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AN INTEGRATED ANALYSIS OF GREEN HIGHWAY ASSESSMENT CRITERIA FOR SUSTAINABLE INFRASTRUCTURE DEVELOPMENT

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Abstract

In line with the Sustainable Development Agenda 2030, all industries are slowly moving toward a greener approach through their activities and practices. The construction industry is a major contributor to overall economic growth as it provides infrastructure and physical facilities for people. However, the activities involved have caused several environmental impacts, such as pollution, climate change, destruction of natural habitats, landfill waste, and overconsumption of global resources. Therefore, this study presents a comprehensive analysis on the infrastructure work, which is the green highway assessment. The assessment criteria and rating methods were derived from seven prominent frameworks, including Greenroads, WISE, GreenLITES, I-LAST, BE2ST, Greenroads Manual, and MyGHI. Moreover, this research evaluates these sustainable criteria across five elements of green highway development: sustainable design and construction activity, energy efficiency, environmental and water management, materials and technology, and social and safety aspects. This research adopted a systematic literature review and comparative analysis to identify commonalities, differences, and gaps in existing assessment frameworks, providing insights into the holistic evaluation of green highways and sustainable infrastructure projects. The findings of this research contribute to advancing the understanding of green highway initiatives, especially in the local context, and policy development in the field of sustainable infrastructure.

Keywords: Green Highway, Assessment, Criteria, Sustainable, Infrastructure

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INTRODUCTION

Innovation and infrastructure are goals in sustainable development. One element of infrastructure is highways, and Malaysia has seen rapid development of a large amount of highway infrastructure (Mohamed Anuar & Ahmad, 2018). The ratio of highways in Malaysia is considerably high compared to the population, with 68 meters per 1,000 urban population (Mohamed Anuar & Abdullah, 2020). In the early 1960s, construction projects, including highway construction, were observed to have adverse effects on the environment, resources, raw materials, and people (Mohd Nusa, et al., 2015). Gambatese & Rajendran (2005) agree that highway construction negatively impacts the environment, directly or indirectly. The construction of highways involves a wide range of activities, including deforestation and earthwork, which have a significant impact on global warming and climate change. Bryce (2008) emphasizes the importance of incorporating best practices that minimize the environmental impact of highway construction.

Most attention and effort in the development of sustainable construction globally has been devoted to buildings (Huang & Yeh, 2008). Experience in sustainable building is useful for promoting green highway construction, but there's limited literature on evaluating it. As a result, developed countries such as the United States and the United Kingdom have implemented green highway approaches to enhance environmental quality and minimize environmental harm. Green highway focuses on improving the environment, transportation system development, ecosystems, urban growth, public health, and surrounding communities (Mohd Affendi et al., 2013).

LITERATURE REVIEW

Overview of Green Highway

The lifecycle of highway construction involves various processes, namely planning, construction, and maintenance. A comprehensive analysis of current research reveals that the definition of a green highway varies based on the perspective of each researcher. Table 1 summarizes the definitions of green highway from previous researchers.

Green highways include more sustainable practices than modern construction techniques, aiming to maximize the lifetime of a highway (Bryce, 2008). Krebs (2009) defined green highway as an effort to go beyond compliance and leave the project area 'better than before' through community partnering, environmental stewardship, and transportation network improvements in safety and functionality. Green highway can also be defined as watershed-driven stormwater management; life cycle energy and emission reduction; recycle, reuse, and renewable; conservation and ecosystem management; and overall societal benefits (Malaysia Highway Authority, 2010).

Muench et al. (2011) defined a green highway as a roadway project that has been designed and constructed to a level of sustainability that is substantially higher than current practices. In addition, a green highway is a highway constructed using materials that emit little to no pollutants and are environmentally friendly (Reddy, 2011). Green highway is also defined as an approach to help developers achieve a friendly environment, ecological responsiveness, and social responsibility to improve long-term profitability and gain a sustained competitive advantage (Zhang et al., 2011). Washington Department of Transportation (2013) defined green highways as an initiative to promote the use of cleaner fuels. Green highway is defined as a roadway design based on a relatively new concept that incorporates transportation functionality and ecological requirements (LLM & UTM, 2014).

Table 1: Definition of Green Highway

Researcher	Definition
Bryce (2008)	Sustainable practices are more advantageous to modern construction techniques as focus on maximizing the lifespan of a highway.
Krebs (2009)	An effort to go to beyond compliance and leave the project area 'better than before' through community partnering, environmental stewardship and transportation network improvements in safety and functionality.
Malaysia Highway Authority (2010)	The watershed driven storm water management, life cycle energy and emission reduction, recycle, reuse and renewable, conservation and ecosystem management and overall societal benefits.
Muench et al., (2011)	Roadway project that has been designed and constructed to a level of sustainability that is substantially higher than current practices.
Reddy (2011)	Highway constructed using materials that emit no or low concentration of pollutants and are environmentally friendly.
Zhang et al. (2011)	Approaches for helping developers achieve friendly environment, ecological responsiveness and social responsibility to improve long-term profitability and gain sustained competitive advantage
Washington Department of Transportation (2013)	Initiative to promote the use of cleaner fuels.
LLM & UTM (2014)	Green Highway is a roadway design based on relatively new concept for roadway design that integrates transportation function and ecology.

Source: Bryce (2008), Krebs (2009), Malaysia Highway Authority (2010), Muench et al. (2011), Reddy (2011), Zhang et al. (2011), Washington Department of Transportation (2013) and LLM&UTM (2014)

Each of the aforementioned definitions of green highway listed above addresses similarities and differences regarding the various approaches to green highway. Based on the comprehensive review, it can be inferred that the concept of green highways represents a novel and forward-thinking approach to infrastructure development, aimed at fostering a safe environment and delivering ecological advantages for future generations. Green Highways can be characterized as the utilization of recycle materials, effective ecosystem management, energy conservation, enhancement of stormwater runoff quality and management, and the maximization of societal benefits.

Green Highway Approaches

Several green highways approach available, which are Greenroads, Washington Internships for Students of Engineering (WISE), GreenLITES, Building Environmentally and Economically Sustainable Transportation (BE^2ST), Illinois Livable and Sustainable Transportation (I-LAST), Greenroads Manual, and Malaysia Green Highway Index (MyGHI). Each approach has its own set of criteria and rating methods for evaluating green highways. These criteria may vary depending on the climate and can be similar or different across different approaches.

Greenroads

Greenroads is the pioneering green road rating system, which established in the United States in 2007. It serves as a voluntary third-party rating system for road projects, aiming to acknowledge and impulse the implementation of sustainable practices in roadway development. The categories of Greenroads are sustainable design, material and resources, stormwater management, energy and environmental control, construction activities, and innovation (Soderlund et al., 2008).

Washington Internship for Students Engineering

WISE is a program designed for engineering students. It established in August 2008 at the University of Missouri in the United States. The program's core objective is to explore and develop innovative strategies in the realm of sustainable transportation, with a particular emphasis on the concept of green highways. The key areas include watershed-driven stormwater management; lifecycle energy and emission reduction; recycle, reuse, and renewable; overall societal benefits; and conservation and ecosystem management (Bryce, 2008).

GreenLITES

The New York State Department of Transportation is committed to improving the quality of transportation infrastructure in ways that minimize impacts on the environment, including the depletion of irreplaceable resources (GreenLITES, 2008). GreenLITES was introduced in September 2009 as a self-certification program that aims to distinguish transportation projects based on their level of integration of sustainable design choices. GreenLITES has five main categories, which are sustainable sites, water quality, material and resources, energy and atmosphere, and innovation (GreenLITES, 2008).

Illinois Livable and Sustainable Transportation
The Illinois Livable and Sustainable Transportation (I-LAST) system established in January 2010 as a comprehensive rating system and guide. I-LAST serves as a robust sustainability performance metric system, jointly developed by the Joint Sustainability Group comprising of the Illinois Department of Transportation, the American Council of Engineering Companies-Illinois, and the Illinois Road and Transportation Builders Association. I-LAST has eight categories of green highway, which are planning, design, environmental, water quality, transportation, lighting, material, and innovation (Illinois Department of Transportation, 2010).

Building Environmentally and Economically Sustainable Transportation
Building Environmentally and Economically Sustainable Transportation is a manual that was initiated by the University of Wisconsin in 2010. BE^2ST outlines six key components of a green highway. The components consist of material reuse or recycling, energy use, water consumption, global warming potential, life cycle cost, and hazardous waste (Recycled Materials Resource Centre & Universiti of Winconsin-Madison, 2010).

Greenroads Manual
The Greenroads Manual was published in 2011 by the University of Washington. It serves as an updated and enhanced version of the initial Greenroads publication from 2007. This comprehensive manual provides in-depth information on every project requirement and voluntary credit incorporated within the Greenroads Rating System. The Greenroads Manual consists of five main criteria of green highway: environment and water, access and equity, construction activities, material and resources, and pavement technologies (Muench et al., 2011).

Malaysia Green Highway Index
MyGHI introduced as an assessment tool for green highways in 2014. The MyGHI serves as a guide for promoting sustainability in roadway design and the adoption of green construction practices. It outlines five categories for the development of green highways, which are sustainable design and construction activity, energy efficiency, environment and water management, materials and technology, and social and safety (LLM & UTM, 2014).

RESEARCH METHODOLOGY
A systematic review of the literature conducted to provide a rational, unbiased, and critical view (Charlton, 2012). The systematic review addressed the research question “What are the criteria related to the green highway assessment”? The keywords and characters required for further database search were determined by reviewing literature related to green highway, green highway approaches, and

criteria of green highway. The search was carried out in commonly used research databases, such as Scopus, Google Scholar, Web of Science, and Science Direct (Xiao & Watson, 2017). The search was conducted using identified keywords such as "Green Highway", "Green Highway Approaches", and "Criteria of Green Highway".

To investigate the most relevant articles addressing the research problem, this study employed specific inclusion and exclusion criteria for a more comprehensive review of selected literature. The criteria are as follows:

1. Publication year: Articles published from 2008 to 2023 were considered, reflecting the rapid expansion of the construction industry.
2. Publication type: Only articles from high-quality, peer-reviewed journals were included.
3. Research domain: Literature unrelated to green highway and criteria of green highway were excluded from the study.

ANALYSIS AND DISCUSSION

All the criteria related to the green highway assessment were listed. The criteria adapted from (1) Greenroads, (2) Washington Internship for Students of Engineering (WISE), (3) GreenLITES, (4) Illinois Livable and Sustainable Transportation (I-Last), (4) Building Environmentally and Economically Sustainable Transportation (BE2ST), (5) Greenroads Manual, and (7) Malaysia Green Highway Index (MyGHI) were analyzed. The analysis was conducted utilizing the five key components identified in the current green highway assessments. Each criterion was comprehensively listed and examined individually. The elements under discussion include: Element 1 - sustainable design and construction activity, Element 2 - energy efficiency, Element 3 - environmental and water management, Element 4 - materials and technology, and Element 5 - social and safety.

Sustainable Design and Construction Activity

Table 2 showcases the classification of sustainable design and construction activities. This classification is comprised of nine criteria and thirteen sub-criteria. The criteria encompass the construction management plan, noise mitigation control, equipment and machinery efficiency, quality management, context-sensitive design, erosion and sedimentation, alignment selection, pollution reduction, and life cycle. These categories guarantee a minimized impact of the highway on the natural environment.

All assessments, with the exception of BE^2ST, indicate the necessity for context-sensitive design in the development of environmentally friendly highways. When designing and constructing highways, the environment must be the primary consideration (New York State Department of Transportation, 2009).

This aligns with the criterion of reducing environmental impact, which necessitates comprehensive assessments. The development of green highways aims to minimize environmental harm (Michigan, 2008).

Furthermore, reducing emission through efficient equipment and machinery was identified as a crucial criterion for all assessments, except for GreenLITES and I-LAST. According to Kibert (2001), the construction sector accounted for 6% of total industrial greenhouse gas (GHG) emissions in the United States in 2002. In Malaysia, the construction industry poses a significant environmental threat due to GHG emissions (Klufallah, et al., 2013). The construction industry in Malaysia ranked 30th globally in terms of carbon emissions (Klufallah et al., 2013). As part of vision 2020, the construction industry aims to reduce carbon emissions by up to 40% (Klufallah, et al., 2014).

The analysis revealed that the sub-criteria of air pollution, as well as erosion and sedimentation, were only addressed by the MyGHI. Malaysia's tropical climate is prone to heavy rainfall, which can result in landslides, flash floods, and other disasters (Che Ahmad & Husin, 2015). As this criterion contradicts the research, it was excluded from the factor analysis process. Air pollution remains a significant issue in Malaysia that needs to be addressed. The largest contributor to air pollution in Malaysia is mobile sources, particularly motor vehicles, which account for 70%–75% of total air pollution (Afroz, et al., 2003). Given that the construction of highways involves numerous machinery, proper planning is essential to minimize gas emissions from both machinery and vehicles.

Table 2: Sustainable design and construction activity

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Construction Management Plan	Waste Management	/	x	x	x	x	/	/
	Air Pollution	x	x	x	x	x	x	/
	Innovation	/	x	x	/	x	x	/
Noise Mitigation Control	Technique	/	x	/	/	x	/	/
	Equipment	x	x	x	x	x	x	/
Equipment And Machinery Efficiency	Natural & Emission Reduction	/	/	x	x	/	/	/
Quality Management	Management Plan & Training	/	x	/	x	x	/	/
Context Sensitive Design	Design Flexibility	/	/	/	/	x	/	/
Erosion & Sedimentation	Erosion & Sedimentation	x	x	x	x	x	x	/
Alignment Selection	Environmental Impact Reduction	/	/	/	/	x	/	/
Pollution Reduction	Air and Noise Pollution	x	/	x	x	x	x	/
	Light Pollution	/	/	x	x	x	/	x

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Life Cycle	Life Cycle Assessment	x	x	x	x	/	/	x

Source: (1) Soderlund et al. (2008), (2) Bryce (2008),(3)GreenLITES (2008), (4)Illinois Department of Transportation (2010), (5)Recycled Materials Resource Centre & Universiti of Winconsin-Madison (2010), (6)Muench et al. (2011) and (7)LLM&UTM (2014)

Energy Efficiency

Table 3 illustrates the energy efficiency category, which seeks to tackle the problem of carbon emissions. Most assessment systems encompass energy efficiency in a broad manner, without specific criteria, with the exception of MyGHI. It shows that MyGHI uniquely prioritizes energy efficiency based on the area. This is demonstrated by the Malaysian scenario, for example, the PLUS Highway spans 772 km from Bukit Kayu Hitam to Johor Bharu, featuring 65 interchanges, 48 lay-bys every 25–50 km, and 24 rest and service areas located every 80–100 km (PLUS Malaysia Berhad, 2014). In contrast, along the highways of Washington spanning 701.88 km, there are only three toll plazas and 48 rest and service areas (Washington State Department of Transportation, 2015).

The MyGHI framework encompasses four key component areas and one policy management aspect to address energy efficiency. These component areas include rest and service areas, toll plazas, compound and car parks, and interchanges. The policy management aspect is further categorized into renewable energy policies, commissioning of building energy systems, and an energy plan for maintenance. It is important to note that MyGHI primarily concentrates on enhancing energy efficiency within these component areas.

Table 3: Energy Efficiency

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Management policy	Renewable energy policies	x	x	x	x	x	x	/
	Commissioning of Building Energy System	x	x	x	x	x	x	/
	Energy Plan for Maintenance	x	x	x	x	x	x	/
Rest & service area	Reduced electrical consumption	x	x	/	/	x	x	/
	Sustainable Infrastructure	x	x	x	x	x	x	/
Toll plaza	Tool booth	x	x	x	x	x	x	/
	Lighting Zone	x	x	x	x	x	x	/
	Administration and supervision	x	x	x	x	x	x	/
Compound and carpark	Energy efficiency performance	x	x	x	x	x	x	/
Interchange	Reduce Energy Consumption	x	x	x	x	x	x	/

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Stray Light/Light Pollution Reduction	x	x	/	/	x	x	/
General	Energy Control	/	x	x	x	x	x	x
	Energy Use	x	x	x	x	/	x	x
	Energy Lifecycle	x	/	x	x	x	x	x
	Material & Resources	x	x	x	x	x	/	x

Source: (1) Soderlund et al. (2008), (2) Bryce (2008),(3)GreenLITES (2008), (4)Illinois Department of Transportation (2010), (5)Recycled Materials Resource Centre & Universiti of Winconsin-Madison (2010), (6)Muench et al. (2011) and (7)LLM&UTM (2014)

Environmental and Water Management

Table 4 presents the category of environmental and water management. This category divided into five criteria and fifteen sub-criteria. The criteria include environmental management systems, stormwater runoff quantity, stormwater runoff quality, ecosystem protection, and water consumption. The category focuses on stormwater management to preserve the ecosystem and protect wildlife. The analysis reveals that Greenroads, Greenroads Manual, and MyGHI meet all criteria for environmental management systems, stormwater runoff quantity, stormwater runoff quality, and ecosystem protection. However, their assessment does not include water consumption. On the other hand, WISE does not include ecosystem protection and water consumption in its assessment.

While BE^{2}ST only highlights water consumption in the environmental and water management category, its objective is to reduce water consumption during highway construction by utilizing alternative designs. A study by Lee et al. (2011) tested the construction of highways using rigid pavement and flexible pavement as alternative materials. The results showed that the use of flexible pavement required less water compared to rigid pavement (Lee, et al., 2011).

The MyGHI focuses on the drainage system. Inefficient drainage system is the main cause of floods in Malaysia (Sadali, 2016). Nowadays, Malaysia experiences heavy rainfall regardless of the season. The Malaysian Meteorological Department reported that many areas in peninsular Malaysia received total rainfall amounts exceeding 60% of the average value (Malaysian Meteorological Department, 2013). In contrast, Sarawak experienced rainfall amounts that were 100% above the average value (Malaysian Meteorological Department, 2013). Therefore, it is crucial for the drainage system to be well-maintained to avoid flash floods.

Table 4: Environmental and water management

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Environmental Management System	EMS Certification	/	x	x	x	x	/	/
	Temporary Stormwater Control	/	x	x	x	x	x	x
	Innovation Stormwater Technology	/	x	x	x	x	x	x

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Water Tracking	x	x	x	x	x	/	x
Stormwater Runoff Quantity	Runoff Flow Control	/	/	/	x	x	/	/
	Disaster Cost Analysis	/	x	x	x	x	/	/
	Drainage System	x	x	x	x	x	x	/
Stormwater Runoff Quality	Water Pollution Reduction	x	/	/	/	x	x	/
	Runoff Treatment and Water Bodies	/	/	/	/	x	/	/
	Reuse Water by Infiltrate Ground Water Table	x	/	x	x	x	x	x
Ecosystem Protection	Habitat Restoration and Protection	x	x	/	/	x	/	/
	Site Vegetation	x	x	/	/	x	/	/
	Tree & Plants	x	x	/	/	x	x	/
	Ecological Connectivity	/	x	/	x	x	/	/
Water Consumption		x	x	x	x	/	x	x

Source: (1) Soderlund et al. (2008), (2) Bryce (2008),(3)GreenLITES (2008), (4)Illinois Department of Transportation (2010), (5)Recycled Materials Resource Centre & Universiti of Winconsin-Madison (2010), (6)Muench et al. (2011) and (7)LLM&UTM (2014)

Material & Technology

Table 5 presents the materials and technology category, which is further divided into four criteria and fifteen sub-criteria. These criteria include innovation and technology, reduce, reuse, and recycle, economical material and pavement, and erosion control. The focus of this category is to prevent the production of excessive waste, pollution, and harmful gas emissions.

The analysis reveals that all assessment systems emphasize the importance of reducing, reusing, and recycling materials in the construction of green highways. Additionally, all assessments highlight the significance of recycling pavement or implementing sustainable techniques in green highway construction. A case study conducted on the Burlington Bypass project, found that pavements made from recycled materials had a service life three years longer than those made from conventional materials. According to Lee et al. (2011), recycled materials possess different engineering properties compared to conventional materials, making them more sustainable.

Table 5: Material & Technology

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Innovation Technology	Research Development	x	x	x	x	x	x	/
	Usage Of Industrial by Product	x	x	/	/	x	x	/
	Sub Grade Improvement / Soil Stabilization	x	x	x	/	x	x	/
	Cool Pavement	/	x	x	x	x	/	/

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Reduce, Reuse & Recycle	Reuse Of Topsoil	x	x	x	/	x	x	/
	Reuse And Recycle of Non-Hazardous Material	/	/	/	/	/	/	/
	Earthwork Balance	x	x	x	/	x	/	/
Economical Material & Pavement	Regional Material	/	x	x	x	x	/	/
	Pavement Design Life	/	x	x	/	x	/	/
	Recycle Pavement/New Sustainable Technique	/	/	/	/	/	/	/
	Permeable Pavement	/	x	x	/	x	/	/
	Quiet Pavement	/	x	x	x	x	/	/
	Warm Mix Asphalt	x	/	x	x	x	/	x
	Pavement Performance Tracking	x	x	x	x	x	/	x
Erosion Control	Soil Biotechnical Engineering Treatments Green Techniques	x	x	/	x	x	x	/

Source: (1) Soderlund et al. (2008), (2) Bryce (2008),(3)GreenLITES (2008), (4)Illinois Department of Transportation (2010), (5)Recycled Materials Resource Centre & Universiti of Winconsin-Madison (2010), (6)Muench et al. (2011) and (7)LLM&UTM (2014)

Social & Safety

Table 6 illustrates the social and safety category, which is divided into six criteria and eighteen sub-criteria. The criteria encompass services and facilities, economy, public acceptance, environment, management issues, and access. The primary focus is to enhance the comfort and safety of highway users, improve the economy, and ensure good environmental quality.

The social and safety aspect is a novel concept in the development of green highways. It serves as both an infrastructure and a means to promote tourism through billboards along the highway (Che Ahmad & Husin, 2015). This approach also drives economic growth by stimulating business activities and creating job opportunities at rest areas, service areas, and toll plazas. The majority of the criteria for the social and safety category are emphasized in the MyGHI, as compared to other assessment systems.

However, the MyGHI does not encompass criteria for pedestrian, bicycle, and transit access. In the hot and humid climate of Malaysia, it may not be suitable to construct pedestrian and bicycle facilities along the highway. On the other hand, in Washington, the District Department of Transportation provides dedicated lanes for bicycles and pedestrians along highways. These facilities encourage people to use bicycles as a means of commuting to work, school, or other destinations, thereby reducing road congestion and greenhouse gas emissions (District Department of Transportation, n.d.).

Table 6: Social & Safety

Criteria	Sub-Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Services & Facilities	Intelligent Traffic System	x	x	x	x	x	/	/
	Provision Of Basic Facilities	x	x	x	x	x	x	/
	Provision Of Additional Facilities	x	x	x	x	x	x	/
Economy	Business Enhancement	x	x	x	x	x	x	/
	Number Of Job Creation	x	x	x	x	x	x	/
	New Development	x	x	x	x	x	x	/
	Tourism	x	x	x	x	x	x	/
Public Acceptance	Perception	x	x	x	x	x	x	/
Environment	Aesthetic Initiative	x	/	x	x	x	x	/
	Landscaping	x	x	x	x	x	x	/
	Scenic Views	x	x	x	x	x	/	x
	Cultural Outreach	x	x	x	x	x	/	x
Management Issue	Road Safety Audit	/	x	x	x	x	/	/
	Contractor Warranty	x	x	x	x	x	/	x
Access	Traffic Flow Improvement	/	x	/	/	x	x	x
	Pedestrian Access	/	x	/	/	x	/	x
	Bicycle Access	/	x	/	/	x	/	x
	Transit Access	x	x	x	/	x	/	x

Source: (1) Soderlund et al. (2008), (2) Bryce (2008),(3)GreenLITES (2008), (4)Illinois Department of Transportation (2010), (5)Recycled Materials Resource Centre & Universiti of Winconsin-Madison (2010), (6)Muench et al. (2011) and (7)LLM&UTM (2014)

Based on the analysis, the category of sustainable design and construction activity for green highways is divided into nine criteria and thirteen sub-criteria, aiming to reduce environmental impacts and increase societal benefits. The need for context-sensitive design emerges as crucial across assessments, highlighting its importance in the development of green highways. The primary focus includes the reduction of environmental impacts, as conventional highways significantly contribute to GHG emissions and air pollution, particularly in Malaysia's construction industry.

The following category, which is energy efficiency, varies accordingly. The MyGHI emphasizes energy efficiency by area, reflecting Malaysia's diverse highway infrastructure compared to other regions mentioned earlier, like Washington. This study summarizes that environmental and water management prioritizes stormwater management and ecosystem preservation, which include various assessments addressing criteria such as environmental management systems, stormwater runoff, and ecosystem protection for green highways. In terms of the materials and technology criterion, it emphasizes waste reduction and emissions through innovation, recycling, and sustainable pavement techniques. The social and safety criterion encompasses services, economic impact, public acceptance, and access, aiming to enhance highway users' comfort, safety measures, and economic opportunities. Among all the frameworks, the MyGHI stands out the most for its comprehensive coverage; however, it does not cover pedestrian and bicycle access criteria due to climate considerations in Malaysia. Overall, these assessments underscore the multifaceted approach required for green highway development in integrating environmental, social, and economic aspects to mitigate environmental impact and promote societal well-being.

CONCLUSION

In conclusion, this research provides a comprehensive analysis of green highway assessment criteria derived from various established frameworks. The study examines five key elements: Element 1 - sustainable design and construction activity, Element 2 - energy efficiency, Element 3 - environmental and water management, Element 4 - materials and technology, and Element 5 - social and safety. This research sheds light on the multifaceted nature of sustainable infrastructure development, especially on green highways. This analysis reveals both commonalities and disparities among existing assessment frameworks, emphasizing the need for a more integrated and holistic approach for green highway initiatives especially tailored to the Malaysian context in terms of its criteria and sub-criteria. These green highway projects can enhance environmental resilience, promote sustainable development, and support social equity. In essence, this study represents a crucial step toward promoting sustainable development practices in construction.

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