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Sustainability rating system for highway design: a key focus for developing sustainable cities and societies in Nigeria.

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Sustainability Rating System for Highway Design:—A key focus for developing sustainable cities and societies in Nigeria.

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Abstract: *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.*

Keywords: analytical hierarchy process, carbon-emission, highway design, sustainability, system thinking, smart-green-rating-system, sustainable cities.

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 (UN-Habitat, 2011; 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 and 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 et al., 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 among 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 gap among practitioners, and the government's inactive environmental policies (Akeel et al., 2019). Most projects in Nigeria, are evaluated using traditional concepts with fewer considerations for sustainability (Hussin et al., 2013)—Although these conventional construction techniques are valuable, however, it lacks a practical sustainability assessment strategy, which indeed has direct and indirect impacts on future sustainable cities. On this note, most developing countries in Africa are unable to determine, implement or measure sustainability during infrastructure development (Okoro et al., 2019). Synthesising the reviewed points, we might reasonably assume that Nigeria designers and highway decision-makers should progress from the conventional design approach to the green design development concept, thereby nurturing innovation in building sustainable resilient cities. Using a conventional highway design approach lacks a sustainability assessment rating concept, which hinders the measuring and quantifying actual green (sustainable) design practice. A quantitative assessment to fulfil Nigeria's social, economic, and environmental requirements in highway design is currently uncertain.

This study argues to develop a functional sustainability assessment rating to evaluate highway design in Nigeria, by using—(a *Smart Green Rating System*). The sustainability assessment rating indicators, and credit award certification can support the Nigerian highway transport agencies, foreign investors, and private designers to identify and fill in knowledge gaps in practice and concepts across the triple bottom line. The benefits and findings of this research will offer Nigerian neighbouring countries sharing similar environmental challenges, to catch up with highway design sustainability assessment.

2. Background

The United Nations Sustainable Development Goals (SDGs) through its 71st session General Assembly of 2017—positioned to achieve a better future for all. These identified environmental challenges opened a wide range of research in developing sustainable construction in highway projects (Newman et al., 2012; Wang et al., 2015; Huang et al., 2018). Although much of the earlier research focused more on highway construction (Ibrahim and Shaker, 2019; Newman et al., 2012; Montgomery et al., 2014; Zhang, 2018). Other research on highways aimed at the use of recycled materials for pavement construction (Lee et al., 2010; Tao et al., 2010; Bolden et al., 2013; Nwakaire et al., 2020). Relatively few studies in the past considered research to evaluate the implementation of highway design sustainability assessment (Tsai and Chang, 2012; Jha et al., 2011). There are research attempts to develop assessment criteria for highway design, for instance, using a checklist as a practical sustainability tool (Tsai and Chang, 2012; Nigeria Highway Manual Part 1 Design, 2013). However, when considering the absence of a dedicated sustainability assessment rating system for highway design, critics continue to question the strategies and effectiveness of the proposed sustainability assessment of highway design (Cottril and Derrible, 2015; Lew 2016).

This criticism led to other scrutiny concerning—why the bulk of highway design sustainability assessment indicators were modelled based on the building construction sustainability rating system called the— 'Leadership in Energy and Environmental Design' (Tsai and Chang, 2012; Mattinzioli et al., 2020). The argument of Mattinzioli et al (2020) provided an insight that no standard or documented source is explicitly dedicated to sustainability assessment of highway design and construction. At the time of this review, South Africa is the only African country on a pilot study considering implementing a green framework called "Sustainable Roads Forum" (SuRF) for highway sustainability assessment (SANRAL, 2019). However, given the review, it is worth noting that one of the primary reasons, a highway design rating system is yet to be fully developed is due to the use of a "one size for all-purpose solution" (*a concept of generalisation*), which undermines sustainability knowledge (Mattinzioli et al., 2020). This study will argue to develop a stand-alone sustainability assessment rating system for highway design for Nigeria.

2.2 Highway development challenges in Nigeria

Ibrahim and Shaker (2019) resonate that the lack of quantitative assessment of sustainability practice undermines the usefulness and objective of roads and highway projects. In Nigeria, highway design engineers and licensed road safety auditors have the sole privilege and authority towards implementing highway design decisions, from the preliminary to the implementation stage (Nigeria Highway Manual Part 1 Design, 2013)— consequently, the benefits associated with using a dedicated sustainability assessment rating system to assess compliance with the triple bottom line are missed in Nigeria highway design development. These missed opportunities include—prospect to reduce depletion to the natural environment, using recycled materials for pavement design and construction, reducing pollution due to construction, and exploring opportunities to identify best practices and innovative ideas. The much-utilised environmental practice during highway design in Nigeria is through the use and implementation of the Environmental Impact Assessment (EIA) Act 86 of 1992— to access development impact across the concept of sustainability (Nigeria Highway Manual Part 1 Design, 2013). EIA has been criticised that it is unable to provide a feedback loop in the context of protecting biodiversity—such as habitat fragmentation, loss of wild fauna, groundwater impacts (Loro et al., 2014). Bassi et al., (2012) reiterated another drawback of EIA, is the inability to follow up procedures, for instance, every EIA in a project is an end to its cycle— there are no identified best practices worth emulating for future implementations in other projects.

What are the appropriate highway sustainability indicators in assessing highway design protocols in Nigeria? What are the quantifiable credit award points suitable for the certification of highway design in Nigeria? Based on the research questions, this study critically evaluates the approach used in sustainable highway design, and emphasis is developing a practical sustainability assessment indicator and a framework for highway design assessment in Nigeria.

2.2.1 Relationship of development and challenges of climate change in Nigeria

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 exposed to extreme weather events, and 6% of the landmass is estimated to be severely degraded (The World Bank, 2019),— and that equally affects the ecology and desertification. In the coming decades, documented evidence suggests a significant increase in temperature rise in Nigeria (Haider, 2019). The evidence cited by Haider (2019: 8), suggest that climate projection in Nigeria is taking a serious toll across the Nigerian environment, "it predicts temperature increase of 0.4 to 1°C over the period 2020 – 2050, and a further increase up to 3.2°C by 2050, and a further regional increase of 4.5°C between 2081-2100". The occurrence of climate change in Nigeria is a result of industry pollutions and the impact as a result of the construction industry (Okedere et al., 2021). Statistics evidence have shown that Nigeria is second among the biggest emitters of greenhouse gases in Africa (Carbon brief, 2020; Hamilton and Kelly, 2017; Okedere et al., 2021). Nigeria's government pledged to reduce greenhouse gas emissions by 20% by 2030 (Carbon brief, 2020). Currently, Nigeria's annual carbon emission is estimated at a minimum of 100 million tons per annum in the past few years, and the manufacturing and the construction industry amount to 6.7

million tons of released carbon annually (Ritchie and Roser, 2021). These emissions are a result of a knowledge gap in measurable the environmental impact of development (Abdulkadir et al., 2017).

3.0 Research methodology

3.1 Stage 1 literature review

Figure 1, displays the research design framework. Stage 1 is a need to collect information, to analyse sustainability assessment trends, a literature review was conducted from— existing highway design manual, journals, current sustainability assessment rating system, Environmental Impact Assessment (EIA) report. Besides, literature review resolves dialogues, it reviews to create an overview and allows a critical evaluation for a researcher to identify and fill in knowledge gaps (Creswell 2014)— also it provides a core foundation during data mining (Zhang 2018). Table 1 displays preliminary highway design assessment indicators identified within the literature review—these indicators are thematically classified into four categories, namely— (*technical, environmental, economic and social*).

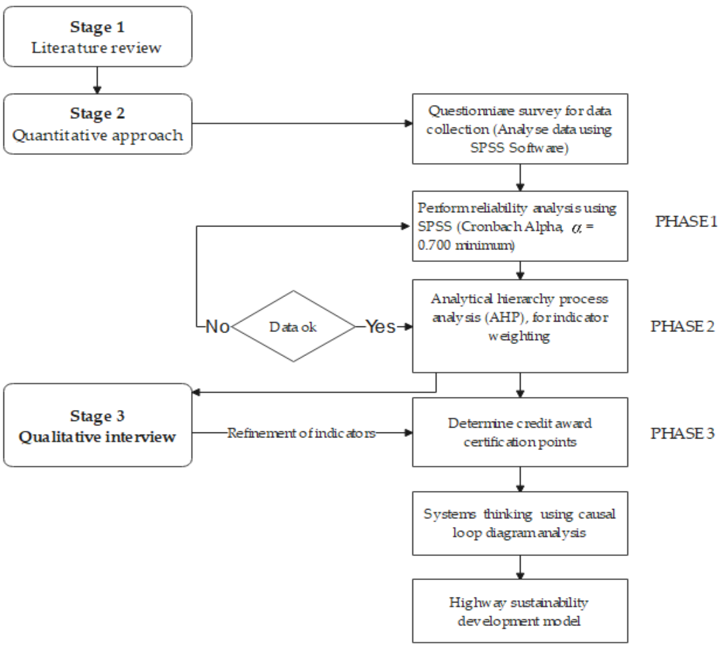


Fig 1. Conceptual research framework

Table 1. Primary category design assessment indicators

SN°	Category	Subcategory
A	Technical	A1: Basic design control
		A2: Horizontal curves
		A3: Vertical alignment
		A4: Cross-section
		A5: Drainage and erosion control
		A6: Pavement design
B	Environmental	B1: Impact of fragmented alignment
		B2: Wildlife accommodation
		B3: Environmental pollution
C	Economic	C1: Cost-benefit analysis
D	Social	D1: Context-sensitive analysis
		D2: Intermodal facility and rest areas

3.2 Stage 2 quantitative approach (survey)

The use of an online questionnaire survey data collection practice is an opportunity to reach out to a wider population of— (*experts and practitioners in the Nigerian highway design*) to provide information with a narrow scope of inquiries. Figure 1, stage 2, is the "quantitative approach," which involves using a questionnaire survey to collect data from Nigeria. The sampling technique considered is to select an absolute sample size that represents the entire population (Taherdoost, 2017). A good advantage of the quantitative research approach is using smaller sample groups to make inferences about the larger population (Bartlett et al., 2001). The research instrument targeted Highway Engineers working with the government sector, Academia, Private Practitioners and the Engineering Community of Practice society across Nigeria. The primary target of the questionnaire was for the participants in highway design to contribute to knowledge through data collection for analysis, and to identify results in answering the research questions. The targeted median years of the respondents ranged from 5 years to 20 years in the highway design sector. This approach was taken to accommodate a wide range of early career, medium and top-level career respondents. These respondents were contacted using purposive sample techniques—this is the concept of using cognitive judgement to select participants through a non-probability collection from the Engineering Community of Practice (CoP), government transport departments and private practitioners.

Please refer to Table A:1 in Appendix 'A' for the Likert scale questionnaire prototype used to gain knowledge insight from the respondents. The format used is the Likert scale which has the highest value as (5) and represents very high significance and (0) which is not significant.

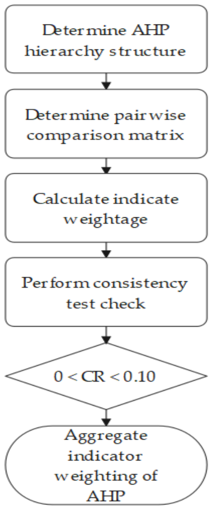
3.2.1 Stage 2 Phase 1 (*Figure 1*)— Reliability of collected data

Respondents were presented with the concepts associated with sustainability assessment indicators for highway design to assign a Likert scale in form of feedback. The feedback rate from the respondents provided 83% —(33 respondents completed the questionnaire out of 40 issued out). Eighty-five per cent (85%) of respondents are Civil Engineers, and the rest of the respondents account for fifteen per cent (15%). For the collected data, the reliability analysis of a questionnaire survey scale indicates a stability check against the occurrence of random error, as that affirms the quality of data collected (Strang, 2015). Cronbach's Alpha is a measure of 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, 2016). The data collected from the online questionnaire for this research were analysed using Statistical Package for Social Science (SPSS) software to determine reliability tests. The achieved Cronbach alpha for the analysed collected online data is α= .857.

3.2.2 Stage 2 Phase 2 (*Figure 1*) – Analytical hierarchy process (AHP)

The collected data from Figure 1 stage 2 (quantitative approach) is analysed in stage 2 phase 1, which act as an input into the analytical hierarchy process—see Figure 2 for the AHP framework analysis. The AHP is used to determine the weight rating for the sustainability assessment indicator for highway design— and to provide inputs into the causal loop diagram. The causal loop is utilised to establish distinct subsets of archetypes—this is an approach utilised to explore the pattern in identifying cause-and-effect, and the potential to identify other indicators missed during the literature review. Furthermore, to enhance the consistency of the causal loop diagram, a validation process was implemented, through two (2) expert opinion inputs. Further discussion on this is in section 5.

The analytical hierarchy process (AHP) enables decision-makers to operate objectively by choosing various alternatives from a set of criteria (Brunelli, 2015; Omotayo et al., 2020; Saaty and Vargas, 2012). 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, such as;—Handfield et al. (2002) used AHP to determine criteria in selecting suppliers' procurement strategies; AHP has been utilised to select competency among contractors (Fong and Choi, 2000). Omotayo et al. (2020) utilised AHP and other techniques to determine criticality factors influencing the effective implementation of kaizen costing. Uchehara et al., (2020) applied AHP to propose reducing carbon emission using a process management approach.



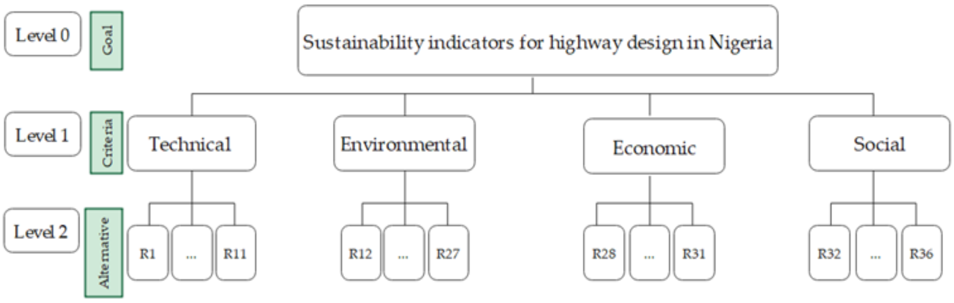


Figure 3. AHP development structure

Figure 2. Framework for analytical hierarchy process

AHP development structure for this research is displayed in Figure 3. Level 0 is the goal to be achieved. Level 1 is the primary category of the sustainability assessment criteria. Level 2 is the alternative indicators analysed using the AHP pairwise comparison method. To analyse pairwise comparison (see *equation 1*), a set of matrix rules applies for pairwise matrix 'A', which represents $n \times n$ matrix, where n is the number factor $a_1, a_2, a_3 \ldots\ldots a_n$. Each entry a_{ij} of matrix 'A,' (where i, is the row, and j is an element of column).

$$A = (a_{ij}) = n \; x \; n = \begin{bmatrix} 1 & a_{12} & a_{1n} \\ 1/a_{21} & 1 & a_{2n} \\ 1/a_{n1} & 1/a_{n2} & 1 \end{bmatrix} \qquad \textbf{Equation} \quad \textbf{(1)}$$

The value a_{ji} is statistical data for decision-makers opinions and expert judgement. All components in the pairwise matrix are positive $a_{ji} > 0$, and specific requirements must be met, such that a_{ji} (diagonal)=1, and $a_{ji} = \frac{1}{aji}$ (*reciprocal*), where i, and j represents real numbers = $1, 2, 3 \ldots\ldots n$.

4. Data analysis and discussion

The data analysis was emerged—from a range of Likert scale scoring from the respondents. The average mean for each assigned score across the thirty-six (36) indicators is tabulated in an Excel sheet. This tabulated average mean for each sustainability indicator value is input into AHP for pairwise analysis. Tables 2, 3 on page 7, and Table A2, A3 in appendix 'A' display weighing for each sustainability assessment indicator across social, environmental, technical and economic concepts. Below are equations 2, 3 and 4 on page 8 for steps to calculate the internal consistency ratio of the data analysed within the AHP, using Thomas Saaty's concept. Saaty's consistency ratio for all the sustainability categories is satisfactory, see values on the top of Table 2, 3 on page 7, and Table A2, A3 in appendix 'A'.

Table 2. Technical sustainability judgement matrix

Consistency ratio = 0.043 < 0.10; Weighing = 0.091; λ = 11.640; n = 11

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	WEIGHT %
R1	0.111	0.190	0.160	0.158	0.154	0.026	0.143	0.133	0.133	0.133	0.133	0.134
R2	0.056	0.095	0.080	0.079	0.077	0.156	0.071	0.133	0.133	0.133	0.133	0.104
R3	0.056	0.095	0.080	0.079	0.077	0.156	0.071	0.067	0.067	0.067	0.067	0.080
R4	0.111	0.190	0.160	0.158	0.154	0.234	0.143	0.133	0.133	0.133	0.133	0.153
R5	0.056	0.095	0.080	0.079	0.077	0.156	0.071	0.067	0.067	0.067	0.067	0.080
R6	0.333	0.048	0.040	0.053	0.077	0.078	0.143	0.133	0.133	0.133	0.133	0.119
R7	0.056	0.095	0.080	0.079	0.077	0.039	0.071	0.067	0.067	0.067	0.067	0.069
R8	0.056	0.048	0.080	0.079	0.077	0.039	0.071	0.067	0.067	0.067	0.067	0.065
R9	0.056	0.048	0.080	0.079	0.077	0.039	0.071	0.067	0.067	0.067	0.067	0.065
R10	0.056	0.048	0.080	0.079	0.077	0.039	0.071	0.067	0.067	0.067	0.067	0.065
R11	0.056	0.048	0.080	0.079	0.077	0.039	0.071	0.067	0.067	0.067	0.067	0.065
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table 3. Environmental sustainability judgement matrix

Consistency ratio = 0.0017 < 0.10; Weighing = 0.063; λ = 15.960; n = 16

	R12	R13	R14	R15	R16	R17	R18	R19	R20	R21	R22	R23	R24	R25	R26	R27	WEIGHT %
R12	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R13	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R14	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R15	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.038	0.036	0.036	0.036	0.036	0.036	0.036
R16	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.038	0.036	0.036	0.036	0.036	0.036	0.036
R17	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R18	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R19	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R20	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R21	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.038	0.036	0.036	0.036	0.036	0.036	0.036
R22	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.038	0.036	0.036	0.036	0.036	0.036	0.036
R23	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R24	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.019	0.071	0.071	0.071	0.071	0.071	0.068
R25	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R26	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
R27	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.075	0.071	0.071	0.071	0.071	0.071	0.072
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.000**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

4.1 Saaty's Consistency Ratio

The conventional eigenvector method for estimating weighing in AHP shows a way of measuring the consistency of the pairwise comparison matrix (Alonso and Lamata, 2006; Saaty and Vargas, 2012; Brunelli, 2015; Omotayo et al., 2020). However, when the pairwise comparison in the matrix is not consistent, then the matrix is contradictory. Saaty defined the consistency index (CI) of a pairwise comparison matrix as follows:—

CI = $\frac{\lambda max - n}{n - 1}$; **Equation (2)**

where λmax is maximum eigenvalue;— where n is the total number of criteria evaluated.

The consistency ratio: (C.R.) = $\frac{CI}{RI}$ **Equation (3)**

Where R.I—is Saaty's Random Ratio, and C.R < 0.10 for acceptance criteria **Equation (4)**

4.2 Stage 3 – (qualitative interview) to refine sustainability assessment indicators

Figure 1, stage 3, phase 3 illustrates the research framework to conduct qualitative interviews. The process involves;—refining the initial weighing scores of the sustainability rating system for highway design using expert opinion. It is noteworthy to explain the significance of using expert opinion to validate and refine sustainability indicators. Validation of collected data helps build credibility, accountability and it throws more insight into problem-solving (Strang, 2015). Using validation is necessary to demonstrate the accuracy of information (Creswell, 2014). In stage 3 phase 3 Figure 1, "qualitative validity" involves a researcher checking the accuracy of data by employing specific procedures" (Creswell, 2014). In his analysis, Creswell identified strategies to validate data under the qualitative approach. In this research, validation achieved using "expert member checking", it involves using industry participants in Nigeria to refine the accuracy of data collected.

To select participants for the qualitative interview, snowball sampling techniques were utilised. Snowball sample techniques involve when a researcher relies on CoP networks to identify initial related sample participants (*selection is based on years of experience and relevance to highway design career*). Furthermore, the participant recommends and identifies other relevant colleagues to participate in the study. Thus, this sampling technique enables the building and collecting of data. A total of eight invitations were sent to respondents with six agreeing to participate. Below is the evaluation steps followed to implement data collected from expert opinion refinements, for the sustainability indicators.

4.2.1 Sustainability assessment weighings for indicators

For this analysis, the strategy proposed by Zhang (2018) is adopted—using arithmetic average mean to integrate expert opinion from the interview. The below-tabulated weighing arithmetic means equations 5 and 6, were used to refine the sustainability indicators weight score, which was initially summarised in Tables 2, 3 and Table A1 and A2 in appendix A. The arithmetic mean under this research measured central tendency known as the average, which is tabulated as follows:-

$\bar{S}$ is the symbol of arithmetic mean, n is the number of observations denoted, $S_1 + S_2 + \ldots\ldots\ldots S_n$ is given by: $\bar{S} = (S_1 + S_2 + \ldots\ldots\ldots\ldots S_n) / n$ **Equation (5)**

Therefore, Ai = weighing of indicators i, $\bar{S}$ = arithmetic average value for indicators i,
Summation is $\sum_{i=0}^{n} Ai * \bar{S} = ;1;\ 0 < Ai < 1$ **Equation (6)**

The entire mathematical calculation process is plainly described as multiplying the value of each stand-alone weighing score for the indicators across Tables 2 and 3, Table A1 and A2, with the average arithmetic, mean value $\bar{S}$—:(which is obtained from expert opinion mean value using second Likert scale divided by the total number of participant '*n*') The obtained values present the final sustainability assessment weighing score, see Table 4, under column *'score'*.

Table 4 assessment result update for sustainability indicator rating—highway design

Category	Indicators	Code	Mean[a]	Weight	Score	Rank
Technical indicators	Traffic volume count	R1	5.800	0.134	0.558	10th
	Speed limit	R2	5.320	0.104	0.451	13th
	Terrain analysis	R3	5.440	0.080	0.320	16th
	Stopping sight distance	R4	5.560	0.153	0.689	9th
	Safe radius of the curve	R5	5.320	0.080	0.387	14th
	Safe superelevation	R6	4.440	0.119	0.476	12th
	Catchment basin for stormwater	R7	5.320	0.069	0.253	27th
	Profile and vertical curves	R8	4.760	0.065	0.293	21st
	Safe cross-section and geometric elements	R9	5.240	0.065	0.260	26th
	Sustainable, flexible pavement	R10	5.160	0.065	0.228	30th
	Culvert and gully pots and stormwater	R11	5.360	0.065	0.206	32nd
		Mean average	**5.247**	**0.091**	**0.374**	
Environmental Indicators	Reduce habitat fragmentation alignment	R12	4.680	0.072	0.312	17th-18th
	Impact on farmland and habitat	R13	4.560	0.072	0.312	17th-18th
	Ecological connectivity	R14	4.720	0.072	0.324	15th
	Enhance air quality	R15	4.360	0.036	0.132	35th
	Watershed restoration	R16	4.280	0.036	0.156	33rd
	Climate preparedness and resilience	R17	4.960	0.072	0.312	17th-18th
	Renewable energy use	R18	4.640	0.072	0.252	29th-28th
	Avoid groundwater pollution	R19	4.840	0.072	0.264	22nd-24th
	Reduce greenhouse gas emission	R20	5.160	0.072	0.264	22nd-24th
	Material design reuse	R21	4.280	0.036	0.144	34th
	Highway sound barrier wall	R22	3.920	0.036	0.126	36th
	Eliminate environmental pollution	R23	4.880	0.072	0.252	29th-28th
	Long-life design	R24	5.320	0.068	0.227	31st
	Runoff flow control	R25	5.440	0.072	0.264	22nd-24th
	Smart infrastructure	R26	4.680	0.072	0.300	20th
	Measurement and verification	R27	5.040	0.072	0.264	25th
		Mean average	**4.735**	**0.063**	**0.244**	
Economic Indicators	Lifecycle cost analysis	R28	5.360	0.217	0.868	6th
	Cost-benefit ratio	R29	4.960	0.284	1.136	2nd
	Return on Investment	R30	4.880	0.216	0.936	5th
	Innovative ideas	R31	4.760	0.284	1.278	1st
		Mean average	**4.990**	**0.250**	**1.055**	
Social indicators	Community engagement	R32	4.800	0.218	0.799	7th
	Intermodal connectivity	R33	4.400	0.129	0.495	11th
	Travel time reduction	R34	5.080	0.218	0.763	8th
	Protect cultural and natural heritage	R35	5.120	0.218	0.945	4th
	Serviceability	R36	5.121	0.218	1.017	3rd
	Mean average		**4.904**	**0.200**	**0.804**	
Total average (Technical + Environment +Economic + social)			**5.005**	**0.150**	**0.619**	

The average mean value tabulated from the Likert scale

See Table 4 for the ranking of the indicators across the four primary categories. Findings from the analytical hierarchy process evaluation revealed sustainability assessment indicators related to "economic and social" are mostly preferred in sustainable highway design development in Nigeria—these identified foremost desired sustainability indicators ranked between 1st to 10th. A possible explanation for this might be a preference of the experts to align sustainable development with the conventional development approach in the use of triple constraint of time, cost and scope. The next most desired sustainability rating system is the 'technical indicators' and 'economic indicators are least, desired. The inconsistency sustainability ranking across the primary categories could be a result of the literacy noted knowledge gap in Nigeria towards the implementation of sustainability concepts and awareness (Akeel et al., 2019). The overall aggregating of the analytical hierarchy process and mean averaged score from the Excel sheet is presented in Figure 4.

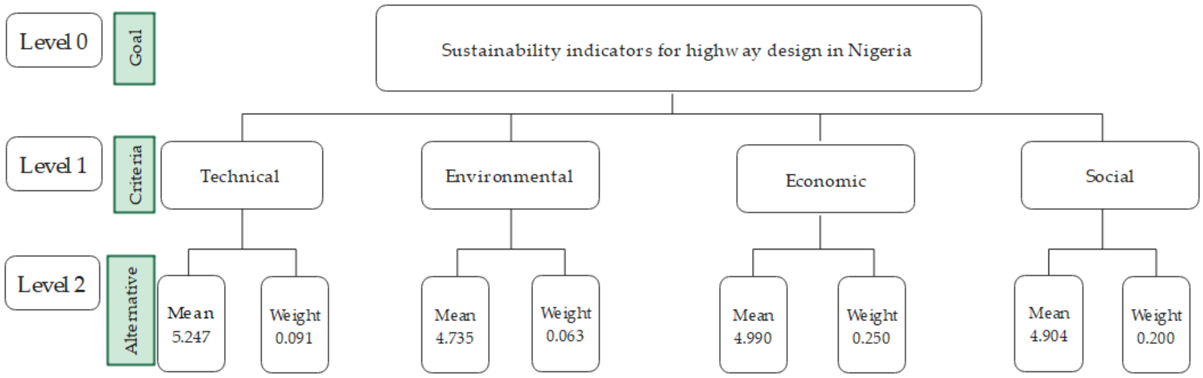


Figure 4. Aggregated mean and weighing across the primary category of indicators

5. Systems thinking

In this study, systems thinking is employed as a tool of feasibility approach to comprehend the relationships of an archetype within a system boundary. Archetypes are subsets of a causal loop diagram utilised to reveal rational relationships among variables (Omotayo et al., 2020). System thinking is a familiar concept utilised to determine how causal relationships and feedbacks perform in everyday challenges (Haraldsson, 2004). Systems thinking deals with the organisation of logic and integration of disciplines to understand patterns and relationships of a complex boundary. Primarily, it is about taking a problem apart, and reassembling it to understand its components and 'internal' feedback relationships. Other primary benefits of using the causal loop diagram approach are that it provides support when representing the cause-and-effect relationships between two or more variables. Another primary aim of systems thinking (causal loop diagram) is the tendency to reveal attributes, and phenomena outside the use of traditional qualitative and quantitative approaches (Omotayo et al., 2020; Miki et al., 2015).

In systems thinking, external and internal variables usually interact to reveal the most likely outcome when a positive change occurs, either increasing or decreasing a variable in a system— (*these variables are the sustainability indicators*). These external and internal variables are obtained from Table 4—and below Figure 5 is a graph illustrating selection criteria, for both external and internal variables. Employed is the upper and lower limits of the indicators using range (1.4 max – 0.3 min).

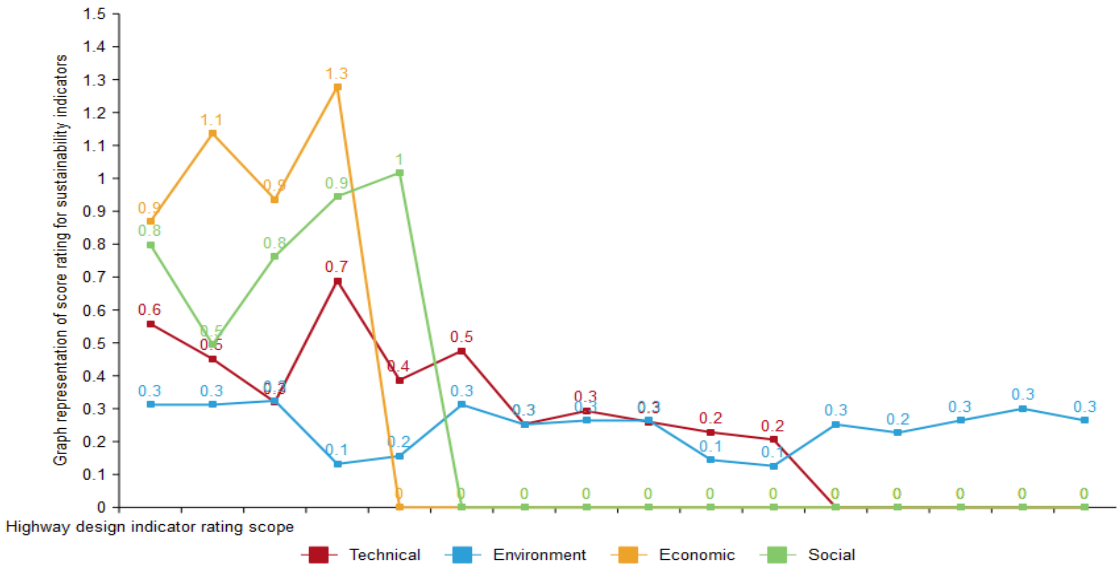


Figure 5. Selection range of external and internal variables for system thinking analysis

Figure 6 displays internal variables—these are variables the highway designers and decision-makers are in control of, such as lifecycle cost analysis, cost benefits ratio, return on investments and innovative ideas. The external variables are constraints to the designers and decision-makers. The below-listed variables will be expanded and analysed using the context of the causal loop diagram.

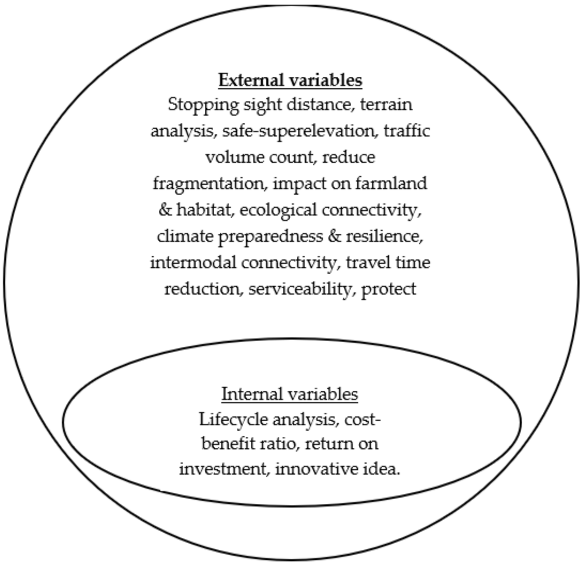


Figure 6. System boundaries for external and internal variables.

Notable conventions within the casual-loop diagram (CLD) consists of when variables connected with arrows, having a polarity of (+) or (-), indicating an influence on another variable due to the feedback effect. The arrow in Figure 7a indicates a causality pattern, having 'Reinforcing' behaviour variable— 'A' at the tail causes a change to the variable 'B', which is at the head of the arrow. The letter 'R' at the midpoint of the loop depicts a reinforcing behaviour following the same direction.

Figure 7b, 'Balancing behaviour' (denoted as a 'B'),' the minus sign at the edge of the arrowhead indicates that variable 'A' at the tail and the variable 'B' at the head changes in the opposite direction. So, if there is an increase at the tail, then the head decreases, and when the tail decreases, the head increases.

Figure 7. Reinforcing and Balancing pattern in Causal loop diagram

The external and internal variables in Figure 6 is utilised to generate the initial causal loop diagram in Figure 8— this further provided the concept to develop archetypes, which is a subset of the causal loop diagram for the sustainability assessment indicators.

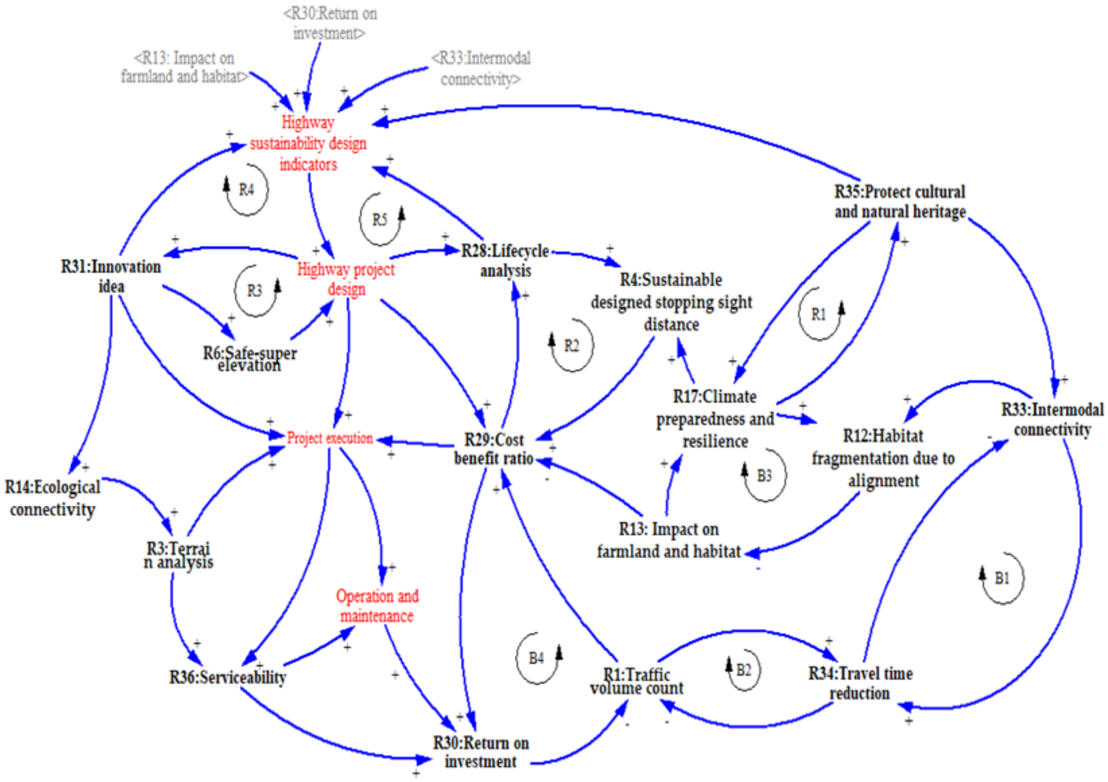
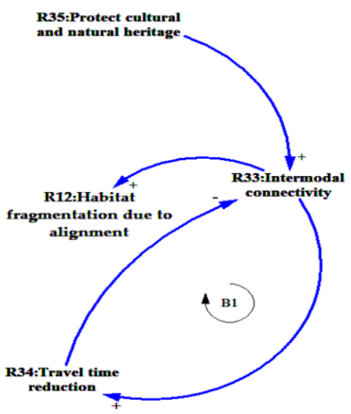


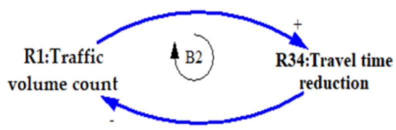
Figure 8. Initial Causal loop diagram

In figure 8, the primary aim of generating the causal loop diagram is to reveal other unidentified variables (*which are sustainability assessment indicators*). The red fonts variables in above Figure 8 are inputs made through validation by an academic expert and a highway designer. Furthermore, the initial causal loop diagram is identified using archetype, and that revealed challenges and clusters of sustainability assessment disparities. The various archetypes displayed in Table 5, represent distinctly reinforcing and balancing loop effect because of the polarity difference of the arrow and their variables.

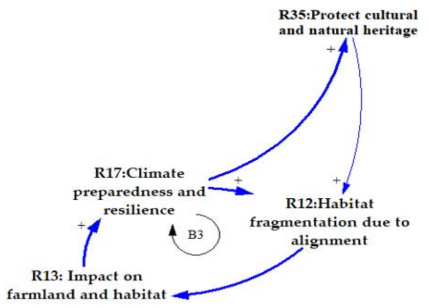
Findings of analysis from the subset archetypes identified more indicators, which are omitted during the literature review, such as—(*agency cost, maintenance cost, and user cost)* which are essentials within the economic sustainability concept. However, these indicators are re-introduced in Figure 10—which is a model to aid sustainability assessment protocol for highway design in Nigeria.

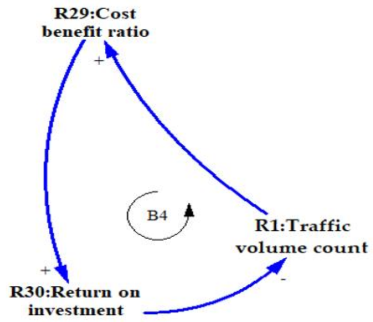
Table 5. Distinct archetype



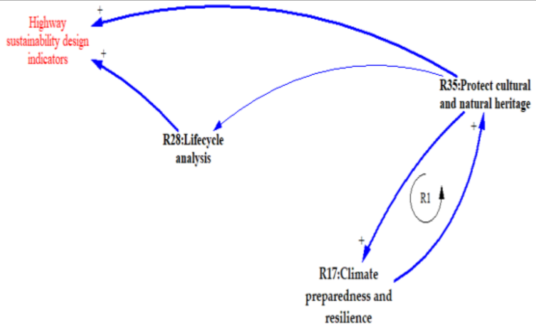


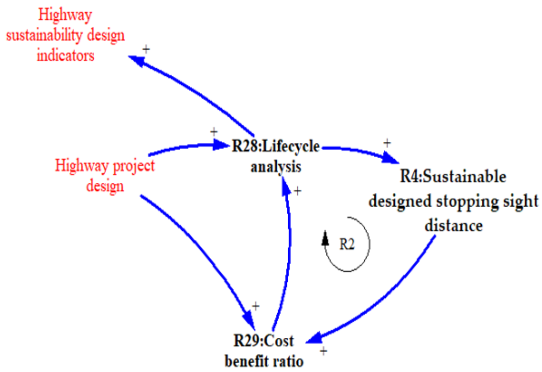
Archetype B1—enhance intermodal connectivity	**Archetype B2—travel time reduction process**



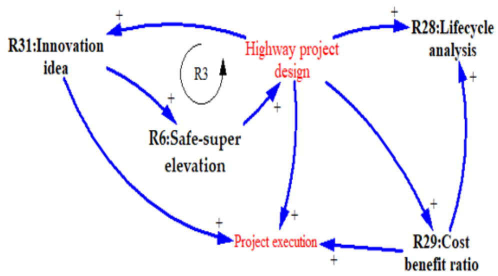


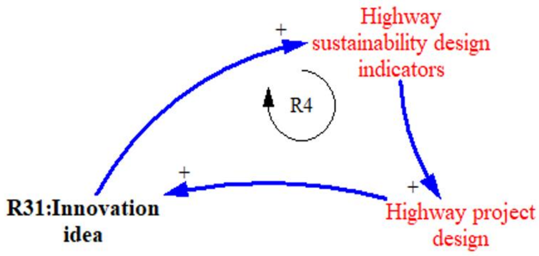
Archetype B3—environmental preparedness **Archetype B4—economical process**



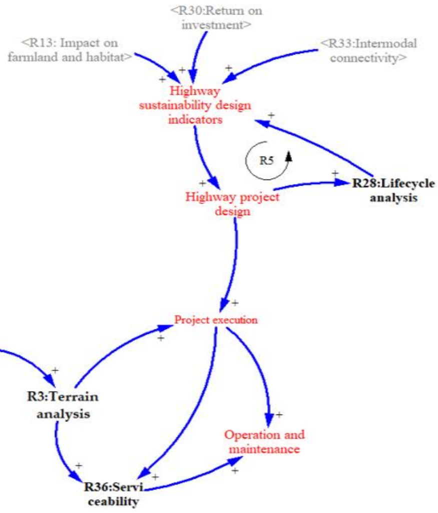


Archetype R1—lifecycle analysis process **Archetype R2—safe stopping distance**





Archetype R3—innovative idea **Archetype R4—design process**



Archetype R5—ecological process

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6. Limitation of current design practice in Nigeria and the way forward

The use of conventional highway design methods in Nigeria has focused primarily on the triple constraint of a triangle, project management and the environmental impact assessment concept (Dania et al., 2007). These conventional design methods are essential but signify short-term development schemes, and that creates a gap between theory and practice in achieving sustainability. Tsai and Chang, (2012) stated that it is difficult for engineering designers to incorporate sustainability concepts into their designs because of knowledge gaps. Moreover, the design stage should be a pivotal point to add quantified sustainability concepts. However, in Nigeria, the focus has been on the use of conventional design approaches, such as—, EIA regulation, safety audit checklist, to determine the preliminary, concept and detailed design (Nigeria Ministry of Works Highway Manual Code of Procedure 2013).

There are opportunities missed to include sustainability in highway design development phases which create learning and knowledge gaps. These gaps in knowledge result in dissatisfaction towards infrastructure development strategies, for example, these are the fragmentation of natural habitats, lack of ecological connectivity, the release of carbon and waste pollution, no energy conservation plan, inadequate quality management plan for infrastructure development, no innovative sustainable plan, nor the proposal to design asphalt pavement using recycled materials.

The current study aimed to determine an appropriate sustainability rating system and credit award certification level in assessing and managing the highway design cycle in Nigeria. A total of thirty-six sustainability indicators, with four categories, are developed. The sustainability indicators facilitate a wide range of gains in reducing the use of excessive energy, environmental protection, the ability to initiate and implement green design innovation, reduce pollution, use recycled materials in asphalt pavement mix design, resources management, in reducing global warming and in building sustainable cities and society.

To enhance benefits associated with the above-analysed archetypes and inputs from expert opinion towards refinement of thirty-sixty (36) sustainability indicators. Table 6 displays recommended credit certification criteria for highway design, which should be considered for implementation alongside Table 4, and Figure 10, which is the proposed sustainability application framework.

Table 6. Smart Green Certification level for highway design in Nigeria

Smart green highway rating system™	*Recognised: type of certification involves design that incorporated least minimal sustainable practice, with the aim of beneficial impacts and the potential to advance towards incredible innovation.
Smart green highway rating system™	***Silver**: type of certification involves good design that incorporated minimal sustainable practice, with the aim of beneficial impacts and the potential to advance towards incredible innovation.
Smart green highway rating system™	***Gold**: type of certification involves commendable design that incorporated considerable sustainable practice, aiming for beneficial impacts and potentials to advance towards incredible innovation.
Smart green highway rating system™	***Evergreen**: type of certification involves excellent design that incorporated the highest sustainable practice, with the aim of continuous innovation worthy of practice across the industry

*Evergreen level: 39 – 33 ; *Gold level: 33 – 30 ; *Silver level: 30 – 27, *Recognised level 27 – 25.

According to Greenroad manual v1.5(2011), assessing a highway project using sustainability indicators and credit points helps challenge the teams beyond the minimum environmental, social, and economic practice. The sustainability rating system awards credits points in a project, enhance best practices and reduces global warming potential. That enable projects to earn credit points for the award of either evergreen, gold, silver or simply a recognised designed project that satisfied regulations. The rating system should be implemented in a project from the onset during the "preparation phase" to develop a strategy for sustainability implementation (see Figure 9). Further, each highway design protocol is required to develop a sustainable development plan to implement Technical, Environmental, Economic and Social attributes.

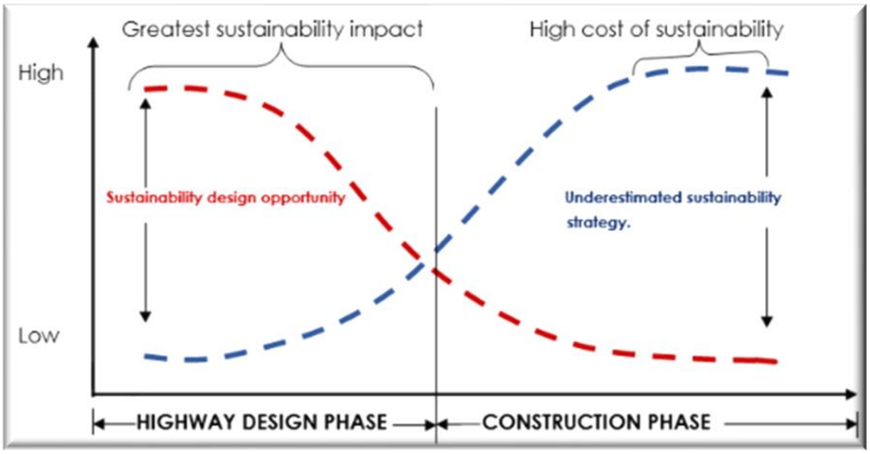

Figure 9. Influence of early decisions for highway design sustainability.

6.1 Acknowledgement of limitations

The reliability of the developed highway design sustainability assessment model should be validated through implementation in highway design projects in Nigeria using a case study. Case study or onsite validation helps to identify limitations, strengths, and areas for improvement.

The proposed sustainability rating system is not an avenue to use a checklist tick box to award credit points and certification levels, thereby undermining the benefits. There is a need to develop a sustainability design cycle framework using a documentary plan, processes, techniques across sustainable management for the preliminary, concept, and detailed design phase. Only through that approach will the proposed sustainability assessment indicators play a meaningful role and innovative benefits (see Figure 10 for a proposed application framework).

Furthermore, a written sustainability design plan should be based on extensive cumulative and innovative documentary research over a period in Nigeria highway design projects. There should be a strong preference in considering the use of local materials(recycled), innovative sustainability for practical implementation. The proposed sustainability indicators in this research are applicable only for a new highway and road project. For highway maintenance, separate research should collect data to identify relevant sustainability indicators and frameworks.

6.2 Weighing logic and framework limitation:

Some direct action of sustainability indicators implementation may be complex to measure. However, the application and documentation of good practice across a similar range of projects will provide invaluable data and evidence in making a future decision for improvement and assessments. In this research, a minimum value of one point is assigned to each indicator (see Table 7 in the appendix area). These values may change (due to best practice, and innovation in sustainability assessment in a project).

7. Conclusion

Building smartly, preserving the global environment has been the primary focus of the United Nations and the international communities, now that the planet is at the verge of a tipping point to reduce the further rise of 1.5°C, against climate change catastrophe. The use of a sustainability assessment rating system to develop green highways has been existing in a few developed countries of the world. But highway development in Nigeria is still lacking the literacy and practical knowledge to implement sustainability assessment. The research developed thirty-six dedicated sustainability assessment indicators and a framework model to aid highway design implementation in Nigeria. Each of these indicators has an assigned credit point through expert opinion, and a proposed Smart Green Certification level to aid in systematic endorsement of highway design protocols. However, the below findings are worth noting—

- This study has identified that unsustainable city infrastructure development contributes to environmental degradation, such as rapid resources depletion, pollution —leaving behind an ecological footprint. Nearly 19.5 million hectares are destroyed due to urban growth and road construction, which amount to 400 – 2000 hectares per kilometre.
- Nigeria is considered one of the few nations anticipated to have rapid urban and population growth, which will put pressure to provide a backlog of infrastructure development in raising the standard of living—however, that will strain the available resources and in raising carbon footprint. Nigeria highway sector lacks the knowledge and skills to implement sustainability assessment strategy due to the literacy gap in sustainability, social context barrier and low stakeholders experience.

Therefore, the implication of this research in the field of knowledge is to strengthen the idea by drawing insight into the challenges and a need for the adoption of design sustainability implementation in the Nigerian highway context. Besides, this research provides the first comprehensive assessment to adopt a sustainability design assessment strategy for Nigeria.

Whilst this study did not confirm either with a pilot study of the assessment outcome in projects in Nigeria— it did partially substantiate to identify the benefits. The identified limitation can be enhanced through case studies and pilot surveys—A key strength of the current study is to develop initial sustainability assessment indicators, award credit points, certification framework and model. More research is now needed to broadly examine benefits, strategy and concepts towards adopting sustainability assessment for the Nigeria highway design. The findings of this study have a number of important implications, such as for the future practice within the West Africa context, industry practitioners and Transport governmental agencies to emulate strategy, benefits and impacts associated with the discussed subject.

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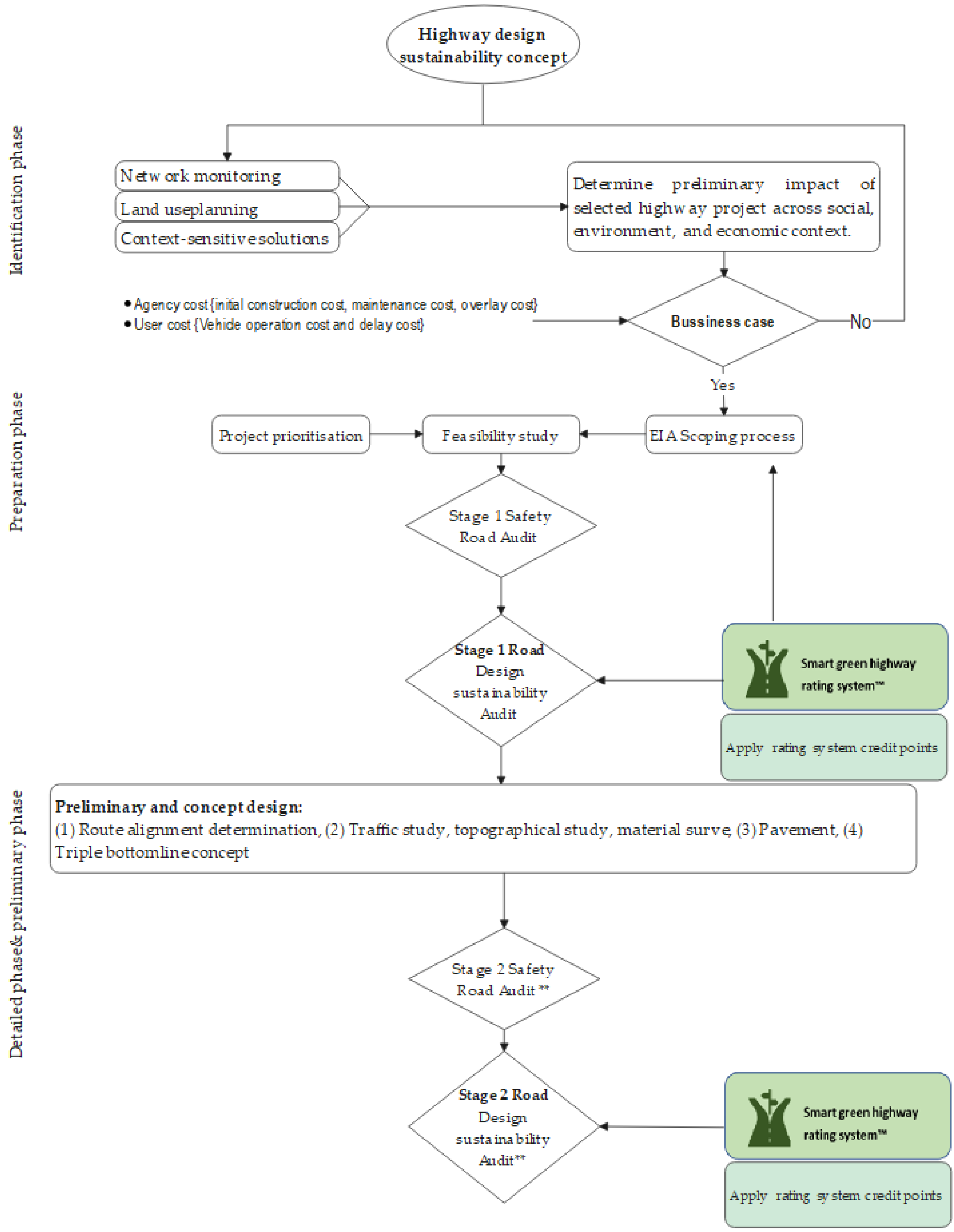
Conflicts of Interest: The authors declare no conflict of interest



*** Implementation is in conjunction with developed sustainability implementation plan*

Figure 10. Proposed sustainability application framework.

Table 7: —Pilot survey for credit point assigned to sustainability assessment design indicators

Category	Indicators	Indicator description	Point
Environmental	Reduce habitat fragmentation alignment	Protect existing greenspace, restore wetland	**1**
	Impact on farmland and habitat	Avoid degradation and destruction	**1**
	Ecological connectivity	Improve wildlife access and mobility across roads	**1**
	Enhance air quality	Roadside vegetation improves air quality	**1**
	Watershed restoration	Restore natural aquatic ecosystem in design	**0**
	Climate preparedness and resilience	Avoid flooding risks & GHG across an ecosystem	**1**
	Renewable energy use	Design to use solar, wind and hydroelectric energy	**0**
	Avoid groundwater pollution	Avoid the use of harmful dangerous substances	**1**
	Reduce greenhouse gas emission	Regulate equipment and material design pollution	**1**
	Material design reuse	Re-use and recycle waste and demolished facility	**1**
	Highway sound barrier wall	Design to limit sound pollution	**0**
	Eliminate environmental pollution	Design to limit pollution as stipulated by W.H.O	**1**
	Long-life design	Use new pavement technology for design	**1**
	Runoff flow control	Design runoff control measures to limit pollution	**1**
	Smart infrastructure	Design smart sustainable highway project	**1**
	Measurement and verification	Measure sustainability and compare best practices	**1**
Technical	Traffic volume count	Document pattern of traffic behaviour and impact	**1**
	Speed limit	Integrate smart highway with the design speed limit	**1**
	Terrain analysis	Model terrain to limit cut and fill surface	**1**
	Stopping sight distance	Consider factors:-driver, vehicle and roadway	**1**
	Safe radius of the curve	Use minimum curvature, use broken back curves.	**1**
	Safe superelevation	Design superelevation for safety and optimal speed	**1**
	Catchment basin for stormwater	Design surface runoff collection basins	**0**
	Profile and vertical curves	Design profile and curves to balance cut and fill, etc	**1**
	Safe cross-section and geometric	Analyse functional classification and benefits	**1**
	Sustainable, flexible pavement	Design pavement with 40% recycled materials	**1**
	Culvert and gully pots and stormwater	Improve Best Management Practice	**0**
Economic	Lifecycle cost analysis	Calculate agency cost, user cost, delay cost etc	**1**
	Cost-benefit ratio	Evaluate the cost of sustainability across project	**1**
	Return on Investment	Determine benefits across sustainability model	**1**
	Innovative ideas	Share sustainability best practices in design	**1**
Social	Community engagement	Use Context sensitive solution for design	**1**
	Intermodal connectivity	Integrate design across other forms of transport	**0**
	Travel time reduction	Determine optimal alignment and obstructions	**1**
	Protect cultural and natural heritage	Enhance social and cultural context in community	**1**
	Serviceability	Design roughness, surface distress, skid resistance and structural capacity	**1**

APPENDIX A

TABLE: A1—Likert Scale questionnaire prototype

Developing sustainability rating system for the Nigerian highway design: 0, 1, 2, 3, 4, 5 Likert
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 highway design?
Assign Likert scale to a range of indicators (0 = not relevant to 5= very high significance)
Part B:
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 – R36)?

Table A2. Economic sustainability judgement matrix

Consistency ratio = 0.076 < 0.10; Weight = ;0.250; λ= 4.252 ; n = 4

	R28	R29	R30	R31	WEIGHT %
R28	0.182	0.143	0.400	0.143	0.217
R29	0.364	0.286	0.200	0.286	0.284
R30	0.091	0.286	0.200	0.286	0.216
R31	0.364	0.286	0.200	0.286	0.284
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table A3. Social sustainability judgement matrix

Consistency ratio = 0.043 < 0.10; Weight = 0.200; λ= 5.192 ; n = 5

	R32	R33	R34	R35	R36	WEIGHT %
R32	0.200	0.222	0.222	0.222	0.222	0.218
R33	0.200	0.111	0.111	0.111	0.111	0.129
R34	0.200	0.222	0.222	0.222	0.222	0.218
R35	0.200	0.222	0.222	0.222	0.222	0.218
R36	0.200	0.222	0.222	0.222	0.222	0.218
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

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