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Evaluating Sustainable Green Road and Green Belt Practices in Sragen Regency: A Delphi-Based Assessment

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ABSTRACT

Sustainable road rating systems are increasingly adopted globally; however, their effectiveness as reliable assessment tools often require deeper empirical validation. This study quantitatively evaluated a certified green road in Sragen Regency, Indonesia, by statistically linking on-the-ground ecological data to its assessment score. A validated Delphi-based instrument ($n = 17$ experts, Cronbach's $\alpha = 0.987$) was used for the assessment. Roadside vegetation was surveyed at five points to calculate landscape (gamma) and local (alpha) biodiversity using the Shannon Index, with a one-sample t-test assessing local diversity significance against an ecological benchmark ($H' = 1.5$, indicating moderate biodiversity). The road achieved a three-star certification with a score of 39.55. However, a critical discrepancy emerged: while landscape-level diversity was high ($H'\gamma = 2.24$), the mean local diversity was statistically low ($H'\alpha = 0.78$, $p < 0.001$), a paradox explained by high species turnover between sites. This study concludes that certification scores can mask significant ecological weaknesses. High landscape diversity does not equate to healthy local ecosystems, highlighting the critical need for multi-scale metrics in rating systems to accurately reflect on-the-ground sustainability.

Introduction

Roads play a fundamental role in everyday life as they are the primary means of supporting economic activities, social interactions, and emergency services. Furthermore, road infrastructure significantly contributes to the development of smart cities and sustainable infrastructure systems [1,2]. In the context of the 2030 Sustainable Development Goals (SDGs), the existence of roads is directly linked to achieving SDGs 2, 9, 11, 13, and 17 [3,4]. Therefore, road planning needs to be viewed as part of a system integrated with the natural environment, so that development can support, rather than degrade environmental quality [5,6]. To achieve this, comprehensive integration of ecological, social, and economic aspects is required from the planning to construction stages, which is increasingly facilitated by the use of structured desirability assessment instruments to support data-driven decision-making [2].

Several invited assessment systems have been initiated and used in various countries, each with its own approach, focus, and scope. While CEEQUAL v6 and Envision v3 provide comprehensive evaluation frameworks, they are quite complex and not specifically designed for road infrastructure projects. Meanwhile, building environment and economic sustainability tool (BE2ST)-in-Highways emphasizes quantitative approaches, such as life cycle cost analysis (LCCA) and noise evaluation. Infrastructure voluntary evaluation sustainability tool (INVEST) serves as a guiding tool in project management, but does not yet include an explicit rating system. Green leadership in transportation environmental sustainability (GreenLITES), on the other hand, emphasizes ecological benefits, although it still requires additional integration with LCCA analysis. GreenPave has a more limited scope, focusing on pavement works [7–9]. Unlike these systems, the Green Road Rating System is the only third-party certification scheme specifically

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developed for highway projects, with a comprehensive assessment approach throughout the project life cycle. These characteristics make green roads highly relevant, particularly for developing countries facing accelerated infrastructure development and demands for environmental sustainability.

Vegetation along roadways plays a critical role in delivering ecosystem services, including carbon sequestration, microclimate regulation, air purification, noise mitigation, and biodiversity enhancement [10,11]. The effectiveness of these services is influenced by species composition, structural diversity, spatial distribution, and landscape connectivity. The strategic selection of native species and deliberate landscape design can enhance ecological resilience and improve the capacity of roadside environments to adapt to climate variability [12–15]. Previous studies have developed eco-friendly road rating systems, applied quantitative approaches such as analytic hierarchy process (AHP) analysis, utilized Indonesia green road rating tool (InRT) aligned with global reporting initiative (GRI) and united nations sustainable development goals (UN SDGs) standards, and analysed multiple green road projects to quantify environmental impacts, carbon footprints, and energy use in road work [16–19]. However, these studies rarely examine whether high certification scores correspond to measurable ecological performance, revealing a potential "performance gap" that may misinform policy and investment decisions.

This study aims to investigate this critical gap through an in-depth case study of the Sukowati Highway in Sragen Regency, Indonesia, a region with emerging green city characteristics that also experiences moderate road damage [20,21]. This research focuses on three main objectives, namely: (1) assessing the ecological condition of vegetation along roadsides, (2) identifying the level of road diversity through a green road ranking system that has been validated using the Delphi Method, and (3) examining the relationship between certification scores and ecological performance measured in the field. By combining ecological data from direct observation and systematic biodiversity assessments, this study aims to assess the extent to which formal certification results accurately reflect ecological conditions. The results of this study are expected to serve as a basis for improving the poverty evaluation framework, supporting data-driven policies, and encouraging the development of more resilient, environmentally friendly road infrastructure.

Materials and Methods

Study Area

This research is conducted in Sragen Regency, Central Java Province, Indonesia, with Sukowati Highway being designated as the primary object of study, as it serves as the main arterial road in the city center. Geographically, this road section is approximately 5.2 km long and stretches from 7°25'45.0"S to 7°26'30.0"S and from 111°00'15.0"E to 111°01'00.0"E. Sukowati Highway is identified as the main transportation corridor connecting various administrative and organizational areas in Sragen Regency. We selected this location based on its potential to implement the green infrastructure concept, particularly for the development of sustainable green roads and green belts.

Data Collection

This study employed a multi-stage, mixed-method design. The first stage involved a quantitative field survey to assess the on-the-ground ecological conditions of roadside vegetation. The second stage utilized a two-round Delphi method with regional experts to validate a set of sustainability indicators for a green road assessment instrument. In the final stage, the validated instrument was used to score the highway's sustainability level, and the results were statistically compared with ecological condition data to analyse the primary research question. The following sections describe these stages in detail, starting with a descriptive quantitative survey of roadside vegetation conditions and continuing with the Delphi-based validation of the assessment instrument.

A descriptive quantitative approach was used to identify existing vegetation conditions along the roadside. The sampling method was carried out systematically at 5 plot locations measuring 10 × 10 meters at 5 location points with a distance between points of 1.6 km to obtain a broader representation of the condition of roadside vegetation (Figure 1). This plot-based sampling design follows a corridor-scale assessment approach commonly applied in road ecological studies, where a limited number of representative plots is considered sufficient to capture spatial variability in linear infrastructure environments [22,23]. Data were collected through a field survey method by recording vegetation types following Ministerial Regulation Number 5 of 2012 based on plant groups, namely trees, shrubs, and grasses [24]. In addition, each plant was calculated based on the number and distribution in the plot at each location point. Visual documentation was also conducted to support the descriptive analysis and validity of the vegetation types found.

This study uses the two-round Delphi method to identify and validate green road sustainability indicators. The Delphi Method is suitable for research problems that require collective thinking to explain future strategies that cannot be adequately solved [25]. Data were collected using questionnaires distributed to the expert judgments of 17 experts and stakeholders. A literature review was conducted to determine the relationships between the parties. The determination of the justification of influence and importance in stakeholder mapping analysis [26] is described in Table 1.

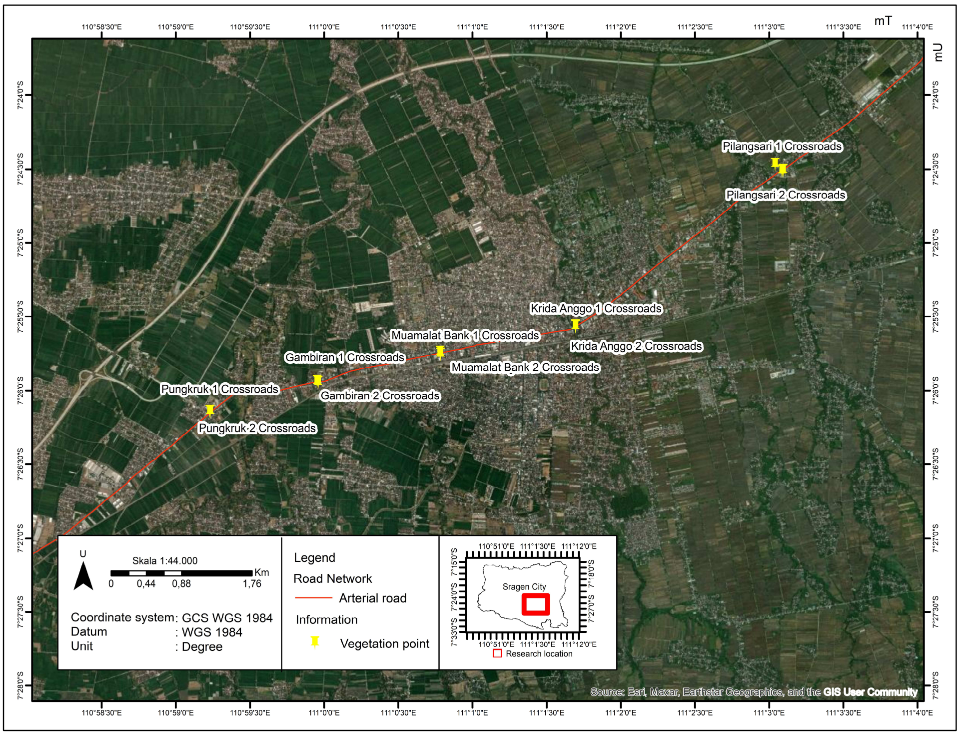

Figure 1. Location map of the Sukowati Highway research site in Sragen Regency, Central Java, Indonesia. The map shows an approximately 8 km long road corridor analyzed in this study, with five systematic roadside vegetation sampling plots distributed along the main arterial route.

Table 1. Stakeholder mapping and expert representation in the Delphi questionnaire for green road sustainability assessment. The table presents stakeholder groups involved in the Delphi assessment, including their influence and importance levels (1–5) and the number of respondents in each category. These experts provided judgments used to validate the sustainability indicators in this study.

Stakeholder groups	Influence level (1-5)	Importance level (1-5)	Number of samples
Government/Agency			
Development planning agency at sub-national level	4	4	2
Public works department	3	4	2
Department of transportation	4	3	2
Road & bridge construction	4	4	2
Environment agency	3	3	2
Public housing, settlement, land, and spatial planning office	4	3	1
Road users			
Community	5	4	3
Academics			
Road infrastructure	4	4	1
Transportation	3	4	1
Environmentalist	3	3	1
Sum			17

The respondent assessment questionnaire was designed using the Guttman scale to gain knowledge insights from the interviewees, with the assessment items reflecting various aspects of road sustainability. In addition, the level of road sustainability was assessed based on the Green Road Rating System instrument, as stated in the Guidelines of the Directorate General of Highways PD 02-2018 [27]. This instrument covers five main categories: environmental conservation (water, air, and nature), transportation and society, construction activities, materials and natural resources, and pavement technology. The assessment questionnaire was adjusted to field conditions and reassessed by experts participating in the Delphi process.

Data Analysis

Data analysis represented a critical stage of this study, implemented within a structured and systematic methodological framework. The complete sequence of analytical stages is shown visually in the flowchart in Figure 2, which facilitates a clear understanding of the research workflow. The methodology adopted a dual-approach design, integrating quantitative ecological data with qualitative expert assessments. The first approach focused on evaluating the ecological quality of roadside vegetation and produced a quantitative score in the form of the Shannon–Wiener Diversity Index (H’). In contrast, the second employed the Delphi Method to validate the assessment instrument and measure expert consensus. Combining these two analytical results yielded a unified metric, the green road performing score, which served as the primary reference for assessing the overall sustainability of green roads and green belts in this study.

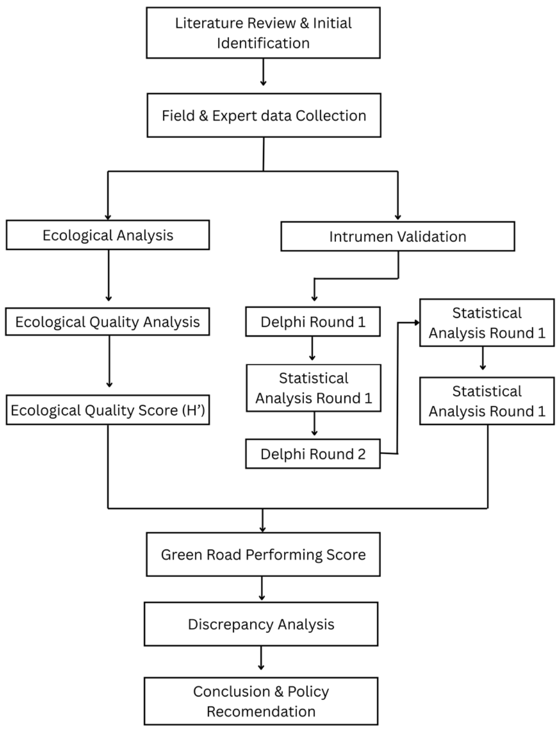

Figure 2. Analytical flowchart of the research process for evaluating green road and Green Belt sustainability. The flowchart illustrates the main stages of the research, including literature review, field and expert data collection, ecological analysis of roadside vegetation, and Delphi-based instrument validation. The outputs from these analyses are integrated to produce the green road performing score used for the final sustainability evaluation.

Vegetation data were analyzed to identify species diversity and dominance levels, spatial distribution patterns at each observation point, and the ecological functions of each species, with reference to the latest and relevant scientific literature. The main parameters used in evaluating roadside vegetation include ecological species richness, family composition, and the roles of these species. To obtain a more representative picture of the local ecosystem condition, the Shannon–Wiener Diversity Index (H') was calculated on five observation plots, because this index considers the number of species while reporting their relative abundance. Furthermore, to understand the overall structural diversity along the road corridor, the analysis was carried out by dividing biodiversity into alpha (α) components, such as local diversity, beta (β), which describes species turnover between locations, and gamma (γ), which represents total diversity at the landscape scale.

Data obtained from the Delphi Method were analyzed using IBM SPSS Statistics for Windows version 23.0. Assessment of the content validity and internal reliability of the instrument was conducted by calculating the Content Validity Index (CVI) and Cronbach's alpha. The level of agreement between experts in each Delphi round was then measured using Kendall's concordance coefficient (W), which reflects the consistency of assessments within the panel. In addition, this study examined the instrument's structural validity and internal consistency using the reproducibility coefficient (CR) and scalability coefficient (CS), which reflect the clarity of its dimensional structure and the robustness of its measurement capability.

An evaluation of the condition of road infrastructure in Sragen Regency was conducted to assess its level of compliance with the criteria established in the Green Road Rating System. After data collection was completed, analysis continued using a quantitative descriptive approach based on the results of a field survey, specifically regarding the physical aspects and environmental conditions of each road segment. The next stage involved assessing the level of implementation of the green road concept using four certification levels. This certification provides formal recognition of a road project's achievements in meeting sustainability principles. Specific criteria, threshold values, and minimum scores determine each certification level. In accordance with the PD 02-2018 guidelines, road sections that have met the technical requirements—including a life-cycle cost analysis and complete environmental documentation—can be submitted for certification. The certification level classification is determined by a score range: a score below 20.00 indicates a low category, a score between 20.01 and 44.99 indicates a medium category, and a score above 45.00 indicates the highest level. This assessment framework provides a standardized basis for evaluating the sustainability performance of road infrastructure projects [28].

To test the main hypothesis regarding the possible discrepancy between the formal assessment results and actual ecological conditions in the field, a one-sample t-test was used. This test compared the average local biodiversity value in the five observation plots (the mean H′ from Phase 1) with a predetermined ecological reference value ($\mu = 1.5$). This reference value represents the lower limit of the moderate biodiversity category, as a Shannon–Wiener index of around 1.5 is generally associated with a transition from low to moderate ecological conditions across empirical studies [29–31]. The analysis was conducted with a significance level (α) of 0.05, where a p-value smaller than this limit indicates that the observed level of biodiversity is significantly lower than the reference value.

Results and Discussion

Result

Characteristics of Existing Road Conditions

Vegetation diversity at the study site was analysed by identifying 334 individual plants, including trees, shrubs, and bushes (Table 2). The inventory results showed that the shrub group had the highest number of individuals, namely 252, followed by shrubs with 63 individuals, and trees with only 19 individuals. This composition represents the characteristics of the vegetation structure that forms in the local ecosystem. In general, the vegetation is dominated by shrubs, which account for approximately 75.4% of the total identified individuals, while bushes account for 18.9% and trees only 5.7%. Variations in the number and dominance of vegetation types at each observation point indicate differences in spatial distribution patterns, as shown in Table 2, which presents the percentage composition of vegetation along the roadside.

Based on the species removal results presented in Table 3, *Hymenocallis littoralis* (commonly known as the beach lily) of the Amaryllidaceae family was the most dominant species, with 110 individuals. The dominance of this species indicates that the environmental conditions at the research site are relatively favourable for its growth. These results are in line with the findings of Priya et al. [32], who reported that *Hymenocallis littoralis* shows high tolerance to variations in soil conditions, adapts to different light intensities, and is relatively resistant to potential negative impacts on human health and the environment.

The ecological conditions of vegetation along the roadside were quantitatively analyzed using data from five sample points. The results of the diversity analysis indicate that biodiversity along the road corridor tends to be low. The average H′ was 0.78, with a standard deviation of 0.19, indicating a low, relatively homogeneous level of diversity. The range of index values obtained was 0.50 to 1.01. This finding reflects limitations in both species richness and the level of uniformity of vegetation communities in the roadside area.

Table 2. Distribution and proportion of tree, shrub, and bush cover vegetation by roadside location in Sragen Regency. The table presents the number of trees, shrub, and bush vegetation recorded at five roadside sampling locations. It also shows the total abundance and percentage contribution of each vegetation type to the overall vegetation cover along the road corridor.

No.	Plant type	Location	Sum	Total	Percentage (%)
1.	Tree	Point I	1	19	5.7
		Point II	4		
		Point III	4		
		Point IV	5		
		Point V	5		
2.	Shrubs	Point I	16	63	18.9
		Point II	6		
		Point III	1		
		Point IV	2		
		Point V	38		
3.	Bushes	Point I	0	252	75.4
		Point II	58		
		Point III	65		
		Point IV	59		
		Point V	70		
Total vegetation				334	100

Table 3. Types, families, and ecological distribution of vegetation species observed along the Sukowati Highway, Sragen Regency. The table lists the vegetation species identified along the roadside corridor, including their common names, scientific names, and plant families. It also presents the number of individuals recorded for each species.

Plant type	Latin name		Sum
	Species name	Family	
Dogfennel	*Eupatorium capillifolium*	Casuarinaceae	16
Frangipani	*Plumeria rugba*	Apocynaceae	1
Indian mast tree	*Polyalthia longifolia*	Annonaceae	6
Beach spider lily	*Hymenocallis littoralis*	Amaryllidaceae	110
Manaca	*Brunsfelsia uniflora (pohl.) d.don*	Solanaceae	1
Golden dewdrop, skyflower	*Duranta erecta L.*	Verbenaceae	1
Jungle geranium	*Ixora coccinea L.*	Rubiaceae	1
Siamese rough bush	*Streblus alper*	Moraceae	3
Paper flower	*Bougainvillea glabra chois*	Nyctaginaceae	3
Weeping fig	*Ficus Benjamina*	Moraceae	1
Narra	*Pterocarpus indicus*	Fabaceae	2
Mexican petunia	*Ruellia simplex*	Acanthaceae	45
Chinese croton	*Excoecaria cochinchinensis*	Euphorbiaceae	9
Moses-in-the-cradle	*Tradescantia spathacea*	Commelinaceae	40
Red lip tre	*Syrgium myrtifolium*	Mytraceae	5
Spanish cherry	*Mimusops elengi*	Sapodilla	2
Fern tree	*Filicium Decipiens*	Sapindaceae	2
Java plum	*Syrgium cumini*	Mytraceae	1
Areca palm	Dypsis lutescens	Arecaceae	1
Golden trumpet tree	*Tabebuia aurea*	Apocynaceae	3
Ceylon bowstring hemp	*Sanseviera zeylanica*	Asparagaceae	14
False heater	*Cuphea hyssopifolia*	Lythraceae	2
Crape jasmine	*Tabernaemontana divaricata*	Apocynaceae	12
Cuban cigar plant	*Calathea lutea*	Marantaceae	17
Brazillian joyweed	*Alternanthera brasiliana*	Amaranthaceae	35
Canna lily	*Cannax generalis*	Cannaceae	1

Green Road Evaluation

Descriptive statistics

A descriptive analysis was employed to summarize expert responses across all sustainability indicators. The initial round of the Delphi Method was conducted on October 11, 2024, involving 17 experts who assessed 68 questionnaire items developed using the Guttman scale. Based on the results of this round, the questionnaire was refined to 33 items. The second Delphi round took place on December 18, 2024, with the participation of 15 experts who re-evaluated the refined set. Details of the revised items are presented in Table 4.

Table 4. Descriptive statistics of expert ratings obtained through the Delphi Method for green road sustainability indicators. This table presents the descriptive statistics of expert ratings for green road sustainability indicator categories obtained through a two-round Delphi process with 17 experts. The statistics include minimum and maximum values, mean scores, and standard deviations for each indicator category to illustrate the distribution of expert assessments.

Criteria	Mini I	Min II	Max I	Max II	Mean I	Mean II	SD I	SD II
KL. Categories Environmental, Water, Air and Nature Conservation	0.000	0.000	0.917	1.000	0.842	0.405	0.342	0.364
CE. Categories Transportation and Society	0.000	0.000	1.000	1.000	0.776	0.206	0.413	0.362
AK. Categories of construction implementation activities	0.000	0.000	1.000	1.000	0.838	0.683	0.356	0.478
MS. Categories of materials and natural resources	0.000	0.000	1.000	1.000	0.600	0.233	0.487	0.432
TP. Categories Pavement Technology	0.000	0.000	1.000	1.000	0.750	0.156	0.423	0.373

The descriptive analysis revealed a decline in the mean values across all categories in the second Delphi round, indicating a refinement of expert perspectives following the provision of feedback. The most notable reductions were observed in the transportation and society and pavement technology categories, which declined from 0.776 to 0.206 and from 0.75 to 0.156, respectively. These findings align with those of Hesselink et al. [33], who stated that in the Delphi Method, the decrease in mean values between rounds reflects the process of aligning opinions among the experts involved. Concerning standard deviation (SD), three categories demonstrated improved consistency in expert responses, whereas the remaining two categories exhibited greater variability in opinion. Overall, the SD values in the second round remained below 0.5, suggesting a relatively good consensus among the experts. This is consistent with the findings of Schifano and Niederberger [34], who stated that in the Delphi study, low elementary school scores indicate consistency and good agreement among the participants.

Green road assessment instrument validation results

A two-round Delphi procedure with 17 experts was conducted to evaluate the reliability of the green road sustainability instrument. Expert judgments were used to obtain a CVI, which provides an initial indication of item relevance. Consistence of expert opinion was further examined using Kendall's W, with higher values indicating greater consensus. Additionally, internal consistency was assessed using the Guttman scaling framework, in which Reproducibility (CR) and Scalability (CS) coefficients were calculated from the response structure. The combined results of the second Delphi round are reported in Table 5.

The validation results of the Delphi instrument indicate strong psychometric quality across all assessed dimensions. As measured by the scale-level content validity index (S-CVI), content validity reached a value of 0.93, surpassing the recommended threshold of 0.90 and confirming excellent validity. Reliability testing using Cronbach's alpha yielded a coefficient of 0.987, indicating a very high level of internal consistency. S-CVI assessment is recommended with a minimum S-CVI value of 0.9 to reflect the validity of the content, which can be categorized as good content validity [35–37]. Consensus analysis using Kendall's W increased from 0.158 to 0.427, with a statistically significant p-value < 0.001, reflecting a moderate but improving level of agreement among experts [38,39]. The CR showed a value of 0.915, exceeding the minimum standard of 0.90 and demonstrating excellent reproducibility, while the CS achieved a value of 0.922, well above the 0.60 benchmark, indicating strong scalability. These findings suggest that the revised instrument possesses a robust hierarchical structure and high scalability. CR and CS values above the threshold of 0.6 signify that the responses provided by experts can be regarded as both valid an reliable [40,41].

Table 5. Summary of Delphi Instrument Validation Results from Final Round Including CVI, Cronbach's Alpha, Kendall's W, CR, and CS Values. This table summarises the validation results of the green road assessment instrument from the final round of the Delphi method, which included expert evaluations. The reported statistics include the Content Validity Index (S-CVI), Cronbach's alpha for reliability, Kendall's coefficient of concordance (W) for expert consensus, and the coefficients of reproducibility (CR) and scalability (CS), indicating that the instrument meets the required validity, reliability, and scalability thresholds. All analyses were conducted based on responses from 17 experts at the $\alpha = 0.05$ significance level, and the threshold values follow commonly accepted methodological standards. Kendall's W shows a statistically significant level of agreement among experts ($p < 0.001$), although the strength of agreement is categorised as moderate.

Validation aspects	Statistical tests used	Minimum value	Coefficient value	Interpretation
Content validity	S-CVI	> 0.90	0.93	Valid
Reliability test	Alpha Cronbach	> 0.90	0.987	Reliable
Consensus analysis	Kendall's W	> 0.7 (strong)	0.427	Moderate agreement
Reproducibility	CR	> 0.90	0.915	Excellent reproducibility
Scalability	CS	> 0.60	0.922	Strong scalability

Abbreviations: S-CVI =Scale Level Content Validity Index; CR = Coefficient of Reproducibility; CS = Coefficient of Scalability.

Green road classification based on green road rating system

This assessment refers to PD 04-2018, which categorizes green road certification into four levels, ranging from one to four stars. As presented in Table 6, the assessment results for the Sragen Highway indicate varying levels of achievement across different categories. The environmental conservation (11.53) and pavement technology (10.35) categories obtained relatively high scores, whereas the transportation and community (3.91) and natural resource materials (5.58) categories showed lower performance. A total score of 39.55 places the Sragen Highway at the 3-star certification level, reflecting a moderate degree of sustainability according to the established green road standards.

Table 6. Results of the green roads assessment for the Sukowati Highway based on five sustainability categories. This table presents the results of the green roads sustainability assessment for the Sukowati Highway based on five evaluation categories, including environmental conservation, transportation and society, construction implementation activities, materials and natural resources, and pavement technology. The total scores for each category are shown to illustrate the overall sustainability performance of the highway project.

No.	Criterion	Total values
1.	Categories environmental, water, air and nature conservation	11.53
2.	Categories transportation and society	3.91
3.	Categories of construction implementation activities	8.18
4.	Categories of materials and natural resources	5.58
5.	Categories pavement technology	10.35
Total		39.55

The 3-star certification indicates that the existing green road design in the Sragen District has implemented considerable sustainable practices and achieved a beneficial impact and has the potential to advance toward extraordinary innovation [20]. According to Zhang et al. [41], sustainability rating systems award credit points in a project, improve best practices, and reduce the potential for global warming. Although some aspects of sustainability implementation may be challenging to quantify in the short term, the consistent application and documentation of these practices across comparable projects can generate critical data and evidence to inform future improvements and policy decisions.

An inferential statistical test was performed to ascertain the significance of the observed low biodiversity. A one-sample t-test benchmarked the sample mean diversity against a moderate ecological standard ($\mu = 1.5$). The outcomes of this analysis, presented in Table 7, corroborate that the mean diversity of the roadside vegetation is significantly lower than the benchmark. This finding supplies the quantitative evidence necessary for a robust green road evaluation. In addition, a multi-scale partitioning analysis was applied to examine biodiversity structure across spatial scales, with the results presented in Table 7. The analysis breaks down diversity into its local (alpha), inter-site turnover (beta), and total landscape (gamma) components. The findings show that total landscape diversity is high ($H\gamma' = 2.24$); however, this is mainly driven by elevated species turnover between sites ($H\beta' = 1.46$) rather than richness within local sampling areas.

Table 7. Statistical analysis of local and landscape vegetation diversity. This table presents the statistical analysis of vegetation diversity along the roadside of the Sukowati Highway, including descriptive statistics, hypothesis testing, and diversity partitioning metrics. The results indicate low local (alpha) diversity but high landscape (gamma) diversity driven by strong species turnover (beta), with the mean diversity significantly below the benchmark value.

Parameter	Value	Interpretation
Descriptive statistics		
Sample mean	0.78	Low local diversity
Sample standard deviation	0.19	-
Hypothesis test result		
T-statistic	–8.36	Significant below benchmark
P-value (one-tailed)	≈ 0.001	Significant* at α = 0.05
Species turnover (beta)	1.46	High species turnover
Total landscape diversity (gamma)	2.24	High landscape diversity

*The results of the one-tailed T-test compare the sample mean (n=5) with the reference hypothesis value (μ_o = 1.5) at a significance level of α = 0.05. The degrees of freedom (df) are 4.

Discussion

The central finding of this study reveals a critical discrepancy between the Sragen Highway's three-star green road certification and the actual ecological conditions of roadside vegetation. The findings indicate that, although biodiversity at the landscape scale is relatively high (Hγ′ = 2.24), a different condition is observed at the observation site level. The diversity value at the sample points is relatively low, with an average Hα′ of 0.78 ($p < 0.001$). This difference indicates that the certification results obtained do not fully reflect actual ecological conditions in the field. In several previous studies, a similar trend has been reported, in which the assessment process places greater emphasis on fulfilling design criteria than on directly measuring ecological performance [42–44]. Therefore, this gap is important to note, especially in efforts to improve the accuracy and relevance of the green infrastructure certification system to actual environmental conditions.

Vegetation along the road corridor comprises 26 species, with varying levels of abundance. Several species with important ecological functions, such as *Eupatorium capillifolium*, *Sansevieria zeylanica*, *Polyalthia longifolia*, *Ficus benjamina*, and *Syzygium myrtifolium*, play a role in absorbing vehicle pollutants (CO, CO_2, NO_2, $PM_{2.5}$, and PM_{10}) and helping reduce noise [45–47]. However, the relatively small number of individuals in these species (e.g., only 1 of *Ficus benjamina* and 6 of *Polyalthia longifolia*) means that their ecological contribution is not optimal [48,49]. At the same time, much of the vegetation is actually dominated by ornamental and ground-cover species, most notably *Hymenocallis littoralis* (110 individuals), followed by *Ruellia simplex* (45) and *Alternanthera brasiliana* (35). Although these species enhance the visual aspect of the streetscape, their role in the main ecological functions is relatively lower, thus indicating the need to rebalance planting strategies by prioritizing more functionally effective species [22,50,51].

The green road certification process was supported by a two-round Delphi assessment, which yielded a highly reliable and valid instrument (S-CVI = 0.93; Cronbach's α > 0.97). Expert consensus increased moderately but significantly (Kendall's W from 0.158 to 0.427). Despite methodological robustness, the certification process primarily rewarded the presence of sustainable practices rather than verified ecological performance [41,52,53]. Consequently, local ecological variability, particularly differences in alpha diversity, was not fully captured by the rating system. This limitation highlights the need to complement expert-based evaluations with measurable ecological indicators.

The green road rating of 39.55 (three stars) largely reflects compliance with design standards rather than measurable ecological outcomes [54,55]. High scores in the ecological conservation and pavement technology categories were supported by diverse vegetation functioning as an environmental buffer [56–58]. However, the dominance of ornamental and ground-cover species suggests that visible greening was prioritized over ecological effectiveness. From a management and policy perspective, this emphasis may lead to an overestimation of sustainability performance when certification results are interpreted as proxies for ecological quality. Strengthening rating indicators by incorporating site-scale ecological functionality and post-construction performance assessments would improve governance outcomes [59]. These findings demonstrate how ecological performance metrics can directly inform policy refinement and on-site vegetation management strategies within Green Road implementation.

The findings of this study have important implications for sustainability governance and green infrastructure planning. The observed mismatch between certification scores and local biodiversity indicates that future green road frameworks should incorporate multi-scale, verifiable ecological indicators, particularly local diversity metrics such as $H\alpha'$. Practical improvements, including increasing the proportion of functionally critical species, optimizing planting density, and developing connected green corridors, could enhance biodiversity, air quality, and noise mitigation. These measures would also improve the ecological validity of Green Road ratings. Implementing such strategies requires a shift from fragmented, low-diversity planting schemes toward functionally integrated roadside ecosystems.

One limitation of this study is the relatively small sample size (five observation plots) and the low abundance of species with important ecological functions, which limit the generalizability of the results. Therefore, the findings obtained need to be interpreted with caution, especially when used as a basis for design and policy formulation. This condition may also be one factor explaining why certification results do not fully reflect ecological conditions at the site level. Future research should expand the spatial scope of sampling, develop function-based vegetation standards, and conduct long-term monitoring of certification performance and ecological conditions. These steps are crucial to encourage the development of a more adaptive Green Road assessment system that integrates design with measurable ecological sustainability.

Conclusions

This study begins with the question of the correspondence between sustainability ranking results and actual ecological conditions in the field, using Sukowati Highway in Sragen Regency as the study site. Ecological conditions were traced through direct observation of roadside vegetation, then interpreted using a biodiversity index to characterize its biodiversity. Meanwhile, the level of road sustainability was determined using a Green Road assessment system compiled through the Delphi Method and expert input. The assessment results showed that the road section received a three-star certification with a score of 39.55, but the resulting ecological picture did not fully align with this achievement. At the landscape scale, the diversity value was high ($H\gamma'$ = 2.24), but at the observation point level, it was low (average $H\alpha'$ = 0.78). It had not reached the expected threshold, indicating limitations in ecological functions at the site scale. This discrepancy indicates that the certification results do not fully represent actual ecological conditions, especially at the local level. Given that the analysis is based on a limited number of sample points in a single road corridor, further studies are needed with wider spatial coverage, involving several road segments, and supported by long-term monitoring, to provide a stronger empirical basis for evaluating the sustainability of green roads.

Author Contributions

UA: Conceptualization, Methodology, Software, Investigation, Writing – Review and Editing; **MM:** Conceptualization, Methodology, Review & Editing; and **WA:** Conceptualization, Methodology, Review & Editing.

AI Writing Statement

During the preparation of this work, the authors used Chat-GPT (Open AI) in order to identify grammatical errors and improve readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflicts of interest

The authors declare that there is no conflict of interest in the publication of this paper.

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