asian nations will account for 35% of the urban increase in the future, and there is a scientific projection that further megacities will emerge. Besides, sustainable cities and societies are those that strive to leave a net-zero carbon footprint through smart urban planning and city management. So, in developing public transport scheme, it is essential to manage and implement sustainability assessment performance. In Nigeria, there is a sustainability literacy gap, due to a lack of measurable sustainability techniques, and this has resulted in social, economic and environmental dissatisfaction towards completed highways and roads in the cities. The roads and highways are considered an essential part of modern daily life and will play a key role in the development of sustainable cities. To bridge the knowledge gap, this study argues to develop a sustainability assessment rating system in evaluating highway and road designs in Nigeria. Thirty-six (36) sustainability indicators relevant in assessing highway design are identified along with the sustainability application framework. The findings contribute to gaining insight into climate change impact, and the benefits it makes in adopting an assessment rating system in highway development to decrease climate change catastrophe.

1. Introduction

According to the United Nation's Department of Economic and Social Affairs (UN-DESA, 2018), 55% of the world population (roughly 4.2 billion) currently lives in cities and this will increase to 2.5 billion, bringing it to a total of 6.7 billion by 2050. Currently, the world's cities occupy roughly 3% of the planet's land, this occupied area accounts for 67–76% of global energy consumption and emits nearly, 76–77% of the planet's carbon emissions (United Nations Habitat Annual Report 2010; UN-World Urbanisation Prospect, 2018). It is anticipated that this value will double up by the end of this century. Nigeria's current population is estimated at 200 million, with the presence of megacities—*(A city with more than 10 million inhabitants is considered a megacity)*. Statistics from the UN-DESA (2018) suggest that world urban population growth are expected to concentrate mainly in a few countries including (Nigeria, China and India), which account for 35% urban increase across the globe.

This rapid urbanisation growth will exert pressure across the biodiversity of the developing world, including Nigeria. Infrastructure development in megacities is a contributory cause of environmental degradation, resources depletion, and ecological footprint (Abubakar & Aina, 2019). According to United Nations Environmental Development Programme (UN-UNEP, 2002), road construction accounts for the loss of forest cover. Moreover, the adverse impact of anthropogenic activities on forest cover, and carbon emissions in Nigeria is documented by Federal Department of Forestry Nigeria (2019). According to Ofori (1998), developing countries lack basic infrastructures and managerial capacity, such that to provide a backlog of infrastructure development to raise their standard of living, will strain the worlds available resources. Therefore the key solution is the adoption of sustainable development dimensions. The barrier in achieving sustainability within the construction sector in Nigeria are social context, management, and low stakeholders experience (Olowosile, Oke & Aigbavboa, 2019)—hence the lack of a unifying framework to attain sustainable infrastructure is evident. The readiness to improve sustainability ranks low in Africa, and Nigeria is ranked amongst the lowest, with a 36.5% index, the highest in Africa is Seychelles with 51.2%. Across the globe, the highest-ranked sustainability index is Norway, with 76.8% (Notre Dame Global Adaptation initiative, 2019).

The sustainability low ranking in Nigeria is a result of the literacy

* Corresponding author.
E-mail address: i.uchehara@rgu.ac.uk (I. Uchehara).

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1. Sustainability rating system for highway design:—A key focus for developing sustainable cities and societies in Nigeria (Ikechukwu Uchehara; David Moore; Naeimeh Jarfarifar; Temitope Omotayo) - 2022

HIGHWAY SUSTAINABILITY CONSTRUCTION: REDUCING CARBON EMISSIONS USING PROCESS MANAGEMENT

Ikechukwu Uchehara[1], Mansur Hamma-adama and David Moore

Scott Sutherland School of Architecture and Built Environment, Robert Gordon University Aberdeen, AB10 7GJ, UK

Carbon emission is a critical issue in infrastructure development, in which the highway construction industry is inclusive. Previous studies suggest that continuous carbon emission across the highway projects is due to the use of different types of construction equipment, and their inherent activities. Several research studies focused on arbitrary evaluation in order to reduce carbon emission using simulation, life-cycle analysis, and multi-criteria optimisation. The general lack of methodological rigours questions the effectiveness of those carbon reduction methods. In addition, some of those studies do not show subtle improvement in carbon reduction, and some of the findings are restricted for use. The study aims to develop an integrated technique and a better understanding of using process management in reducing carbon emissions in highway construction projects. A unique approach using the literature review as the mode of enquiry is used, which enables the use of secondary information as inputs to the analytical hierarchy process. The result shows that 'Strategy' has the highest weight score. The pattern of results indicates that a new paradigm shift is required in the use of strategic process management approach in highway carbon reduction. Two contributions are made: firstly, early decision-making, to include carbon reduction strategy during the highway feasibility study and tender phases. Secondly, to use the proposed strategic process management framework in determining realistic carbon reduction strategies across the highway construction sector.

Keywords: carbon-management, climate emergency, sustainability, infrastructure

INTRODUCTION

Carbon emission depletion has been an issue of great interest in a wide range of fields. The research constitutes relatively a new area, which emerged from a need to reduce carbon emissions during the highway construction projects. Kellogg (1978) revealed that in the past four decades, scientists and international communities had raised the alarm on the threat posed as a result of human-induced anthropogenic activities. Ripple *et al.*, (2017) warned that the risks associated with carbon emissions continue to rise dramatically. The identified perils due to carbon emissions are global warming, change in landscapes, sea-level rising and coastal flooding. The pre-industrial values of carbon emission were fewer than 300 parts per million (ppm), and

[1] i.uchehara@rgu.ac.uk

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Rubberised concrete confined with thin-walled steel profiles; a ductile composite for building structures

Naeimeh Jafarifar[a], Alireza Bagheri Sabbagh[b], Ikechukwu Uchehara[a]

[a] School of Architecture and Built Environment, Robert Gordon University, Scotland, UK
[b] School of Engineering, University of Aberdeen, Scotland, UK

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ABSTRACT

Tyre components are high-quality materials, which can be utilised and disposed into construction projects. Despite its high ductility and impact resistance, rubberised concrete (RuC) with high rubber content has a strength much lower than that of conventional concrete. Previous research shows that confinement by a jacket material can significantly improve the strength of RuC. This paper presents how infilling RuC to cold-formed steel (CFS) sections improves strength of RuC and local-buckling-resistance of CFS thin-walled sections, resulting composite elements where the advantage of each material cancels out the disadvantage of another. In this research, the composite RuC-CFS elements are developed and tested with the purpose of using them for structural frames with high energy dissipation capacity under extreme loading conditions, while providing resource-efficiency by using lightweight CFS and recycled RuC materials. To enable infilling long steel hollow sections for beams and columns, the experimental RuC mixes are designed for self-compaction (SCC). The results reveal that 35 % rubber content (by volume) and 3 mm thickness of the CFS profile (S275 grade) gives the best performance of the composite by adding 19 % to the capacity of the individual constitute materials.

1. Introduction

Huge quantities of used tyres are a threat to the environment being extremely durable and non-biodegradable. Tyre components, including rubber, high-strength steel cord, wire and textile, are high-quality materials, which can be utilised and disposed into construction projects [15,16,1,23]. Extensive research has been carried out in the past two decades, for using crumb rubber or various size rubber particles as a replacement for mineral aggregates in concrete [1,23,14,24,27,21,10,9,12,13,25,11].

Using rubber aggregate in concrete can enhance its ductility, impact resistance, and energy absorption, although high amounts of rubber (more than 20 %) can negatively affect the strength properties of RuC [23,14]. This can be due to lower stiffness of rubber aggregate compared to mineral aggregates or due to poor adhesion between rubber and cement binder. Replacement of mineral aggregates in concrete with high rubber contents (replacement volumes greater than 50–60 %) may result in a compressive strength much lower (up to 90 %) than that of conventional concrete. However, studies show that confinement of RuC by a jacket material significantly improves compressive strength of RuC to a level suitable for structural applications. Highly confined rubberised concrete can lead to high-strength and highly deformable concrete elements and structures [24]. Various materials have been used for confining RuC, including fibre reinforced polymer (FRP) jackets [27], glass FRP (GFRP) pipes [21], and cold-formed steel (CFS) tubes [10,9,12,13,25].

Compared to conventional hot-rolled sections, CFS is more resource-efficient, less expensive to manufacture, and of a greater flexibility for production. The load-bearing capacity of non-composite CFS frame structures is normally dominated by premature local/distortional buckling of their thin-walled sectional elements [4,5,26,22]. This inhibits fast uptake of CFS framed structures, especially in multi-storey construction. Infilling RuC to CFS hollow sections, apart from improving the strength properties of RuC through confinement, has the additional benefit of restraining CFS and delaying its premature local buckling failure. This increases the load bearing capacity of these composite elements. The high ductility of RuC is very compatible with steel deformability, and the energy absorption capacity of the composite

Abbreviations: RuC, Rubberised Concrete; CFS, Cold-Formed Steel; SCC, Self-Compacting Concrete; RuC-CFS, Rubberised Concrete infilled into Cold-Formed Steel profile; FRP, Fibre Reinforced Polymer; GFRP, Glass Fibre Reinforced Polymer; RuSCC, Rubberised Self-Compacting Concrete; RCC, Roller-Compacted Concrete; RuRCC, Rubberised Roller-Compacted Concrete.

E-mail addresses: n.jafarifar@rgu.ac.uk (N. Jafarifar), alireza.bsabbagh@abdn.ac.uk (A. Bagheri Sabbagh), i.uchehara@rgu.ac.uk (I. Uchehara).

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3. Rubberised concrete confined with thin-walled steel profiles; a ductile composite for building structures (Naeimeh Jafarifar; Alireza Bagher Sabbagh; Ikechukwu Uchehara) – 2023

APPENDIX 'H'

Smart Green Certification level for highway design in Nigeria

Smart green highway rating system™	***Recognized**: type of certification involves design that incorporated least minimal sustainable practice, with aim of useful impacts and the potential to advance towards excellent innovation.
Smart green highway rating system™	***Silver**: type of ceritifcation involves sufficient design that incorporated minimal sustainable practice, with aim of beneficial impacts and the potential to advance towards excellent innovation.
Smart green highway rating system™	***Gold**: type of certification involves commedable design that incorporated considerable sustainable practice, with aim of useful impacts and potentials to advance towards excellent innovation.
Smart green highway rating system™	***Evergreen**: type of certification involves excellent design that incorporated highest sustainable practice, with aim of continous innovation worthy of practice across the industry

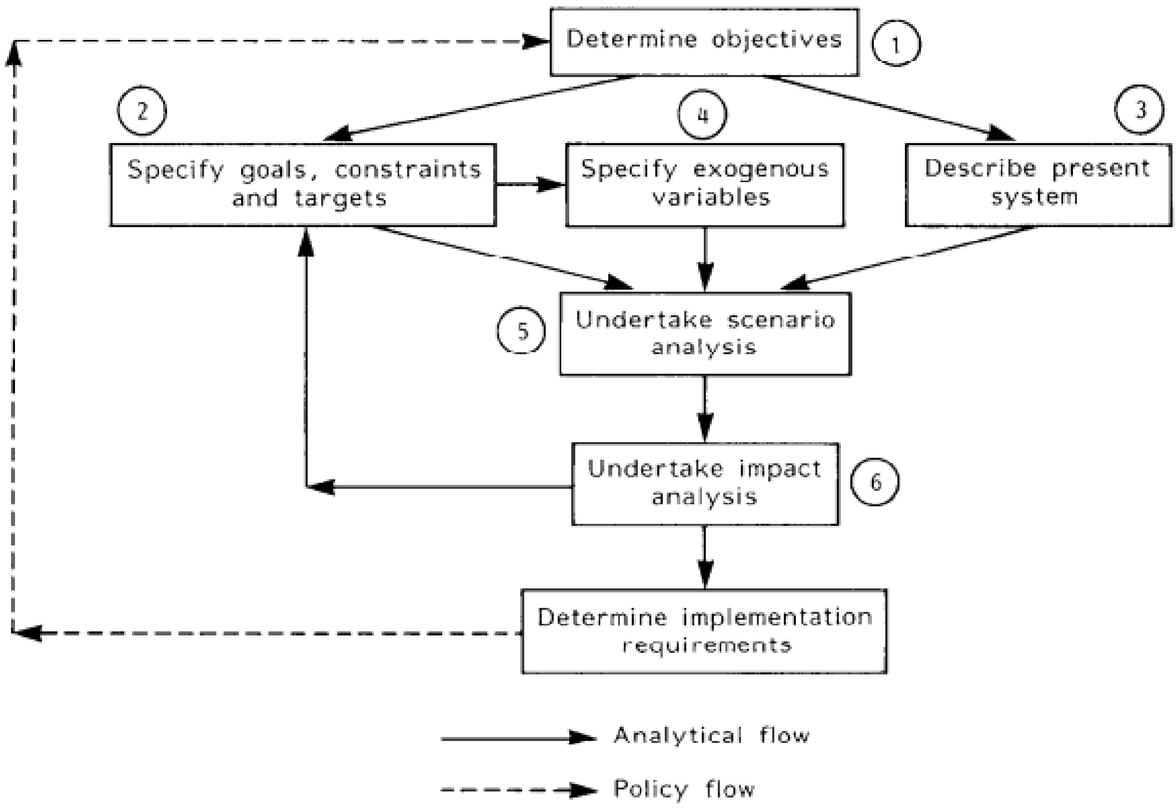
*Evergreen level: 39 – 33; *Gold level: 33 – 30; *Silver level: 30 – 27, *Recognised level 27 – 25.

APPENDIX I

Confidence level	Z score
80%	1.28
85%	1.44
90%	1.65
95%	1.96
99%	2.58

APPENDIX J

Highway design and construction back-casting model



Outline of generic backcasting method   Adapted from Robison, (1990).

Step-1 <u>determine objectives</u>

The purpose of analysis is to determine appropriate preliminary highway design and construction indicators required in reducing adverse impact of development in Nigeria. The focus is on the three pillars of sustainability and technical factors.

Step-2 <u>specify goals, constraints, and targets</u>

In this research, what was done in step 2 is to identify adverse impact of highway development outlined in chapter 2 Tables 2.7, 2.8, and 2.9. These identified challenges due to adverse impact are considered in terms of impact on the ecology and how can that impact be turned into a positive outcome using selected indicators from literature. This helps to determine desired sustainable future development. In this case goals taken is to select indicators across each category of challenges identified due to highway development, these are through, social, environmental, economic, engineering, project management and health safety issues. The constraint in step 2 is to ensure a particular category of sustainability is not more than the required indicator, trade-off made is to gain insight from literature with regards to areas of focus, where highway development impacts are noted to identify indicators necessary to achieve the goals of the back casting. The exogenous variables are policies which can help to influence sustainability indicator development, but this is out of scope for this research.

Step-3 describe present system

The present system considered in adverse impact adverse impact of highway development in Nigeria, these are categorised across social challenges, technical challenges, environmental challenges, economic challenges, engineering challenges, project management challenges and safety and health challenges (refer to Table 2.8).

Step-4 specify exogenous variables

These are factors not considered within back casting analysis, focus is only on highway design and construction sustainability indicators, issues like sustainability policy are not considered, which are exogenous variables (external).

Step-5 undertake scenario analysis

The model developed by Becker (2010) in Table 3.6 is utilised, this involved determining each indicator for the potential resilience, collaboration and auto-sufficient in resolving unsustainable issues identified.

Step-6 undertake impact analysis

A risk matrix (high, medium, and low) is utilised to determine adequacy of the selected indicators based on the matrix ecological framework of Becker (2010).

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