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# Ecological Character Education for Sustainable Road Development: Strategies for Integrating Green Infrastructure in Indonesia

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## Abstract

*Road infrastructure development is essential for improving regional connectivity and economic growth; however, it remains dominated by conventional gray infrastructure approaches that often overlook ecological sustainability. Although sustainable infrastructure has been widely investigated, limited studies have examined how ecological character education can strengthen environmentally responsible planning among infrastructure stakeholders. This study aimed to (1) examine the educational dimensions of ecological character among stakeholders involved in road infrastructure planning, (2) identify the internal and external factors influencing ecological character development, and (3) formulate education-based strategies using SWOT analysis. A descriptive-analytical mixed-methods case study was conducted along the Kepanjen–Pagak Road Section, Malang Regency, Indonesia. Data were collected from purposively selected government officials, planning consultants, academics, infrastructure practitioners, and community representatives through interviews, field observations, questionnaires, and document analysis. Qualitative data were analyzed thematically, while quantitative data were analyzed using IFAS, EFAS, SWOT, and QSPM. The findings indicate that ecological character development is influenced by environmental literacy, stakeholder collaboration, institutional commitment, and participatory planning but remains constrained by conventional gray infrastructure practices and weak cross-sectoral coordination. The IFAS score of 2.72 and EFAS score of 2.82 positioned the study in Quadrant I, indicating strong internal capacity and favorable external opportunities to strengthen ecological character through education-oriented strategies. This study extends ecological character education beyond formal educational settings by integrating it into infrastructure governance and professional practice. It also proposes a SWOT-based framework that supports stakeholder capacity building, sustainability competency development, and environmentally responsible road infrastructure planning.*


**Keyword:** *Ecological Character Education, Green Infrastructure, Sustainable Road Construction, Environmental Management, SWOT Analysis.*

## 1. INTRODUCTION

Infrastructure actors may possess limited ecological literacy or lack the environmental knowledge and competencies required to embed ecological considerations into road development (Steiner et al., 2013; Lewinsohn et al., 2011). This educational deficit is a fundamental barrier to sustainable infrastructure, because technically sound engineering solutions cannot, by themselves, generate environmentally responsible practice unless planners, contractors, and communities also acquire the ecological knowledge, values, and sense of moral responsibility needed to act on that knowledge (Fasikhi et al., 2023).

Road infrastructure development is a fundamental component in supporting regional growth, improving connectivity between regions, and accelerating economic activity (Lau et al., 2023). However, conventional road development remains predominantly oriented toward a gray-infrastructure approach that emphasizes road capacity, traffic flow, and construction efficiency without optimal consideration of ecological dimensions, frequently reducing roadside vegetation, increasing stormwater runoff, and degrading air quality (Wemple et al., 2018). One of the most significant impacts of road construction is the loss of roadside vegetation, which fulfills critical ecological functions such as carbon absorption, air-pollutant filtering, micro-temperature regulation, and stormwater control (Säumel, et al., 2016). As global awareness of sustainable development grows, green infrastructure has emerged as a relevant approach that enables roads to function not only as transportation facilities but also as components of ecological systems.

In this study, ecological character education is defined as a deliberate and structured educational process aimed at cultivating individuals' ecological knowledge, environmental values, moral responsibility, and behavioral competence, so that environmentally responsible decisions become an internalized disposition rather than an externally imposed compliance requirement (Orr, 1992; Stern, 2000). Within infrastructure development, this educational process is not confined to formal classroom instruction; it can also occur experientially, through planners', engineers', and communities' direct engagement with ecological problems encountered during project design, construction, and monitoring. Infrastructure-planning processes that require stakeholders to decide which trees to preserve, to weigh trade-offs between construction efficiency and ecosystem services, or to negotiate environmental safeguards with community function as informal learning settings in which ecological character can be developed or, conversely, left underdeveloped (Wiek et al., 2011; Brundiers et al., 2021).

Building on this definition, the study adopts a conceptual framework linking six interrelated components of ecological character: (1) ecological knowledge, understanding of ecosystem functions and the environmental consequences of infrastructure decisions; (2) environmental values, an internalized concern for ecological wellbeing that extends beyond regulatory compliance; (3) moral responsibility, a felt obligation to protect environmental quality for present and future stakeholders; (4) participatory decision-making, the capacity and willingness to involve diverse stakeholders in environmentally relevant choices; (5) professional practice, the translation of ecological knowledge and values into planning, design, and construction routines; and (6) sustainable infrastructure behavior, the observable actions, such as vegetation preservation, adaptive design, and monitoring, that result from the preceding components (Wiek et al., 2011; Brundiers et al., 2021). This framework guided the design of the data-collection instruments and the interpretation of the SWOT findings reported in Section 3.

The educational setting examined in this study is the professional and community learning environment surrounding the Kepanjen Pagak Road Section in Malang Regency, encompassing formal government training programs, informal knowledge exchange among planning consultants and engineers, and community environmental awareness activities associated with the project. This setting was selected because road-development projects of this scale routinely place technical, administrative, and community actors in situations that demand environmentally relevant judgment, making it a suitable context in which to examine how ecological character is expressed, supported, or constrained. Despite a substantial body of research on green infrastructure, a clear gap remains in the literature. First, previous green infrastructure studies have focused predominantly on engineering and environmental-performance outcomes. Second, limited research has examined the educational values and stakeholder-learning processes involved in green road development (Schifman et al., 2017). Third, although environmental education, sustainability competencies, and green infrastructure have been examined in different contexts, limited research has explicitly integrated ecological character education with infrastructure planning within Indonesian local-government contexts. This gap is particularly evident at the intersection of environmental education, stakeholder learning, and infrastructure governance, where ecological values and competencies have yet to be systematically examined as components of infrastructure planning practice.

Accordingly, this study addresses the following research questions: (1) What are the existing conditions of green infrastructure integration, and what do these conditions reveal about stakeholders' ecological character (2) What internal and external factors influence the development of ecological character values in sustainable road-infrastructure practice (3) What education-based strategies can be formulated, through SWOT analysis, to strengthen ecological character among infrastructure stakeholders. This study contributes theoretically by extending ecological literacy and value belief norm perspectives into the domain of infrastructure-planning education; practically by translating SWOT findings into concrete stakeholder learning strategies rather than purely technical recommendations; and contextually by examining these dynamics within an Indonesian local government road-development setting that has received limited prior attention in the literature (Firmansyah, 2025).

The Kepanjen Pagak Road Section in Malang Regency represents a strategic corridor connecting central government areas, residential zones, commercial centers, and agricultural areas. Capacity-improvement works pose potential impacts on approximately 159 existing roadside trees, underscoring the need for a strategic approach that maintains transportation function without compromising ecological function. This study applies SWOT analysis to identify internal and external factors influencing green infrastructure integration and ecological character development, with the aim of formulating systematic, applicable, and educationally grounded strategies for sustainable road development.

## 2. METHODS

This study employed a descriptive-analytical design using an integrated qualitative and quantitative approach to examine the integration of green infrastructure and the development of ecological character in road infrastructure planning. The study was conducted along the Kepanjen–Pagak Road Section in Malang Regency, East Java, Indonesia. The study area was selected because the corridor is undergoing infrastructure improvement and contains important ecological components, particularly roadside vegetation, drainage systems, green open spaces, and adjacent land uses that are relevant to sustainable road development. Field data were collected throughout 2026 to assess existing environmental conditions and the institutional and stakeholder factors influencing green infrastructure integration.

The descriptive-analytical approach was used to describe and interpret the physical, environmental, institutional, and stakeholder conditions of the road corridor. The quantitative component was subsequently used to identify and evaluate internal and external strategic factors through the Internal Factor Analysis Summary (IFAS) and External Factor Analysis Summary (EFAS), followed by SWOT analysis to determine the strategic position and formulate alternative strategies.

The study used both primary and secondary data. Primary data were obtained through field observations, semi-structured interviews, and structured questionnaires. Secondary data were obtained from government regulations, planning documents, technical reports, statistical publications, and relevant scientific literature. Participants were selected purposively based on their direct involvement, professional expertise, or local knowledge related to road infrastructure planning, environmental management, and green infrastructure. The stakeholder groups included officials from the Public Works and Spatial Planning Agency (DPUBM), officials from the Regional Development Planning Agency (Bappeda), planning consultants, infrastructure practitioners, academics specializing in transportation and environmental planning, and community representatives residing along the Kepanjen–Pagak Road Section.

Semi-structured interviews were used to obtain information concerning existing development policies, institutional coordination, implementation constraints, environmental considerations, and opportunities for integrating green infrastructure. The questionnaire was used to obtain stakeholder assessments of the internal and external factors identified through the preliminary investigation. The questionnaire employed a four-point Likert scale ranging from 1 (*very weak*) to 4 (*very strong*).

Data collection consisted of five complementary activities: literature review, field observation, semi-structured interviews, structured questionnaire surveys, and document analysis. Field observations documented roadside vegetation, drainage conditions, green open spaces, adjacent land use, and other environmental characteristics of the corridor. The observations were supported by direct measurements, field notes, and photographic documentation. Interviews were then conducted with key stakeholders to explore institutional arrangements, environmental awareness, coordination among agencies, implementation constraints, and opportunities for sustainable infrastructure development. Questionnaire data were collected to assess the relative importance and current condition of the strategic factors influencing green infrastructure integration. Documentary data were used to examine relevant regulations, planning policies, technical documents, and institutional arrangements.

The different data sources were triangulated to compare information obtained from field observations, stakeholder interviews, questionnaire responses, and documentary sources before the strategic factors and recommendations were finalized.

The structured questionnaire was developed from the strategic factors identified through the literature review, field observations, documentary analysis, and stakeholder interviews. The instrument was designed to assess the internal and external factors subsequently included in the IFAS and EFAS matrices. Before administration, the questionnaire underwent expert review to assess the relevance, clarity, and adequacy of the items. The study also assessed the validity and reliability of the instrument before its use in the main data collection.

Because the available research records do not report the numerical results of the validity and reliability tests, no coefficient is reported here without verification from the original statistical output. The final questionnaire was used to obtain the factor ratings and weights required for the IFAS and EFAS analyses. The resulting matrices formed the quantitative basis for the subsequent SWOT analysis.

The strategic analysis followed three sequential stages. First, internal factors representing strengths and weaknesses and external factors representing opportunities and threats were identified from the integrated findings of observations, interviews, questionnaires, and documentary analysis. Second, each factor was assigned a weight according to its relative importance and a rating representing its current condition. The weighted score was calculated by multiplying the weight by the corresponding rating. The resulting scores were aggregated into the IFAS and EFAS matrices. Third, the total IFAS and EFAS scores were used to determine the strategic position of green infrastructure integration within the SWOT Cartesian matrix. The analysis produced an IFAS score of 2.72 and an EFAS score of 2.82, which positioned the study in Quadrant I. The resulting position was subsequently used to formulate SO, ST, WO, and WT strategic alternatives.

To further assess the strategic alternatives generated through SWOT, the study employed the Quantitative Strategic Planning Matrix (QSPM) as a quantitative cross-check. The weights of the internal and external factors were retained from the IFAS and EFAS matrices. Each strategic alternative was assessed using an Attractiveness Score (AS) ranging from 1 to 4, and the resulting Total Attractiveness Score (TAS) was calculated by multiplying the factor weight by its corresponding AS and summing the resulting values across factors.

The QSPM procedure used in this study represents a **simplified, first-order validation** based on the existing empirical data rather than a full independent expert-panel elicitation of attractiveness scores. The resulting TAS values were used to rank the four strategic alternatives and to cross-check the strategic position obtained from the SWOT analysis. The SO strategy obtained the highest TAS of 4.74, followed by ST (3.82), WO (3.72), and WT (2.80).

The study complied with applicable ethical research principles. Before data collection, all interview and questionnaire participants were informed about the purpose and procedures of the study, the voluntary nature of participation, confidentiality of their responses, and their right to withdraw from the study. Written informed consent was obtained from participants before their participation.

## 3. RESULTS AND DISCUSSION

### 3.1. Existing Conditions of Green Infrastructure Implementation

The findings indicate that the implementation of green infrastructure along the Kepanjen–Pagak Road Section remains fragmented and has not yet been systematically integrated into road infrastructure planning and implementation. Although the corridor contains approximately 159 roadside trees that provide essential ecosystem services including carbon sequestration, air-quality improvement, microclimate regulation, stormwater retention, biodiversity conservation, and landscape enhancement these ecological assets are not consistently recognized as strategic components of transportation infrastructure. Instead, field observations revealed that roadside vegetation is frequently treated as a physical obstacle to road capacity expansion, resulting in tree removal, root-system disturbance caused by drainage excavation, canopy pruning, and insufficient protection during construction activities(Hohmann et al., 2025). These findings suggest that ecological considerations remain secondary to engineering priorities, limiting the capacity of infrastructure projects to simultaneously achieve transportation and environmental objectives.

The dominance of conventional gray infrastructure further reinforces this condition. Road development continues to prioritize engineering efficiency, traffic capacity, and construction feasibility, whereas ecological functions receive comparatively limited consideration during planning and implementation. This orientation is reflected in the extensive use of concrete-based drainage systems designed primarily to accelerate surface water discharge rather than to enhance infiltration, groundwater recharge, and ecosystem resilience through nature-based solutions. Consequently, opportunities to integrate green infrastructure into road design remain underutilized despite growing international recognition of ecosystem-based infrastructure as an essential strategy for climate adaptation and sustainable urban development.

These findings support the argument that sustainable infrastructure challenges cannot be explained solely by technical limitations but must also be understood from an educational perspective. Orr (1992) argues that many environmental problems originate from deficiencies in ecological literacy rather than from the absence of technological capability. Likewise, Stern's (2000) Value Belief Norm theory explains that environmentally responsible behavior emerges when ecological knowledge is transformed into internalized environmental values and moral responsibility(Yilmaz et al., 2025). In the present study, the limited integration of green infrastructure indicates that ecological knowledge has not yet been consistently translated into professional planning practices or organizational decision making. Technical competence alone appears insufficient to promote environmentally responsible infrastructure development when ecological values are not embedded within institutional culture and stakeholder behavior.

Institutional evidence further demonstrates that ecological character has not yet become an integral element of infrastructure governance. Interviews with stakeholders revealed limited coordination among agencies responsible for public works, environmental management, and regional planning, with environmental considerations frequently introduced only after engineering designs and budget allocations had already been finalized. Such fragmented decision-making constrains interdisciplinary collaboration and reduces opportunities to incorporate ecological objectives into the early stages of infrastructure planning. These findings are consistent with previous studies emphasizing that the successful implementation of green infrastructure depends not only on engineering innovation but also on collaborative governance, stakeholder participation, and shared environmental responsibility (Cardinale, 2023).

From the perspective of ecological character education, the findings reveal that the principal challenge extends beyond physical infrastructure toward the development of stakeholders' ecological competencies (Manso et al., 2021). Ecological knowledge, environmental values, moral responsibility, participatory decision-making, and environmentally responsible professional practice have not yet been fully institutionalized within planning processes. As a result, infrastructure decisions continue to emphasize short-term engineering performance over long-term ecosystem sustainability (Chapa et al., 2020). This finding demonstrates that ecological character should be understood as a professional competency that influences how planners, engineers, government officials, and communities evaluate environmental consequences, negotiate development priorities, and integrate sustainability principles into infrastructure projects.

Unlike previous studies that have primarily evaluated green infrastructure from engineering, environmental, or policy perspectives, this study demonstrates that the effectiveness of green infrastructure implementation is also determined by educational factors. By positioning ecological character education as a foundational element of sustainable infrastructure planning, the study extends ecological literacy and Value Belief Norm perspectives into the field of infrastructure governance. The findings therefore suggest that strengthening ecological literacy, cultivating environmental values, promoting interdisciplinary learning, and institutionalizing stakeholder capacity-building programs are essential strategies for transforming conventional gray infrastructure practices into environmentally responsible and socially sustainable infrastructure systems.

**Table 1.** Existing Conditions of Green Infrastructure Integration on Kepanjen Pagak Road Section

| No. | Aspect | Existing Condition | Environmental Impact |
|---|---|---|---|
| 1 | Roadside Vegetation | ±159 existing trees affected by road widening activities | Reduced ecological services; loss of carbon sequestration, temperature regulation, and stormwater control functions |
| 2 | Drainage System | Dominated by conventional concrete drainage without infiltration features | Increased surface runoff, reduced groundwater recharge, elevated flood risk |
| 3 | Road Design | Conventional engineering approach focused on capacity and efficiency | Limited environmental adaptation; absence of green design elements |
| 4 | Institutional Support | Weak inter-agency coordination; environmental aspects treated as secondary | Low policy integration; insufficient environmental safeguards during construction |
| 5 | Public Awareness | Moderate environmental awareness among local communities | Limited public participation in environmental protection advocacy |

Table 1 summarizes the existing conditions of green infrastructure integration along the Kepanjen Pagak Road Section based on field observations, document analysis, and stakeholder interviews. The findings indicate that green infrastructure has not yet been comprehensively integrated into road planning and implementation. Instead, the development process remains largely oriented toward conventional gray infrastructure, prioritizing transportation efficiency and engineering performance over ecological sustainability. Regarding roadside vegetation, approximately 159 trees were identified within the road widening corridor, many of which were affected by construction activities. Existing vegetation has not been systematically incorporated into the road design despite its important ecological functions. The reduction of roadside trees has contributed to the loss of ecosystem services, including carbon sequestration, microclimate regulation through shading, biodiversity support, and stormwater interception.

The drainage system is predominantly composed of conventional concrete channels designed to rapidly convey surface runoff. No significant application of green drainage components, such as bioswales, infiltration trenches, rain gardens, or permeable pavement, was observed. Consequently, rainfall is discharged directly into drainage networks, reducing groundwater recharge while increasing surface runoff and the potential for localized flooding during periods of intense precipitation. In terms of road design, the project primarily follows conventional engineering principles emphasizing traffic capacity, geometric standards, and structural durability. Ecological considerations, including landscape connectivity, habitat preservation, and climate adaptation measures, remain relatively limited. As a result, opportunities to integrate green infrastructure elements that could improve environmental resilience have not been fully utilized.

Institutional assessment further revealed that coordination among agencies responsible for transportation, environmental management, and spatial planning remains insufficient. Although environmental regulations exist, their implementation during planning and construction has not been fully synchronized across institutions (Reinwald et al., 2024). This fragmented governance limits the effectiveness of environmental safeguards and constrains the broader adoption of green infrastructure principles. Public awareness of environmental conservation was found to be moderate. While many local residents recognize the importance of roadside vegetation for providing shade and improving environmental quality, community participation in environmental planning, monitoring, and conservation activities remains limited. Strengthening public engagement through participatory planning and environmental education could therefore enhance support for sustainable infrastructure development (Walther et al., 2025). Overall, these findings demonstrate that the integration of green infrastructure along the Kepanjen Pagak Road Section remains partial and fragmented. Existing roadside vegetation, drainage systems, institutional arrangements, and community participation have not yet been integrated into a comprehensive ecological framework(Sari et al., 2025). Consequently, the current road development approach continues to rely predominantly on gray infrastructure, resulting in reduced ecological functions and limiting the long-term sustainability of transportation infrastructure.

### 3.2. Identification of Internal and External Strategic Factors

The findings reveal that the implementation of green infrastructure integration along the Kepanjen Pagak Road Section is influenced by a combination of internal strengths and weaknesses as well as external opportunities and threats. The SWOT analysis indicates that the road corridor possesses considerable internal strengths that can support the transition toward more environmentally sustainable infrastructure development (Radionova et al., 2023). One of the principal strengths is the presence of existing roadside vegetation, which continues to provide essential ecosystem services despite the impacts of road widening. Field observations identified mature roadside trees that contribute to carbon sequestration, microclimate regulation through shading, stormwater interception, air pollution reduction, and habitat provision for urban biodiversity. These findings are consistent with the ecosystem services framework proposed by the Millennium Ecosystem Assessment (2005), which emphasizes that natural ecosystems deliver regulating, provisioning, supporting, and cultural services essential for human well-being. In the context of transportation infrastructure, roadside vegetation functions as natural capital capable of enhancing environmental quality while improving the resilience of road ecosystems (Hadiyati & Fatkhurahman, 2024).

Another important strength is the strategic role of the Kepanjen Pagak Road Section in supporting regional connectivity and economic development. As one of the main transportation corridors, the road accommodates significant mobility of people and goods, making it an appropriate location for implementing sustainable infrastructure innovations. Rather than viewing economic development and environmental conservation as competing objectives, the findings suggest that both can be integrated through green infrastructure planning. This perspective aligns with the principles of sustainable development introduced by the Brundtland Commission (1987), which advocates balancing economic growth, environmental protection, and social well-being to ensure that present development does not compromise the needs of future generations. The findings further demonstrate that existing policy directions provide an enabling institutional environment for green infrastructure implementation (Prabowo et al., 2025). National and regional planning documents increasingly promote environmentally responsible infrastructure development, climate adaptation, and ecosystem conservation. However, field evidence suggests that these policy commitments have not yet been consistently translated into engineering practice. This implementation gap reflects the governance challenges frequently discussed in sustainable infrastructure literature, where effective environmental management depends not only on regulatory frameworks but also on institutional coordination, policy integration, and implementation capacity.

Stakeholder interviews also revealed growing environmental awareness among government agencies, infrastructure practitioners, academics, and local communities. Respondents generally acknowledged the ecological importance of preserving roadside vegetation and incorporating environmentally adaptive design into future road projects. According to the Theory of Planned Behavior developed by Ajzen (1991), environmental awareness and positive attitudes toward conservation can strengthen behavioral intentions to support sustainable development (Dermawan et al., 2023). Nevertheless, awareness alone is insufficient to generate meaningful environmental outcomes without institutional support, technical capacity, and participatory decision-making mechanisms.

Field observations additionally indicate that the existing road corridor still offers considerable opportunities for adaptive green infrastructure interventions. Several sections possess adequate spatial conditions for integrating bioswales, infiltration trenches, permeable pavements, rain gardens, and additional roadside vegetation without substantially affecting road functionality. These findings support the concept of Nature-Based Solutions (NBS) proposed by the International Union for Conservation of Nature (IUCN), which emphasizes the use of natural processes and ecosystem functions to address societal challenges, including flood mitigation, climate adaptation, biodiversity conservation, and sustainable urban development (Silvério et al., 2025). Green infrastructure, as a practical application of Nature-Based Solutions, enables transportation systems to perform engineering functions while simultaneously delivering long-term ecological benefits.

Overall, these findings suggest that the primary challenge is not the absence of ecological potential but the limited integration of ecological principles into infrastructure planning and implementation. Existing vegetation resources, supportive policy frameworks, increasing stakeholder awareness, and opportunities for adaptive road design collectively provide a strong foundation for mainstreaming green infrastructure within future road development projects. Strengthening institutional coordination, incorporating ecological criteria into engineering design standards, and expanding stakeholder participation are therefore essential to transforming conventional gray infrastructure into resilient and sustainable transportation systems.

**Table 2.** Internal Strength Factors for Green Infrastructure Integration

| No. | Strength Factors |
|---|---|
| S1 | Availability of existing roadside trees providing active ecological services |
| S2 | Strategic road function supporting regional economic development |
| S3 | Supportive policy direction toward sustainable infrastructure development |
| S4 | Increasing environmental awareness among local government and practitioners |
| S5 | Potential for environmentally adaptive and ecologically sensitive road design |

The internal strengths identified in the integration of green infrastructure indicate that the Kepanjen–Pagak Road Section has several existing assets that can support more environmentally responsible road development. The availability of existing roadside trees provides ecological services that can contribute to environmental quality, while the strategic function of the road supports regional economic development and strengthens the importance of sustainable infrastructure planning. In addition, the supportive policy direction toward sustainable infrastructure provides an institutional foundation for integrating ecological considerations into road development. Increasing environmental awareness among local government officials and practitioners further strengthens the capacity to incorporate environmental considerations into decision-making. Finally, the potential for environmentally adaptive and ecologically sensitive road design creates an opportunity to translate these existing strengths into practical infrastructure solutions that balance transportation functions with ecological needs.

**Table 3.** Internal Weakness Factors for Green Infrastructure Integration

| No. | Weakness Factors |
|---|---|
| **W1** | Dominance of gray infrastructure approach in road planning and design |
| **W2** | Limited budget allocation for green infrastructure implementation |
| **W3** | Weak inter-agency coordination in integrated environmental management |
| **W4** | Lack of technical preservation guidelines for existing roadside vegetation |
| **W5** | Low integration of environmental considerations in road planning process |

Weaknesses, despite existing strengths, several weaknesses constrain effective implementation, including: (1) dominance of conventional gray infrastructure planning approaches; (2) limited budget allocation for green infrastructure components; (3) weak institutional coordination among relevant agencies; (4) insufficient technical guidelines for existing vegetation preservation during construction; and (5) low integration of environmental considerations in the planning process (Colle et al., 2023).

**Table 4.** External Opportunity Factors for Green Infrastructure Integration

| No. | Opportunity Factors |
|---|---|
| O1 | National policy support for sustainable development and green infrastructure |
| O2 | Growing implementation of SDGs principles in infrastructure planning |
| O3 | Technological advancement in green infrastructure and sustainable drainage |
| O4 | Increasing public environmental awareness and community advocacy |
| O5 | Academic and institutional research support for evidence-based planning |

Opportunities, significant external opportunities supporting green infrastructure integration include: (1) national commitment toward sustainable development through SDG implementation and green infrastructure policies; (2) technological advancements in sustainable drainage systems and ecosystem-based infrastructure planning; (3) growing public awareness regarding environmental quality and climate resilience; (4) support from academic institutions and environmental research communities; and (5) availability of international funding mechanisms for green infrastructure investment (Cohen-Shacham et al., 2019; European (Rahmalia et al., 2023).

**Table 5.** External Threat Factors for Green Infrastructure Integration

| No. | Threat Factors |
|---|---|
| T1 | Limited funding availability for environmental components in road projects |
| T2 | Policy inconsistency and changes in development priorities |
| T3 | Economic pressure for rapid infrastructure development |
| T4 | Stakeholder conflicts of interest and land-use pressure |
| T5 | Climate change impacts increasing environmental vulnerability |

Threats, key external threats include: (1) budget limitations prioritizing short-term construction efficiency over long-term environmental sustainability; (2) policy inconsistency and development priority changes weakening implementation continuity; (3)

economic pressure for rapid infrastructure expansion; (4) conflicts of interest among stakeholders and land-use pressure along the corridor; and (5) climate change impacts including increased rainfall intensity and temperature rise, further intensifying environmental vulnerability (Iskandar et al., 2022).

### 3.3. IFAS and EFAS Matrix Analysis

The IFAS matrix analysis (Table 8) indicates that the implementation of green infrastructure along the Kepanjen Pagak Road Section is supported by relatively strong internal conditions, as reflected by a total IFAS score of 2.72. This result suggests that the study area possesses sufficient internal capacity to support the integration of ecological principles into future road development initiatives. Among the identified strengths, the availability of existing roadside vegetation and increasing policy support for sustainable infrastructure received the highest weighted scores, demonstrating their strategic importance in facilitating green infrastructure implementation. Field observations confirmed that roadside trees continue to provide multiple ecosystem services, including carbon sequestration, microclimate regulation, stormwater interception, air quality improvement, and habitat connectivity. In addition, stakeholder interviews revealed growing institutional commitment to incorporating environmental considerations into transportation planning and infrastructure development (Dhari, 2021).

Conversely, weak inter-agency coordination and limited financial allocation were identified as the principal internal weaknesses. These constraints primarily affect planning synchronization, implementation efficiency, long-term maintenance, and monitoring of green infrastructure components. Nevertheless, the cumulative strength score substantially exceeds the identified weaknesses, indicating that existing institutional and ecological resources provide a favorable basis for implementing sustainable road development strategies (Hidayanti et al., 2023). These findings demonstrate that the successful integration of green infrastructure depends not only on the availability of ecological assets but also on institutional capacity to manage and optimize those assets effectively. This interpretation is consistent with the concept of Green Infrastructure proposed by Benedict and McMahon (2006), who describe green infrastructure as an interconnected ecological network that preserves ecosystem functions while simultaneously supporting economic development and community well-being. From this perspective, existing roadside vegetation should be regarded as strategic ecological infrastructure rather than merely aesthetic landscape elements (Suryatman et al., 2021).

Furthermore, the findings support the Ecosystem Services Framework developed by the Millennium Ecosystem Assessment (2005), which emphasizes that natural ecosystems generate regulating, supporting, provisioning, and cultural services that contribute directly to environmental sustainability and human welfare. The ecological functions identified during field observations including stormwater regulation, carbon sequestration, and temperature moderation represent regulating ecosystem services that enhance the environmental performance and climate resilience of transportation infrastructure (Firnanda et al., 2024). The relatively high IFAS score also reflects increasing institutional readiness to adopt sustainable infrastructure practices. This finding aligns with the principles of Sustainable Development introduced by the World Commission on Environment and Development (WCED, 1987), which emphasize the integration of economic development, environmental protection, and social well-being within infrastructure planning. The presence of supportive policy frameworks and growing stakeholder awareness indicates that the transition from conventional gray infrastructure toward green infrastructure is becoming increasingly feasible. However, strengthening institutional coordination and ensuring adequate financial investment remain essential to fully realize the ecological and socio-economic benefits of green infrastructure implementation (Allo et al., 2024).

Overall, the IFAS analysis demonstrates that the Kepanjen Pagak Road Section possesses substantial internal strengths that outweigh existing weaknesses. These conditions provide a solid strategic foundation for mainstreaming green infrastructure into future road development through ecosystem-based planning, stronger institutional collaboration, and adaptive engineering practices capable of improving both environmental quality and transportation performance.

**Table 6.** IFAS (Internal Factor Analysis Summary) Matrix

| Internal Factors | Weight | Rating | Score |
|---|---|---|---|
| STRENGTHS | | | |
| S1: Availability of existing roadside trees | 0.15 | 4 | 0.60 |
| S2: Strategic road function for regional development | 0.10 | 3 | 0.30 |
| S3: Sustainable infrastructure policy support | 0.12 | 4 | 0.48 |
| S4: Environmental awareness improvement | 0.08 | 3 | 0.24 |
| S5: Potential for adaptive road design | 0.10 | 3 | 0.30 |
| WEAKNESSES | | | |
| W1: Dominance of gray infrastructure approach | 0.12 | 2 | 0.24 |
| W2: Limited budget allocation | 0.10 | 2 | 0.20 |
| W3: Weak institutional coordination | 0.10 | 1 | 0.10 |
| W4: Lack of technical preservation guidelines | 0.08 | 2 | 0.16 |
| W5: Low environmental integration in planning | 0.05 | 2 | 0.10 |
| TOTAL IFAS SCORE | 1.00 | | 2.72 |

EFAS Matrix Analysis, The EFAS matrix analysis (Table 9) indicates that national sustainability policy support and green infrastructure technology development represent the most influential opportunities. Budget constraints and policy inconsistency constitute the major external threats. The total EFAS score of 2.82 demonstrates that external opportunities are relatively favorable and can be leveraged to strengthen strategic environmental management in road development(Prabowo et al., 2025).

**Table 7.** EFAS (External Factor Analysis Summary) Matrix

| External Factors | Weight | Rating | Score |
|---|---|---|---|
| OPPORTUNITIES | | | |
| O1: National sustainability policy support | 0.15 | 4 | 0.60 |
| O2: SDGs implementation support | 0.10 | 3 | 0.30 |
| O3: Green infrastructure technology development | 0.12 | 4 | 0.48 |
| O4: Increasing public environmental awareness | 0.08 | 3 | 0.24 |
| O5: Academic and institutional research support | 0.10 | 3 | 0.30 |
| THREATS | | | |
| T1: Limited funding availability | 0.15 | 2 | 0.30 |
| T2: Policy inconsistency and priority changes | 0.10 | 2 | 0.20 |
| T3: Economic pressure for rapid development | 0.08 | 2 | 0.16 |
| T4: Stakeholder conflict of interest | 0.07 | 2 | 0.14 |
| T5: Climate change and environmental vulnerability | 0.05 | 2 | 0.10 |

| | | |
|---|---|---|
| TOTAL EFAS SCORE | 1.00 | 2.82 |

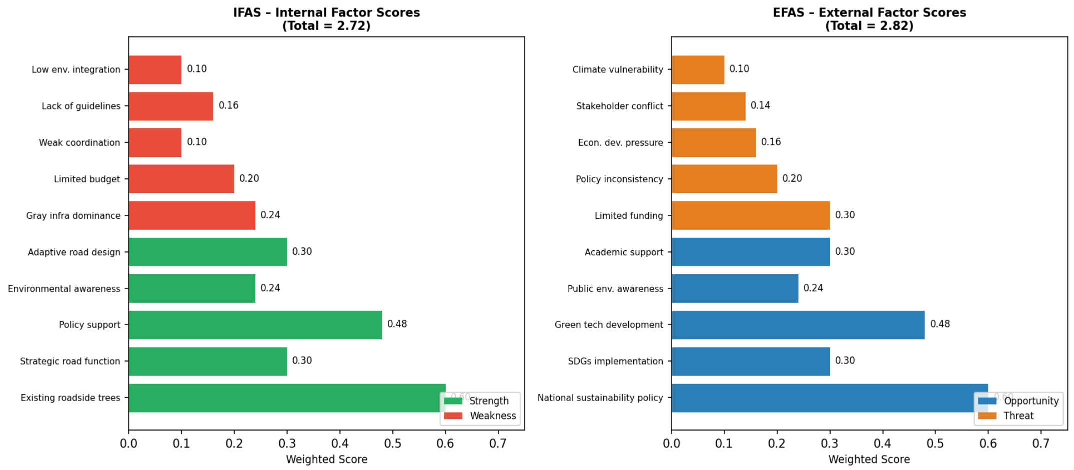


**Figure 1.** IFAS and EFAS Weighted Score Distribution by Strategic Factor

The strategic position of green infrastructure integration was determined using the total IFAS and EFAS scores. The internal coordinate was calculated as X = S − W = 1.92 − 0.80 = 1.12, while the external coordinate was calculated as Y = O − T = 1.92 − 0.90 = 1.02. Thus, the SWOT coordinates were (1.12, 1.02), placing the study in Quadrant I (Aggressive Strategy). This position indicates strong internal capacity and favorable external opportunities, supporting proactive strategies for integrating green infrastructure into road development (Rindiani & Ali, 2025). Quadrant I strategy emphasizes optimization of strengths to maximize available opportunities, meaning that existing roadside vegetation, policy support, and strategic road functions should be fully leveraged to advance sustainable road development.

**Table 8.** SWOT Strategic Position Summary

| Indicator | Score |
|---|---|
| Total Strength Score (S) | 1.92 |
| Total Weakness Score (W) | 0.80 |
| Total Opportunity Score (O) | 1.92 |
| Total Threat Score (T) | 0.90 |
| Internal Coordinate (X = S – W) | +1.12 |
| External Coordinate (Y = O – T) | +1.02 |
| Strategic Position | QUADRANT I (Aggressive Strategy) |

### 3.4. SWOT Matrix Strategy Formulation

The SWOT analysis generated four strategic alternatives for enhancing green infrastructure integration along the Kepanjen Pagak Road Section, namely Strength Opportunity (SO), Weakness Opportunity (WO), Strength Threat (ST), and Weakness Threat (WT) strategies. The interaction between internal and external factors positioned the study in Quadrant I, indicating that the cumulative strengths exceed the identified weaknesses while external opportunities outweigh potential threats. This strategic position demonstrates that the road corridor possesses favorable environmental, institutional, and policy conditions for advancing green infrastructure implementation through a proactive development approach (Arraya & Triono, 2026). The Quadrant I position is primarily supported by several dominant internal strengths identified during field observations, stakeholder interviews, and document analysis. Existing roadside vegetation continues to provide valuable ecological functions, including carbon sequestration, microclimate regulation, stormwater interception, and landscape connectivity. In addition, the Kepanjen Pagak Road Section serves as a strategic transportation corridor that supports regional accessibility and economic development, thereby creating substantial opportunities to integrate ecological considerations into future infrastructure improvement programs. Institutional commitment toward sustainable infrastructure has also strengthened through national and regional policy directions that increasingly emphasize environmental protection, climate resilience, and ecosystem conservation (Hariyadi, 2020). Furthermore, interviews with government representatives, academics, infrastructure practitioners, and local communities indicate growing awareness of the importance of incorporating ecological principles into road development planning.

The analysis also demonstrates that external opportunities substantially exceed existing threats. Advances in environmentally adaptive engineering practices, increasing policy support for sustainable infrastructure, wider recognition of climate change adaptation, and the availability of nature based planning approaches provide favorable conditions for accelerating green infrastructure implementation. Although challenges remain, including conventional engineering practices, limited institutional coordination, and budgetary constraints, these factors do not outweigh the considerable opportunities available for transforming the existing road corridor into a more environmentally resilient transportation system. Among the four strategic alternatives, the Strength Opportunity (SO) strategy emerged as the highest priority for future development. This finding indicates that the most effective approach is not merely to overcome existing weaknesses but to maximize the ecological, institutional, and policy strengths already available. Rather than relying exclusively on conventional gray infrastructure, road development should capitalize on existing environmental assets as the foundation for sustainable infrastructure planning (Amelia et al., 2022).

Priority SO strategies include preserving existing roadside trees during future road improvement projects, integrating green infrastructure components such as bioswales, infiltration trenches, rain gardens, permeable pavements, and additional roadside vegetation into road design, strengthening inter-agency coordination among transportation, environmental, and spatial planning institutions, and translating environmental policy commitments into measurable technical design standards (Dokyi, 2025). These strategic actions are expected to improve ecosystem resilience, reduce surface runoff, enhance biodiversity conservation, strengthen climate adaptation capacity, and maintain transportation performance simultaneously. These findings demonstrate that successful green infrastructure implementation depends not only on engineering innovation but also on the effective integration of ecological resources, institutional governance, stakeholder participation, and supportive policy frameworks (Ikhwan et al., 2025). The results therefore suggest a gradual transition from conventional gray infrastructure toward an ecosystem-based infrastructure model in which environmental sustainability becomes an integral component of transportation planning rather than a complementary consideration. Such an approach is expected to increase the long-term resilience, environmental performance, and sustainability of road infrastructure while simultaneously supporting regional socio-economic development.

**Table 9.** SO Strategy (Strength Opportunity)

| No. | SO Strategies |
|---|---|
| SO1 | Preserve and integrate existing roadside trees as primary green infrastructure assets in all road design phases |
| SO2 | Develop and implement environmentally adaptive road design standards incorporating ecological corridor principles |

| | |
|---|---|
| SO3 | Strengthen sustainable infrastructure policy implementation through binding technical regulations and enforcement mechanisms |
| SO4 | Utilize green infrastructure technology for sustainable drainage and integrated vegetation management systems |
| SO5 | Develop collaborative planning frameworks with academic institutions for evidence-based green infrastructure implementation |

WO Strategy (Weakness Opportunity), WO strategies minimize weaknesses by leveraging available opportunities. Institutional coordination weaknesses can be addressed through policy integration and multi-stakeholder collaboration, while limited technical guidelines can be supplemented through research-based planning support and sustainable infrastructure standards.

**Table 10.** WO Strategy (Weakness Opportunity)

| No. | WO Strategies |
|---|---|
| WO1 | Establish formal inter-agency coordination mechanisms integrating environmental considerations in road planning processes |
| WO2 | Develop comprehensive technical guidelines for existing vegetation preservation during road construction activities |
| WO3 | Increase dedicated environmental budgeting allocation in road development projects proportional to construction costs |
| WO4 | Implement capacity building programs for infrastructure planners on green infrastructure concepts and applications |
| WO5 | Integrate environmental performance indicators as mandatory criteria in road planning and evaluation systems |

Strategy (Strength–Threat), ST strategies leverage internal strengths to reduce external threat impacts. Existing ecological assets and policy support should be deployed to mitigate risks from climate change, policy inconsistency, and rapid development pressure (Hakim, 2020).

**Table 11.** ST Strategy (Strength Threat)

| No. | ST Strategies |
|---|---|
| ST1 | Establish legal protection mechanisms for existing roadside vegetation through regional regulations and environmental decrees |
| ST2 | Apply climate-resilient road planning principles incorporating projected climate change scenarios in design standards |
| ST3 | Develop long-term environmental monitoring systems for roadside vegetation health and ecological performance evaluation |
| ST4 | Promote sustainable investment models combining public funding with private sector and CSR mechanisms for green infrastructure |
| ST5 | Strengthen community participation mechanisms in environmental monitoring and vegetation protection programs |

**Table 12.** WT Strategy (Weakness–Threat)

| No. | WT Strategies |
|---|---|
| WT1 | Strengthen institutional coordination mechanisms among transportation, environmental, and spatial planning agencies to reduce fragmented implementation and prevent conflicts in green infrastructure development. |
| WT2 | Develop cost-efficient green infrastructure implementation schemes by prioritizing low-cost and high-impact interventions that can be integrated into existing road improvement programs under limited budget conditions. |

| | |
|---|---|
| WT3 | Establish clear technical guidelines and standard operating procedures for vegetation preservation, green infrastructure installation, and environmental safeguards to reduce implementation uncertainty and minimize ecological risks. |
| WT4 | Develop participatory conflict-prevention mechanisms involving government agencies, infrastructure practitioners, and local communities to address potential conflicts related to land use, vegetation removal, construction impacts, and environmental protection. |
| WT5 | Implement phased environmental monitoring and risk-management programs to identify ecological impacts at an early stage and enable corrective action while minimizing financial, institutional, and implementation risks. |

WT Strategy (Weakness–Threat), WT strategies are defensive approaches aimed at minimizing weaknesses while avoiding threats, focusing on institutional strengthening, budget efficiency, and conflict prevention to reduce implementation risks(SUVOROVA et al., 2024).

### 3.5. SWOT Validation Using the Quantitative Strategic Planning Matrix (QSPM)

To address the potential subjectivity inherent in a single SWOT/IFAS–EFAS analysis, this study additionally applied the Quantitative Strategic Planning Matrix (QSPM) as an indicative quantitative cross-check of the four strategic alternatives generated from the SWOT analysis, namely SO, WO, ST, and WT strategies. QSPM evaluates each strategic alternative by multiplying the weight of each key internal and external factor, retained from the IFAS and EFAS matrices in Tables 8 and 9, by an Attractiveness Score (AS) ranging from 1 (not attractive) to 4 (highly attractive). The resulting products are summed to obtain a Total Attractiveness Score (TAS) for each strategic alternative, with higher TAS values indicating greater relative strategic attractiveness. In this study, however, the AS values were not independently elicited from a separate expert panel; for relevant factors, they were derived from the empirical ratings used in the IFAS and EFAS analysis. Consequently, the resulting QSPM should be interpreted as an **indicative prioritization and cross-check of the SWOT results rather than as an independent validation**. This procedure provides a first-order indication of the relative priority of the four strategic alternatives while retaining the limitations associated with the reuse of the underlying IFAS/EFAS ratings. A full QSPM assessment based on independently elicited Attractiveness Scores from a qualified expert panel is recommended for future research.

**Table 13.** QSPM Total Attractiveness Score (TAS) Summary

| Strategic Alternative | Total Attractiveness Score (TAS) | Rank |
|---|---|---|
| SO (Strength–Opportunity) | 4.74 | 1 |
| ST (Strength–Threat) | 3.82 | 2 |
| WO (Weakness–Opportunity) | 3.72 | 3 |
| WT (Weakness–Threat) | 2.80 | 4 |

The QSPM results corroborate the Cartesian SWOT positioning reported in Table 10: the SO strategy obtained the highest Total Attractiveness Score (TAS = 4.74), confirming that maximizing existing strengths – particularly roadside vegetation assets and supportive sustainability policy – to capture available opportunities constitutes the most strategically attractive course of action for the Kepanjen–Pagak corridor. The ST strategy ranked second (TAS = 3.82), reflecting the relevance of deploying institutional and ecological strengths to mitigate external threats such as climate change and policy inconsistency, while the WO (TAS = 3.72) and WT (TAS = 2.80) strategies ranked lower, indicating that although addressing internal weaknesses remains necessary, doing so is comparatively less strategically decisive than leveraging existing strengths. This convergence between the Cartesian SWOT quadrant analysis and the independently computed QSPM ranking strengthens the methodological credibility of the SO-strategy prioritization presented in this study.

### 3.6. Theoretical Implications for Ecological Character Education and Education for Sustainable Development (ESD)

The findings can be further situated within the broader theoretical landscape of sustainability education. Beyond Orr's (1992) ecological literacy and Stern's (2000) Value Belief Norm theory already discussed above, the six-component ecological character framework used in this study – ecological knowledge, environmental values, moral responsibility, participatory decision-making, professional practice, and sustainable infrastructure behavior – closely parallels the learning-domain structure articulated in UNESCO's (2017) Education for Sustainable Development (ESD) framework, which integrates cognitive (knowing), socio-emotional (valuing), and behavioral (acting) domains of sustainability competence. Ecological knowledge and professional practice in this study map onto the cognitive domain, environmental values and moral responsibility onto the socio-emotional domain, and participatory decision-making and sustainable infrastructure behavior onto the behavioral domain. This alignment suggests that the low integration of green infrastructure identified along the Kepanjen–Pagak corridor reflects not a single missing competency but an underdevelopment across all three ESD domains simultaneously, reinforcing the argument that technical interventions alone are unlikely to be sufficient.

The finding that ecological character can develop informally through stakeholders' direct engagement with planning dilemmas – such as deciding which roadside trees to preserve – is consistent with Sterling's (2001) concept of transformative sustainability education, which holds that deep, durable shifts in environmental values and practice are more readily cultivated through situated, experience-based learning than through transmissive instruction alone. This is further supported by Kolb's (1984) experiential learning cycle, in which concrete experience (encountering an ecological trade-off on site), reflective observation (weighing construction efficiency against ecosystem services), abstract conceptualization (formulating design or policy responses), and active experimentation (implementing and monitoring green infrastructure measures) together constitute a complete learning loop. Infrastructure planning processes, in this sense, function as an informal curriculum in which planners, engineers, officials, and communities cyclically develop ecological character through iterative practice rather than through a single training event.

Positioning SWOT-based strategy formulation itself as a pedagogical act also resonates with the eight key competencies for sustainability identified by UNESCO (2017) – including systems-thinking, anticipatory, normative, strategic, collaboration, critical-thinking, self-awareness, and integrated problem-solving competencies. The process of jointly identifying strengths, weaknesses, opportunities, and threats, and subsequently negotiating priority strategies among government officials, consultants, practitioners, academics, and community representatives, exercises strategic and collaborative competencies in particular, suggesting that participatory strategic-planning exercises can themselves serve as a vehicle for ESD, consistent with Wals's (2015) call to extend sustainability learning beyond formal classrooms into professional and civic life. Taken together, these theoretical connections support this study's central contribution: that ecological character education is not confined to schools or training modules but can be intentionally embedded within infrastructure governance processes themselves, offering a concrete, replicable pathway for operationalizing ESD within technical, non-educational sectors such as road-infrastructure planning.

## 4. CONCLUSION

This study demonstrates that green infrastructure integration along the Kepanjen–Pagak Road Section remains limited, with road development still dominated by conventional gray infrastructure. The findings identify 159 existing roadside trees as valuable ecological assets that have not yet been systematically incorporated into road planning. SWOT analysis positioned the study in Quadrant I (X = +1.12; Y = +1.02), indicating that strong internal capacities and favorable external opportunities support proactive implementation of green infrastructure through roadside vegetation conservation, adaptive road design, strengthened institutional coordination, and environmentally responsive policy implementation. The principal educational finding is that ecological character can be strengthened through collaborative infrastructure planning involving government agencies, infrastructure practitioners, academics, and local communities. This finding extends the perspective of ecological character and sustainability education by demonstrating that environmental learning is fostered not only in formal educational settings but also through participation in environmentally responsible planning and decision-making processes.

Theoretically, this study enriches the understanding of ecological character education by integrating sustainability education with green infrastructure planning. Practically, it provides a foundation for developing stakeholder-training modules and sustainability competency indicators to strengthen the environmental capacity of planners, engineers, public officials, and local communities. From a policy perspective, the findings support the incorporation of ecological principles into technical road design standards, institutional collaboration, and regional infrastructure planning to promote environmentally responsible development.This study is subject to several limitations, including its single-case design, purposive sampling, the subjective weighting process inherent in SWOT analysis, the absence of experimental validation and longitudinal assessment, and consequently limited generalizability. Future research should validate the proposed framework across multiple road corridors and evaluate the effectiveness of stakeholder-training programs and sustainability competency indicators in supporting long-term green infrastructure implementation.

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