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The Business Case for Sustainable Road Infrastructure Development

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16. Abstract

This study developed a business-case framework for embedding sustainability into the Indiana Department of Transportation's (INDOT) practices. The study first identified the role of sustainability in road infrastructure development, and then discussed strategic plans, sustainability programs, and institutional challenges that shape how sustainability actions are conceived and executed. The study reviewed existing sustainability rating systems, established exposure metrics, and subsequently developed a business-case framework called the Road Infrastructure Sustainability Evaluation (RISE) to guide INDOT in embedding sustainability across the full infrastructure lifecycle, from planning through end-of-life. RISE follows a multicriteria analysis approach, incorporating indicator selection, criteria evaluation, weighting, normalization, and final amalgamation to generate an interpretable sustainability score based on project inputs and outcomes. The RISE Excel spreadsheet was developed to demonstrate this framework. By quantifying sustainability-related benefits and costs, RISE supports evidence-based justification for project decisions and investment choices. The tool was demonstrated and validated through a case study involving a real-world highway project in Indiana. In the case study, survey responses from the agency's personnel were used to establish the criteria weights to reflect their priorities and preferences, and normalization and amalgamation were carried out to yield a single sustainability RISE score for the case study project under consideration. The case study results indicated a strong propensity toward stakeholder engagement, habitat connectivity, and transparent governance, while also identifying opportunities for improvement in local sourcing, material reuse, emissions-reduction strategies, and the integration of financial sustainability metrics. The study then addressed in-house sustainability knowledge management at INDOT, analyzing survey feedback from personnel in diverse roles. This helped the researchers assess the current levels of sustainability awareness in the agency, diagnose the primary barriers to adoption, and develop a roadmap for strengthening the agency's overall capacity to plan, design, build, operate, and maintain its infrastructure in more sustainable ways.

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EXECUTIVE SUMMARY

Sustainable road infrastructure development has emerged as a critical priority amid growing environmental concerns, rising infrastructure investments, and increasing societal demand for resilient and equitable transportation systems. In the United States alone, annual spending on highways and roads has risen from $196.2 billion in 2002 to $233.3 billion in 2021, adjusted for inflation, underscoring the economic importance of transportation networks. However, conventional project delivery models often prioritize cost efficiency and engineering performance, while overlooking long-term environmental, social, and economic impacts. In response to these challenges, this study introduces the Road Infrastructure Sustainability Evaluation framework, or RISE, a lifecycle-based tool developed to embed sustainability directly into road infrastructure planning, design, construction, operations, maintenance, and end-of-life phases. Unlike existing national and international rating systems, RISE uniquely classifies sustainability metrics by project phase, enabling more precise, actionable assessments throughout the infrastructure lifecycle.

The study, conducted in partnership with the Indiana Department of Transportation (INDOT), incorporates input from professionals across the agency to prioritize sustainability indicators using structured survey methods. The RISE framework evaluates 31 indicators and 96 criteria across environmental, social, and economic dimensions, producing a weighted, phase-specific score for each project. The study identified significant opportunities and challenges in integrating sustainability into road infrastructure development through the application of the RISE framework. One of the key findings is that existing rating systems, such as CEEQUAL, GreenLITES, and Envision, often lack phase-specific evaluation and adaptability to local agency needs. RISE addresses this gap by introducing a practitioner-informed, lifecycle-based approach that classifies sustainability indicators across four distinct project phases: Planning and Design, Construction, Operations and Maintenance, and End-of-Life.

Through the structured weighting of 31 sustainability indicators and 96 evaluation criteria, RISE enables tailored assessment of economic, environmental, and social performance. The professional survey conducted with INDOT staff revealed varying priorities across project phases. Economic feasibility and stakeholder engagement dominated early phases, while environmental controls were most emphasized during construction and maintenance. End-of-life considerations, often neglected in traditional approaches, were also included and weighted for financial stewardship.

Application of the RISE tool to the I-69 Finish Line project yielded a 44.5% score during the construction phase, categorized as "Good Practice." The case study highlighted strengths in stakeholder engagement, habitat connectivity, and environmental controls, while revealing gaps in local sourcing, renewable energy integration, and financial performance metrics. Survey results also indicated barriers to the adoption of sustainable practices within INDOT, including high up-front costs, lack of formal training, and limited cross-functional integration. These findings underscore the need for capacity-building, funding reforms, and governance adjustments to institutionalize sustainability across the project lifecycle.

The study identified five areas for possible implementation. First, INDOT can offer recurring staff training in sustainable road infrastructure through the Local Technical Assistance Program (LTAP), internal offices, or academic partners, using online courses, workshops, and targeted sessions for key project phases. Second, sustainability goals can be integrated into individual and departmental evaluations by setting measurable targets across planning, construction, and maintenance activities. Third, periodic sustainability-focused communications, including case studies, best practices, and thematic content, can be launched via newsletters, webinars, and ongoing programs such as road school, the Civil Engineering Professional Development Seminar (CEPDS), and LTAP events. Fourth, budget mechanisms can be developed to allocate funds for sustainable design, materials, innovation pilots, and incentives rewarding sustainability achievements. Fifth, phase-specific RISE checklists and scorecards can be embedded into workflows, with ongoing monitoring of usage, sustainability scores, and cost effectiveness to guide improvements and statewide benchmarking.

Overall, the RISE framework provides public agencies with a transparent, data-driven approach to evaluating and implementing sustainable infrastructure practices. By aligning project delivery with long-term societal, environmental, and fiscal goals, the framework supports more resilient, equitable, and financially responsible road infrastructure development.

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1. INTRODUCTION

1.1 The Role of Sustainability in Road Infrastructure Development

The State and Local governments in the United States spent approximately $206 billion on the construction and maintenance of highways and roads in 2021 (Urban Institute, n.d.), underscoring the economic and societal importance of a well-functioning transportation network. State and local government spending on highways and roads significantly increased by nearly 19% between 2002 ($196.2 billion) and 2021 ($233.3 billion), when measured in 2025 inflation-adjusted dollars (as detailed in Figure 1.1).

Roads serve as the backbone of mobility, facilitating trade, economic growth, and social connectivity (Broniewicz & Ogrodnik, 2020). However, this development comes at a significant environmental cost, as road infrastructure projects contribute substantially to greenhouse gas (GHG) emissions. Estimates suggest that between 11.9 to 13.3 megatons of annual GHG emissions can be attributed to the production and use of construction materials alone, exacerbating climate change concerns (AzariJafari et al., 2023). This dual impact—where roads provide essential services but simultaneously impose environmental burdens—highlights the need for a more sustainable approach to infrastructure development. As such, over the past few decades, sustainability has become a pivotal consideration in the development of road infrastructure worldwide.

The concept of sustainability refers to “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations [UN], 1987). This foundational concept has shaped the global discourse on development and serves as a guiding principle in the pursuit of more responsible and future-oriented infrastructure systems.

Sustainable Road Infrastructure Development (SRID) is an emerging paradigm that seeks to balance economic, environmental, social, and institutional factors to ensure long-term resilience and viability (Ametepey et al., 2023; Vijayakumar et al., 2024). SRID is aligned with the UN’s Sustainable Development Goals (SDGs), aiming to minimize ecological impacts while maximizing economic and social benefits (Jeon & Amekudzi, 2005; United Nations Environment Programme, 2022; Yanamandra, 2020). This holistic approach incorporates innovative construction materials, energy-efficient processes, and sustainable land-use planning to mitigate the adverse externalities traditionally associated with road infrastructure development. Additionally, institutional and governance frameworks play a crucial role in driving sustainable practices, ensuring that policies, funding mechanisms, and regulations support durable, environmentally responsible infrastructure.

Historically, road infrastructure development has prioritized cost efficiency and engineering performance, often neglecting broader environmental sustainability impacts and long-term economic sustainability (Alnsour, 2020; Vijayakumar et al., 2023b). However, a truly sustainable approach must account for these externalities by evaluating impacts on the Triple Bottom Line (TBL): economic, social, and environmental (Elkington, 1997) throughout the entire infrastructure lifecycle (Sinha & Labi, 2007). Road infrastructure development projects (RIDP) typically progress through distinct phases, including Planning, Design, Construction, Operations, Monitoring and Maintenance, and End of Life (see Figure 1.2), each presenting unique challenges and opportunities for sustainability integration.

The Planning and Design phases are particularly crucial, as decisions regarding alignment, materials, construction methods, and multimodal integration determine the long-term sustainability of a project. Early adoption of low-carbon materials, energy-efficient designs, and climate resilience strategies can mitigate negative environmental and social effects (Beukes et al., 2012; Dagenais et al., 2024; Dash et al., 2022).

The Construction phase generates immediate environmental and economic impacts, including high energy consumption, material use, and emissions from machinery and transport. Implementing sustainable construction techniques, such as

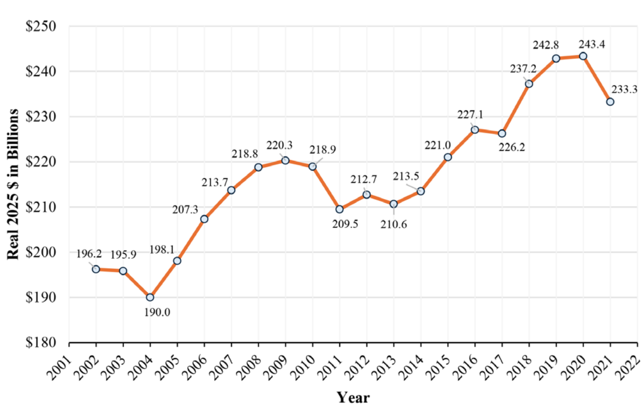

Figure 1.1 State and Local Total Highways and Roads Expenditures. Data Source: U.S. Census Bureau, 2025.

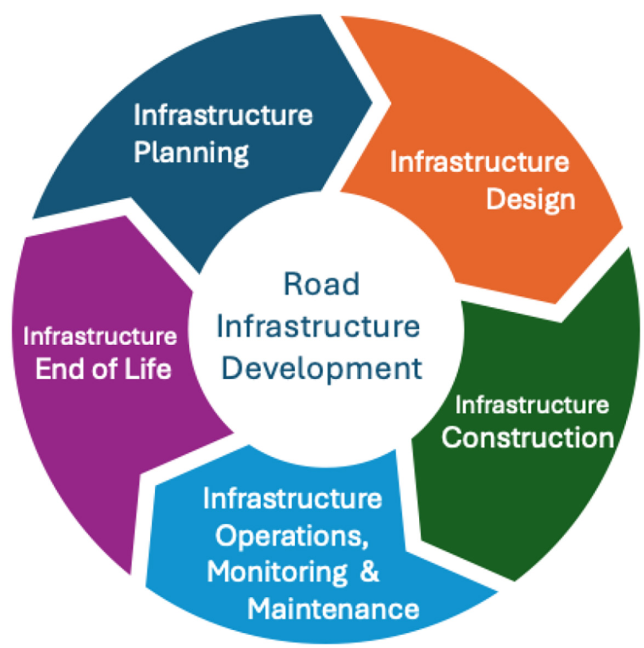

Figure 1.2 Road Infrastructure Development Phases.

low-carbon materials, optimized logistics, and waste reduction strategies, can reduce these effects (Connolly et al., 2023; Han & Thakur, 2015; Muench et al., 2019; Willar et al., 2020). Social sustainability considerations, including worker safety and community engagement, also play a key role (Vijayakumar et al., 2023b). However, strict budgets and time constraints often lead to trade-offs between efficiency and sustainability making it essential for sustainability frameworks to set practical benchmarks that encourage greener construction methods without compromising feasibility.

Beyond construction, the Operations, Monitoring, and Maintenance phase significantly affects long-term emissions, road performance, and costs. Poor maintenance accelerates deterioration, increasing emissions from vehicles and raising the need for costly repairs (Denysiuk et al., 2016). Sustainable practices, such as recycled pavement materials, predictive maintenance, and smart traffic management, can improve road longevity while reducing environmental impact (Borghetti et al., 2024; Fawzy et al., 2024; Liu et al., 2022).

The End-of-Life phase is often overlooked, yet it offers critical opportunities to integrate circular-economy principles through reuse, recycling, and responsible material decommissioning. Traditional road deconstruction generates substantial waste, but sustainable strategies—such as asphalt recycling and repurposing road elements for future projects—can significantly reduce landfill contributions (Antunes et al., 2023; Landi et al., 2020; Santos et al., 2018). Unfortunately, current rating systems rarely account for end-of-life sustainability, limiting their ability to promote a full-lifecycle approach to infrastructure sustainability.

1.1.1 Conventional Practices and Limitations

Taken together, these phase-specific challenges highlight how deeply traditional practices still shape roadway development and why understanding the limitations of conventional construction approaches is essential before exploring the role of sustainability rating systems. Specifically, conventional road construction methods heavily use nonrenewable resources and energy-intensive processes, contributing to environmental degradation and exacerbating climate-related challenges (Celauro et al., 2017; Perri et al., 2023) In response to these concerns, there has been a growing movement to integrate sustainability principles into RIDP through the application of rating systems and performance indicators (Paredes & Herrera, 2020). These methodologies provide quantifiable metrics that enable stakeholders to assess and improve the sustainability of infrastructure projects, thereby fostering more responsible and forward-thinking development practices (Clevenger et al., 2013).

Moreover, the adoption of sustainability rating systems has played a significant role in institutionalizing sustainability within the infrastructure sector (Simpson et al., 2014). These frameworks, designed to evaluate and promote sustainable practices, have been developed and implemented globally with varying scopes and assessment methodologies. The evolution of sustainability rating systems began over two decades ago with the introduction of CEEQUAL in the United Kingdom, followed by GreenLITES in the United States in 2008 and more widely recognized frameworks such as BE2ST-in-Highways, ENVISION, Greenroads, and INVEST emerging in 2010 (Mattinzioli et al., 2020). Each of these systems differs in its scope, assessment criteria, and stakeholder involvement, with some placing a greater emphasis on environmental sustainability, while others prioritize economic viability or social well-being.

The rising scale of roadway investments (Figure 1.1) and the clearly measurable environmental burdens—from embodied carbon in construction materials to long-term maintenance emissions—make clear that sustainability can no longer be treated as an optional add-on. As Figure 1.2 illustrates, each phase of Road Infrastructure Development (RID) offers distinct opportunities to reduce life-cycle impacts and enhance resilience. Yet conventional practices and even many existing rating systems leave critical gaps in phase-specific measurement, local adaptability, and whole-of-life accountability (Bueno et al., 2015; Clevenger et al., 2013; Mehraban et al., 2025). The challenge for a public agency such as the Indiana Department of Transportation (INDOT) is to embed tailored metrics and decision-support tools directly into its planning, design, construction, and maintenance.

1.2 Project Objectives and Scope

INDOT's commitment to sustainable development reflects the need to manage transportation assets in ways that not only reduce environmental and social impacts but also enhance long-term economic, community, and ecological benefits. This direction acknowledges the finite nature of natural resources and the importance of responsible stewardship of infrastructure. This study was undertaken to support that goal through the following core objectives:

- Identify sustainability opportunities across all phases of the road infrastructure lifecycle, including planning, design, construction, operations, maintenance, and end-of-life.
- Develop sustainability metrics and indicators for assessing project performance.
- Establish a business-case sustainability framework to evaluate projects based on measurable sustainability outcomes.
- Assess cross-sector sustainability effects, including implications for materials suppliers, utilities, and local agencies.
- Identify pathways for integrating sustainability into INDOT's culture and decision-making.
- Evaluate carbon-credit market mechanisms and the potential for Indiana to participate in such programs.

The work centers on the creation and application of the framework, which provides a structured, multicriteria method for sustainability evaluation guided by practitioner input.

1.3 Structure of the Report

This report is organized into six substantive chapters followed by four appendices, each designed to guide the reader from foundational concepts in sustainable road infrastructure through practical application and strategic recommendations.

Chapter 1 introduces the role of sustainability in road infrastructure development, outlines the limitations of conventional approaches, and defines the project's scope and objectives. It concludes by summarizing how the remainder of the report is organized.

Chapter 2 explores how sustainability can be embedded in road infrastructure delivery, beginning with statewide and agency-level strategies and continuing through project-level considerations across the Planning, Design, Construction, Operations and Maintenance, and End-of-Life phases. This chapter also discusses cross-lifecycle strategies and institutional challenges associated with implementation.

Chapter 3 examines how sustainability in RID projects can be measured, reviewing rating systems, mapping evaluation criteria to the TBL, and describing the use of multicriteria decision analysis—including alternatives development, indicator definition, weighting, normalization, and amalgamation. Lessons learned from existing frameworks are summarized at the end of the chapter.

Chapter 4 presents the development of the Road Infrastructure Sustainability Evaluation (RISE) business-case framework. It documents the selection of sustainability indicators, the assignment of weights through a structured survey, and the application of normalization and aggregation approaches. The chapter also compares RISE with existing rating systems and explains how weights were finalized across pillars and indicators.

Chapter 5 demonstrates the application of RISE through a case study of the I-69 Finish Line project. The chapter describes the evaluation process, scoring outcomes across environmental, social, and economic pillars, and highlights insights for improvement based on observed results.

Chapter 6 focuses on advancing sustainability within INDOT, drawing on survey findings related to awareness, barriers, priority initiatives, and preferred training channels. This chapter concludes with implementation-oriented recommendations to support the integration of sustainable practices.

Chapter 7 provides conclusions, summarizes key findings, outlines study limitations, and identifies future research and implementation opportunities, including considerations related to emerging technologies, public health resilience, and ethical governance.

The main chapters are followed by references and appendices, including a carbon credit market analysis, the survey instrument, the full RISE evaluation criteria, and details of multicriteria analysis.

2. EMBEDDING SUSTAINABILITY IN ROAD INFRASTRUCTURE DEVELOPMENT

2.1 Sustainability Considerations in Civil Infrastructure Systems

Traditionally, civil engineering has emphasized the optimization of cost, performance, and safety in the design and implementation of infrastructure systems (Cywinski, 2001). However, the growing urgency of climate change, resource depletion, and environmental degradation has made it clear that a paradigm shift toward sustainable development is not only necessary but imperative (Braham & Casillas, 2020). In this evolving context, sustainability in civil infrastructure is defined as the practice of designing, constructing, and maintaining systems that minimize environmental harm, promote social aspects, and support long-term economic resilience (Jeon & Amekudzi, 2005). This shift reflects a broader alignment with global initiatives such as the UN's SDGs, which advocate for resilient and environmentally responsible infrastructure systems (UN, 2023).

Civil infrastructure systems—spanning transportation networks, buildings, water supply, and waste management—are inherently complex, resource-intensive, and long-lived (Labi, 2014). These characteristics position them, paradoxically, as both contributors to and potential mitigators of global sustainability challenges. Infrastructure planning and design decisions can have far-reaching implications on land use, mobility, energy consumption, and ecological health (Jeon et al., 2013). As such, the role of civil engineers has expanded beyond technical feasibility and cost effectiveness to include considerations of environmental protection, and lifecycle sustainability performance (Saidi et al., 2018).

From a professional standpoint, the American Society of Civil Engineers (ASCE) reinforces the importance of sustainability in engineering practice. In Policy Statement 418, ASCE encourages professionals to adhere to two guiding principles: "do the right project" and "do the project right." This means civil engineers are called not only to evaluate the necessity and impact of a project on the TBL dimensions, economic, environmental, and social, but also to ensure its responsible delivery throughout all phases, from conception to end-of-life (ASCE, 2023).

To put these principles into practice, a range of tools and frameworks have been developed to incorporate sustainability-related assessments in civil engineering systems development. These include lifecycle assessment (LCA), environmental product declarations (EPDs), sustainability rating systems such as LEED and Envision, and multicriteria decision analysis (MCDA) techniques (Labi, 2014; Miterev et al., 2020; Munda et al., 1994; Navarro et al., 2019; Sinha & Labi, 2007). While these methods offer valuable guidance, challenges persist in standardizing practices, measuring long-term performance, and reconciling diverse stakeholder values (Clevenger et al., 2013; Mattinzioli et al., 2020; Mehraban et al., 2025). Moreover, the fragmented application of sustainability indicators across agencies and disciplines often leads to inconsistent and incomplete assessments (Barnes et al., 2018).

Furthermore, the economic dimension of sustainability in civil engineering infrastructure centers on economic development, efficiency, and financial feasibility, including whether projects generate jobs, yield positive returns on investment, and remain financially viable across construction, operations, and maintenance (Labi, 2014). Institutions such as the World Bank, UN, and Organization for Economic Co-operation and Development (OECD) prioritize these considerations, and Goodman and Hastak (2006) warn that poor economic performance leads to misallocated funds, weakened financial stability, and reduced stakeholder trust. Economic impacts may be evaluated at regional or project-specific levels—ranging from output, wages, and employment to capital investment, productivity, and property value appreciation—and may occur as direct, induced, or multiplier effects over short, medium, or long-term scales. Resource flows, representing total material movement within economic processes, also remain a key indicator of infrastructure sustainability (Labi, 2014). To better understand sustainability aspects, their impacts are examined at two levels: statewide considerations and project-level activities.

2.2 Agency Level and Statewide Systemic Considerations

The first and foremost area where sustainability must be integrated is within the state department of transportation (DOT) itself. This section of the report explores in-house opportunities for fostering sustainable development, focusing on how sustainability can be incorporated into the agency's programs, policies, strategies, and day-to-day operations. By embedding sustainability at the agency level, DOTs can lead by example and set a foundation for broader, statewide impact.

2.2.1 Strategic Plans and Sustainability Programs

Strategic plans are documents that identify the DOT's mission, goals, vision, values, and strategies for managing and improving transportation infrastructure within their respective states. They are a core part of any DOT, as they shape the way in which the agency operates and evaluates itself. Incorporating sustainability into the strategic plan is an effective way to ensure that sustainability is integrated not only in-house but also in the field and across different project lifecycles. One of the best ways to do this is to use a sustainability plan. A sustainability plan, or program, serves as a guide for integrating sustainable practices into a DOT's operations and decision-making processes. The main challenge is that creating a sustainability program can be quite difficult and requires significant effort. That said, some state DOTs have already accomplished this. Both the Oregon Department of Transportation (ODOT) and the Arizona Department of Transportation (ADOT) have sustainability programs and policies that other DOTs could use as references to help them create their own.

ODOT's sustainability framework is outlined across three volumes: Setting the Context (ODOT, 2008), which introduces ODOT's sustainability vision and seven priority areas; Sustainability Management Framework for ODOT's Internal Operations (ODOT, 2015), which defines goals, strategies, and performance measures for in-house practices; and Sustainability Management Framework for Oregon's Transportation System, which extends guidance to statewide public and private systems and identifies ODOT's role in supporting partner agencies. ODOT's program is administered by a Sustainability Program Manager, overseen by the multidisciplinary ODOT Sustainability Council, and supported by Sustainability Project Teams that advance initiatives. Progress is tracked through annual Sustainability Progress Reports (published since 2010), ensuring transparency in achievements and ongoing work. The 2015 plan focuses on seven priority areas, supported by Strategic Sustainability Analysis (SSA) for policy evaluation (Amekudzi et al., 2011), with economic considerations emphasizing local purchasing, small-business participation, and lifecycle cost analysis to strengthen long-term financial sustainability.

The *Complete Transportation Guidebook* is ADOT's version of a sustainability plan (ADOT, 2016). It should be noted that this guidebook was designed specifically for ADOT to enhance and support existing ADOT initiatives, processes, and standards. The term "complete transportation" is interchangeable with sustainable transportation, so for purposes of this report, it will be referred to as such. This guidebook introduces seven core strategies for incorporating sustainability into transportation, each with an in-depth description. Understanding the context in which an agency or facility operates is critical, and the guidebook explores the context and types in Arizona. This guidebook goes on to discuss how sustainability principles could be implemented and how they should influence choices in ADOT's infrastructure development processes.

Similar to a strategic plan, a sustainability plan serves as a guide for integrating sustainable practices into DOT's operations and decision-making processes. In addition to the USDOT plan, there exist at least two other DOTs that have sustainability plans which INDOT could use for reference: Washington D.C. (District of Columbia Department of Transportation [DDOT]) and ODOT. DDOT's Sustainability Plan (DDOT, 2010) begins by introducing eight priority areas, along with goals, recommended actions, and performance measures for each area. In order to monitor the progress of the priority areas, DDOT is required to submit an annual report detailing their progress and possible improvements that could be made to the sustainability plan. This report is written by the DDOT Sustainability Coordinator, who is also responsible for the training of DDOT personnel in sustainability-related information, an approach INDOT could adopt.

2.2.2 Sustainability During an Agency's Operations

Companies and agencies worldwide are changing how they operate, and state DOTs are no exception. In 2022, the U.S. Department of Transportation (USDOT) released its plan to "achieve net-zero emissions economy-wide by 2050" (USDOT, 2022), highlighting actions such as transitioning to zero-emission vehicles and shifting to net-zero-energy buildings powered by clean sources. These goals influenced internal planning and program development within USDOT at the time. However, in 2025, the federal policy landscape changed following the issuance of the *Unleashing American Energy* Executive Order (Exec. Order 14154, 2025). The order directs federal agencies to review, revise, or rescind regulations that may limit or restrict domestic energy production, including oil, natural gas, coal, nuclear generation, and critical mineral extraction. It also revokes several prior directives related to federal climate and emissions policies. This shift places greater federal emphasis on energy development and regulatory changes, changing the context within which USDOT and state DOTs plan and operate. Such changes are not fully reflected in this report, as the survey and other key studies that informed the findings were prepared before the shift in priorities.

The federal and state transportation agencies have developed a wide range of sustainability tools and programs. Beginning

TABLE 2.1
Summary of Focus Areas and Goals for Achieving Sustainable DOT Operations.

DOT/Agency	Focus Areas and Goals*
United States, (USDOT, 2022)	• Carbon Pollution-Free Electricity, Zero Emission Vehicle Fleet. • Net-Zero Emissions Buildings, Campuses, and Installations. • Reducing Waste and Pollution, Sustainable Procurement. • Climate- and Sustainability-Focused Federal Workplace. • Accelerating Progress through Partnerships.
FHWA (FHWA, 2017)	• Developed the INVEST tool to be used by projects and states. • Four modules: System Planning for States (SPS), System Planning for Regions (SPR), Project Development, and Operations and Maintenance. • Provides a numeric sustainability evaluation framework for programs and projects, enabling self-assessment and continuous improvement. • Encourages collaboration and goal alignment across teams. • Sustainability in planning, design, construction, and maintenance. • Helps reduce resource consumption, improve efficiency, and enhance environmental and economic outcomes.
Oregon, (ORDOT, 2015)	• Energy and Climate: Reduce emissions, improve energy efficiency, and promote sustainable transportation. • Resource Flows: Minimize waste, prioritize eco-friendly products, and optimize paper and electronics use. • Environmental Stewardship: Enhance stormwater management, reduce hazardous materials, and conserve water. • Land and Infrastructure: Strategically site facilities and develop high-performance buildings. • Economic Health: Support local businesses, small enterprises, and lifecycle cost analysis. • Health and Safety: Ensure employee safety and promote wellness initiatives.
Illinois (IDOT, 2022, 2023)	• National Electric Vehicle Infrastructure (NEVI) EV charging expansion. • $215 million Carbon Reduction Program funding. • I-LAST sustainability rating system. • Data-driven 2023–28 project-selection tool. • University of Illinois Urbana-Champaign EV adoption research.
Ohio (Center for Environmental Excellence, 2022)	Four-step environmental-commitment process: 1. NEPA-based “Decide” impact analysis. 2. “Write” actionable, measurable commitments. 3. “Communicate” via EnviroNet accountability system. 4. “Follow-through” verification of environmental promises.
Michigan (CDM Smith, 2023; MDOT, 2024)	• 2025–29 “Sustainable Communities” framework. • Complete-Streets design screening. • Statewide carbon-reduction baseline for projects and operations. • Multimodal access and clean-air goals. • Integrated social and mobility initiatives.
Wisconsin (WisDOT, 2023, 2024)	• IIJA-mandated Carbon Reduction Strategy. • 2024 Wisconsin EV Infrastructure Plan. • Statewide passenger and freight charging network. • Alignment of long-term funding with GHG goals.
Minnesota (MnDOT, 2024, 2025b, 2025a)	• Office of Sustainability and Public Health (est. 2022). • 2025–30 Strategic Plan: Economy, environment, society. • Priority: policy integration, tools, communications, training, partnerships. • Annual Sustainability Reports tracking 2023 performance targets. • 2023 targets: Facility GHG, energy use, renewables, fleet electrification, waste diversion.

* The Focus Areas and Goals are retrieved from the corresponding year of the references, not necessarily being maintained to the current time.

with USDOT’s focus areas, including zero-emission fleets, carbon-free electricity, sustainable procurement, and waste reduction (USDOT, 2022), alongside the Federal Highway Administration’s (FHWA) numeric sustainability evaluation framework, INVEST (FHWA, 2017). Midwestern DOTs demonstrate varied implementation paths: Illinois DOT (IDOT) has expanded electric vehicle (EV) infrastructure and developed the I-LAST rating system (Kontou et al., 2022; IDOT, 2012, 2023), Ohio DOT operates through a four-phase National Environmental Policy Act (NEPA)-linked accountability system (Center for Environmental Excellence, 2022), Michigan DOT (MDOT) integrates emissions baselining and equitable multimodal access into its five-year program (CDM Smith, 2023; MDOT, 2024), and Wisconsin DOT (WisDOT, 2023, 2024) has advanced carbon-reduction and EV-network planning to align with Infrastructure Investment and Jobs Act (IIJA) goals. Minnesota DOT (MnDOT, 2024, 2025a, 2025b) stands out with a dedicated Office of Sustainability and Public Health, a three-pillar definition of sustainability, performance-tracked strategic plans through 2030, and measurable internal targets supported by annual sustainability reporting since 2016. Together, these models provide multiple pathways for integrating sustainability across planning, operations, and capital programs, offering comparative insights for agencies like INDOT.

Table 2.1 highlights several focus areas and goals that DOTs are pursuing to foster sustainability in agency operations.

2.2.3 Economic and Financial Considerations

Various economic and financial considerations play a crucial role in statewide systemic planning, including the Fiscal Coordination Framework, Economic Integration Priorities, Policy and Governance, and Technology and Innovation. Research in these areas highlights their contribution to achieving economic sustainability at a systemic level, ensuring efficient resource allocation, financial stability, and long-term economic growth.

2.2.3.1 Funding Mechanisms and Fiscal Coordination. Contemporary research emphasizes the critical role of diversified funding streams in maintaining the viability of transportation infrastructure. Caltrans's multisource funding model demonstrates the effectiveness of blending federal Metropolitan Planning (PL) funds, State Highway Account (SHA) allocations, and Road Maintenance and Rehabilitation Account (SB1) grants to support regional planning activities. (Caltrans, 2024). This approach aligns with the Brookings Institution's findings that leveraging formula-based distributions for 53% of highway revenues achieves greater fiscal stability than relying on single revenue streams (Tomer & Swedberg, 2024). The consolidation of FHWA Section 5303 funds with state-matched appropriations creates a coordinated framework for prioritizing economically strategic corridors, particularly in regions experiencing above-average freight growth (USDOT, 2017).

Interagency coordination emerges as a linchpin for optimizing resource allocation. The American Association of State Highway and Transportation Officials (AASHTO) Transportation Asset Management (TAM) Guide highlights successful models where cross-agency committees reduce redundant expenditures by 18–22% through shared asset management platforms (AASHTO, 2022). This complements Florida's Strategic Intermodal System (SIS) approach, which directs 99% of transportation investments toward facilities demonstrating measurable economic returns through improved supply chain connectivity (USDOT, 2017). However, Taylor and Schweitzer's (2005) analysis of state-MPO collaborations reveals persistent challenges in aligning fiscal priorities, with only 37% of states achieving full consistency between long-range plans and annual capital improvement programs (Tomer & Swedberg, 2024).

2.2.3.2 Lifecycle Cost Management Strategies. Emerging procurement models are reshaping financial risk profiles across project phases. Performance-based contracting frameworks, as implemented in Michigan's intermodal transit centers, transfer 22–28% of lifecycle cost overrun risks to private partners while guaranteeing minimum service levels. This financial innovation proves particularly impactful in operations phases, where National Governors Association (NGA) data show performance-linked maintenance contracts reduce total ownership costs by 18% compared to conventional methods (Burwell & Puentes, 2021).

2.2.3.3 Public-Private Partnerships and Innovative Financing. The evolving landscape of transportation finance reveals three dominant partnership archetypes with distinct economic implications. A few examples are shared below.

- Revenue-risk sharing models exemplified by Virginia's I-66 corridor project, where private operators assume demand risk in exchange for capped public subsidies (Burwell & Puentes, 2021).
- Infrastructure bank arrangements like Florida's SIS revolving fund, generating 6.8% annual returns through strategic loans to high-impact freight projects (USDOT, 2017).
- Technology-backed financing mechanisms using blockchain-enabled toll revenue securitization, reducing transaction costs by 23% in pilot implementations (Zhao et al., 2023; Tian et. al., 2020).

NGA's analysis of state infrastructure banks demonstrates their effectiveness in leveraging federal funds at a 3:1 ratio, though success requires robust project evaluation frameworks to minimize nonperforming loans (Burwell & Puentes, 2021). The economic calculus for PPPs shifts significantly when considering recent research findings that connected vehicle technologies, through improved origin-destination tracking, can enhance toll revenue predictability by 32% (Li, 2024).

2.2.3.4 Economic Impact Alignment and Measurement. Transportation investments increasingly prioritize projects that demonstrate quantifiable economic multipliers. Brookings' evaluation of State Transportation Improvement Program (STIP) processes reveals that regions that incorporate economic development metrics into project scoring systems achieve 14% higher GDP growth in adjacent corridors than peers using traditional engineering criteria (Tomer & Swedberg, 2024). This aligns with Florida's documented 15–30% tax base expansion near strategically located logistics parks, though success requires co-investment in workforce housing and utility infrastructure (USDOT, 2017).

This synthesis of global practices establishes a theoretical foundation for integrating lifecycle financial strategies with statewide economic priorities, while exposing critical implementation challenges in governance structures and impact quantification methodologies. The reviewed models collectively argue for adaptive funding mechanisms that respond to shifting economic conditions rather than relying on static revenue allocations (USDOT, 2017).

2.3 Project Level and In-Field Considerations

Once sustainability has been incorporated into an agency's in-house operations or into statewide systemic considerations, it can be implemented across the different phases of infrastructure development at the project level. Some agencies use different names for phases or include/exclude mention of phases entirely. ADOT uses the following taxonomy: Planning, Scoping, Design, Construction, and Operations and Maintenance. ODOT mentions only four phases: Program Development, Project Development, Construction Management, and Operations and Maintenance. For the purpose of this report, the phases are mentioned: Planning, Design, Construction, and Operations and Maintenance. This section discusses possible opportunities for sustainable development throughout the phases of infrastructure development. Opportunities throughout the project lifecycle are also discussed in this section.

ASCE issued a policy statement outlining the role of civil engineers in sustainable development, stating, "Infrastructure shall be planned, designed, constructed, operated, and maintained, and decommissioned in a manner that addresses quantifiable and non-quantifiable environmental, social, and economic benefits and costs over its entire life cycle" (ASCE, 2023). This section outlines potential opportunities for sustainable development at each phase of the transportation infrastructure cycle. The project-level considerations, including economic sustainability, are discussed in this section, covering planning, design, construction, operations, maintenance, and the entire project lifecycle.

2.3.1 Planning Phase

The planning phase is the first phase of infrastructure development, during which proposed projects are evaluated. The purpose of this phase is to ensure that a selected project fits with what is needed. Some common tasks performed during the planning process include conducting a needs assessment, developing alternative plans, and using a multicriteria decision matrix to select the best plan. Project scoping is also included within this phase. The planning phase is the most vital for sustainable development. According to Labi (2014), "Failure to adequately consider the sustainability elements in this phase is potentially more damaging in the long term compared to any such failing at other phases." In that same policy statement by the ASCE, the first ASCE Principle of Sustainable Development is to "Do the right project" (ASCE, 2023). Before a project is selected, its economic, environmental, and social effects should be evaluated, and all stakeholders should understand them. The "right" project is one that maximizes benefits across the three sustainability pillars while minimizing adverse impacts on affected communities. The project should also align with the agency's strategic plan objectives and goals.

According to Busscher et al. (2015), "Planning literature increasingly stresses that infrastructure planning should be linked to land use and environmental planning if it is to enable integrated, sustainable development." This can be accomplished best using a program-oriented planning approach. This approach focuses on using a program to integrate projects and resources while also helping achieve overall goals that would have been difficult to accomplish in separate projects. According to the FHWA in their highlights of sustainability activities during 2014, "Linking asset management and planning supports the environmental and economic triple bottom line principles of sustainability by improving decisions, extending the life of assets, and reducing the demand for raw materials" (John A. Volpe National Transportation Systems Center, 2014).

For effective planning that considers economic factors, the project should incorporate demand forecasting, cost–benefit analysis, and diverse funding strategies. A comprehensive project finance strategy should be established during the planning phase, incorporating a value-for-money analysis across various contracting strategies to determine the most effective development approach. Additionally, a comprehensive risk mitigation framework should be included to address financial uncertainties through traffic demand analysis, maintenance cost projections, and contingency planning for cost escalations.

Financially sustainable road infrastructure planning relies on strategic economic alignment, prioritizing projects that support industrial corridors, freight mobility, and labor market connectivity. Cost-benefit optimization must extend beyond immediate construction expenses to include long-term externalities, as advocated by the Inter-American Development Bank (IDB, 2018), which highlights that projects yielding \$3–7 in economic returns per dollar invested through supply chain efficiencies justify upfront costs. Complementing this economic perspective, the United Nations Development Programme (UNDP, 2024) notes that, in rural regions, 27.5% of logistics inefficiencies stem from poor road connectivity, underscoring the need for demand-responsive planning in this regard.

Risk mitigation frameworks must address volatile funding landscapes and uncertainties in traffic demand. The Global Infrastructure Hub (GI Hub, 2023) recommends integrating InfraTech solutions, which are digital and nondigital technologies capable of making step-change improvements in economic, social, or environmental outcomes, during planning phases, such as predictive analytics, to reduce long-term maintenance costs by 40%. Concurrently, the OECD (2022) warns that deferred maintenance escalates user costs by 50%, necessitating contingency reserves equivalent to 1.5–2% of annual toll revenues. Strategic prioritization of high-multiplier projects, such as freight corridors, ensures alignment with statewide economic objectives, as demonstrated by Florida's SIS, which directs 99% of investments to assets with measurable returns (IDB, 2018).

2.3.2 Design Phase

The design phase of road infrastructure development plays a critical role in ensuring sustainability, efficiency, and cost-effectiveness by integrating innovative materials and construction methods. Construction 4.0 (Sawhney et al., 2020) offers a framework for digitalizing and modernizing infrastructure projects, incorporating advanced technologies such as three-dimensional (3D) printing, artificial intelligence (AI), and drones to improve efficiency and sustainability. Cyber-physical systems (Pishdad-Bozorgi et al., 2020) further enhance design precision by integrating computational and physical elements, enabling better project management and resource allocation. Selecting sustainable sites and landscapes is essential to minimize environmental disruption and maintain ecosystem balance (Yates & Castro-Lacouture, 2016). Additionally, stormwater management strategies, such as bioswales and porous asphalt, enhance drainage and reduce flooding risks (CH2M HILL & Good Company, 2009). Designing for disassembly ensures that infrastructure components can be recycled at the end of their lifecycle, reducing waste and supporting a circular economy (Eliote et al.,2024).

Material selection during design could help significantly influence the sustainability of highway infrastructure (Lu et al., 2023; Xu & Emberger, 2021). Using recycled materials such as reclaimed asphalt pavement (RAP) and rubberized asphalt reduces environmental impact while enhancing pavement durability (El-Hakim & Tighe, 2012; Meininger et al., 2021). Warm-mix asphalt (WMA) minimizes energy consumption and emissions during production, offering a more sustainable alternative to conventional hot-mix asphalt (Tutu & Tuffour, 2016). Perpetual pavements, designed for long-term performance with minimal maintenance, further enhance sustainability by reducing material consumption and extending roadway lifespan (El-Hakim & Tighe, 2012). FHWA and state agencies like INDOT have actively promoted the use of recycled materials, such as shredded tires and industrial by-products, in highway construction to improve cost efficiency and sustainability (Muench & Van Dam, 2014). These design strategies collectively contribute to a more resilient and environmentally friendly highway infrastructure.

Digital tools like Building Information Modeling (BIM), as implemented by Verston Group (2025), allow stakeholders to visualize and refine designs preconstruction, minimizing errors and material waste. Milani et al. (2021) further stresses that climate-resilient materials, such as asphalt mixes rated for 150% of projected traffic loads, extend asset lifespans by 30–40%.

2.3.3 Construction Phase

During the construction phase of highway infrastructure, sustainability can be enhanced through material procurement, equipment choices, and operational strategies. Adverse environmental impacts can be reduced by optimizing procurement processes and implementing work zone controls (National Academies of Sciences, Engineering, and Medicine [NASEM], 2023). Efficient material management helps minimize resource consumption, energy use, and environmental disruption (Gudmundsson et al., 2016). The use of sustainable heavy construction equipment, such as retrofitted diesel engines and biodiesel fuel, further reduces emissions, though biodiesel may slightly increase NOx emissions (Yates & Castro-Lacouture, 2016). Additionally, advancements such as electric screeds in asphalt paving significantly reduce carbon dioxide emissions, improve air quality, and lower maintenance costs (New York City Department of Transportation, 2013). These strategies contribute to sustainable highway construction with lower environmental impact.

Cost containment strategies prioritize local material procurement and lean construction protocols. Sourcing aggregates within 50-mi radii, as practiced in Michigan's intermodal projects, reduces transportation costs by 18–25% while stimulating regional economies (Milani et al., 2021). The United Nations Development Programme (UNDP, 2024) notes that road construction contracts in Uganda's Karamoja region achieved 30–35% internal rates of return by employing local labor, amplifying economic multipliers through wage circulation. Lean methodologies, such as just-in-time material delivery, further cut storage costs by 12%, as validated by the World Bank's urban transport financing models (Ardila-Gomez & Ortegon-Sanchez, 2015).

Economic multiplier maximization requires intentional workforce policies. The IDB (2018) highlights that mandating 30% local hiring in rural projects, combined with off-season earthwork scheduling, preserves agricultural productivity. Ghana's road maintenance programs demonstrate that such strategies yield 24–32% returns by reducing unemployment and boosting ancillary industries (UNDP, 2024). Concurrently, the Colorado Department of Transportation (CDOT, 2012) emphasizes waste reduction through prefabricated components, diverting 45% of construction debris from landfills and lowering disposal costs.

2.3.4 Operations and Maintenance Phase

During the operations and maintenance phase of highway infrastructure, sustainability can be improved through energy-efficient practices, electrifying maintenance vehicles, and using renewable resources. Maintenance equipment and fleet electrification can significantly reduce adverse environmental effects (NASEM, 2023). Strategic operational decisions, such as optimizing street lighting schedules, help balance road safety with energy consumption (Gudmundsson et al., 2016). Road weather management is crucial for maintaining safe, efficient highways, while renewable energy sources such as solar, wind, and geothermal can power infrastructure operations and reduce reliance on fossil fuels. Additionally, sustainable maintenance practices involve selecting long-lasting materials with minimal environmental impact, including recyclable deicing chemicals and durable infrastructure components (Labi, 2014). These efforts collectively enhance the long-term sustainability and resilience of highway systems.

Performance-based contracting transforms maintenance economics. The OECD (2022) reports that outcome-focused agreements tied to pavement condition indices reduce lifecycle costs by 22%, while AI-driven predictive models, such as Trimble's pavement management systems (Keating, 2023), slash emergency repair expenses by 40%. Dynamic tolling algorithms, as implemented on Virginia's I-66 corridor, adjust rates by 5–15% based on real-time congestion data, optimizing revenue streams during peak demand (IDB, 2018). Adjacent land leasing for utility corridors also accounts for 3–5% of annual operating budgets, as seen in Florida's logistics park co-locations (GI Hub, 2023).

Revenue diversification also mitigates fiscal vulnerabilities. The World Bank advocates blockchain-enabled toll collection, which reduces transaction costs by 23% while improving accountability (Ardila-Gomez & Ortegon-Sanchez, 2015). The U.S. Agency for International Development's (USAID, 2016) Road Sector Sustainability Program underscores that decentralized maintenance crews, equipped with real-time data tools, improve emergency response times by 65%, preventing costly infrastructure failures. These approaches align with Milani et al.'s (2021) recommendation to embed digital twins for continuous asset health monitoring, ensuring budgetary efficiency.

2.3.5 End-of-Life Phase

The end-of-life phase of highway infrastructure focuses on decommissioning, material recovery, and environmental restoration. Full-depth reclamation (FDR) is a key strategy in sustainable pavement systems, allowing for the reuse of existing materials to minimize waste and reduce costs (Van Dam et al., 2015). This process not only decreases the need for new raw materials but also lowers emissions associated with transportation and production. Additionally, sustainable demolition practices aim to maximize the recycling and repurposing of construction materials, such as asphalt, concrete, and steel, ensuring minimal environmental impact. Proper planning at this stage can lead to cost savings, resource conservation, and reduced reliance on landfills, making infrastructure projects more sustainable throughout their lifecycles.

Strategic decommissioning of underutilized routes, exemplified by sub-Saharan Africa's rural access initiatives (International Monetary Fund, 2021), saves $1.2–1.8 million per kilometer in long-term upkeep. The IDB (2018) further advocates adaptive reuse of right-of-way spaces for renewable energy installations, generating ancillary revenue streams post-decommissioning.

End-of-life planning must also address fiscal liabilities. Yanamandra (2020) emphasizes that lifecycle accounting systems, tracking costs over 30-year horizons, prevent budgetary shortfalls during asset retirement. Cotton (2011) complements this with community-focused reuse strategies such as converting abandoned rail corridors into greenways, shown to increase adjacent property values by 15–30% (Ardila-Gomez & Ortegon-Sanchez, 2015), and similarly, the repurposing of historic or select bridges once they no longer serve automobile traffic, allowing these structures to be retained as cultural assets, pedestrian corridors, or recreational spaces rather than removed entirely.

2.3.6 Cross-Lifecycle Strategies

Sustainability in highway infrastructure should be considered across the entire project lifecycle, from planning to demolition and reuse. A holistic approach involves integrating sustainable practices at every stage to minimize environmental impact, reduce costs, and improve efficiency. Performing a LCA and lifecycle cost analysis (LCCA; ASCE, 2023; Van Dam et al., 2015) ensures that decision-making accounts for long-term economic, environmental, and social factors. Sustainability rating systems such as INVEST, Greenroads, Envision, GreenLITES, and LEED provide structured frameworks to evaluate and improve sustainability performance throughout the project (Van Dam et al., 2015).

Lifecycle funding models integrate capitalization reserves and debt optimization. The IDB (2018) recommends reserving 1.5–2% of annual toll revenues for future repairs, while blending 30-year municipal bonds with short-term construction loans reduces interest expenses by 12–18%. The Global Infrastructure Hub (GI Hub, 2023) highlights that InfraTech platforms, such as digital twins, enable real-time return-on-investment tracking across asset subclasses, thereby improving fiscal decision making.

Institutional governance reforms ensure sustained alignment. The World Bank (2024b) stresses multiagency fiscal coordination, such as cross-jurisdictional funding pools, which increase project capacity by 40%. Milani et al. (2021) further advocates embedding sustainability metrics into procurement mandates, requiring 20% recycled materials in state-funded projects. These systemic approaches, combined with adaptive policy frameworks, can help cement economic resilience across infrastructure lifecycles.

2.4 Institutional Challenges and Opportunities

Embedding sustainability within a state DOT presents a suite of institutional hurdles. Traditional agency structures often operate in functional silos—planning, design, construction, maintenance—each governed by distinct performance metrics and funding streams. This fragmentation complicates the adoption of holistic sustainability goals, as success in one division may not translate into demonstrated value for another. Moreover, budgetary and regulatory frameworks remain largely oriented toward near-term deliverables, such as pavement condition and traffic throughput, with little incentive to prioritize life-cycle impacts or lower-carbon materials. The result is a default of familiar practices, even when more sustainable alternatives exist.

Human resource capacity constraints further impede progress. Many DOTs lack dedicated sustainability staff or clear lines of accountability for environmental performance, and training programs seldom cover the full range of exposure metrics, such as embodied carbon, energy use, and maintenance burdens, that a comprehensive approach demands. Data systems are similarly underdeveloped; the necessary information on material sources, energy consumption, or emissions seldom flows smoothly from field teams into central reporting platforms. Without reliable metrics and transparent reporting, it remains difficult to build a compelling business case or secure executive commitment.

Yet these very obstacles point to promising opportunities. Integrating sustainability into the agency's strategic plan and performance dashboards can align all divisions around a shared set of objectives. Digital tools, such as INVEST or the proposed framework in this report, RISE, offer a standardized, score-based approach that can be embedded into procurement, project development, and internal review processes. Formalizing cross-functional sustainability councils or project teams creates dedicated forums for collaboration, ensures knowledge transfer, and accelerates the uptake of best practices.

Finally, partnerships with academic institutions, industry, and peer agencies can bolster internal capacity and foster innovation. Pilot programs, tied to targeted funding or legislative incentives, can demonstrate real-world benefits and build broader support. By seizing these opportunities, while addressing structural, capacity, and data challenges, a DOT can transform sustainability from a peripheral concern into a core driver of project delivery and long-term resilience.

3. MEASURING SUSTAINABILITY IN RID PROJECTS

3.1 Exposure Metrics

RID generally unfolds in multiple phases—Planning, Design, Construction, Operations and Maintenance, and End-of-Life—each presenting distinct challenges and opportunities for evaluation, as previously discussed. In each phase, selecting appropriate exposure metrics is crucial for accurately gauging impacts, comparing project alternatives, and guiding cost-effective, sustainable decisions.

Exposure metrics serve as a means to "normalize" the magnitude of a given criterion, fostering fair comparisons among different proposals. Common examples in transportation include:

- Population
- Vehicle Miles Traveled (VMT)
- Passenger Miles Traveled (PMT)
- Traffic volume
- Number of drivers
- Number of households
- Number of registered vehicles

These metrics offer insights into usage patterns and potential local impacts. For example, FHWA identifies various exposure metrics for safety assessments—such as the number of pedestrian-vehicle interactions, vehicle miles traveled, average annual pedestrian volume, and bicyclist volume—that can be adapted to evaluate economic aspects of sustainable practices (Turner et al., 2017). In addition, reductions in GHG emissions, measured in tons of carbon dioxide, are increasingly recognized as a core metric for judging the effectiveness of interventions designed to minimize the environmental footprint of road projects (Mitoulis et al., 2023).

Based on a review of multiple guidelines and current studies, it is evident that these exposure metrics play a critical role across all phases of the infrastructure lifecycle. Their strategic application helps stakeholders estimate demand, allocate resources, and evaluate various economic and environmental scenarios with greater accuracy. A highlight on how these metrics can guide decision-making across the different phases of RID is presented below.

3.2 Sustainability Rating Systems

3.2.1 Introduction to Sustainability Rating Systems

Sustainability rating systems (SRS) have emerged as essential tools for assessing the environmental, economic, and social impacts of road infrastructure projects. These systems provide a structured framework to evaluate, compare, and improve sustainability performance, guiding decision-makers in integrating sustainable practices into the planning, design, construction, operations, and maintenance phases of road infrastructure development (Mattinzioli et al., 2020). The increasing global trends have underscored the importance of sustainable infrastructure, making these rating systems instrumental in shaping future transportation networks, while considering the TBL first mention by Elkington (1997), where profitable operations are possible with environmentally sound projects with focus on social progress.

Each SRS has a distinct methodology, scope, and certification process, often reflecting regional priorities, policy directives, and institutional frameworks. While some, such as Greenroads and CEEQUAL, emerged from academic and industry collaborations, others, including INVEST and GreenLITES, were developed by government agencies to align sustainability practices with public-sector infrastructure projects. Although these systems share fundamental sustainability principles, they differ significantly in evaluation methods, weighting criteria, and applicability (Clevenger et al., 2013; Mattinzioli et al., 2020; Simpson et al., 2014).

3.2.2 Review of Major SRS in Road Infrastructure

In this section, a detailed analysis of eight major SRS used in road infrastructure development is presented. Academic institutions, government agencies, and nonprofit organizations have developed these systems to assess the environmental, economic, and social impacts of transportation projects. Each system offers a unique approach to evaluating sustainability performance, with differences in structure, scoring methodology, certification levels, and applicability across project phases. By examining the origins, frameworks, and strengths and limitations of each system, this review highlights how SRS contribute to promoting sustainable practices in RIDP. The systems discussed include Envision, CEEQUAL, Greenroads, INVEST, GreenLITES, BE2ST-in-Highways, GreenPave, and I-LAST.

3.2.2.1 Envision. Developed by the Institute for Sustainable Infrastructure (ISI) in collaboration with the Zofnass Program for Sustainable Infrastructure at Harvard University, Envision was introduced in 2012 as a comprehensive, third-party verified SRS for various infrastructure sectors, including transportation, water, and energy systems. The first version was launched in 2011, followed by Envision v2 in 2012, which introduced 60 credits. The most recent version, Envision v3 (ISI, 2018), expanded to 64 credits and incorporated new climate resilience criteria, along with a four-tier certification framework: Verified (20%), Silver (30%), Gold (40%), and Platinum (50%; ISI, 2018). One of Envision's defining features is its holistic approach, evaluating sustainability across five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Resilience. The Quality-of-Life category assesses how infrastructure projects enhance community well-being, mobility, and access. Leadership measures stakeholder engagement, collaboration, and economic planning. Resource Allocation evaluates energy efficiency, water use, and material selection, while Natural World examines land use, conservation, and ecological impacts. Lastly, Climate and Resilience addresses emissions reduction, climate adaptation, and long-term infrastructure durability (ISI, 2018).

Envision follows a two-stage assessment process: a self-assessment checklist in Stage 1 and third-party verification with public recognition in Stage 2. While its rigorous, multisectoral approach enhances credibility, its broad scope may require adaptation for transportation-specific projects, making it more complex to implement in roadway development compared to a dedicated road-specific SRS.

3.2.2.2 CEEQUAL. The Civil Engineering Environmental Quality Assessment and Award (CEEQUAL) was established in 2003 in the United Kingdom as an environmental and social governance rating system for civil engineering projects (BRE Global Limited, 2020). Initially developed under the Institution of Civil Engineers, CEEQUAL merged with BREEAM (Building Research Establishment Environmental Assessment Method) in 2015, strengthening its international credibility and application. CEEQUAL Version 6 (V6) assesses sustainability using 11 weighted categories, including Management (11%), Resilience (12%), Communities and Stakeholders (11%), Land Use and Ecology (12%), Landscape and Historic Environment (9%), Pollution (8%), Materials and Waste (16%), Energy and Carbon (Construction; 5%), Energy and Carbon (Operational; 4%), Water Use (4%), and Transport (8%; BRE Global Limited, 2020). This assessment covers three project phases—Strategy (Planning), Design, and Construction—ensuring that sustainability is considered at all stages of infrastructure development. CEEQUAL's certification levels range from Outstanding (≥90%), Excellent (≥75%), Very Good (≥60%), Good (≥45%), Pass (≥30%), to Unclassified (<30%). While its third-party verification ensures a rigorous and transparent sustainability evaluation, its documentation-intensive process may pose challenges for smaller projects, making it better suited for large-scale infrastructure (Mattinzioli et al., 2020).

3.2.2.3 Greenroads. Developed in 2009 at the University of Washington, Greenroads was one of the first rating systems exclusively designed for roadway projects. Initially an academic initiative, the Sustainable Transport Council (STC, n.d.) now oversees it, a nonprofit public benefit corporation. Greenroads Version 2 (v2) is structured into three primary categories: Project Requirements (12 mandatory credits), Voluntary Core Credits (45 credits), and Voluntary Extra Credits (4 credits). The mandatory credits include key sustainability factors such as ecological impact analysis, lifecycle cost assessment, pollution prevention, waste management, noise and glare control, and social impact analysis. The voluntary credits are further divided into five subcategories: environmental impact, material selection, construction activities, access and livability, and utilities management (STC, n.d.). Greenroads has been implemented internationally in Canada, New Zealand, and Taiwan, showcasing its adaptability beyond the United States. Its strong focus on LCA, emissions reduction, and material optimization makes it a technically robust system. The majority of required criteria are derivatives of codes or laws; and do not present an additional burden to the project team (Clevenger et al., 2013). However, its heavy reliance on voluntary credits can lead to inconsistencies in sustainability evaluation across projects (Wu et al., 2015).

3.2.2.4 INVEST. The Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) was developed in 2011 by FHWA as a self-assessment tool for sustainability evaluation in transportation projects (FHWA, 2024). Unlike other SRS that rely on third-party verification, INVEST allows agencies to assess and improve sustainability performance internally. INVEST operates at four levels: System Planning for States, System Planning for Regions, Project Development, and Operations, Monitoring and Maintenance. The Project Development module includes 33 sustainability criteria, while the Operations, Monitoring and Maintenance module features 14 criteria. The system awards projects Bronze, Silver, Gold, or Platinum certifications based on their total score (FHWA, 2018). One of INVEST's key strengths is its flexibility, allowing agencies to evaluate sustainability at different project phases without requiring external certification. However, as a self-assessment tool, it lacks the accountability and third-party oversight found in Envision or CEEQUAL, making it more subjective and dependent on agency priorities (Clevenger et al., 2013; Mehraban et al., 2025).

3.2.2.5 GreenLITES. The Green Leadership In Transportation Environmental Sustainability (GreenLITES) rating system was launched in 2008 by the New York State Department of Transportation (NYSDOT) as an internal self-assessment tool for evaluating sustainability in transportation projects. Unlike third-party certification systems, GreenLITES is not an externally validated program; instead, it serves as a state-specific performance evaluation tool aimed at guiding decision making and project improvements rather than ranking projects against external benchmarks (Clevenger et al., 2013). GreenLITES evaluates projects across ten sustainability categories, each with a different weight in the overall score. These categories include sustainable alignment selection (16%), context-sensitive solutions (11%), land use and community planning (10%), stormwater management (5%), reuse of materials (5%), improved traffic flow (3%), reduction of electrical and petroleum consumption (5%), improvement of bicycle and pedestrian facilities (29%), noise abatement (13%), and stray light reduction (3%; NYSDOT, 2024). The rating system has four certification levels: Certified, Silver, Gold, and Evergreen, based on a project's cumulative score. GreenLITES offers several advantages over conventional certification-based systems. Its alignment with state policies and transportation objectives ensures that projects integrate sustainable development principles directly into agency workflows. Additionally, because it is an internal tool, it provides greater flexibility for assessing different project types without imposing external constraints. However, its lack of third-party oversight introduces potential bias and subjectivity, as evaluations depend on internal agency reviews rather than independent verification (Mattinzioli et al., 2020; Mehraban et al., 2025).

3.2.2.6 BE2ST-in-Highways. The Building Environmentally and Economically Sustainable Transportation-Infrastructure Highways (BE2ST-in-Highways) rating system was developed in 2010 by the University of Wisconsin-Madison. Unlike general-purpose sustainability rating systems, BE2ST-in-Highways focuses on quantitative assessment methods that integrate real-time data on lifecycle costs and environmental performance (Lee et al., 2010). This system primarily assesses projects in the planning and design phases, evaluating sustainability performance across nine core categories: LCCA, energy consumption, in-situ recycling/total recycling, hazardous waste reduction, water consumption, traffic noise, and social carbon cost (Recycled Materials Resource Center, n.d.). While weight assignments can be determined using the Analytic Hierarchy Process (AHP), this step is not mandatory, allowing for adaptable weighting schemes (Lee et al., 2010).

BE2ST-in-Highways provides three certification levels: Gold (≥90%), Silver (≥75%), and Bronze (≥50%), based on quantitative sustainability metrics. A key strength of this system is its integration of LCAs and real-time sustainability measurements, enabling agencies to quantify the impact of different materials, emissions, and energy use. However, BE2ST-in-Highways is highly technical, requiring specialized knowledge in LCA and sustainability economics, which can make it less accessible for general transportation agencies without dedicated sustainability expertise (Clevenger et al., 2013; Mattinzioli et al., 2020).

3.2.2.7 GreenPave. Developed in 2010 by the Ontario Ministry of Transportation, GreenPave is a pavement-specific sustainability rating system designed to evaluate the environmental impact of road surface materials, energy efficiency, and innovative pavement technologies (Simpson et al., 2014). Unlike broader infrastructure-focused SRS, GreenPave specifically targets pavement engineers, offering a streamlined approach to assessing sustainability in pavement design and construction (Chan et al., 2013). GreenPave evaluates projects based on four main sustainability categories: Pavement Technologies (9 points), Materials and Resources (11 points), Energy and Atmosphere (8 points), and Innovation and Design Process (4 points). The system awards three certification levels: Bronze (10–15 points), Silver (15–20 points), and Gold (20+ points; Simpson et al., 2014). One of GreenPave's major contributions to sustainable transportation infrastructure is its role in promoting Green Discounted Lifecycle Cost Analysis, a method designed to account for sustainability-driven cost savings in pavement investments (Chan et al., 2013). However, the narrow focus on pavement materials and technologies limits its applicability to broader roadway development projects. Additionally, since GreenPave has not been significantly updated since the early 2010s, its continued relevance in the face of evolving sustainability standards remains uncertain (Mehraban et al., 2025; Simpson et al., 2014).

3.2.2.8 I-LAST. The Illinois-Livable and Sustainable Transportation (I-LAST) rating system was developed in 2010 through a partnership between IDOT, the American Council of Engineering Companies (ACEC), and the Illinois Road and Transportation Builders Association. Unlike GreenPave, which is pavement-specific, I-LAST is a broader sustainability framework that applies to entire roadway projects, from planning and design to construction and implementation (IDOT, 2012). I-LAST evaluates projects using nine main sustainability categories: Planning, Design, Environmental Protection, Water Quality, Transportation Efficiency, Lighting, Materials, Innovation, and Construction Practices. Within these categories, the system defines 198 evaluation indicators and allocates a total of more than 300 credits (IDOT, 2012). These indicators enable customized project evaluations, allowing different projects to prioritize sustainability factors based on context-specific needs. One of I-LAST's most valuable attributes is its flexibility, allowing project teams to select sustainability strategies based on project-specific conditions. This adaptive approach makes it particularly useful for agencies and contractors who may not seek external certification but still wish to align with sustainability best practices (Clevenger et al., 2013). However, despite its strong technical framework, I-LAST has seen limited adoption beyond Illinois, restricting its broader national or international impact (Mattinzioli et al., 2020).

3.2.3 Mapping SRS Criteria to the Triple Bottom Line

As previously discussed, sustainability in infrastructure development is often conceptualized through the lens of the TBL, which emphasizes the balance among three key dimensions: economic viability, environmental stewardship, and social progress (Elkington, 1997). Although the boundaries between these pillars are not always rigid, classifying sustainability indicators into these three categories helps clarify how SRS prioritize different aspects of sustainable development in road infrastructure projects.

To assess the relative emphasis of each pillar across major SRSs, the criteria used by eight sustainability rating systems were classified according to their alignment with the economic, environmental, or social dimensions of the TBL. This classification follows a methodological approach similar to that proposed by Mattinzioli et al. (2020) and Mehraban et al. (2025), with an emphasis on minimizing unavoidable overlaps between pillars. Specifically, criteria related to project economy, material efficiency, and resource optimization, such as lifecycle costing and materials recycling, were assigned to the economic pillar. Criteria falling under the social pillar were guided by the Guidelines for Social Life Cycle Assessment of Products and Organizations (Benoît Norris et al., 2020), and include impacts on stakeholders such as workers, local communities, and broader society. Social indicators typically address areas such as human rights, labor conditions, health and safety, cultural heritage, and governance. For the environmental pillar, classification followed the Global Guidance on Environmental Life Cycle Impact Assessment Indicators developed by the (Frischknecht & Jolliet, 2017), and included metrics related to climate change, land use, energy use, emissions, and water resources.

The analysis reveals an imbalance in how SRSs weigh the three dimensions of sustainability. In general, environmental indicators dominate most SRS frameworks, followed by social and then economic indicators. This trend, as reflected in the number of indicators and their weights (Figure 3.1 and Figure 3.2, respectively), aligns with findings from other studies (Clevenger et al., 2013; Mattinzioli et al., 2020; Mehraban et al., 2025). A possible explanation for the strong presence of environmental indicators is that, historically, economic viability has been assessed separately through traditional feasibility studies, while social benefits are often assumed based on the project's intended function. As a result, environmental aspects—which were not systematically included in traditional evaluations—became the primary focus of sustainability-specific assessments.

Figure 3.1 and Figure 3.2 provide a comparative overview of the distribution of criteria and their weights across the three pillars for each of the eight SRSs reviewed. BE2ST-in-Highways places the highest emphasis on environmental sustainability, with 70% of its criteria aligned with this pillar. It is followed

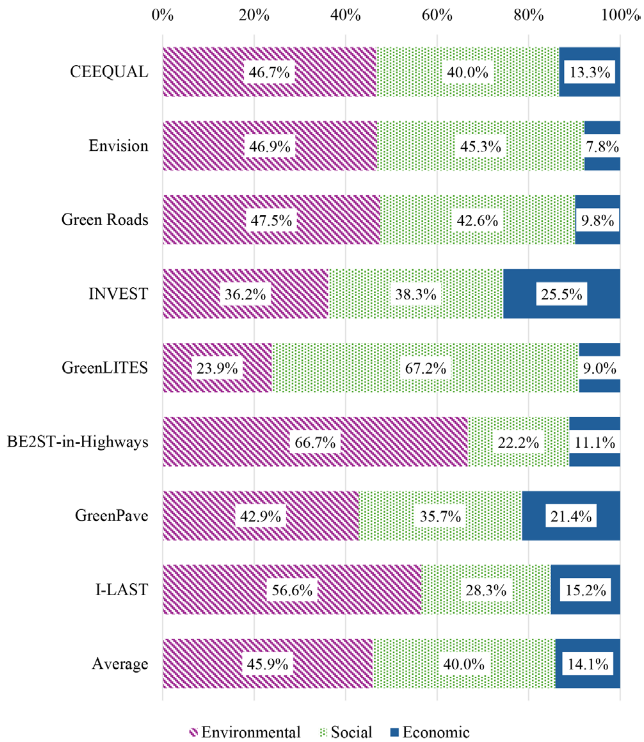

Figure 3.1 Distribution of Indicators on Different SRS Through the TBL.

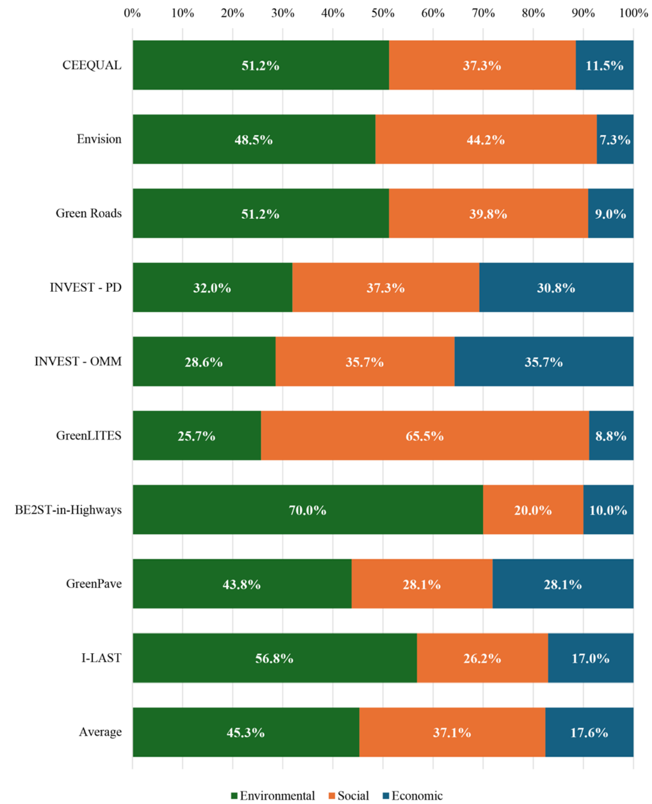

Figure 3.2 Comparison of Weight Contribution of SRS to the TBL.

by I-LAST (56.8%), GreenPave (43.8%), Envision (48.5%), Greenroads and CEEQUAL (both at 51.2%), and INVEST (32% and 28.6% for planning and design, and operations, respectively). The lowest proportion of environmental indicators is found in GreenLITES, with only 25.7% of its criteria weight falling into this category.

In terms of social sustainability, GreenLITES leads significantly, with 65.5% of its criteria addressing social concerns, particularly community planning and active transportation infrastructure. Other notable systems include Envision (42.2%), Greenroads (39.8%), CEEQUAL (37.3%), INVEST (37.3% and 35.7%), and GreenPave (28.1%). In contrast, I-LAST (26.2%) and BE2ST-in-Highways (20%) show the lowest emphasis on social criteria.

The economic pillar, which is consistently the least represented, has its highest weighting in INVEST, where 35.7% and 30.8% of the criteria align with economic sustainability. This is followed by GreenPave (28.1%), I-LAST (17%), CEEQUAL (11.5%), BE2ST-in-Highways (10%), Greenroads (9.0%), GreenLITES (8.8%), and Envision, with the lowest at 7.3%.

When averaging across all eight systems, the distribution of weights is as follows: environmental indicators account for approximately 45.3%, social indicators for 37.1%, and economic indicators for only 17.6% of total criteria. This suggests that while environmental and social factors receive considerable attention in the structure of current SRSs, the economic dimension remains underrepresented (Mattinzioli et al., 2020; Mehraban et al., 2025). Achieving a more balanced and holistic assessment of sustainability in road infrastructure development will require more deliberate inclusion of economic criteria—particularly those that address long-term cost-efficiency, financial risk, and value for money. This can be addressed by carefully weighting indicators, ensuring that all three pillars are proportionally and transparently reflected in evaluation outcomes.

3.3 Multicriteria Decision Analysis in RID

3.3.1 Introduction to Multicriteria Decision Analysis and Sustainability in RID

MCDA is a systematic framework designed to aid decision makers in evaluating alternatives based on multiple criteria of varying importance, measurement scales, and units. It provides a structured methodology for incorporating economic, environmental, and social factors into complex decision-making processes, ensuring that trade-offs are considered transparently and comprehensively (Keeney & Raiffa, 1993). The fundamental steps in MCDA include establishing alternatives, defining performance criteria, and applying weighting techniques to determine the relative importance of different criteria. This process allows decision-makers to systematically compare and rank alternatives, improving the objectivity and consistency of sustainability assessments in infrastructure projects.

In the context of RIDP, MCDA plays a pivotal role in addressing the multidimensional nature of sustainability. Traditional evaluation methods, such as cost–benefit analysis, often fail to capture nonmonetary impacts or the complex interdependencies between environmental, social, and economic dimensions (Sinha & Labi, 2007). MCDA fills this gap by offering a flexible yet rigorous approach that accommodates both quantitative and qualitative criteria. For instance, while lifecycle costs can be measured directly, factors such as community disruption require subjective judgments, which MCDA frameworks are designed to integrate. As a result, MCDA supports more balanced and transparent decision-making, particularly when multiple stakeholders with conflicting priorities are involved.

The use of MCDA has grown significantly in sustainability evaluations for transportation infrastructure, particularly as projects face increasing pressure to meet long-term performance goals. Numerous studies have applied MCDA techniques such as the AHP and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to assess trade-offs between sustainability objectives (Broniewicz & Ogrodnik, 2020; Hamurcu & Eren, 2020; Paredes & Herrera, 2020; Sierra, Pellicer, & Yepes, 2017; Torres-Machi et al., 2019). These methods are particularly useful when decision-makers must simultaneously account for environmental, economic, and social indicators.

3.3.2 Alternatives Establishment

Establishing alternatives is the first and foundational step in any MCDA process. This stage involves defining a set of project or policy options that address a specific decision problem, considering predefined objectives, constraints, and evaluation criteria. In infrastructure decision-making—much like in everyday choices—alternatives are typically assessed based on their expected costs, projected benefits, and alignment with overall project goals and stakeholder priorities.

In the context of transportation, the identification of alternatives plays a critical role, enabling decision-makers to systematically compare different design strategies, policy interventions, or investment scenarios (Arbel & Tong, 1982). These alternatives may include variations in construction materials, geometric design features, or operational approaches—each with its own set of sustainability implications. For example, a decision between traditional and recycled pavement materials may involve trade-offs between cost savings, environmental impact, and long-term durability.

However, despite the central role of alternatives establishment, research has shown that decision-makers often face difficulties in articulating clear objectives when relying solely on personal knowledge or intuition during the alternative development phase (Bond et al., 2008). This can lead to incomplete or biased option sets, undermining the effectiveness of the MCDA process. To address this, the literature proposes several structured approaches to support the formulation of alternatives, including hierarchical modeling of objectives (Colorni & Tsoukiàs, 2020) and process models that incorporate behavioral and cognitive dimensions of decision making (Hämäläinen et al., 2024).

Moreover, it is important to recognize that the development of alternatives is not always a linear or static process. As Ferretti et al. (2019) point out, it is common for new alternatives to emerge after an initial set has been defined, often driven by dissatisfaction with current options or the identification of unforeseen opportunities. These emergent alternatives should be welcomed and incorporated into the evaluation process, as they may lead to more innovative or context-sensitive solutions. Ultimately, the ability to consider and evaluate a diverse set of alternatives ensures a more robust and sustainable decision-making process.

3.3.3 Defining Performance Criteria

Once alternatives have been established, the next essential step in the MCDA process is the definition of performance criteria—the attributes used to evaluate and compare the effectiveness of each alternative. These criteria serve as both quantitative and qualitative benchmarks, guiding the assessment process and ensuring that evaluations are aligned with project objectives, stakeholder values, and contextual priorities (Sinha & Labi, 2007).

In transportation infrastructure management, performance criteria can vary widely depending on the type of project and the concerns of relevant stakeholders. For example, in bridge management systems, commonly used criteria include preservation needs, safety, protective measures, agency costs, and user costs (Patidar et al., 2007). These indicators help define the success or value of each alternative in measurable terms, supporting structured, transparent, and repeatable evaluations (De Neufville & Stafford, 1971).

Moreover, the contextual relevance of certain criteria may shift depending on the nature and location of the project. A project involving urban highways in historic areas may prioritize cultural and architectural preservation, while a rural project may place greater emphasis on accessibility (Labi, 2014). Recognizing this variation is critical to ensuring that sustainability assessments remain responsive to local needs and system-specific challenges.

It is also important to understand that the perceived importance of performance criteria can differ significantly across stakeholders (Sinha et al., 2009). For example, public agencies may emphasize cost-effectiveness, regulatory compliance, and maintenance needs, while community stakeholders or road users may prioritize safety, environmental quality, and accessibility. This divergence in perspective highlights the importance of explicitly incorporating stakeholder views—often addressed during the weighting process—to ensure balanced and equitable evaluations.

Additionally, growing emphasis has been placed on considering sustainability aspects when defining performance criteria (Alabi et al., 2021). Beyond technical and economic factors, criteria such as emissions reduction, resource efficiency, and lifecycle impacts are increasingly prioritized to support cleaner, more resilient infrastructure.

By clearly defining performance criteria at this stage, decision-makers can ensure that the evaluation process remains consistent, comprehensive, and aligned with both project-specific goals and broader sustainability objectives.

3.3.4 Weighting Methods

Assigning weights to performance criteria is a crucial step in MCDA, as it determines the relative importance of each criterion in the decision-making process. Weighting methods help

TABLE 3.1
Summary of Weighting Methods.

N.	Method	Pros	Cons	References
1	Equal Weighting	• Simple and intuitive. • Requires no subjective input from decision-makers. • Useful when stakeholder preferences are undefined, or data is lacking. • Applicable in early-stage infrastructure assessments with limited information.	• Assumes all criteria are equally important, which is rarely the case in practice. • May lead to suboptimal decisions by ignoring the actual relevance of each criterion. • Particularly problematic in sustainability assessments where indicators differ in impact.	Lamptey et al., 2005a; Li, 2003; Sinha & Labi, 2007
2	Direct Weighting	• Allows stakeholders to explicitly express preferences. • Intuitive and easy to implement. • Can be applied through different techniques (point allocation, categorization, ranking).	• Subject to respondent bias and inconsistencies in judgment. • Difficult to use when the number of criteria is large. • May require simplification for less-experienced stakeholders.	Bottomley & Doyle, 2001; Keeney & Raiffa, 1993; Labi, 2014; Odu, 2019; Patidar et al., 2007
3	Regression-based Weighting	• Empirical and data-driven, reducing reliance on subjective judgment. • Suitable when decision-makers can rank or score alternatives but not assign weights. • Captures implicit preferences through statistical modeling.	• Requires large datasets and advanced analytical tools. • May overemphasize criteria that dominate scoring, introducing bias. • Not always practical in early planning stages or data-scarce environments.	Hobbs & Meier, 2000; Patidar et al., 2007
4	Gamble Weighting	• Captures decision-makers' risk attitudes. • Suitable for contexts involving high uncertainty and probabilistic outcomes.	• Cognitively demanding and complex to implement. • Requires hypothetical probability scenarios, which can be hard to conceptualize. • May be unsuitable when best/worst case values are not clearly defined.	Li, 2003; Sinha et al., 2009
5	Pairwise Comparison (AHP and BWM)	• Structured and systematic. • Useful for complex decisions with both qualitative and quantitative criteria. • AHP: Widely adopted; accommodates hierarchical decision problems. • BWM: Reduces number of comparisons and improves consistency.	• AHP: Comparison count increases rapidly with more criteria. • Risk of inconsistency; requires a Consistency Ratio check. • BWM: Requires clear identification of most/least important criteria; still subjective.	AHP: Patidar et al., 2007; Saaty, 1977; Torres-Machi et al., 2019 BWM: Xiaomei et al., 2019; Rezaei, 2015
6	Delphi Method	• Integrates a wide range of expert opinions. • Reduces group pressure and dominant voice effects through anonymity. • Particularly useful for emerging or qualitative sustainability criteria.	• Time-intensive; requires multiple rounds to reach consensus. • Dependent on expert participation and consistency across rounds. • Lacks mathematical checks for consistency; purely judgment-based.	Bendaña et al., 2008; Cavalli-Sforza & Ortolano, 1984; Dalkey & Helmer, 1963; de la Cruz et al., 2008; Mullen, 2003; Sinha & Labi, 2007; Sourani & Sohail, 2015

convert stakeholder preferences into quantifiable values, ensuring that the final evaluation aligns with project priorities and sustainability goals (Paredes & Herrera, 2020). The choice of weighting method depends on the decision context, complexity, and availability of expert input (Bai et al., 2008). Table 3.1 provides a summary of different weighting methods used in MCDA, and the details are provided in Appendix E of this report.

3.3.5 Scaling/Normalization Methods

After assigning weights to decision criteria in MCDA, the next crucial step is scaling or normalization, which ensures that criteria values—often expressed in different units or magnitudes—are converted into a common scale to facilitate comparison (Vafaei et al., 2018). Since infrastructure sustainability assessments often involve diverse indicators, such as economic costs (measured in dollars), environmental impacts (measured in emissions), and social benefits (measured in qualitative scores), normalization is essential for standardizing the data and preventing criteria with larger numerical values from dominating the decision-making process. In most MCDA applications, normalization typically maps raw data to the interval [0,1] or [-1,1], ensuring consistency in the evaluation process (Labi, 2014).

Normalization methods vary depending on whether the criteria represent "benefit attributes" (where higher values are preferred, such as safety improvements) or "cost attributes" (where lower values are preferred, such as emissions or expenses). Similarly, normalization methods vary depending on the quantitative or qualitative nature of the indicator (Labi et al., 2009). The choice of normalization technique significantly impacts the sensitivity and fairness of the evaluation process, as some

TABLE 3.2
Summary of Normalization Methods.

N.	Method	Pros	Cons	References
1	Direct Rating	• Simple and intuitive. • Easy to apply for qualitative criteria or discrete levels. • No need for large datasets; based on expert opinion.	• Highly subjective; may vary significantly between evaluators. • Reduces comparability and objectivity. • Limited use in quantitative data contexts.	Hobbs & Meier, 2000; Sinha & Labi, 2007
2	Mid-Value Splitting	• Captures decision-maker preferences with more nuance. • Reflects perceived indifference points and satisfaction thresholds. • Useful when evaluators are sensitive to performance ranges.	• Time-consuming and requires high respondent involvement. • Complex to implement and not suitable for large datasets.	Keeney & Raiffa, 1993; Sinha & Labi, 2007
3	Vector Normalization	• Preserves proportional differences in criteria. • Avoids dominance of high-magnitude indicators. • Suitable for cases with high variability across indicators.	• Does not guarantee [0,1] bounds. • Comparisons across projects or time periods may be unreliable due to instability of vector norms.	Hwang & Yoon, 1981; Nijkamp, 1977
4	Linear Scale Transformation (Max-Min Normalization)	• Widely used and easy to interpret. • Normalizes values to [0,1] range, ensuring comparability. • Works for both benefit and cost criteria with formula adjustments.	• Highly sensitive to outliers, which can distort results. • Performance depends on data range stability.	Hwang & Yoon, 1981; Talukder et al., 2017
5	Logarithmic Normalization	• Effective for criteria with vastly different magnitudes. • Reduces the influence of extreme values more effectively than linear methods.	• Not suitable for zero or negative values (may produce undefined results). • Requires data transformation and interpretation of logarithmic outputs.	Vafaei et al., 2018; Zavadskas & Turskis, 2008

methods are more resistant to outliers, while others preserve proportional differences in performance. The common normalization methods used in MCDA are summarized in Table 3.2.

3.3.6 Amalgamation Methods

After the criteria values have been weighted and normalized, the next step in MCDA is amalgamation, which integrates these values to compute a final sustainability score for each alternative (Sinha & Labi, 2007). Amalgamation ensures that decision makers can evaluate, rank, and select the best-performing option based on a holistic assessment of all criteria. The general process involves multiplying each normalized value by its assigned weight and summing the results to generate a composite performance score. Different amalgamation techniques offer varying levels of complexity, sensitivity, and interpretability in sustainability assessments (Table 3.3).

3.4 Other Methods for Assessing Sustainability in RID

MCDA has become a leading approach for evaluating sustainability in RIDP. However, it is only one of several methodologies available in the literature. As mentioned before, evaluating sustainability in RIDP requires a systematic and comprehensive approach that accounts for the economic, environmental, and social dimensions of infrastructure performance. Over the years, researchers and practitioners have developed various methodologies to assess, compare, and prioritize sustainable alternatives. These range from traditional economic analyses and LCA to mixed-method approaches, conceptual frameworks, and advanced data-driven techniques. Each method serves a distinct purpose and provides unique insights, depending on the decision context, data availability, and the complexity of the project under consideration.

Economic analyses, particularly cost–benefit analysis (CBA), have long been used to determine the financial feasibility of infrastructure projects (Henke, Cartenì, & Di Francesco, 2020). While CBA remains a foundational method for evaluating project efficiency, it often fails to account for broader social and environmental impacts. This limitation has encouraged the integration of MCDA and other tools that can capture qualitative aspects of sustainability and ensure more balanced assessments (Sinha & Labi, 2007). The combination of economic and multicriteria frameworks enables a more nuanced understanding of the full value of sustainability-oriented interventions.

Lifecycle-based approaches have also gained significant traction in sustainability assessments. Environmental Lifecycle Assessment (E-LCA) examines material use, energy consumption, and emissions over the lifespan of a project, while LCCA focuses on long-term economic performance, including maintenance and operating costs (Arshad et al., 2021; Yang et al., 2018). More recently, Social Lifecycle Assessment (S-LCA) has emerged as a tool to evaluate the societal impacts of infrastructure, and Lifecycle Sustainability Assessment (LCSA) has been introduced to integrate environmental, economic, and social dimensions within a single evaluative framework (Patel & Ruparathna, 2023). These lifecycle methods are particularly valuable when seeking to understand long-term and indirect sustainability outcomes.

TABLE 3.3
Summary of Amalgamation Methods.

N.	Method	Pros	Cons	References
1	Weighted Sum Method (WSM)	• Simple, transparent, and easy to apply. • Widely used in infrastructure evaluations. • Results are straightforward to interpret.	• Assumes linearity and perfect substitutability between criteria. • Fails to capture interactions or synergies among indicators. • May oversimplify trade-offs in sustainability assessments.	Hazelrigg, 2019; Li, 2003; Sinha & Labi, 2007
2	TOPSIS	• Considers both ideal and worst-case solutions. • Balances trade-offs among benefit and cost criteria. • Provides relative closeness score for each alternative.	• Does not account for correlations or interdependencies between criteria. • Sensitive to normalization method and scaling of data.	Bai et al., 2008; Hwang & Yoon, 1981; Papathanasiou & Ploskas, 2018
3	VIKOR	• Incorporates both group utility (overall performance) and individual regret (worst-case performance). • Suitable for compromise-based decision-making. • Effective when decision-makers are hesitant to assign strict weights.	• May not reflect real-world preferences unless supplemented with expert consultation. • Relies on pre-specified compromise coefficient (v), which can affect rankings.	Gul et al., 2016; Opricovic, 1998
4	PROMETHEE	• Uses pairwise comparison without needing assumptions of linearity. • Effective for ranking with multiple conflicting criteria. • Outranking approach provides nuanced evaluation.	• Requires careful selection of preference functions, which may add complexity. • Less intuitive for stakeholders unfamiliar with pairwise flows.	Brans & Vincke, 1985; Pohl & Geldermann, 2024
5	ELECTRE	• Suitable for eliminating dominated alternatives in complex problems. • Captures both agreement and strong opposition among criteria. • Well-suited for decision contexts involving uncertainty or conflicting interests.	• Computationally intensive. • May not produce a full ranking—only identifies non-dominated options	Roy, 1991
6	MOORA	• Fast and computationally efficient. • Combines benefit-cost ratio analysis with straightforward implementation. • Useful for rapid sustainability evaluations across alternatives.	• Less robust for highly complex decision environments. • Interpretation can be sensitive to scaling of benefit vs. cost criteria.	Brauers & Zavadskas, 2006

In addition to standalone methods like MCDA and LCA, hybrid and mixed-method approaches have been used to address the multifaceted nature of sustainability in RIDP. For example, Fuzzy Spatial Multicriteria Analysis (MCA) allows for the integration of geospatial information and subjective expert input while handling uncertainty and imprecision, making it particularly effective in complex decision environments (Song et al., 2021). Conceptual frameworks have also been proposed to provide theoretical guidance on sustainability indicators, stakeholder roles, and methodological structures (Ametepey et al., 2019; Oboroceanu, 2024). These frameworks support the design of tailored sustainability evaluations aligned with context-specific objectives.

Beyond these frameworks, several advanced analytical tools have also been applied in the literature. Data Envelopment Analysis (DEA) has been used to evaluate the efficiency of infrastructure projects based on the relationship between inputs and outputs, allowing decision-makers to identify best-performing alternatives (Stefaniec et al., 2020; Z. Zhang et al., 2015). System Dynamics (SD) has proven useful in modeling the interactions and feedback loops between different components of transportation systems, enabling the simulation of long-term sustainability outcomes under varying policy or environmental conditions (Kaira et al., 2022; Ruiz & Guevara, 2020; Sierra, Pellicer, & Yepes, 2017). Similarly, Bayesian Networks have been used for probabilistic modeling and risk assessment, particularly in contexts where data are incomplete or uncertain (Sierra et al., 2018). These methods offer a high level of analytical sophistication and are particularly suitable for complex infrastructure systems characterized by uncertainty, dynamic behavior, and multiple interacting components.

Given the diversity of methodologies used in sustainability assessments of RIDP, Table 3.4 provides a structured summary of these approaches along with key references, highlighting the breadth of tools available to researchers and practitioners aiming to evaluate sustainability comprehensively.

3.5 Lessons Learned from Rating Systems and Frameworks

The review of eight leading Sustainability Rating Systems—Envision, CEEQUAL, Greenroads, INVEST, GreenLITES, BE2ST-in-Highways, GreenPave, and I-LAST—reveals both common strengths and persistent gaps. Each system offers a structured set of evaluation categories and certification

TABLE 3.4
Methods to Address Sustainability in RID Projects.

Methodology	Specific Methodology		References
Economic Analysis	Cost–Benefit Analysis (CBA)		Henke, Cartenì, & Di Francesco, 2020; Henke, Cartenì, Molitierno, & Errico, 2020; Patidar et al., 2007; Sinha et al., 2009; Sinha & Labi, 2007
Multicriteria Decision Making (MCDA)	Multiattribute Analysis (MADM)	Direct Assignment Approach	Alam et al., 2017; Paredes & Herrera, 2020; Santos et al., 2019; Yang et al., 2018
		Analytical Hierarchical Process (AHP)	Arshad et al., 2021; Broniewicz & Ogrodnik, 2020; Hamurcu & Eren, 2020; Henke, Cartenì, & Di Francesco, 2020; Paredes & Herrera, 2020; Ruiz & Guevara, 2020; Sierra, Pellicer, & Yepes, 2017; Sierra, Yepes, & Pellicer, 2017; Torres-Machí et al., 2015, 2019
		Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	Bai et al., 2012; Broniewicz & Ogrodnik, 2020; Hamurcu & Eren, 2020; Paredes & Herrera, 2020
Lifecycle Analysis	Environmental Lifecycle Assessment (LCA)		Arshad et al., 2021; Yang et al., 2018
	Lifecycle Costing Analysis (LCCA)		Walls & Smith, 1998; Yang et al., 2018
	Social Lifecycle Assessments (S-LCA)		Arshad et al., 2021
	Lifecycle Sustainability Analysis (LCSA)		Arshad et al., 2021; Patel & Ruparathna, 2023
Mixed Methods	Fuzzy Spatial MCA		Song et al., 2021
Conceptual			Ametepey et al., 2019; Oboroceanu, 2024
Others	Data Envelopment Analysis (DEA)		Stefaniec et al., 2021
	System Dynamics (SD)		Kaira et al., 2022; Ruiz & Guevara, 2020; Sierra, Pellicer, & Yepes, 2017
	Choosing by Advantages (CBA)		Torres-Machi et al., 2019
	Bayesian Network		Sierra et al., 2018

NOTE: Some of the methods presented in this table are not mutually exclusive and may be applied in combination. In practice, they can serve complementary roles, enhancing the overall robustness and comprehensiveness of sustainability assessments.

processes that guide project teams through environmental, social, and economic considerations. However, a clear pattern emerges in which environmental criteria typically dominate, social factors receive moderate attention, and economic dimensions are often underweighted. This uneven emphasis can skew decision-making toward ecological performance, potentially at the expense of financial feasibility and local economic impacts.

MCDA techniques—ranging from AHP and Best-Worst Method (BWM) to TOPSIS and VIKOR—have been widely adopted to address the inherent trade-offs among sustainability goals. Weighting, normalization, and amalgamation methods bring rigor and transparency to these choices, yet the diversity of approaches also introduces inconsistency. Subjective weighting without clear stakeholder engagement can undermine credibility, while purely data-driven methods may overlook contextual nuances.

Beyond formal rating tools, complementary methods such as lifecycle assessment (LCA, LCCA, S-LCA), CBA, fuzzy multicriteria models, and analytical techniques (DEA, SD, Bayesian Networks) offer valuable insights at different scales and data levels. These approaches underscore the importance of matching the assessment method to project scope, stakeholder needs, and available information.

In sum, existing frameworks have advanced the practice of sustainability assessment in road infrastructure by providing structured, repeatable processes. Yet the underrepresentation of economic indicators, the lack of standardization in weighting and scoring, and limited adaptability to local contexts persist as significant challenges. Addressing these issues will require more balanced indicator sets, clearer stakeholder-driven weighting protocols, and flexible frameworks that can be tailored to agency priorities and project realities. These lessons inform the design of the RISE framework and guide its emphasis on comprehensive, transparent, and context-sensitive evaluation.

4. BUILDING THE BUSINESS CASE – THE RISE FRAMEWORK

4.1 Overview of the RISE (Road Infrastructure Sustainability Evaluation) Tool

This chapter presents the structure and components of the Road Infrastructure Sustainability Rating Evaluation (RISE), a decision-support framework developed to assess the sustainability performance of RIDPs. RISE was designed to address a key gap in current infrastructure evaluation practices: while public agencies often assess projects based on conventional criteria such as travel time savings, construction costs, and emissions estimates, sustainability considerations are often fragmented, inconsistently applied, or overlooked in decision-making. The RISE framework provides a structured means of incorporating sustainability into project evaluations through a flexible and transparent rating system that is sensitive to contextual, institutional, and phase-specific factors.

The tool comprises 31 sustainability indicators identified through a comprehensive review of peer-reviewed literature, technical guidelines, and rating system documentation. These indicators are categorized under the TBL framework—environmental, social, and economic—and are further supported by 96 evaluation criteria that operationalize how each indicator can be measured in practice. Each evaluation item is rated on a structured scale with five achievement tiers (0 to 100%), promoting consistency and clarity in the assessment process. The weights for the indicators were derived from a structured survey administered to professionals at a transportation agency, who evaluated the relevance of each indicator across the four main phases of RIDP: Planning and Design; Construction; Operations, Monitoring and Maintenance; and End-of-Life. This approach ensures that the tool reflects practitioner priorities while maintaining a balanced representation of all three pillars of sustainability. The following sections describe the sustainability indicators and evaluation criteria used in RISE, followed by the presentation of indicator weights across project phases.

4.2 Development of Alternatives

The first step in the proposed evaluation framework is the development of alternatives, which serves as the foundation for applying MCDA techniques. In infrastructure decision-making, alternatives are sets of project options or design strategies developed to address a specific transportation or development need within a defined context of objectives, constraints, and evaluation criteria. Alternatives can vary widely—from differing material selections and alignment choices to contrasting traffic management approaches—each involving distinct trade-offs in terms of sustainability performance (Bai et al., 2015, 2021). Identifying alternatives allows for a structured comparison of options and supports the selection of the most sustainable project through comprehensive and criteria-based analysis. At this step it is important to distinguish between a feasibility study and a multialternative evaluation. A feasibility study is typically a binary assessment that determines whether a single project or option is viable—that is, whether it should be implemented or not. In contrast, a multialternative evaluation involves comparing several competing options that are all considered feasible, with the goal of selecting the most suitable one based on performance across defined criteria such as cost, environmental impact, or social benefits.

Public agencies are already employing MCDA principles in project selection. Decision-making frameworks commonly used today rely on the evaluation of traditional and widely accepted performance measures, such as travel time savings, traffic volumes, safety outcomes, and lifecycle costs (Vassallo & Bueno, 2021). These metrics are combined—often through benefit–cost analysis, scoring rubrics, or priority matrices—to compare and rank projects based on operational efficiency and economic feasibility. However, while effective for technical evaluation, these approaches rarely account for sustainability comprehensively. Environmental impacts are often limited to regulatory compliance (e.g., emissions thresholds or right-of-way constraints), and social or long-term resilience considerations are frequently underrepresented or excluded entirely (Henke, Cartenì, & Di Francesco, 2020; Jeon et al., 2013).

The RISE tool is proposed as a complement to these existing evaluation systems, offering a structured and transparent approach to integrating sustainability into project assessment. It can serve two primary functions. First, when traditional RIDP performance indicators meet expected thresholds or targets, RISE can help practitioners evaluate which alternative integrates sustainable practices more thoroughly, providing a comparative score (the RISE score) that quantifies sustainability performance across a diverse set of indicators. Second, the RISE score can be used independently as an additional decision criterion, allowing agencies to assign sustainability weight in broader project prioritization exercises. In both cases, RISE functions as a stakeholder-informed, decision-support tool that guides infrastructure planners, policymakers, and engineers in promoting sustainability through more informed, balanced, and data-driven project evaluation.

4.3 Indicator Selection

4.3.1 Identification of Indicators to Measure Sustainability in RID

Sustainability indicators are measurable metrics used to assess and monitor the sustainability performance of infrastructure projects. They play a vital role in capturing the multidimensional impacts of road infrastructure development, enabling decision-makers to evaluate trade-offs across various sustainability domains (Kapatsa et al., 2023). These indicators are typically organized under the three pillars of the TBL: environmental, social, and economic. Environmental indicators assess a project's ecological footprint, social indicators capture its societal benefits and risks, and economic indicators measure financial viability and long-term economic value (Dillman et al., 2023; Jeon & Amekudzi, 2005; Mattinzioli et al., 2020). A structured and comprehensive identification of these criteria or indicators is essential to ensure that sustainability evaluations reflect the full range of impacts associated with RID.

To identify relevant sustainability indicators for the proposed evaluation framework, a systematic literature review was conducted, focusing on peer-reviewed studies, guidelines, and technical reports that addressed sustainability in the context of RIDP. Several key studies in the field have previously reviewed and categorized sustainability indicators. For example, Oboroceanu (2024) developed a conceptual framework for sustainable road infrastructure that emphasized critical dimensions, including energy efficiency, material durability, smart traffic management, and long-term resilience. Their analysis also highlighted key success factors during the operation, monitoring, and maintenance phase, including asset utilization, service quality, lifecycle value, and best practices in Operations, Monitoring, and Maintenance. Vijayakumar et al. (2022) carried out a systematic literature review specifically focused on social sustainability in RID projects, identifying nine major criteria—such as stakeholder participation, employment, health and safety, governance, and macro-social engagement—along with 78 specific indicators. Their work also highlighted the ambiguity of social sustainability metrics, a factor that contributes to the underrepresentation of social considerations in infrastructure planning and decision-making. Similarly, Suprayoga et al. (2020) used both qualitative and quantitative techniques to extract and cluster sustainability indicators in road infrastructure. Their review revealed ten main indicator categories but noted that important dimensions like intergenerational equity and adverse environmental effects were rarely represented in existing SRS frameworks, reinforcing the conclusions made by Vijayakumar et al. (2022). Navarro et al. (2019) on the other hand, reviewed multicriteria evaluation techniques applied to infrastructure sustainability, finding that while the AHP was the most frequently used weighting method in the literature, the Direct Weighting Method was the most commonly applied in practice.

To build on these studies, a systematic literature search was conducted using two primary databases: ScienceDirect and Scite.ai. The search included the following keyword combinations: "Sustainability" AND "Road Infrastructure", "Sustainability" AND "Road Infrastructure Development," and "Sustainability" AND "Road Projects." This search yielded a total of 6,813 documents, including peer-reviewed journal articles, conference proceedings, and book chapters. After removing 129 duplicate entries, the remaining records were screened based on predefined inclusion and exclusion criteria.

Only documents written in English and published within the past 10 years were considered to ensure recency and relevance. Articles were included if they addressed sustainability indicators, evaluation frameworks, or methodologies directly applicable to road infrastructure development. Studies that fell outside this scope or were older than 10 years were excluded from further review.

To facilitate the screening of this large dataset, the documents were imported into ASReview, a machine-learning-based tool for active learning literature reviews (van de Schoot et al., 2021). The software was initially trained using a seed sample of five relevant and five irrelevant articles identified by the research team. As reviewers manually labeled additional papers, the model iteratively refined its relevance predictions and continuously retrained. The review process was terminated when the software flagged 25 consecutive articles as irrelevant, a stopping rule shown to capture at least 95% of relevant literature with high confidence (van de Schoot et al., 2021). This method has been increasingly adopted in recent literature reviews across various disciplines, including transportation (Dillman et al., 2023; Klos et al., 2023), psychology (Franzoi et al., 2024), and medicine (Vaseur et al., 2024).

Following this process, 69 articles were selected for full-text review. Of these, 34 were deemed relevant to the identification and evaluation of sustainability indicators in RIDP. These papers formed the foundation for indicator selection in this framework. The complete screening process is summarized in Figure 4.1.

After full-text screening and analysis, the sustainability indicators extracted from the literature were categorized based on the TBL framework. Three primary categories were defined—Environmental, Social, and Economic. In addition, indicators were linked to different phases of the infrastructure lifecycle: Planning & Design; Construction; Operations, Monitoring, and Maintenance; and End of Life.

In total, 31 distinct sustainability indicators were identified through the literature review and systematically classified under the three pillars of the TBL: environmental, social, and economic. Each indicator was further defined using one or more evaluation criteria—measurable elements or metrics drawn from the literature that operationalize how the indicator can be assessed in practice. In total, 96 evaluation criteria were compiled to support the measurement of the 31 indicators. This structured approach allows for a nuanced and comprehensive assessment of sustainability performance across all phases of road infrastructure development, while also enabling comparability across projects and adaptability to varying contexts.

4.3.2 Sustainability Indicators Used in RISE

Three categories of sustainability indicators were defined based on the TBL: environmental, social, and economic. Within the environmental category, six subcategories were identified: resource utilization efficiency, sustainable materials and resources, waste management, habitat and biodiversity management, pollution control, and climate resilience. Fifteen indicators and their respective evaluation items or performance measures were identified in the environmental category,

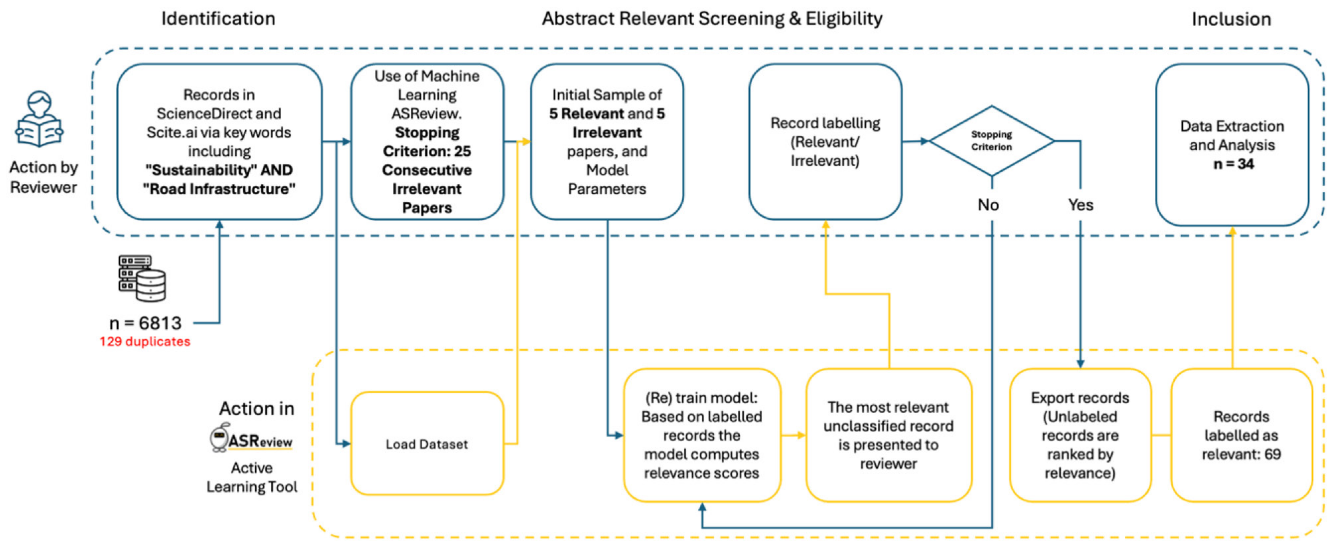

Figure 4.1 Systematic Review Process.

primarily covering the entire lifecycle of the project, including the planning, design, and construction phases.

The social category was divided into seven subcategories: employment, mobility and accessibility, community health and safety, societal well-being, cultural and heritage integration, socioeconomic repercussions, and governance and human rights. Twelve indicators were defined in the social category, with their respective performance measures, predominantly focusing on the whole project perspective and planning and design phases. The economic category was defined with two subcategories: Investment Return Metrics and Cost Management. Investment Return Metrics are represented by common economic indicators used in infrastructure economic analyses, such as net present value, internal rate of return, and payback period. These indicators focus on evaluating the efficiency and profitability of investments over the project lifecycle. On the other hand, Cost Management refers to the control of overall project costs per unit of output or activity, including operation costs, investment costs, disposal costs, maintenance costs, and other lifecycle expenditures. The following subsections describe the indicators grouped under each TBL category. A complete overview, including subcategories, indicators, and evaluation criteria, is provided in Table 4.1, while the achievement tiers for scoring are presented in Appendix D.

4.3.2.1 Environmental Sustainability Indicators

4.3.2.1.1 Energy Conservation. Energy conservation is a fundamental pillar of environmental sustainability in infrastructure. In RIDPs, this indicator assesses efforts to reduce energy consumption and promote clean energy usage across all project phases. Key strategies include the adoption of renewable energy sources (e.g., solar panels for lighting and signage), the integration of energy-efficient construction machinery, and the promotion of energy monitoring systems throughout the infrastructure's operation (Kapatsa et al., 2023; Kissi et al., 2023; Suprayoga et al., 2020). Three evaluation criteria support this indicator: (1) the adoption of renewable energy sources, (2) implementation of energy-saving technologies and practices, and (3) promotion of energy consumption monitoring plans. These practices not only reduce GHG emissions but also contribute to long-term cost savings and climate resilience (Navarro et al., 2019; Sumabrata et al., 2022).

4.3.2.1.2 Resource Efficiency. Resource efficiency focuses on minimizing the use of raw materials and energy-intensive equipment to reduce environmental degradation. By optimizing construction methods, promoting material reuse, and minimizing waste generation, RIDPs can reduce their environmental footprint while improving economic performance (Suprayoga et al., 2020; World Bank, 2016). This indicator is assessed using two criteria: (1) the use of energy-efficient construction machinery and vehicles, and (2) efficient use of construction materials to prevent overuse and unnecessary waste. It supports sustainable construction practices and aligns with broader circular economy principles (Kapatsa et al., 2023; Navarro et al., 2019).

4.3.2.1.3 Water Efficiency. Efficient water management is essential for reducing pressure on freshwater resources and mitigating stormwater-related risks. In RIDPs, water efficiency can be enhanced through the reuse of greywater, stormwater harvesting, and integration of low-impact technologies (Suprayoga et al., 2020). This indicator includes four evaluation criteria: (1) use of greywater for construction and maintenance, (2) development of a water management plan, (3) integration of stormwater runoff strategies, and (4) implementation of water harvesting systems. These practices contribute to both environmental protection and operational resilience (Kapatsa et al., 2023; Sumabrata et al., 2022).

4.3.2.1.4 Material Selection. Selecting sustainable materials is vital for reducing the embodied carbon and environmental impact of road infrastructure. Emphasis is placed on using

TABLE 4.1
RISE: Sustainability Indicators.

Category	Subcategory		Indicator		Evaluation Criteria		Project Wide: All Phases	Planning and Design	Construction	Operations, Monitoring, and Maintenance
Environmental	E.1	Resource Utilization Efficiency	E.1.1	Energy Conservation	E.1.1.1	Adoption of renewable energy sources (e.g., solar, wind)	Navarro et al., 2019; Sumabrata et al., 2022; Suprayoga et al., 2020	Kapatsa et al., 2023; Kissi et al., 2023	Kapatsa et al., 2023	
					E.1.1.2	Implementation of energy-saving technologies and practices				
					E.1.1.3	Promotion of energy consumption monitoring plan				
			E.1.2	Resource Efficiency	E.1.2.1	Use of energy-efficient machinery and vehicles	Navarro et al., 2019; Suprayoga et al., 2020	Kapatsa et al., 2023	Kapatsa et al., 2023	
					E.1.2.2	Efficient use of construction materials to reduce waste				
			E.1.3	Water Efficiency	E.1.3.1	Grey water reuse	Sumabrata et al., 2022; Suprayoga et al., 2020	Kapatsa et al., 2023	Kapatsa et al., 2023	
					E.1.3.2	Control of water use				
					E.1.3.3	Storm water runoff management				
					E.1.3.4	Rainwater harvesting				
	E.2	Sustainable Materials and resources	E.2.1	Material Selection	E.2.1.1	Recyclable materials	Sumabrata et al., 2022; Suprayoga et al., 2020	Kapatsa et al., 2023; Kissi et al., 2023	Kapatsa et al., 2023; Torres-Machi et al., 2019; Yang et al 2018	
					E.2.1.2	Use of natural resources (soil, wood, bamboo, etc.)				
					E.2.1.3	Durable material resources				
					E.2.1.4	Re-use of pavement materials for construction				
					E.2.1.5	Virgin Material consumption				
			E.2.2	Local Sourcing	E.2.2.1	Sustainable Procurement of materials (Locally available)				
	E.3	Waste Management	E 3.1	Waste Reduction and Recycling	E.3.1.1	Waste collection	Navarro et al., 2019; Sumabrata et al., 2022; Suprayoga et al., 2020	Kapatsa et al., 2023	Wu et al., 2015	
					E.3.1.2	Recycling and reuse of waste				
			E.3.2	Environmental Impact of Waste	E.3.2.1	Ozone depletion				
					E.3.2.2	Eutrophication				
	E.4	Habitat and Biodiversity Management	E.4.1	Habitat Fragmentation and Connectivity	E.4.1.1	Barrier effect reduction for wildlife movement	Navarro et al., 2019; Suprayoga et al., 2020	Hamurcu & Eren, 2020		
					E.4.1.2	Habitat connectivity enhancement				
					E.4.1.3	Protection of valuable habitats and natural (ecological) areas				
			E.4.2	Land Use Management	E.4.2.1	Density of land use				
					E.4.2.2	Minimization of productive land conversion				
	E 5	Pollution Control	E.5.1	Air Pollution Control	E.5.1.1	Reduction of vehicular emissions (specify pollutants like NOx, CO, PM10, CO2)	Navarro et al., 2019; Suprayoga et al., 2020	Hamurcu & Eren, 2020; Henke, Cartenì, & Di Francesco, 2020; Henke, Cartenì, Molitierno, Errico, 2020	Torres-Machi et al., 2019	Ruiz & Guevara, 2020
			E.5.2	Light and Noise Pollution	E.5.2.1	Decrease in light pollution from roadways				
					E.5.2.2	Noise and vibration levels control during construction and operation				
			E.5.3	Dust Management	E.5.3.1	Dust suppression measures during construction phases				

(*Continued*)

TABLE 4.1
RISE: Sustainability Indicators. *(Continued)*

Category		Subcategory		Indicator		Evaluation Criteria	Project Wide: All Phases	Planning and Design	Construction	Operations, Monitoring, and Maintenance
Environmental	E.6	Climate Resilience	E.6.1	Green Gas Emission	E.6.1.1	GHG emissions reduction strategies				Alam et al., 2017; Stefaniec et al., 2021
			E.6.2	Adaptation to Climate Impacts	E.6.2.1	Integration of climate-adaptive landscaping (e.g., heat-resilient plant species)	Ametepey et al., 2019, 2023; Suprayoga et al., 2020	Henke, Cartenì, Molitierno, Errico, 2020; Kissi et al., 2023		
					E.6.2.2	Disaster risk reduction in design (addressing erosion, landslides, floods)				
			E.6.3	Stormwater Control and Management	E.6.3.1	Stormwater runoff management to reduce volume and peak flow				
Social	S.1	Employment	S.1.1	Comprehensive Health and Safety Measures at Work	S.1.1.1	Working conditions	Arshad et al., 2021; Kapatsa et al., 2023; Sumabrata et al., 2022	Sierra, Yepes, & Pellicer, 2017		Stefaniec et al., 2021
					S.1.1.2	Health and safety training				
					S.1.1.3	Provision of personal protective equipment (PPE)				
					S.1.1.4	Onsite medical services				
					S.1.1.5	Safety measures (e.g., site hoarding, safety warnings)				
					S.1.1.6	Traffic accident rates involving personal injury or death				
			S.1.2	Promoting Employee Well-being	S.1.2.1	Employment of local labor	Kapatsa et al., 2023	Sierra et al., 2018		
					S.1.2.2	Employee well-being and benefits				
					S.1.2.3	Equal rights and opportunities across diverse groups				
			S.1.3	Ensuring Workplace Integrity and Fair Practices	S.1.3.1	Job stability and security	Vijayakumar et al., 2022, 2023a, 2023b; Sierra, Pellicer, & Yepes, 2017; Sierra, Yepes, & Pellicer, 2017	Sierra, Pellicer, & Yepes, 2017; Sierra, Yepes, & Pellicer, 2017		
					S.1.3.2	Non-discriminatory hiring practices				
					S.1.3.3	Anti-corruption measures				
					S.1.3.4	Fair remuneration and reasonable workload				
					S.1.3.5	Knowledge and skills transfer				
			S.1.4	Active and Inclusive Stakeholder Involvement	S.1.4.1	Stakeholder acceptability	Ametepey et al., 2019, 2023; Sumabrata et al., 2022; Vijayakumar et al., 2022, 2023a, 2023b	Kapatsa et al., 2023; Sierra et al., 2018; Sierra, Yepes, & Pellicer, 2017	Kapatsa et al., 2023	
					S.1.4.2	Early involvement of stakeholders				
					S.1.4.3	Timely and relevant information sharing				
					S.1.4.4	Freedom of participation in decision-making				
	S.2	Mobility and Accessibility	S.2.1	Improvement Measures in Mobility and Accessibility	S.2.1.1	Project achieves measurable travel time savings for users	Labi et al., 2019; Suprayoga et al., 2020; Vijayakumar et al., 2022, 2023a, 2023b	Henke, Cartenì, Molitierno, Errico, 2020; Sierra et al., 2018; Sierra, Piqueras, et al., 2017; Torres-Machi et al., 2019		Stefaniec et al., 2021
					S.2.1.2	Project reduces Road User Costs (RUCs) compared to pre-project conditions				
					S.2.1.3	Enhancement of service levels				
					S.2.1.4	Increased passenger movement				
					S.2.1.5	Improved access to public services				
					S.2.1.6	Enhanced access to transit				
					S.2.1.7	Increase in active mobility				

(Continued)

TABLE 4.1
RISE: Sustainability Indicators. *(Continued)*

Category	Subcategory		Indicator			Evaluation Criteria	Project Wide: All Phases	Planning and Design	Construction	Operations, Monitoring, and Maintenance
Social					S.2.1.8	Reduced traffic flow impairments				
					S.2.1.9	Support for multimodal				
	S.3	Community Health and Safety	S.3.1	Quality of Life Improvements	S.3.1.1	Emission impact reduction on human health	Arshad et al., 2021; Navarro et al., 2019; Suprayoga et al., 2020; Vijayakumar et al., 2022, 2023a, 2023b; Henke, et. al, 2020; Sierra, Pellicer, & Yepes, 2017	Henke, Cartenì, & Di Francesco, 2020; Sierra, Pellicer, & Yepes, 2017		
					S.3.1.3	Promotion of art, culture, and community values				
					S.3.1.4	Improvement in social cohesion and aesthetics				
					S.3.1.5	Educational opportunities				
			S.3.2	Community Safety and Risk Reduction	S.3.2.1	Accident rate reduction	Navarro et al., 2019	Henke, et. al., 2020; Henke, Molitierno, et al., 2020; Sierra et al., 2018; Torres-Machi et al., 2019		
					S.3.2.2	Risk of accidents per output unit				
					S.3.2.3	Safety-related expenses				
					S.3.2.4	Immediate impact on road safety				
	S.4	Societal Well-being	S.4.1	Societal Well-being for Vulnerable Groups	S.4.1.1	Environmental quality for vulnerable groups	Suprayoga et al., 2020; Vijayakumar et al., 2022, 2023a, 2023b	Suprayoga, 2020		Stefaniec et al., 2021
					S.4.1.2	Economic development enhancement				
					S.4.1.3	Reduction of pollution impacts on vulnerable groups				
					S.4.1.4	Enhancement of physical and social mobility for all				
	S.5	Cultural and Heritage Integration	S.5.1	Cultural Preservation and Integration with Local Character	S.5.1.1	Protection of archaeological and historical sites	Suprayoga, 2020; Suprayoga et al., 2020; Vijayakumar et al., 2022, 2023a, 2023b	Sierra et al., 2018		
					S.5.1.2	Enhancement of local identity and global reputation				
					S.5.1.3	Design integration with local character				
					S.5.1.4	Expertise in managing cultural heritage				
	S.6	Socioeconomic Repercussions	S.6.1	Compensation and Relocation Practices that Preserve Dignity	S.6.1.1	Fair compensation strategies	Arshad et al., 2021; Gkritza et al., 2008; Vijayakumar et al., 2022, 2023a, 2023b	Henke, Cartenì, & Di Francesco, 2020		
			S.6.2	Socioeconomic Impacts of Projects Socioeconomic Impacts of Projects	S.6.1.2	Dignity preservation during displacement				
					S.6.1.3	Management of land acquisition and involuntary resettlement				
					S.6.2.1	Socioeconomic benefits at the regional and national levels				
					S.6.2.2	Promotion of social marketing opportunities				
					S.6.2.3	Monitoring of project impacts on local economies				
					S.6.2.4	Transport cost analysis for cars and freight				
					S.6.2.5	Tourism enhancement strategies				

(Continued)

TABLE 4.1
RISE: Sustainability Indicators. *(Continued)*

Category	Subcategory		Indicator		Evaluation Criteria		Project Wide: All Phases	Planning and Design	Construction	Operations, Monitoring, and Maintenance
Social	S.7	Governance and Human Rights	S.7.1	Governance Compliance and Transparent Decision-Making	S.7.1.1	Adherence to anti-discrimination norms	Arshad et al., 2021; Vijayakumar et al., 2022, 2023a, 2023b			
					S.7.1.2	Compliance with governmental rules and regulations				
					S.7.1.3	Transparency in contractor selection				
					S.7.1.4	Allocation of adequate resources for long-term social sustainability				
Economic	EC.1	Investment Return Metrics	EC.1. 1	Net Present Value (NPV)	EC.1.1.1	Total net benefit or cost over the project's life discounted to present value	Arshad et al., 2021; Sumabrata et al., 2022	Henke, Cartenì, Molitierno, Errico, 2020; Torres-Machi et al., 2019		Alam et al., 2017
			EC.1. 2	Internal Rate of Return (IRR)	EC.1.2.1	Expected compound annual rate of return generated by the project		Henke, Cartenì, Molitierno, Errico, 2020		
			EC.1. 3	Payback Period	EC.1.3.1	Time required to recover the investment cost				
	EC.2	Cost Management	EC.2. 1	Overall Project Costs	EC.2.1.1	Operation Costs	Navarro et al., 2019	Henke, Cartenì, & Di Francesco, 2020; Torres-Machi et al., 2019		Ruiz & Guevara, 2020
					EC.2.1.2	Investment Cost				
					EC.2.1.3	Unit cost of construction, maintenance, rehabilitation. and reconstruction				
					EC.2.1.4	Installation costs				
					EC.2.1.5	Disposal Costs				
					EC.2.1.6	Maintenance Costs				

locally sourced, recyclable, durable, and non-toxic materials (Z.-j. Dong et al., 2019; Kapatsa et al., 2023; Leng et al., 2018; Sumabrata et al., 2022; Suprayoga, 2020; Zhong et al., 2018). This indicator is supported by five evaluation criteria: (1) promotion of recyclable materials, (2) responsible use of natural resources, (3) compliance with durability standards, (4) reuse of pavement materials, and (5) control of virgin material consumption. These practices extend infrastructure lifespan and reduce lifecycle costs (Torres-Machi et al., 2019; Yang et al., 2018).

4.3.2.1.5 Local Sourcing. Local sourcing reduces emissions associated with material transport, supports regional economies, and fosters local engagement. This indicator promotes procurement strategies that prioritize materials available near the project site (Suprayoga, 2020; Yang et al., 2018). Evaluation focuses on the inclusion of a procurement plan that prioritizes local suppliers. This contributes to lower carbon emissions, faster delivery times, and enhanced public acceptance of infrastructure investments.

4.3.2.1.6 Waste Reduction and Recycling. Minimizing construction and demolition waste is critical to improving material efficiency and reducing landfill dependency. This indicator encourages waste diversion and reuse practices during construction and maintenance (Kapatsa et al., 2023; Navarro et al., 2019; Sumabrata et al., 2022). It is evaluated through two criteria: (1) presence of a waste management plan, and (2) actual recycling and reuse of construction and demolition waste. These practices align with global waste reduction targets and promote circularity (Suprayoga, 2020).

4.3.2.1.7 Environmental Impact of Waste. This indicator emphasizes the ecological risks posed by improperly handled waste, such as ozone depletion, eutrophication, and soil contamination (Suprayoga, 2020). It complements waste reduction efforts by focusing on the toxicity and long-term consequences of disposal practices. Two evaluation items are included: (1) consideration of ozone-depleting waste impacts, and (2) evaluation of eutrophication potential from construction runoff or waste. These measures address broader ecological sustainability goals (Navarro et al., 2019).

4.3.2.1.8 Habitat Fragmentation and Connectivity. Road infrastructure can disrupt wildlife habitats and ecological corridors. This indicator evaluates measures taken to maintain or restore habitat connectivity (Suprayoga, 2020; World Bank, 2016). Three criteria are used for assessment: (1) reduction of barrier effects on wildlife movement, (2) enhancement of habitat connectivity through crossings or corridors, and (3) protection of adjacent ecological zones. These efforts support biodiversity conservation and regulatory compliance.

4.3.2.1.9 Land Use Management. Efficient land use planning helps reduce urban sprawl, protect natural ecosystems, and promote compact development. This indicator evaluates whether infrastructure projects preserve high-value land and avoid unnecessary land conversion (Hamurcu & Eren, 2020). It is assessed through two criteria: (1) minimization of land conversion, and (2) protection of ecologically or agriculturally valuable land. Projects that score well demonstrate strategic siting and long-term land stewardship (Navarro et al., 2019).

4.3.2.1.10 Air Pollution Control. Air pollution from vehicle emissions, roadway users, and construction activities can significantly impact public health. This indicator promotes the use of cleaner fuels, low-emission machinery, and air quality mitigation strategies (Henke, Cartenì, & Di Francesco, 2020; Torres-Machi et al., 2019). Evaluation is based on the inclusion of an emissions reduction strategy, encompassing vehicle fleet efficiency, low-emission zones, and vegetation buffers (Navarro et al., 2019; Ruiz & Guevara, 2020). Additional measures such as high-occupancy vehicle (HOV) lanes, congestion reduction strategies, and active mobility alternatives can also reduce per-user emissions and improve air quality over the asset's lifetime.

4.3.2.1.11 Light and Noise Pollution. Light and noise from road infrastructure can adversely affect communities and wildlife. This indicator seeks to reduce these impacts through design and operational controls (Henke, Cartenì, & Di Francesco, 2020). Two evaluation items support this indicator: (1) implementation of measures to reduce light pollution, and (2) management of noise and vibration during construction and operation (Kapatsa et al., 2023).

4.3.2.1.12 Dust Management. Dust from construction activities can cause respiratory problems and degrade air quality. This indicator focuses on active dust suppression and particulate control (Kapatsa et al., 2023; Navarro et al., 2019). Mitigation practices include water spraying, soil stabilization, and equipment enclosures. This indicator helps maintain environmental standards and protects worker and community health.

4.3.2.1.13 Greenhouse Gas Emissions. Reducing GHG emissions is essential to mitigating climate change. This indicator assesses whether RIDPs incorporate strategies for carbon footprint reduction (Ametepey et al., 2023; Henke, Cartenì, & Di Francesco, 2020; Kissi et al., 2023). Evaluation includes the presence of a GHG reduction strategy, either as a standalone plan or part of broader national or agency-level decarbonization efforts (Alam et al., 2017; Suprayoga et al., 2020). Recent shifts in U.S. federal energy and environmental policy, notably under the 2025 federal executive order prioritizing increased energy production and regulatory review, are reshaping the institutional context in which such GHG reduction strategies are planned and implemented.

4.3.2.1.14 Adaptation to Climate Impacts. Infrastructure must be resilient to extreme weather, floods, and long-term climate shifts. This indicator evaluates whether adaptation measures are included in project design and implementation (Suprayoga, 2020). There are two criteria that guide evaluation: (1) climate-adaptive landscaping with drought-resistant and native species, and (2) disaster risk reduction planning, including erosion, flood, and landslide mitigation.

4.3.2.1.15 Stormwater Control and Management. Effective stormwater control helps prevent flooding and waterway pollution. This indicator assesses green infrastructure integration and runoff management (Kissi et al., 2023; Suprayoga et al., 2020). Evaluation considers whether low-impact development techniques and stormwater systems (e.g., bioswales, permeable pavements) are included in the project design to improve hydrological performance.

4.3.2.2 Social Sustainability Indicators

4.3.2.2.1 Comprehensive Health and Safety Measures at Work. Ensuring safe and healthy working environments is a cornerstone of socially responsible infrastructure development. RIDPs involve numerous field operations, often under high-risk conditions, which makes the protection of workers' health and safety a top priority. Effective safety management not only mitigates accidents but also enhances productivity and workforce morale (Arshad et al., 2021; Kapatsa et al., 2023; Stefaniec et al., 2021). This indicator is assessed through six criteria: (1) compliance with labor and health regulations, (2) mandatory health and safety training programs, (3) provision of personal protective equipment (PPE), (4) access to on-site medical services, (5) visible safety infrastructure (e.g., signage and barriers), and (6) tracking and reduction of traffic-related injury and fatality rates. These measures collectively ensure a proactive and comprehensive approach to occupational safety.

4.3.2.2.2 Promoting Employee Well-being. Well-being in the workplace goes beyond safety—they encompass physical, emotional, and economic support systems that empower employees and encourage retention. In RIDPs, unbiased hiring practices and access to basic welfare programs strengthen social legitimacy and reinforce ethical project delivery (Kapatsa et al., 2023; Sierra et al., 2018; World Bank, 2016). This indicator has three evaluation criteria, including prioritizing local labor in hiring and providing employee well-being programs, such as healthcare and leave benefits. These practices help ensure that the workforce reflects local demographics and that all employees are supported equitably.

4.3.2.2.3 Ensuring Workplace Integrity and Fair Practices. Integrity in labor practices is essential to maintaining worker rights and building trust among stakeholders. RIDPs often involve a diverse, multitiered labor force where risks of discrimination, corruption, and instability can emerge. This indicator promotes long-term employment, ethical recruitment, and continuous professional development (Suprayoga et al., 2020; Vijayakumar et al., 2022, 2023a). Five evaluation criteria are used: (1) job stability and career continuity, (2) non-discriminatory hiring policies with periodic audits, (3) anti-corruption training and frameworks, (4) fair pay and workload policies, and (5) capacity-building programs for knowledge and skills transfer. These practices support human capital development and reduce social friction within the workforce.

4.3.2.2.4 Active and Comprehensive Stakeholder Involvement. Stakeholder involvement is essential for developing infrastructure that reflects local needs and values. Engaging community members early in the planning process builds transparency, reduces resistance, and promotes a sense of ownership (Ametepey et al., 2019; Kapatsa et al., 2023; Sumabrata et al., 2022; World Bank, 2016). This indicator includes four evaluation items: (1) assessment of stakeholder acceptability, (2) early engagement of stakeholders (at least 12 months prior to implementation), (3) regular updates and transparent communication, and (4) inclusion of participatory mechanisms such as town halls or advisory boards. These practices ensure responsiveness in decision-making.

4.3.2.2.5 Improvement Measures in Mobility and Accessibility. Improved mobility and accessibility directly impact people's ability to access jobs, services, and opportunities. RIDPs must address mobility for all users—particularly vulnerable groups—and ensure connectivity to essential services and public transport (Henke, Cartenì, & Di Francesco, 2020; Labi et al., 2019; Suprayoga et al., 2020; Vijayakumar et al., 2023b). This indicator is assessed through nine criteria: (1) travel time reduction, (2) lower user transport costs, (3) improvement in level of service, (4) increased passenger throughput, (5) better access to public services, (6) enhanced transit connections, (7) promotion of walking and cycling, (8) reduction in traffic disruptions, and (9) support for multimodal integration. These criteria reflect holistic and equitable transportation planning.

4.3.2.2.6 Quality of Life Improvements. Infrastructure projects should improve the quality of life for surrounding communities—not just through transportation efficiency but also through environmental, educational, and cultural enhancements. This indicator evaluates whether projects foster community well-being and environmental livability (Arshad et al., 2021; Navarro et al., 2019; Suprayoga et al., 2020). The five criteria for this indicator include: (1) reduced exposure to harmful emissions, (2) local environmental enhancements (e.g., cleaner air, water), (3) incorporation of cultural and public art features, (4) community cohesion initiatives, and (5) public education or outreach on sustainability and infrastructure. These efforts improve social integration and long-term public satisfaction.

4.3.2.2.7 Community Safety and Risk Reduction. Safety is not limited to the worksite; it also extends to communities who interact with the infrastructure daily. This indicator measures whether RIDPs incorporate design and operational strategies to reduce traffic accidents and improve user safety (Henke, Cartenì, Molitierno, Errico, 2020; Sinha & Labi, 2007; Torres-Machi et al., 2019; World Bank, 2016). Evaluation is based on four criteria: (1) measurable reduction in accident rates (e.g., ≥30%), (2) implementation of infrastructure-specific risk assessments, (3) budget allocation for safety improvements, and (4) deployment of immediate safety measures such as lighting, signage, and crossings. These actions show a commitment to protecting users and nearby residents.

4.3.2.2.8 Societal Well-being for Vulnerable Groups. RIDPs must consider the needs of marginalized and vulnerable groups. It includes access to clean environments, mobility, and economic opportunities, promotes overall development, and mitigates social disparities (Stefaniec et al., 2021; Suprayoga et al., 2020; Vijayakumar et al., 2022). This indicator includes four evaluation criteria: (1) provision of environmental quality, (2) creation of local economic development programs, (3) targeted pollution mitigation in sensitive areas, and (4) improvements in mobility for people with disabilities, women, children, and elderly populations.

4.3.2.2.9 Cultural Preservation, Integration with Local Character and Context Sensitive Design. Cultural sensitivity is a vital part of socially sustainable infrastructure. This indicator ensures that RIDPs respect and integrate local identity, heritage, and traditions—particularly when traversing culturally significant regions (Sierra et al., 2018; Sinha & Labi, 2007; Suprayoga, 2020; Vijayakumar et al., 2022; World Bank, 2016). The indicator is evaluated through five items: (1) protection of archaeological and historic sites, (2) reinforcement of local identity and cultural relevance, (3) integration of local design features and aesthetics, (4) involvement of heritage experts during planning and construction, and (5) promotion of community identity through project design or programming.

4.3.2.2.10 Compensation and Relocation Practices that Preserve Dignity. When land acquisition or displacement is necessary, socially sustainable RIDPs ensure that affected persons are compensated fairly and relocated with dignity. Poorly managed resettlement can lead to long-term community fragmentation and economic hardship (Arshad et al., 2021; Henke, Cartenì, & Di Francesco, 2020; Vijayakumar et al., 2023a; World Bank, 2016). Three criteria guide this indicator: (1) provision of fair and timely compensation, (2) implementation of resettlement plans that ensure economic and social reintegration, and (3) compliance with international frameworks (e.g., International Finance Corporation Performance Standards, World Bank Environmental and Social Standards, etc.) to protect displaced populations.

4.3.2.2.11 Socioeconomic Impacts of Projects. Beyond mobility improvements, RIDPs can stimulate broader socioeconomic gains. This indicator evaluates long-term contributions to regional economies, employment, tourism, and behavioral change (Gkritza et al., 2008; Torres-Machi et al., 2019; Vijayakumar et al., 2023a). It is assessed through five items: (1) promotion of macro- and micro-level socioeconomic benefits, (2) development of social marketing or awareness campaigns, (3) systems for monitoring project impacts over time, (4) detailed transport cost analysis, and (5) strategies to enhance tourism and regional attractiveness.

4.3.2.2.12 Governance Compliance and Transparent Decision-Making. Sound governance underpins all aspects of social sustainability. This indicator assesses compliance with laws, ethical procurement practices, and the long-term institutional support required to maintain social sustainability goals (Arshad et al., 2021; Vijayakumar et al., 2022). Four criteria are used: (1) compliance with anti-discrimination and civil rights laws, (2) adherence to national and local regulations throughout the project lifecycle, (3) transparency in contractor selection and bidding, and (4) allocation of resources for long-term social outcomes such as education or safety programs.

4.3.2.3 Economic Sustainability Indicators

4.3.2.3.1 Net Present Value. Net Present Value (NPV) is one of the most widely used indicators for assessing the economic feasibility of infrastructure projects. It represents the difference between the present value of benefits and the present value of costs over a defined time horizon. A positive NPV indicates that a project is expected to generate net economic gains, making it a preferred metric for prioritizing investments in capital-intensive projects such as RIDPs (Alam et al., 2017; Henke, Cartenì, & Di Francesco, 2020; Sinha & Labi, 2007; Sumabrata et al., 2022; Torres-Machi et al., 2019). This indicator is evaluated through a single criterion: whether the project achieves a positive NPV based on a comprehensive benefit–cost analysis. Projects demonstrating a robust positive NPV can be considered financially sustainable, reflecting strong value-for-money performance and support for long-term economic development.

4.3.2.3.2 Internal Rate of Return. The Internal Rate of Return (IRR) serves as a complementary economic indicator to NPV, measuring the rate at which the present value of a project's net benefits equals zero. In other words, it identifies the discount rate that makes the NPV of all cash flows equal to zero (Sinha & Labi, 2007; Stermole et al., 2019; World Bank, 2011). IRR is particularly useful in comparing projects of varying scales or timelines and is often used in conjunction with cost–benefit analysis to evaluate investment attractiveness (Henke, Cartenì, & Di Francesco, 2020; Squire & van der Tak, 1975; World Bank, 2024a).

This indicator is evaluated using one criterion: whether the IRR exceeds the discount rate or minimum acceptable rate of return (MARR) defined by the agency or funding body. A higher IRR indicates greater profitability and economic resilience, particularly under uncertain economic conditions.

4.3.2.3.3 Payback Period. The payback period measures the time required for a project to recover its initial investment through accrued benefits. Unlike NPV and IRR, which provide comprehensive lifecycle insights, the payback period offers a straightforward risk assessment tool by highlighting liquidity and early-stage performance (World Bank, 2011). This is particularly relevant for projects funded through public-private partnerships or where capital availability is limited (Feng & Zhang, 2022; Henke, Cartenì, & Di Francesco, 2020; Stermole et al., 2019). This indicator is evaluated through a single criterion: the number of years it takes for the cumulative benefits to match or exceed the total investment. Shorter payback periods are preferred, as they reduce exposure to operational and financial risks and improve project flexibility.

4.3.2.3.4 Overall Project Costs. Efficient cost management throughout the lifecycle of RIDPs is a fundamental aspect of economic sustainability. While many evaluations focus on initial capital costs, a sustainable project must account for expenditures beyond the construction phase, including operation, maintenance, rehabilitation, and end-of-life disposal (Henke, Cartenì, & Di Francesco, 2020; Navarro et al., 2019; Ruiz & Guevara, 2020; Torres-Machi et al., 2019). Integrating a comprehensive cost strategy helps ensure that projects remain economically viable over time while maximizing infrastructure value and minimizing financial risk.

This indicator is evaluated through six performance criteria that capture cost considerations from a lifecycle perspective. These include: (1) operation costs—evaluated based on the presence of a long-term plan to minimize recurring expenditures; (2) investment cost—assessed based on whether the project remains within budget and includes contingency strategies; (3) unit cost of construction, maintenance, rehabilitation, and reconstruction—determined through cost-per-output analysis to ensure efficiency; (4) installation costs—measured by strategies aimed at balancing cost and infrastructure performance; (5) disposal costs—reflecting the end-of-life costs for materials and components, with an emphasis on reuse and recycling where applicable; and (6) maintenance costs—evaluated by the existence of a preventive maintenance plan designed to optimize lifecycle performance and reduce premature degradation.

4.4 Indicator Weighting

4.4.1 Weighting Methodology

To determine the relative importance of sustainability indicators in the RISE framework, a survey was designed and administered to transportation professionals working at INDOT. The objective was to derive indicator weights that reflect informed professional judgment across the three pillars of sustainability: environmental, social, and economic. Participants were selected through a convenience sampling strategy, focusing on managers and technical staff engaged in various stages of road infrastructure development. The survey also captured respondents' experience and familiarity with different RIDP phases, including planning, design, construction, operations, and maintenance.

The research protocol was reviewed and approved under IRB#2024-1450 as an exempt study by Purdue University's Institutional Review Board (IRB). No personal-identifiable information was collected, ensuring respondent anonymity and compliance with ethical standards. The survey was distributed using an anonymous online link. Of the 45 professionals invited, a 44% rate was achieved.

Respondents were asked to rate each sustainability indicator on a five-point Likert scale from 1 to 5, where 1 = Not Relevant, 2 = Slightly Relevant, 3 = Moderately Relevant, 4 = Very Relevant, and 5 = Extremely Relevant. Each indicator was considered within its corresponding sustainability pillar and evaluated based on its relevance to different RIDP lifecycle phases: Planning & Design; Construction; Operations, Monitoring and Maintenance; and End-of-Life.

To analyze the survey results, the Relative Importance Index (RII) method was used (Equation 4.1). The RII is a direct weighting technique that quantifies the perceived importance of different criteria based on ordinal survey data. The RII for each indicator is calculated using the following formula:

$$RII = \frac{\sum_{i=1}^{n}\left(f_i * i\right)}{A * N} \qquad \text{Equation 4.1}$$

Where:

f_i = frequency of respondents who selected a particular rating (i.e., how many rated it as 1, 2, 3, etc.),

i = the numerical value of the Likert scale (ranging from 1 to 5),

n = number of Likert scale levels,

A = the highest possible score on the scale (5 in this case),

N = the total number of respondents.

This calculation yields a value between 0 and 1, where higher values indicate greater perceived importance. For example, an indicator with a value close to 1 was consistently rated as highly relevant by most participants.

To help interpret the results and categorize the importance of each indicator, RII values were grouped into five bands. (Akadiri, 2011):

- An RII between 0.80 and 1.00 is considered High importance (H),
- Between 0.60 and 0.79 as High-Medium (H–M),
- Between 0.40 and 0.59 as Medium (M),
- Between 0.20 and 0.39 as Medium-Low (M–L),
- And any value below 0.20 is interpreted as Low importance (L)

Using this method, RII scores are calculated for all sustainability indicators across the three TBL categories. To develop aggregate weights for the environmental, social, and economic pillars, the average RII was computed for each sustainability category. Rather than summing the RII values—which would disproportionately favor pillars with more indicators—an averaging approach was used to ensure each pillar's overall importance was derived from the perceived significance of its indicators rather than the number of items it contains. This method balances the influence of each pillar regardless of the quantity of indicators assigned to it. Once the average RII for each pillar was calculated, a normalization step was applied to derive the final weights. This approach was implemented separately for each RIDP phase: Planning & Design; Construction; Operations, Monitoring and Maintenance; and End-of-Life, allowing the framework to reflect how the perceived relevance of sustainability dimensions shifts over the infrastructure lifecycle. Finally, to determine the final weight of each individual indicator, the normalized RII value of the indicator within its respective sustainability pillar was multiplied by the overall weight of its pillar, as shown in Equation 4.2.

$$Weight_j = W_i * \left(\frac{RII_j}{\sum_{j \in i} RII_j}\right) \qquad \text{Equation 4.2}$$

This methodology is used to establish the baseline weights for the RISE framework, incorporating all identified indicators and accounting for the three core sustainability pillars—environmental, social, and economic. These baseline weights reflect a comprehensive evaluation scenario where all indicators are deemed relevant and applicable. However, recognizing that the applicability of indicators may vary depending on the type of RIDP and the specific priorities of implementing agencies, the framework is designed to be adaptable. In cases where a subset of indicators is selected, the indicator and pillar weights are recalibrated using the same two-step methodology. This adjustment process leverages the original RII values to proportionally redistribute weights, ensuring that the framework remains consistent, scalable, and responsive to diverse project contexts.

The selection of the RII method was informed by the large number of indicators proposed in the RISE framework. While methods such as the Analytic Hierarchy Process (AHP) were initially considered and even piloted, most respondents reported discomfort and fatigue due to the large number of pairwise comparisons required. AHP, although robust, becomes increasingly impractical when more than a dozen criteria are involved, as the number of comparisons increases exponentially (Henke, Cartenì, Molitierno, Errico, 2020; Sinha & Labi, 2007). In contrast, RII offers a more intuitive and time-efficient approach, allowing respondents to provide meaningful input without the cognitive burden associated with complex judgment tasks. (Aboushady & El-Sawy, 2013). For this reason, RII was considered the most suitable and practical method for deriving the indicator weights.

4.4.2 *Survey Respondents Profile*

As mentioned before, a structured survey was designed and administered to transportation professionals at INDOT to derive weights for sustainability indicators in RIDPs. These weights, used within the RISE framework, were developed using the RII methodology and are grounded in the professional judgment of individuals with direct experience in planning, design, construction, operation, and management of road infrastructure. A total of 20 professionals completed the questionnaire. Table 4.2 summarizes the demographic and professional profile of survey respondents whose expertise shaped the weighting process. Given that the RISE weighting relies on expert judgment, it is essential to understand the qualifications, experience, and disciplinary backgrounds of participants to assess the quality and credibility of the data collected.

The respondents were notably experienced, with 70% reporting more than 10 years of professional experience in their respective fields. An additional 20% indicated between 7 and 9 years of experience, one respondent had between 1 and 3 years, and one had less than one year of experience. This distribution indicates that the vast majority of the survey contributors were seasoned professionals with extensive knowledge of RIDP processes.

In terms of educational attainment, the group was also highly qualified. A majority (50%) held a bachelor's degree, while 40% had obtained a master's degree. One respondent (5%) reported holding an associate degree, and another (5%) held a doctoral degree. This suggests a solid academic foundation, with many respondents likely having been exposed to advanced concepts related to engineering design, infrastructure sustainability, and project evaluation.

The survey also captured a broad spectrum of professional roles. The most frequently reported position was Executive (30%), representing leadership and strategic decision-making roles within the transportation agency. Other roles included General Managers (10%), Planning Engineers (10%), Project Managers (5%), and Sustainability Managers (5%). Importantly, 40% of participants categorized themselves under "Other," encompassing a variety of technical and planning roles such as geotechnical engineers, materials testing specialists, environmental planners, public outreach professionals, and highway engineers. This diversity enhances the robustness of the responses by incorporating both strategic and operational perspectives. Academic specialization was similarly varied. Civil Engineering emerged as the dominant field of study, with 57% of respondents identifying it as their primary academic background. Other disciplines, such as Urban Planning (9%), Transportation Engineering (4%), and Public Policy (4%). Notably, six respondents indicated additional fields including law, political science, industrial technology, healthcare,

TABLE 4.2
Demographic Information of the Participants.

Characteristics	Frequency	Percent
Experience		
Less than 1 year	1	5%
1 to 3 years	1	5%
7 to 9 years	4	20%
More than 10 years	14	70%
Education Level		
Bachelor's Degree	10	50%
Master's Degree	7	40%
Associate degree	1	5%
Doctoral Degree	1	5%
Position of Respondent		
Executive	6	30%
General Manager	2	10%
Planning Engineer	2	10%
Project Manager	1	5%
Sustainability Manager	1	5%
Other *	8	40%
Major Field of Study		
Civil Engineering	13	57%
Urban Planning	2	9%
Transportation Engineering	1	4%
Policy Studies	1	4%
Other **	6	26%

NOTE: *Other positions of respondents include: (1) Material Testing Engineer, (1) Public Outreach, (1) Environmental assessment professional, (1) Geotechnical Engineer, (1) Director of Planning, (1) Highway Engineering Director, and (2) Planner. ** Other major fields of study include: (1) Industrial technology, (1) Law, (1) Healthcare and general studies, (2) Ecology, evolution, and behavior, natural resources management, and (1) Political science ecology, and natural resource management. This interdisciplinary composition highlights the diverse perspectives that inform infrastructure sustainability decisions and reflects the multifaceted nature of RIDPs.

Overall, the range of roles, depth of professional experience, and breadth of academic backgrounds among respondents offer a well-rounded foundation for the RISE weighting process. The diversity in viewpoints—from technical implementation to policy-level decision-making—ensures that the weights applied to sustainability indicators are both practical and holistic. This combination enhances the credibility of the resulting framework and supports its applicability in real-world infrastructure evaluation and planning.

4.4.3 Relative Importance Index Analysis

Following the methodology detailed in Section 4.4.1 and applying Equation 4.1, RII values were calculated for each of the 31 sustainability indicators across the four main phases of RIDP: Planning and Design; Construction; Operations, Monitoring, and Maintenance; and End-of-Life. These calculations were based on responses provided by experienced professionals, who assessed each indicator using a Likert scale from 1 to 5. The use of RII allows for a direct interpretation of the relative significance of each indicator within its respective phase, translating professional opinion into a normalized, comparable scale. This step ensures that the final weighting scheme used in RISE reflects the practical judgment of practitioners working in infrastructure development, aligning academic methods with real-world expertise.

The results of the RII analysis are presented in Table 4.3 through Table 4.6. Table 4.3 shows the RII scores and ranks for the Planning and Design phase, while Table 4.4, Table 4.5, and Table 4.6 present the results for the Construction, Operations and Maintenance, and End-of-Life phases, respectively. Each table includes the computed RII value, the overall ranking of each indicator within the phase, and its classification under each sustainability pillar.

TABLE 4.3
RII for the Planning and Design Phase.

Pillar	Code	Indicator	RII	Ranking by Pillar	Phase Ranking	Importance Level
Environmental	E.1.1	Energy Conservation	0.575	6	20	M
	E.1.2	Resource Efficiency	0.447	15	31	M
	E.1.3	Water Efficiency	0.482	12	28	M
	E.2.1	Material Selection	0.753	1	6	H-M
	E.2.2	Local Sourcing	0.471	14	30	M
	E.3.1	Waste Reduction and Recycling	0.550	8	23	M
	E.3.2	Environmental Impact of Waste	0.553	7	22	M
	E.4.1	Habitat Fragmentation and Connectivity	0.656	5	16	H-M
	E.4.2	Land Use Management	0.722	2	8	H-M
	E.5.1	Air Pollution Control	0.529	9	24	M
	E.5.2	Light and Noise Pollution	0.700	3	9	H-M
	E.5.3	Dust Management	0.471	13	29	M
	E.6.1	Green Gas Emission	0.506	11	27	M
	E.6.2	Adaptation to Climate Impacts	0.682	4	11	H-M
	E.6.3	Water Management	0.525	10	25	M
Social	S.1.1	Comprehensive Health and Safety Measures at Work	0.563	11	21	M
	S.1.2	Promoting Employee Well-being and Equity	0.507	12	26	M
	S.1.3	Ensuring Workplace Integrity and Fair Practices	0.600	9	18	H-M
	S.1.4	Active and Inclusive Stakeholder Involvement	0.788	1	1	H-M
	S.2.1	Improvement Measures in Mobility and Accessibility	0.788	2	2	H-M
	S.3.1	Quality of Life Improvements	0.635	8	17	H-M
	S.3.2	Community Safety and Risk Reduction	0.765	4	5	H-M
	S.4.1	Societal Well-being and Equity for Vulnerable Groups	0.588	10	19	M
	S.5.1	Cultural Preservation and Integration with Local Character	0.682	6	12	H-M
	S.6.1	Compensation and Relocation Practices that Preserve Dignity	0.694	5	10	H-M
	S.6.2	Socioeconomic Impacts of Projects	0.659	7	13	H-M
	S.7.1	Governance Compliance and Transparent Decision-Making	0.775	3	3	H-M
Economic	EC.1.1	Net Present Value (NPV)	0.738	2	7	H-M
	EC.1.2	Internal Rate of Return (IRR)	0.657	3	14	H-M
	EC.1.3	Payback Period	0.657	4	15	H-M
	EC.2.1	Overall Project Costs	0.775	1	4	H-M

TABLE 4.4
RII for the Construction Phase.

Pillar	Code	Indicator	RII	Ranking by Pillar	Phase Ranking	Importance Level
Environmental	E.1.1	Energy Conservation	0.576	10	15	M
	E.1.2	Resource Efficiency	0.622	5	8	H-M
	E.1.3	Water Efficiency	0.613	7	10	H-M
	E.2.1	Material Selection	0.644	2	3	H-M
	E.2.2	Local Sourcing	0.613	6	9	H-M
	E.3.1	Waste Reduction and Recycling	0.675	1	2	H-M
	E.3.2	Environmental Impact of Waste	0.520	13	22	M
	E.4.1	Habitat Fragmentation and Connectivity	0.475	14	27	M
	E.4.2	Land Use Management	0.475	15	28	M
	E.5.1	Air Pollution Control	0.640	3	4	H-M
	E.5.2	Light and Noise Pollution	0.550	12	20	M
	E.5.3	Dust Management	0.624	4	7	H-M
	E.6.1	Green Gas Emission	0.613	8	11	H-M
	E.6.2	Adaptation to Climate Impacts	0.613	9	12	H-M
	E.6.3	Water Management	0.573	11	17	M
Social	S.1.1	Comprehensive Health and Safety Measures at Work	0.688	1	1	H-M
	S.1.2	Promoting Employee Well-being and Equity	0.520	7	23	M
	S.1.3	Ensuring Workplace Integrity and Fair Practices	0.600	3	13	H-M
	S.1.4	Active and Inclusive Stakeholder Involvement	0.575	5	16	M
	S.2.1	Improvement Measures in Mobility and Accessibility	0.565	6	18	M
	S.3.1	Quality of Life Improvements	0.488	9	26	M
	S.3.2	Community Safety and Risk Reduction	0.588	4	14	M
	S.4.1	Societal Well-being and Equity for Vulnerable Groups	0.475	10	29	M
	S.5.1	Cultural Preservation and Integration with Local Character	0.459	11	30	M
	S.6.1	Compensation and Relocation Practices that Preserve Dignity	0.450	12	31	M
	S.6.2	Socioeconomic Impacts of Projects	0.513	8	24	M
	S.7.1	Governance Compliance and Transparent Decision-Making	0.638	2	5	H-M
Economic	EC.1.1	Net Present Value (NPV)	0.529	3	21	M
	EC.1.2	Internal Rate of Return (IRR)	0.500	4	25	M
	EC.1.3	Payback Period	0.557	2	19	M
	EC.2.1	Overall Project Costs	0.627	1	6	H-M

TABLE 4.5
RII for the Operations and Maintenance Phases.

Pillar	Code	Indicator	RII	Ranking by Pillar	Phase Ranking	Importance Level
Environmental	E.1.1	Energy Conservation	0.576	10	15	M
	E.1.2	Resource Efficiency	0.622	5	8	H-M
	E.1.3	Water Efficiency	0.613	7	10	H-M
	E.2.1	Material Selection	0.644	2	3	H-M
	E.2.2	Local Sourcing	0.613	6	9	H-M
	E.3.1	Waste Reduction and Recycling	0.675	1	2	H-M
	E.3.2	Environmental Impact of Waste	0.520	13	22	M
	E.4.1	Habitat Fragmentation and Connectivity	0.475	14	27	M
	E.4.2	Land Use Management	0.475	15	28	M
	E.5.1	Air Pollution Control	0.640	3	4	H-M
	E.5.2	Light and Noise Pollution	0.550	12	20	M
	E.5.3	Dust Management	0.624	4	7	H-M
	E.6.1	Green Gas Emission	0.613	8	11	H-M
	E.6.2	Adaptation to Climate Impacts	0.613	9	12	H-M
	E.6.3	Water Management	0.573	11	17	M

(*Continued*)

TABLE 4.5
RII for the Operations and Maintenance Phases. *(Continued)*

Pillar	Code	Indicator	RII	Ranking by Pillar	Phase Ranking	Importance Level
Social	S.1.1	Comprehensive Health and Safety Measures at Work	0.688	1	1	H-M
	S.1.2	Promoting Employee Well-being and Equity	0.520	7	23	M
	S.1.3	Ensuring Workplace Integrity and Fair Practices	0.600	3	13	H-M
	S.1.4	Active and Inclusive Stakeholder Involvement	0.575	5	16	M
	S.2.1	Improvement Measures in Mobility and Accessibility	0.565	6	18	M
	S.3.1	Quality of Life Improvements	0.488	9	26	M
	S.3.2	Community Safety and Risk Reduction	0.588	4	14	M
	S.4.1	Societal Well-being and Equity for Vulnerable Groups	0.475	10	29	M
	S.5.1	Cultural Preservation and Integration with Local Character	0.459	11	30	M
	S.6.1	Compensation and Relocation Practices that Preserve Dignity	0.450	12	31	M
	S.6.2	Socioeconomic Impacts of Projects	0.513	8	24	M
	S.7.1	Governance Compliance and Transparent Decision-Making	0.638	2	5	H-M
Economic	EC.1.1	Net Present Value (NPV)	0.529	3	21	M
	EC.1.2	Internal Rate of Return (IRR)	0.500	4	25	M
	EC.1.3	Payback Period	0.557	2	19	M
	EC.2.1	Overall Project Costs	0.627	1	6	H-M

TABLE 4.6
RII for the End-of-Life Phase.

Pillar	Code	Indicator	RII	Ranking by Pillar	Phase Ranking	Importance Level
Environmental	E.1.1	Energy Conservation	0.482	10	22	M
	E.1.2	Resource Efficiency	0.482	11	23	M
	E.1.3	Water Efficiency	0.494	9	20	M
	E.2.1	Material Selection	0.667	2	2	H-M
	E.2.2	Local Sourcing	0.500	8	17	M
	E.3.1	Waste Reduction and Recycling	0.675	1	1	H-M
	E.3.2	Environmental Impact of Waste	0.600	3	5	H-M
	E.4.1	Habitat Fragmentation and Connectivity	0.440	15	28	M
	E.4.2	Land Use Management	0.467	12	24	M
	E.5.1	Air Pollution Control	0.507	7	16	M
	E.5.2	Light and Noise Pollution	0.467	13	25	M
	E.5.3	Dust Management	0.538	4	12	M
	E.6.1	Green Gas Emission	0.529	6	15	M
	E.6.2	Adaptation to Climate Impacts	0.533	5	13	M
	E.6.3	Water Management	0.467	14	26	M
Social	S.1.1	Comprehensive Health and Safety Measures at Work	0.557	3	8	M
	S.1.2	Promoting Employee Well-being and Equity	0.500	7	18	M
	S.1.3	Ensuring Workplace Integrity and Fair Practices	0.543	5	10	M
	S.1.4	Active and Inclusive Stakeholder Involvement	0.600	2	6	H-M
	S.2.1	Improvement Measures in Mobility and Accessibility	0.547	4	9	M
	S.3.1	Quality of Life Improvements	0.486	8	21	M
	S.3.2	Community Safety and Risk Reduction	0.533	6	14	M
	S.4.1	Societal Well-being and Equity for Vulnerable Groups	0.400	12	31	M
	S.5.1	Cultural Preservation and Integration with Local Character	0.440	10	29	M
	S.6.1	Compensation and Relocation Practices that Preserve Dignity	0.453	9	27	M
	S.6.2	Socioeconomic Impacts of Projects	0.440	11	30	M
	S.7.1	Governance Compliance and Transparent Decision-Making	0.667	1	3	H-M
Economic	EC.1.1	Net Present Value (NPV)	0.543	3	11	M
	EC.1.2	Internal Rate of Return (IRR)	0.500	4	19	M
	EC.1.3	Payback Period	0.600	2	7	H-M
	EC.2.1	Overall Project Costs	0.629	1	4	H-M

4.4.4 Discussion of RII Findings

4.4.4.1 Planning and Design Phases. The planning and design phases represent a critical stage in the lifecycle of RIDPs, where foundational decisions are made regarding project alignment, material selection, construction methodologies, and multimodal integration. These decisions shape the project's potential to meet the current and future needs of the population. As shown in Table 4.3, the RII values provide valuable insights into practitioner priorities during this phase.

Notably, social sustainability indicators dominate the top of the ranking, reflecting a strong emphasis on stakeholder engagement and human-centered outcomes. The indicators Active and Inclusive Stakeholder Involvement (S.1.4) and Improvement Measures in Mobility and Accessibility (S.2.1) both achieved the highest RII score of 0.788, followed closely by Governance Compliance and Transparent Decision-Making (S.7.1) with an RII of 0.775. These results highlight the prioritization of planning processes, equitable access, and institutional accountability during early project development. This trend aligns with the current policy and planning focus on transparency and public participation, as outlined in state-level guidelines (INDOT, n.d.c). Additional social indicators, such as Community Safety and Risk Reduction (S.3.2) and Compensation and Relocation Practices that Preserve Dignity (S.6.1), also ranked within the top ten, further emphasizing the importance placed on safety and equitable treatment of affected populations during the planning phase.

Economic indicators, though fewer in number, also ranked highly in importance. Overall Project Costs (EC.2.1) and Net Present Value (EC.1.1) were ranked fourth and seventh, respectively, both classified as High-Medium in importance. This underscores the continued relevance of economic feasibility and lifecycle cost considerations in early project evaluation (Sinha & Labi, 2007). Other economic indicators, such as Internal Rate of Return (EC.1.2) and Payback Period (EC.1.3), appeared within the top 15, reflecting practitioners' focus on return-on-investment metrics when selecting and justifying project alternatives.

In contrast, environmental indicators—although more numerous—tended to rank in the middle to lower range. Among them, Material Selection (E.2.1) and Land Use Management (E.4.2) stood out, ranked 6th and 8th respectively, reflecting awareness of resource efficiency and sustainable spatial planning practices (INDOT, 2018b, n.d.a). Other indicators such as Light and Noise Pollution (E.5.2) and Adaptation to Climate Impacts (E.6.2) also received relatively favorable scores. However, the majority of environmental indicators—including Resource Efficiency (E.1.2), Local Sourcing (E.2.2), and Dust Management (E.5.3)—were positioned lower in the ranking and rated with medium levels of importance. These findings suggest that while environmental sustainability is recognized, it may be considered less critical during the early decision-making stages compared to social and financial concerns, or its evaluation may be intentionally deferred to later project phases.

4.4.4.2 Construction Phase. The construction phase of RIDPs marks a significant shift in sustainability priorities, moving away from stakeholder engagement and governance—as emphasized during the planning and design phase—toward more operational and resource-focused concerns. The RII results for this phase, presented in Table 4.4, highlight the practical demands and immediate environmental and safety challenges encountered during on-site execution.

Environmental indicators take center stage in this phase. Dust Management (E.5.3) ranks highest among all indicators, with an RII of 0.789, reflecting the urgent need to control particulate emissions and maintain air quality during active construction (Mattinzioli et al., 2020). Other high-ranking environmental indicators include Resource Efficiency (E.1.2) and Material Selection (E.2.1), both with RIIs of 0.700, underscoring a strong focus on minimizing material waste and adopting sustainable construction practices. Additional indicators such as Waste Reduction and Recycling (E.3.1), Local Sourcing (E.2.2), and Greenhouse Gas Emissions (E.6.1) also received moderate-to-high RIIs, reinforcing the importance of site-level emissions management and sustainability practices during the construction process. On the other hand, environmental indicators such as Habitat Fragmentation and Connectivity (E.4.1), Environmental Impact of Waste (E.3.2), and Adaptation to Climate Impacts (E.6.2) were rated lower, suggesting their relevance is perceived to align more with other project phases, particularly planning and operations. While environmental concerns dominate, social sustainability indicators maintain strong presence, particularly those related to occupational health and safety. Comprehensive Health and Safety Measures at Work (S.1.1) ranked 5th overall with an RII of 0.700, highlighting the critical importance of protecting construction workers through proper safety protocols. Other social indicators—including Community Safety and Risk Reduction (S.3.2), Governance Compliance and Transparent Decision-Making (S.7.1), and Active and Inclusive Stakeholder Involvement (S.1.4)—also ranked within the top 15, indicating that despite the operational focus of this phase, issues of transparency, safety, and public trust remain central. Conversely, social indicators addressing long-term impacts, such as Compensation and Relocation Practices (S.6.1) and Socioeconomic Impacts (S.6.2), ranked lower, likely reflecting the perception that their influence is diminished during this more immediate, execution-focused stage.

Economic indicators continue to be relevant, although their overall prominence declines relative to the planning phase. Overall Project Costs (EC.2.1) remains a key concern, ranking 2nd overall with an RII of 0.707, reinforcing the importance of cost management and budget adherence during the high-expenditure construction phase (H. Zhang & Zhou, 2023). Other economic indicators such as Payback Period (EC.1.3), Internal Rate of Return (EC.1.2), and Net Present Value (EC.1.1) received medium importance rankings, indicating that while financial performance remains a consideration, it takes a secondary role to immediate construction efficiency and environmental control during this phase.

4.4.4.3 Operations and Maintenance Phase. During the operations and maintenance phase of RIDPs, sustainability priorities shift toward ensuring long-term system performance, operational efficiency, and continuous service delivery. This stage requires balancing infrastructure upkeep with sustained environmental stewardship and social responsibility (Kapatsa et al., 2023). The RII results for this phase reveal a more balanced distribution across the three pillars, with strong representation from environmental and social indicators and moderate emphasis on economic ones.

Environmental indicators gain increased importance in this phase, with several ranking among the top ten. Waste Reduction and Recycling (E.3.1) is ranked second overall with an RII of 0.675, emphasizing the growing focus on minimizing operational waste and promoting circular practices. Material Selection (E.2.1) and Air Pollution Control (E.5.1) follow closely, ranked third and fourth respectively, reflecting concerns over long-term emissions and material durability. Other environmental indicators such as Dust Management (E.5.3), Local Sourcing (E.2.2), Greenhouse Gas Emissions (E.6.1), and Adaptation to Climate Impacts (E.6.2) also rank highly, reinforcing the multifaceted nature of environmental priorities during the operations stage. In contrast, indicators like Habitat Fragmentation and Connectivity (E.4.1), Land Use Management (E.4.2), and Environmental Impact of Waste (E.3.2) appear lower in the rankings, likely due to their relevance being greater in earlier project phases.

Social indicators continue to play a critical role, particularly those focused on workforce safety, institutional transparency, and ethical practices. Comprehensive Health and Safety Measures at Work (S.1.1) emerges as the highest-ranked indicator overall, with an RII of 0.688, underscoring the enduring importance of occupational safety even after construction concludes. Governance Compliance and Transparent Decision-Making (S.7.1) also ranks within the top five, reflecting ongoing expectations for clear procedures, accountability, and regulatory compliance during project operation. Other high-performing social indicators include Ensuring Workplace Integrity and Fair Practices (S.1.3) and Community Safety and Risk Reduction (S.3.2), indicating that public well-being and labor ethics remain important considerations. Conversely, socially focused indicators such as Compensation and Relocation (S.6.1) and Societal Well-being and Equity for Vulnerable Groups (S.5.1) receive lower scores, suggesting these issues are viewed as more critical during planning and early implementation rather than during ongoing maintenance.

In terms of economic indicators, the emphasis during this phase shifts toward cost efficiency and long-term financial sustainability. Overall Project Costs (EC.2.1) ranks sixth overall, maintaining its importance across phases and reinforcing the need for continued attention to budget control and resource optimization. However, indicators typically associated with initial investment decisions—Net Present Value (EC.1.1), Internal Rate of Return (EC.1.2), and Payback Period (EC.1.3)—rank lower, reflecting the reduced relevance of investment performance once the infrastructure is in use. Instead, the focus is placed on managing lifecycle costs and ensuring value is sustained over time.

4.4.4.4 End-of-life Phase. In the end-of-life phase of RIDPs, sustainability priorities are shaped by concerns about infrastructure legacy, responsible decommissioning, and long-term environmental and financial consequences (Sinha & Labi, 2007). This phase highlights the importance of resource recovery, safe dismantling procedures, and cost-effective project closure. The RII values for this phase, presented in Table 4.6, reveal a strong shift toward environmental considerations, with fewer indicators from the social and economic pillars ranking at the top.

Environmental indicators dominate this phase, occupying six of the top ten positions. Waste Reduction and Recycling (E.3.1) emerges as the highest-ranked indicator overall (RII: 0.675), underscoring the critical need to prioritize the reuse of materials and proper waste disposal once infrastructure reaches the end of its service life. Material Selection (E.2.1) ranks second (RII: 0.667), reinforcing the long-term impact of early design choices on recyclability and environmental performance during deconstruction. Environmental Impact of Waste (E.3.2) also scores highly (5th overall), highlighting growing awareness of post-project ecological consequences such as landfill use, contamination, and toxicity. Despite this strong environmental focus, indicators such as Habitat Fragmentation and Connectivity (E.4.1), Land Use Management (E.4.2), and Water Management (E.6.3) are rated among the lowest, likely reflecting a reduced perceived impact of land or water issues when a project is decommissioned.

The social pillar presents a more moderate role in the end-of-life phase. While most social indicators fall within the middle or lower end of the rankings, a few stand out. Governance Compliance and Transparent Decision-Making (S.7.1) ranks third overall (RII: 0.667), suggesting that institutional accountability and adherence to regulatory frameworks remain important during project closure. Active and Inclusive Stakeholder Involvement (S.1.4) also appears among the top-ranked indicators (sixth overall, RII: 0.600), indicating that open communication with affected communities is still valued during decommissioning (Vijayakumar et al., 2023b). However, indicators related to longer-term community outcomes, such as Societal Well-being for Vulnerable Groups (S.4.1) and Socioeconomic Impacts of Projects (S.6.2), fall to the bottom of the rankings. These results suggest that social development are viewed as less central at this stage, where the focus often shifts to procedural closure rather than transformative impact. Economic indicators maintain relevance in this final phase, though to a lesser extent than in earlier stages. Overall Project Costs (EC.2.1) and Payback Period (EC.1.3) rank fourth and seventh overall, respectively, reflecting concerns over the financial implications of dismantling, material recovery, and final reporting. These indicators highlight the need for fiscal responsibility in concluding the infrastructure lifecycle. Conversely, Net Present Value (EC.1.1) and Internal Rate of Return (EC.1.2) receive lower RII values, likely due to the limited usefulness of forward-looking financial assessments once operational benefits cease.

4.4.5 Weights for RISE Sustainability Pillars

The weights developed for the three sustainability pillars across the four RIDP phases are presented in Table 4.7. These weights, derived from the RII analysis of individual indicators,

TABLE 4.7
Weights of Sustainability Pillars Across Phases of RIDP.

Category	Planning and Design	Construction	Operations, Monitoring and Maintenance	End-of-life
Economic	36%	33%	33%	35%
Environmental	30%	35%	35%	33%
Social	34%	32%	32%	32%

NOTE: Cell colors represent the relative magnitude of the weights within each phase—green indicates the highest value, yellow represents a mid-range value, and red denotes the lowest value.

reflect how professionals prioritize the economic, environmental, and social dimensions of sustainability as a project progresses through its lifecycle.

In the Planning and Design phase, the economic pillar holds the greatest weight at 36%, suggesting that financial feasibility, return on investment, and cost–benefit assessments are considered paramount when formulating project alternatives. This finding underscores the importance of securing funding and optimizing project value early in the decision-making process. Close behind, the social pillar accounts for 34%, indicating that stakeholder involvement, community well-being, and equitable access remain integral concerns during initial planning. Meanwhile, the environmental pillar receives a comparatively lower weight (30%), reflecting a tendency for environmental considerations to be acknowledged but not prioritized during conceptual stages, where few physical interventions have yet taken place.

During the Construction phase, there is a notable shift: the environmental pillar becomes the most prominent, rising to 35%. This reflects growing recognition of the environmental impacts generated during construction activities—such as emissions, resource consumption, waste generation, and dust management—making mitigation strategies crucial. The economic pillar maintains a stable weight at 33%, as cost control, resource efficiency, and budget adherence remain critical to successful project delivery. The social pillar, while still valued at 32%, shows a slight decline, suggesting that social engagement and inclusivity, although important, are somewhat less emphasized during the operational aspects of construction.

In the Operations and Maintenance phase, the environmental pillar continues to lead with a weight of 35%, the highest assigned to this pillar across all phases. This is consistent with ongoing environmental responsibilities during infrastructure use, including emissions control, material durability, and water and energy efficiency (Suprayoga et al., 2020). The economic pillar remains stable at 33%, underscoring the importance of long-term cost control, operational efficiency, and financial stewardship. The social pillar sees a minor decline to 32%, highlighting that while worker safety and public service quality still matter, these aspects are somewhat overshadowed by the technical and environmental demands of sustained operation.

Finally, in the End-of-Life phase, the economic pillar regains prominence, reaching 35%, nearly mirroring its Planning and Design phase value. This resurgence reflects growing concern over the financial implications of decommissioning, material recovery, and lifecycle closure strategies (Torres-Machí et al., 2015). The environmental pillar remains highly relevant at 33%, indicating sustained attention to waste reduction, emissions, and ecological recovery during the dismantling or repurposing of infrastructure. The social pillar, however, drops to its lowest overall weight at 32%, suggesting that once projects reach the end of their functional life, social impacts become less visible or are perceived as having already been addressed in earlier phases. It is also important to note that cost savings relate primarily to the economic pillar of sustainability. While useful, financial metrics alone do not capture the full spectrum of benefits associated with sustainable practices. Social and environmental gains, such as improved community wellbeing, reduced ecological impacts, and enhanced long-term asset resilience, may exceed the value of direct monetary savings.

4.4.6 Weights for RISE Sustainability Indicators

Table 4.8 presents the normalized weights for the 31 sustainability indicators used in the RISE framework across the four phases of a RIDP: Planning and Design, Construction, Operations, Monitoring and Maintenance, and End-of-life. These weights reflect the perceived influence of each indicator on decision-making, based on the professional judgments gathered through the survey. The methodological details used to derive these weights—specifically the application of the RII and the normalization process conducted by phase—are described in Section 3.4. A key consideration when interpreting Table 4.4 is the unequal distribution of indicators across the three sustainability pillars. The economic pillar consists of only four indicators, while the social and environmental pillars include 12 and 15 indicators, respectively. As a result, individual economic indicators inherently contribute a larger share of the total weight in each phase. This structural asymmetry explains why economic indicators consistently appear among the highest-weighted in all four phases. Indicators such as Overall Project Costs, NPV, IRR, and Payback Period typically receive weights between 7% and 10%, reinforcing their central role in sustainability-related decisions across the project lifecycle. As illustrated by the color-coded scale in Table 4.4, which highlights the highest values in green, middle values in yellow, and lowest values in red, there is a notable progression in indicator emphasis throughout the phases.

In the Planning and Design phase, environmental indicators tend to hold the lowest weight values—generally between 1.5% and 2.5%—while social and economic indicators dominate the upper range. This suggests that early-stage evaluations are more heavily influenced by financial feasibility, project justification, and stakeholder engagement. Indicators like Active and Inclusive Stakeholder Involvement, Improvement Measures in Mobility and Accessibility, and the four core economic indicators rank highest during this phase, reflecting the strategic and participatory priorities of professionals at the outset of RIDPs. In contrast, a notable shift occurs in the Construction and Operations, Monitoring and Maintenance phases, where the relevance of environmental indicators increases substantially. Indicators such as Dust Management, Resource Efficiency, Waste Reduction and Recycling, Air Pollution Control, and

TABLE 4.8
Weights for RISE Sustainability Indicators.

Pillar	Code	Indicator	Planning and Design	Construction	Operations, Monitoring & Maintenance	End-of-life
Environmental	E.1.1	Energy Conservation	1.96%	2.08%	2.28%	2.00%
	E.1.2	Resource Efficiency	1.53%	2.63%	2.46%	2.00%
	E.1.3	Water Efficiency	1.65%	2.53%	2.42%	2.05%
	E.2.1	Material Selection	2.57%	2.63%	2.55%	2.77%
	E.2.2	Local Sourcing	1.61%	2.44%	2.42%	2.08%
	E.3.1	Waste Reduction and Recycling	1.88%	2.56%	2.67%	2.80%
	E.3.2	Environmental Impact of Waste	1.89%	2.02%	2.05%	2.49%
	E.4.1	Habitat Fragmentation and Connectivity	2.24%	1.90%	1.88%	1.83%
	E.4.2	Land Use Management	2.47%	2.08%	1.88%	1.94%
	E.5.1	Air Pollution Control	1.81%	2.30%	2.53%	2.10%
	E.5.2	Light and Noise Pollution	2.39%	2.21%	2.17%	1.94%
	E.5.3	Dust Management	1.61%	2.96%	2.46%	2.23%
	E.6.1	Green Gas Emission	1.73%	2.34%	2.42%	2.20%
	E.6.2	Adaptation to Climate Impacts	2.33%	2.03%	2.42%	2.22%
	E.6.3	Water Management	1.79%	2.16%	2.26%	1.94%
Social	S.1.1	Comprehensive Health and Safety Measures at Work	2.40%	3.28%	3.39%	2.89%
	S.1.2	Promoting Employee Well-being and Equity	2.16%	2.44%	2.57%	2.60%
	S.1.3	Ensuring Workplace Integrity and Fair Practices	2.56%	2.93%	2.96%	2.82%
	S.1.4	Active and Inclusive Stakeholder Involvement	3.36%	2.93%	2.84%	3.12%
	S.2.1	Improvement Measures in Mobility and Accessibility	3.36%	2.87%	2.79%	2.84%
	S.3.1	Quality of Life Improvements	2.71%	2.35%	2.41%	2.52%
	S.3.2	Community Safety and Risk Reduction	3.26%	3.11%	2.90%	2.77%
	S.4.1	Societal Well-being and Equity for Vulnerable Groups	2.51%	2.15%	2.35%	2.08%
	S.5.1	Cultural Preservation and Integration with Local Character	2.91%	2.65%	2.27%	2.28%
	S.6.1	Compensation and Relocation Practices that Preserve Dignity	2.96%	2.35%	2.22%	2.35%
	S.6.2	Socioeconomic Impacts of Projects	2.81%	2.29%	2.53%	2.28%
	S.7.1	Governance Compliance and Transparent Decision-Making	3.31%	3.17%	3.15%	3.46%
Economic	EC.1.1	Net Present Value (NPV)	9.46%	7.24%	7.83%	8.46%
	EC.1.2	Internal Rate of Return (IRR)	8.42%	7.44%	7.41%	7.79%
	EC.1.3	Payback Period	8.42%	8.01%	8.25%	9.35%
	EC.2.1	Overall Project Costs	9.93%	9.95%	9.28%	9.79%

NOTE: Cell colors represent the relative magnitude of the weights within each pillar of sustainability for each phase, going from the highest (green) to the lowest (red).

Material Selection see their weights rise, with several exceeding 2.5%. This reflects heightened awareness of the environmental footprint of active construction and the long-term performance of infrastructure. While social and economic indicators remain relevant, they decline slightly in these phases, resulting in a more balanced representation of all three pillars.

By the End-of-life phase, the importance of environmental considerations remains high, particularly for indicators linked to reuse, recycling, and post-project ecological impacts. Waste Reduction and Recycling (2.80%), Material Selection (2.77%), and Environmental Impact of Waste (2.49%) are among the most influential indicators, highlighting the environmental priorities associated with infrastructure decommissioning. Meanwhile, economic indicators such as Overall Project Costs (9.79%) and Payback Period (9.35%) remain dominant, underscoring the financial implications of project closure. Social indicators, on the other hand, display lower relative weights in this phase, suggesting that social objectives are either achieved earlier in the project lifecycle or considered less pressing during decommissioning.

4.4.7 Comparison of RISE with Existing SRS

To contextualize the development of the RISE framework, a comparison was conducted with established SRS, including INVEST, Envision, BE2ST-in-Highways, CEEQUAL, and Greenroads. Table 4.9 presents a high-level comparison across key dimensions, highlighting the latest version, rating methodology, assessment type, rating classifications, and the phases considered by each system. This overview underscores the methodological distinctions and scope of each SRS relative to RISE, particularly in their treatment of project lifecycle phases and sustainability pillars.

TABLE 4.9
Comparison of RISE With Existing SRS.

	CEEQUAL	Envision	BE2ST-in-Highways	GreenLITES	Greenroads	INVEST	GreenPave	I-LAST	RISE
Latest Version and Year	v6 - 2019	v3 - 2018	v1-2010	v2-2010	v2-2017	v1.3 - 2018	v2.1 - 2017	v2.02 - 2021	v1 - 2025
Rating Method	Completion of mandatory criteria and sum of awarded credits	Sum of credit criteria	Screening process, followed by a quantitative assessment	Sum of criteria	Sum of criteria	Sum of criteria	Sum of criteria	Sum of criteria	Weighted sum of criteria
Assessment Type	Third-party	Third Party	Self-assessment	Self-assessment	Third-party	Self-assessment	Self-assessment	Self-assessment	Self-assessment
Rating Classifications	Outstanding (≥90%), Excellent (≥75%), Very Good (≥60%), Good (≥45%), Pass (≥30%), to Unclassified (<30%)	Platinum (≥50%), Gold (≥40%), Silver (≥30%), and Verified (≥20%)	Gold (90%), Silver (75%), Bronze (50%)	Evergreen (≥98%), Gold (≥90%), Silver (≥67%), and Certified (≥33%)	Evergreen (80 points),Gold (60 points), Silver (50 points), and Bronze (40 points)	Platinum (≥60%), Gold (≥50%), Silver (≥40%), Bronze (≥30%).	Trillium (Non defined yet), Gold (≥20 points), Silver (<20 points), and Bronze (<15 points)	Percentage (No certification or rating classes)	Leading practice (≥80%), advanced practice (≥60%), good practice (≥40%), basic practice (≥20%), minimal practice (<20%)
Phases Considered	Design and Construction*	Design	Design	Design and Operation	Design and Construction	Design, Construction, and Operations and Maintenance*	Construction, Operations and Maintenance	Planning and Design, Construction	Planning and Design, Construction, Operations, Monitoring, and Maintenance, End-of-life*

NOTE: *These SRS considered different weighting for distinctive RIDP phases

Figure 4.2, Figure 4.3, and Figure 4.4 further compare the weight distribution among the three sustainability pillars (Environmental, Social, and Economic) for each SRS during the Planning and Design, Construction, and Operations, Monitoring, and Maintenance phases.

Figure 4.2 illustrates the distribution of weights among the three pillars of sustainability for different SRS frameworks applicable to the Planning and Design phase. RISE exhibits a well-balanced distribution, with slightly higher emphasis on the economic (36%) and social (34%) pillars compared to the environmental dimension (30%). This balanced profile is comparable to that of INVEST, which also distributes its weights relatively evenly during this phase, assigning 37% to Social, 32% to Environmental, and 31% to Economic sustainability. In contrast, most of the other systems display a strong bias toward a single pillar. For example, GreenLITES heavily emphasizes the social dimension (65%), while I-LAST, Greenroads, BE2ST-in-Highways, and CEEQUAL prioritize environmental considerations, assigning between 49% and 70% of the weight to the environmental pillar. These differences highlight how RISE and INVEST promote a more integrated sustainability evaluation during early project stages, whereas other SRS tend to concentrate attention predominantly on either environmental or social outcomes.

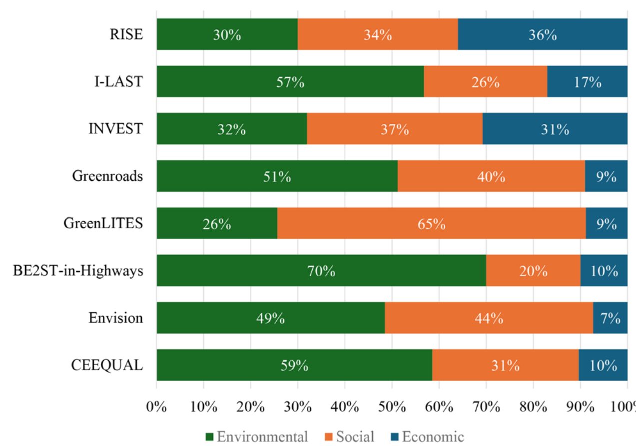

Figure 4.2 Weight Contribution of RISE and Other SRS During Planning and Design Phase.

Figure 4.3 presents the distribution of weights among the three sustainability pillars for SRS frameworks applicable to the Construction phase. RISE assigns the highest weight to the Environmental pillar (35%), followed closely by the Economic (33%) and Social (32%) pillars, reflecting a balanced yet environmentally conscious approach during construction activities.

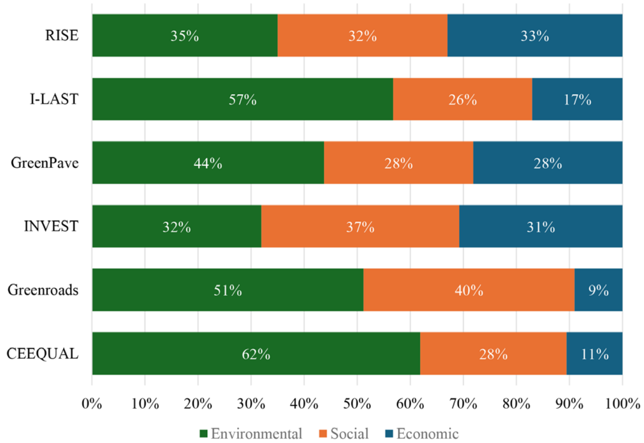

Figure 4.3 Weight Contribution of RISE and Other SRS During Construction Phase.

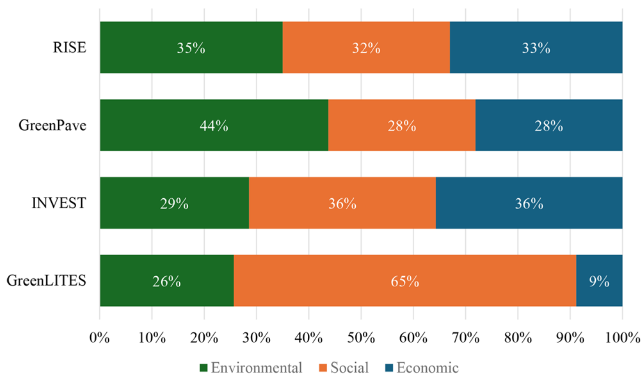

Figure 4.4 Weight Contribution of RISE and Other SRS During Operations Phase.

This pattern closely resembles GreenPave, which also prioritizes Environmental indicators while distributing equal emphasis between Social and Economic pillars. Across all SRS analyzed for this phase, a consistent trend emerges: Environmental indicators are given the highest relative weight, followed by Social, and then Economic considerations. Even among systems with varying scopes, such as INVEST and Greenroads, the Economic pillar consistently receives the smallest share, with the highest economic weight being 31% in INVEST—very similar to RISE's 33%. These results suggest a collective recognition across rating systems that construction activities present heightened environmental risks, requiring greater mitigation efforts relative to economic or social factors.

Figure 4.4 illustrates the distribution of weights among the three pillars for the Operations, Monitoring, and Maintenance phase. In this phase, RISE assigns the highest weight to Environmental indicators (35%), followed closely by Economic (33%) and Social (32%) considerations, maintaining a well-balanced structure. RISE shows strong resemblance to GreenPave, which also prioritizes Environmental factors while assigning similar importance to Social and Economic pillars. However, other SRS frameworks differ notably: for example, INVEST assigns higher weights to Social and Economic indicators (36% each), while GreenLITES places overwhelming emphasis on the Social pillar (65%), minimizing attention to Environmental and Economic dimensions. This comparison highlights that while many frameworks recognize social responsibility during operations, RISE maintains a broader balance across all pillars, reinforcing the need for sustained environmental stewardship and financial viability throughout the infrastructure lifecycle.

It is important to note that while several existing SRS frameworks comprehensively address the Planning and Design, Construction, and Operations, Monitoring, and Maintenance phases, none of them are explicitly designed to evaluate sustainability performance during the End-of-Life phase of infrastructure projects. Consequently, no meaningful comparison can be made for this phase between RISE and other frameworks. What makes RISE unique is its derivation of phase-specific weights based on professional input, uncovering important shifts in the relative importance of the environmental, social, and economic pillars across the RIDP lifecycle. By explicitly capturing these dynamics, RISE advances a more responsive and lifecycle-aware sustainability evaluation approach, addressing a critical limitation in traditional systems.

4.5 Normalization

Normalization is a critical step in the RISE framework to ensure that sustainability indicators—each with different units of measurement and scales—can be fairly compared and aggregated. To address the challenges posed by the diverse nature of these indicators, this study adopts a structured rating scale approach, which standardizes all indicators onto a common 0–4 point scale. This method simplifies evaluation for practitioners while preserving the integrity and comparability of results.

Each indicator identified is evaluated against an ideal scenario, using five achievement tiers: 0%, 25%, 50%, 75%, and 100% compliance with sustainability objectives. These tiers correspond to point values from 0 to 4, forming a linear utility scale (Figure 4.5). This approach ensures that each incremental step toward full compliance—whether moving from 25% to 50% or from 75% to 100%—is rewarded equally, reflecting the assumption of uniform utility across all levels of improvement. The effect of each indicator on the overall sustainability score is ultimately moderated by the weights derived in Section 3.4, thus maintaining consistency in how importance is factored into the analysis.

The use of structured rating scales with qualitative descriptors enhances the robustness of the evaluation process compared to more open-ended direct rating methods. While direct rating (e.g., assigning a score from 0 to 100) is intuitive, it often suffers from inconsistencies, as evaluators may interpret performance levels differently (Aboushady & El-Sawy, 2013; Sinha & Labi, 2007). In contrast, structured scales provide clear anchor points and standardized descriptions that guide the evaluator. For example, a score of 0 for an environmental indicator like renewable energy adoption might correspond to "no adoption of renewable energy sources," while a score of 4 would reflect "full reliance on renewable energy (e.g., 100% of site operations)."

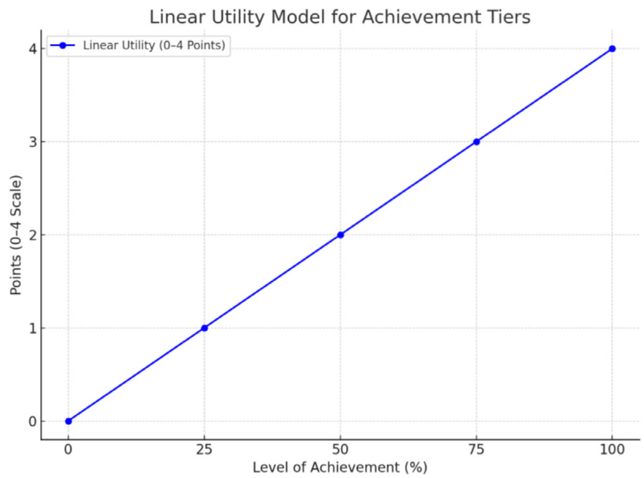

Figure 4.5 Linear Utility Model for Achievement Tiers.

This structured approach reduces subjectivity, improves inter-rater reliability, and enhances the transparency of the evaluation process, under the assumption of certainty and risk neutral decisions (Sinha & Labi, 2007).

Structured scales also offer significant benefits in multiproject and cross-regional evaluations, where consistency in how performance is assessed is essential. When applied across multiple projects or geographic contexts, these standardized scales enable more effective benchmarking, identification of best practices, and comparison of sustainability outcomes (Sala et al., 2015). Another practical advantage of this approach is that it supports capacity building among practitioners and evaluators. By offering a clear reference framework for scoring, structured scales lower the barrier to entry for those with limited experience in sustainability assessments (Waas et al., 2014). This promotes broader adoption of the RISE framework and supports consistent training and application across agencies and project types.

From a methodological standpoint, structured rating scales also facilitate sensitivity analysis and model refinement. Each discrete score can be mapped to a corresponding quantitative benchmark, enabling analysts to test the impact of individual indicators or explore alternative assumptions about performance thresholds and point allocations.

The use of discrete achievement levels is also consistent with the design logic of other widely adopted sustainability frameworks, including INVEST, Envision, and Greenroads (Arbel & Tong, 1982; FHWA, 2018; ISI, 2018; STC, n.d.). These systems commonly apply point-based methods and assign credits or scores based on defined thresholds of performance. The RISE framework follows a similar philosophy by anchoring its scoring system in a 0–4 scale, directly corresponding to the five performance tiers.

4.6 Amalgamation

After the indicators and their corresponding evaluation criteria have been identified, assessed, and normalized using structured rating scales, the final step in the RISE framework is to amalgamate these values into a single sustainability score for each project or alternative. This score enables decision-makers to compare, rank, or select among competing infrastructure projects based on their overall sustainability performance (Labi, 2014).

RISE is designed to be flexible and adaptable to different project types and institutional contexts. Evaluators can select the indicators and evaluation criteria that are most relevant to the type of project being assessed and aligned with the agency's values or sustainability goals. This flexibility ensures that the tool remains practical and context sensitive. However, it is essential to emphasize that once a set of indicators and evaluation criteria has been selected for an assessment, this same set must be consistently applied across all alternatives or projects being compared. This consistency is crucial to maintain the integrity and fairness of the evaluation process, ensuring that performance differences reflect genuine sustainability outcomes rather than variations in the criteria used.

For this study, the Weighted Sum Method (WSM)—outlined in Appendix Section E.3.1 —is adopted to calculate the final RISE score. This technique involves multiplying the score of each indicator by its assigned weight (as derived in Section 3.4) and then summing the weighted values across all selected indicators. The WSM is widely used in sustainability assessments due to its simplicity, transparency, and ease of interpretation (Hazelrigg, 2019; Li, 2003).

Since each indicator in RISE may include one or more evaluation criteria, the process begins by calculating the maximum possible score for the selected set of criteria. This is defined as the number of evaluation criteria used in the assessment multiplied by the maximum score achievable per criterion—in this case, 4 points. For example, if 20 evaluation items are selected, the maximum attainable score would be 80 points.

Mathematically, the amalgamation process can be expressed as:

$$RISE_{Score} = \sum_{i=1}^{n} \left(\frac{\sum_{j=1}^{m_i} s_{ij}}{m_i * 4} \right) * w_i \qquad \text{Equation 4.3}$$

Where:

n = Total number of selected indicators.

m_i = number of evaluation criteria under indicator *i*.

s_{ij} = Score for evaluation criterion j of indicator *i*.

w_i = weight of indicator *i*.

The result is a percentage score that reflects the degree of sustainability achieved by the project relative to its maximum potential under the selected criteria. This score offers an intuitive and actionable summary that can be used in decision-making processes such as project prioritization, funding allocation, or performance benchmarking.

To aid interpretation, final scores are classified into five RISE sustainability categories shown in Table 4.10. These categories help translate technical assessments into clear communication tools for both technical and no-technical stakeholders, reinforcing transparency and accountability in sustainability evaluations.

The percentage thresholds for the RISE sustainability categories were designed to reflect graduated levels of sustainability

TABLE 4.10
RISE Score Categories.

RISE Category	Score Range	Description
Minimal Practice	0–19%	The project exhibits negligible consideration for sustainability. Most applicable indicators were not addressed, and sustainability measures are either absent or entirely symbolic. Major improvements are needed across environmental, social, and economic dimensions to align with basic standards.
Basic Practice	20–39%	The project meets minimal sustainability expectations, with partial efforts across several indicators. While some criteria are addressed, implementation is limited, often lacking integration or long-term effectiveness. This level reflects an early-stage commitment or compliance-based approach, requiring significant scaling and alignment with best practices.
Good Practice	40–59%	The project demonstrates a reasonable commitment to sustainability. Several criteria are actively addressed across all dimensions, though some gaps remain in performance, integration, or innovation. This level indicates a solid foundation, providing room for enhancement.
Advanced Practice	60–79%	The project performs strongly across most sustainability indicators. Strategies are well-integrated and aligned with recognized standards, demonstrating clear and measurable impacts. It reflects a mature approach to sustainable infrastructure, with stakeholder collaboration, lifecycle thinking, and long-term value creation being evident.
Leading Practice	80–100%	The project exemplifies sustainability leadership. It addresses nearly all relevant indicators with high levels of achievement, innovation, and inclusivity. Practices exceed standard compliance, often setting benchmarks for others.

integration, ranging from minimal to exemplary performance. These score ranges correspond to the degree of indicator fulfillment, the presence of integrated sustainability practices, and the extent to which a project moves beyond basic compliance toward strategic and transformative outcomes. This structure is consistent with tiered performance models used in existing sustainability rating systems such as INVEST, CEEQUAL, and BE2ST-in-Highways (BRE Global Limited, 2020; FHWA, 2018; Recycled Materials Resource Center, n.d.). It is important to note that, as this represents the first version of the RISE framework, these achievement thresholds have been provisionally established but not yet empirically calibrated. Future calibration will be informed by the evaluation of additional RIDPs using RISE, enabling refinement of category boundaries based on broader data and practitioner feedback.

In conclusion, the amalgamation process completes the RISE methodology by transforming detailed, multicriteria evaluations into a unified score that supports comparative assessment, strategic decision-making, and the promotion of sustainability best practices in road infrastructure development.

5. CASE STUDY: APPLICATION OF RISE TO THE I-69 FINISH LINE PROJECT

5.1 Introduction

The I-69 Finish Line is the sixth and final section of the Interstate 69 (I-69) corridor connecting Evansville to Indianapolis, marking a major milestone in Indiana's statewide infrastructure development strategy (Figure 5.1). This final segment upgrades the existing State Road 37 (SR 37) to interstate standards from Martinsville to Indianapolis (Figure 5.2), transforming the corridor into a fully functional, high-capacity interstate highway. The project scope includes the elimination of at-grade crossings, construction of new overpasses and underpasses, establishment of local access roads, and the introduction of new interstate access points—altogether enhancing regional mobility, safety, and connectivity.

Originally scheduled for substantial completion by December 2024, the project reached a critical milestone with the opening of the I-465 interchange on December 16, 2024. Full traffic access was opened by the end of 2024, with minor construction activities continuing through spring and summer of 2025 (INDOT, n.d.b). The most recent financial plan update estimates the total project cost at $2.063 billion (INDOT, 2024).

The I-69 Finish Line represents a prototypical RIDP with tangible impacts across all three pillars of sustainability—environmental, social, and economic. Each pillar has been addressed independently through environmental impact assessments, community outreach, and financial planning documents (INDOT, 2024; USDOT et al., 2018). However, to the best of the author's knowledge, no integrated sustainability evaluation framework has been used to assess the project holistically across all dimensions.

This chapter demonstrates the application of the RISE framework to the I-69 Finish Line project during its ongoing construction phase. The primary objective is to showcase how RISE could consolidate complex sustainability considerations into a structured, transparent decision-support tool for evaluating RIDPs. The chapter begins by outlining the context of the project and the supporting documentation used for assessment. It then details the selection of sustainability indicators and corresponding evaluation criteria relevant to the construction phase. Next, each selected criterion is evaluated using RISE's structured achievement tiers based on available project documentation. The results are then aggregated to compute the overall RISE score, followed by a discussion of the project's sustainability performance, key strengths, areas for improvement, and broader insights for future infrastructure evaluations.

5.2 Project Context and Documentation

The I-69 Finish Line project represents one of the most significant infrastructure investments currently underway in the state of Indiana. The project encompasses five major

Figure 5.1 I-69 Project Sections. Source: INDOT, n.d.b.

Figure 5.2 I-69 Finish Line Map. Source: INDOT, n.d.b.

construction contracts and involves the development of 26 mi of new interstate highway. In addition, it includes 35 lane miles of new local access roads, the construction of 39 new bridges, and the rehabilitation or replacement of 35 existing bridges (INDOT, n.d.d). Fourteen overpasses and underpasses are also being constructed to eliminate at-grade crossings and improve traffic continuity, alongside the introduction of ten new interstate access points to enhance regional connectivity and mobility (INDOT, 2024).

The environmental review and project approval process for the corridor followed a comprehensive two-tiered approach in accordance with NEPA. A Tier I Record of Decision (ROD) for the full I-69 corridor from Evansville to Indianapolis was issued in March 2004. Subsequently, INDOT received FHWA approval for the Tier II Final Environmental Impact Statement (FEIS) and ROD for Section 6—the I-69 Finish Line—on February 1, 2018 (USDOT et al., 2018). This review process considered various technical, environmental, and economic criteria to determine the optimal alignment and scope of work.

RISE is designed to complement traditional RIDP evaluation practices by offering a structured means of assessing sustainability once key performance thresholds have been met. In the case of I-69 Finish Line, the final alignment and design were selected based on several conventional metrics, including engineering complexity, right-of-way acquisition requirements, traffic safety improvements, estimated costs, and environmental impacts such as affected water bodies, land conversion, and mitigation area needs. This case study applies the RISE tool to the selected alternative of the I-69 Finish Line project with the objective of evaluating the extent to which sustainability considerations have been incorporated into it. It is assumed that the level of sustainability integration would have been consistent across all project alternatives, allowing this evaluation to serve as a representative assessment for the entire RIDP. The resulting RISE score can be used to benchmark the project's sustainability performance and may be compared with similar infrastructure projects either within the state of Indiana or in other jurisdictions.

The evaluation is based on a review of publicly available project documentation and supplementary materials provided by INDOT. Key references include the I-69 Section 6 Tier II FEIS (USDOT et al., 2018), the I-69 Financial Plan Annual Update 2024 (INDOT, 2024), and additional technical documents and appendices related to environmental mitigation and project execution (INDOT, n.d.d). These sources provide the evidence necessary to score the relevant indicators within the RISE framework, allowing for a comprehensive and objective assessment of sustainability performance during the construction phase.

5.3 Selection of Indicators and Evaluation Criteria

All 31 sustainability indicators defined within the RISE framework were considered in the evaluation of the I-69 Finish Line project; however, not all 96 evaluation criteria were applied. To maintain comprehensive coverage across the environmental, social, and economic dimensions, at least one evaluation criterion was selected for each indicator. The selection was carried out by the author based on the relevance of each criterion to the specific context of the project and the availability of supporting documentation. The indicators and evaluation items selected are shown in Chapter 4 of the report. RISE is designed to offer flexibility, allowing practitioners to tailor the assessment by selecting criteria that align with the values and strategic goals of the implementing agency. This approach ensures that the evaluation remains context-sensitive while preserving methodological consistency and enabling meaningful comparison across RIDs.

5.4 Evaluation Using RISE Structured Rating Scales

The selected evaluation criteria were assessed using the RISE structured rating scales, which provide standardized achievement tiers to ensure consistency and transparency. The construction-phase weights developed in Chapter 4 of this report were applied to reflect the current stage of the I-69 Finish Line project. The evaluation is presented in Table 5.1.

5.5 RISE Score Calculation and Results

Table 5.2 presents the results of the RISE score calculation for the I-69 Finish Line project, including the computed scores for each indicator, their corresponding weights, and individual contributions to the final score. The table also displays the total RISE score, representing the overall sustainability performance of the project during the construction phase.

5.6 Discussion and Insights for Improvement

5.6.1 Environmental Pillar

The I-69 Finish Line project demonstrates notable strengths in several key areas of environmental sustainability, particularly in habitat preservation, stormwater management, and disaster risk reduction. One of the project's most commendable practices is the strategic approach to habitat fragmentation and connectivity. All nine identified wildlife movement corridors were accounted for with dedicated crossings—underpasses, green bridges, and culverts—ensuring ecological continuity from design through implementation. Similarly, robust erosion and flood control strategies were integrated early in project development. The project includes a comprehensive disaster risk reduction plan with clear measures for erosion control and flood prevention. This is complemented by the implementation of a Stormwater Pollution Prevention Plan that follows INDOT's Water Management Field Guide (INDOT, 2018a), effectively addressing stormwater runoff and water quality concerns.

Additional good practices include the consistent application of dust suppression measures at construction sites, in full compliance with INDOT Standard Specifications (INDOT, 2016), and the integration of noise abatement solutions in sensitive areas along the corridor. While the project does not include a formal light pollution mitigation plan, the use of non-diffuse lighting demonstrates an awareness of community and environmental concerns. These initiatives, while sometimes standard in large-scale infrastructure projects, reflect a strong baseline commitment to environmental responsibility during construction.

Despite these positive efforts, there remain several opportunities to enhance the project's environmental performance. While contractors such as Walsh Construction Co. and Milestone emphasize energy efficiency at the corporate level (Walsh Construction, n.d.), no project-specific energy conservation or monitoring plan was identified. Likewise, although INDOT specifications promote the use of reclaimed materials, there is no formalized plan for maximizing recyclable material use or diverting construction waste from landfills. Current waste efforts appear focused more on management than on reduction at the source.

Similarly, local sourcing is reportedly practiced. However, no procurement plan explicitly prioritizing local materials was found—an area that could offer both environmental and regional

TABLE 5.1
RISE Evaluation for I-69 Finish Line.

Pillar		Indicator		Evaluation criteria	Relevant (Y/ N)	Achievement Level	Score	Remarks
Environmental	E.1.1	Energy Conservation	E.1.1.1	Adoption of renewable energy sources (e.g., solar, wind)	No	Non-Applicable	0	Contractors Walsh Construction Co and Milestone, among others highlight the importance of energy efficiency, however no direct plan exists for the I-69 Finish line project in specific (Walsh Construction, n.d.).
			E.1.1.2	Implementation of energy-saving technologies and practices	Yes	25% Compliance	1	
			E.1.1.3	Promotion of energy consumption monitoring plan	No	Non-Applicable	0	
	E.1.2	Resource Efficiency	E.1.2.1	Use of energy-efficient machinery and vehicles	No	Non-Applicable	0	Some efforts to optimize materials, but waste reduction is minimal with a stronger focus on the management of the waste.
			E.1.2.2	Efficient use of construction materials to reduce waste	Yes	25% Compliance	1	
	E.1.3	Water Efficiency	E.1.3.1	Grey water reuse	No	Non-Applicable	0	No rainwater harvesting plan was developed or considered for the construction of the project.
			E.1.3.2	Control of water use	No	Non-Applicable	0	
			E.1.3.3	Storm water runoff management	No	Non-Applicable	0	
			E.1.3.4	Rainwater harvesting	Yes	0% Compliance	0	
	E.2.1	Material Selection	E.2.1.1	Recyclable materials	Yes	0% Compliance	0	Although the INDOT standard specifications (INDOT, 2016) stated guidelines for the use of reclaimed asphalt pavement, and other materials, no recyclable materials plan was found to be strictly applied to the construction of the project.
			E.2.1.2	Use of natural resources (soil, wood, bamboo, etc.)	No	Non-Applicable	0	
			E.2.1.3	Durable material resources	No	Non-Applicable	0	
			E.2.1.4	Re-use of pavement materials for construction	No	Non-Applicable	0	
			E.2.1.5	Virgin Material consumption	No	Non-Applicable	0	
	E.2.2	Local Sourcing	E.2.2.1	Sustainable Procurement of materials (Locally available)	Yes	0% Compliance	0	No procurement plan for the project prioritizing local materials was found.
	E.3.1	Waste Reduction and Recycling	E.3.1.1	Waste collection	No	Non-Applicable	0	No diversion plan from landfills or minimal diversion efforts were found in the documentation of the project.
			E.3.1.2	Recycling and reuse of waste	Yes	0% Compliance	0	
	E.3.2	Environmental Impact of Waste	E.3.2.1	Ozone depletion	No	Non-Applicable	0	Strong design features including infiltration basins, connected to grass-lined roadside ditches; salt application is optimized, and evaluation of alternative substances is in place.
			E.3.2.2	Eutrophication	Yes	75% Compliance	3	
	E.4.1	Habitat Fragmentation and Connectivity	E.4.1.1	Barrier effect reduction for wildlife movement	Yes	100% Compliance	4	All 9 identified wildlife movement corridors have appropriate crossings, underpasses, or green bridges. Ensuring the protection of the corridor from the design to the construction phase
			E.4.1.2	Habitat connectivity enhancement	No	Non-Applicable	0	
			E.4.1.3	Protection of valuable habitats and natural (ecological) areas	No	Non-Applicable	0	
	E.4.2	Land Use Management	E.4.2.1	Density of land use	No	Non-Applicable	0	361 acres of the total right of way of 2075 acres is converted. (17.4%), and 4 out of the 443 relocations are agricultural
			E.4.2.2	Minimization of productive land conversion	Yes	75% Compliance	3	
	E.5.1	Air Pollution Control	E.5.1.1	Reduction of vehicular emissions (specify pollutants like NOx, CO, PM10, CO2)	Yes	50% Compliance	2	Partial emissions reduction strategy with some measures in place to control for mobile source air toxics and diesel emissions.
	E.5.2	Light and Noise Pollution	E.5.2.1	Decrease in light pollution from roadways	Yes	75% Compliance	3	Noise abatement measures have been listed in identified sensitive areas along the project. Non-diffuse lighting is considered but no special attention is given to light pollution.
			E.5.2.2	Noise and vibration levels control during construction and operation	Yes	100% Compliance	4	
	E.5.3	Dust Management	E.5.3.1	Dust suppression measures during construction phases	Yes	100% Compliance	4	All construction sites fully implement dust suppression techniques where the need has been identified, following INDOT standard specifications (INDOT, 2016).

(*Continued*)

TABLE 5.1
RISE Evaluation for I-69 Finish Line. (*Continued*)

Pillar		Indicator		Evaluation criteria	Relevant (Y/ N)	Achievement Level	Score	Remarks
Environmental	E.6.1	Green Gas Emission	E.6.1.1	GHG emissions reduction strategies	Yes	50% Compliance	2	Partial GHG reduction strategy that addresses both direct and indirect emissions but lacks comprehensive measures.
	E.6.2	Adaptation to Climate Impacts	E.6.2.1	Integration of climate-adaptive landscaping (e.g., heat-resilient plant species)	No	Non-Applicable	0	Fully comprehensive disaster risk reduction plan integrated, addressing erosion, and flood lands on the project. An erosion control plan was developed.
			E.6.2.2	Disaster risk reduction in design (addressing erosion, landslides, floods)	Yes	100% Compliance	4	
	E.6.3	Water Management	E.6.3.1	Stormwater runoff management to reduce volume and peak flow	Yes	100% Compliance	4	Project developed a stormwater pollution prevention plan following the INDOT storm Water Management Field Guide (INDOT, 2018a)
Social	S.1.1	Comprehensive Health and Safety Measures at Work	S.1.1.1	Working conditions	No	Non-Applicable	0	Basic plan to reduce work-related fatalities and traffic accidents exists but with minimal implementation and impact. Workforce safety measures are mainly taken by the contractor (Henry, 2023), but no plan with effective safety measures is specifically mentioned for the project
			S.1.1.2	Health and safety training	No	Non-Applicable	0	
			S.1.1.3	Provision of personal protective equipment (PPE)	No	Non-Applicable	0	
			S.1.1.4	Onsite medical services	No	Non-Applicable	0	
			S.1.1.5	Safety measures (e.g., site hoarding, safety warnings)	No	Non-Applicable	0	
			S.1.1.6	Traffic accident rates involving personal injury or death	Yes	25% Compliance	1	
	S.1.2	Promoting Employee Well-being and Equity	S.1.2.1	Employment of local labor	Yes	0% Compliance	0	No specific initiatives to hire local labor were defined for the project
			S.1.2.2	Employee well-being and benefits	No	Non-Applicable	0	
			S.1.2.3	Equal rights and opportunities across diverse groups	No	Non-Applicable	0	
	S.1.3	Ensuring Workplace Integrity and Fair Practices	S.1.3.1	Job stability and security	No	Non-Applicable	0	No specific training or upskilling opportunities are provided within the project construction. Fully developed framework with all stakeholders trained on ethical practices and transparency to prevent corruption.
			S.1.3.2	Non-discriminatory hiring practices	No	Non-Applicable	0	
			S.1.3.3	Anti-corruption measures	No	Non-Applicable	0	
			S.1.3.4	Fair remuneration and reasonable workload	No	Non-Applicable	0	
			S.1.3.5	Knowledge and skills transfer	Yes	0% Compliance	0	
	S.1.4	Active and Inclusive Stakeholder Involvement	S.1.4.1	Stakeholder acceptability	Yes	100% Compliance	4	85% of stakeholder approval was achieved based on consultations and surveys results. Additionally, stakeholders were engaged with more than 12 months before the project start date, with active involvement of different stakeholders. On top of it, project updates are shared through the website of the project in a timely matter (at least once per month).
			S.1.4.2	Early involvement of stakeholders	Yes	100% Compliance	4	
			S.1.4.3	Timely and relevant information sharing	Yes	100% Compliance	4	
			S.1.4.4	Freedom of participation in decision-making	No	Non-Applicable	0	
	S.2.1	Improvement Measures in Mobility and Accessibility	S.2.1.1	Project achieves measurable travel time savings for users	Yes	50% Compliance	2	Project provides clear, measurable improvements in access to multiple points of interest such as schools, universities, religious facilities, health centers, fire departments, etc. with documented outcomes or accessibility analysis. The final alignment for the project highlights a reduction in travel time of 8% to the Indianapolis airport, 22% to downtown Indianapolis, and 19% to I-69 Northeast, averaging 16% reduction in projected travel time reduction.
			S.2.1.2	Project reduces Road User Costs (RUCs) compared to pre-project conditions.	No	Non-Applicable	0	
			S.2.1.3	Enhancement of service levels	No	Non-Applicable	0	
			S.2.1.4	Increased passenger movement	No	Non-Applicable	0	
			S.2.1.5	Improved access to public services	Yes	100% Compliance	4	
			S.2.1.6	Enhanced access to transit	No	Non-Applicable	0	
			S.2.1.7	Increase in active mobility	No	Non-Applicable	0	
			S.2.1.8	Reduced traffic flow impairments	No	Non-Applicable	0	
			S.2.1.9	Support for multimodal	No	Non-Applicable	0	

(*Continued*)

TABLE 5.1
RISE Evaluation for I-69 Finish Line. (*Continued*)

Pillar		Indicator		Evaluation criteria	Relevant (Y/ N)	Achievement Level	Score	Remarks
Social	S.3.1	Quality of Life Improvements	S.3.1.1	Emission impact reduction on human health	No	Non-Applicable	0	Moderate enhancements such as improved sidewalks and pedestrian facilities to support social cohesion.
			S.3.1.3	Promotion of art, culture, and community values	No	Non-Applicable	0	
			S.3.1.4	Improvement in social cohesion and aesthetics	Yes	50% Compliance	2	
			S.3.1.5	Educational opportunities	No	Non-Applicable	0	
	S.3.2	Community Safety and Risk Reduction	S.3.2.1	Accident rate reduction	Yes	75% Compliance	3	17.2% reduction in crash rates (PD and Fatal), with a 21.4% reduction in the cost of crashes.
			S.3.2.2	Risk of accidents per output unit	No	Non-Applicable	0	
			S.3.2.3	Safety-related expenses	No	Non-Applicable	0	
			S.3.2.4	Immediate impact on road safety	No	Non-Applicable	0	
	S.4.1	Societal Well-being and Equity for Vulnerable Groups	S.4.1.1	Equitable environmental quality for vulnerable groups	No	Non-Applicable	0	A fully integrated universal accessibility approach that ensures barrier-free mobility for all population groups across the project area, benefiting the local community—including block groups with elevated minority and low-income populations—by providing increased mobility and connectivity.
			S.4.1.2	Economic development enhancement	No	Non-Applicable	0	
			S.4.1.3	Reduction of pollution impacts on vulnerable groups	No	Non-Applicable	0	
			S.4.1.4	Enhancement of physical and social mobility for all	Yes	100% Compliance	4	
	S.5.1	Cultural Preservation and Integration with Local Character	S.5.1.1	Protection of archaeological and historical sites	No	Non-Applicable	0	Full and thoughtful integration of architectural and cultural heritage in design for the Morgan Johnson and Marion County, resulting in a project that authentically reflects local character.
			S.5.1.2	Enhancement of local identity and global reputation	No	Non-Applicable	0	
			S.5.1.3	Design integration with local character	Yes	100% Compliance	4	
			S.5.1.4	Expertise in managing cultural heritage	No	Non-Applicable	0	
	S.6.1	Compensation and Relocation Practices that Preserve Dignity	S.6.1.1	Fair compensation strategies	Yes	100% Compliance	4	The project maintained a fair and equitable property acquisition process to ensure adequate consideration and compensation for federally funded transportation projects, following laws and programs including the Uniform Act, and the INDOT relocation program and relocation advisory assistance program, ensuring a fair compensation, comprehensive relocation assistance, livelihood restoration, and post-relocation support. (FHWA, 2014).
			S.6.1.2	Dignity preservation during displacement	No	Non-Applicable	0	
			S.6.1.3	Management of land acquisition and involuntary resettlement	No	Non-Applicable	0	
	S.6.2	Socioeconomic Impacts of Projects	S.6.2.1	Socioeconomic benefits at regional and national levels	Yes	100% Compliance	4	Over $1.7 Billion expected increase in regional wages, and over $2.4 Billion increase in regional GDP.
			S.6.2.2	Promotion of social marketing opportunities	No	Non-Applicable	0	
			S.6.2.3	Monitoring of project impacts on local economies	No	Non-Applicable	0	
			S.6.2.4	Transport cost analysis for cars and freight	No	Non-Applicable	0	
			S.6.2.5	Tourism enhancement strategies	No	Non-Applicable	0	
	S.7.1	Governance Compliance and Transparent Decision-Making	S.7.1.1	Adherence to anti-discrimination norms	No	Non-Applicable	0	Full and demonstrable compliance with all relevant regulations, including permits, audits, and review procedures. Fully transparent, accountable, and fair procurement process, with independent oversight, audit trails, and public disclosure of selection outcomes.
			S.7.1.2	Compliance with governmental rules and regulations	Yes	100% Compliance	4	
			S.7.1.3	Transparency in contractor selection	Yes	100% Compliance	4	
			S.7.1.4	Allocation of adequate resources for long-term social sustainability	No	Non-Applicable	0	
Economic	EC.1.1	Net Present Value (NPV)	EC.1.1.1	Total net benefit or cost over the project's life discounted to present value.	Yes	0% Compliance	0	No Net Present Value (NPV) analysis is carried out to balance the economic value of the benefits of the project compared to the present value of the costs.
	EC.1.2	Internal Rate of Return (IRR)	EC.1.2.1	Expected compound annual rate of return generated by the project.	Yes	0% Compliance	0	No IRR analysis is carried out given the public funding nature of the project.
	EC.1.3	Payback Period	EC.1.3.1	Time required to recover the cost of the investment.	Yes	0% Compliance	0	No Payback period analysis is carried out given the public funding nature of the project.

(*Continued*)

TABLE 5.1
RISE Evaluation for I-69 Finish Line. (*Continued*)

Pillar	Indicator		Evaluation criteria		Relevant (Y/ N)	Achievement Level	Score	Remarks
Economic	EC.2.1	Overall Project Costs	EC.2.1.1	Operation Costs	No	0% Compliance	0	Since the first initial financial plan in 2018, to the latest update in 2024 the cost of the project has increased in $428.93 million, or 26.2% with respect to the initial investment cost of the project. However, there have been significant cost savings achieved via integrated planning, efficient contracting, or rapid deployment techniques, with verified performance quality.
			EC.2.1.2	Investment Cost	Yes	25% Compliance	1	
			EC.2.1.3	Unit cost of construction, maintenance, rehabilitation, and reconstruction	No	Non-Applicable	0	
			EC.2.1.4	Installation costs	Yes	75% Compliance	3	
			EC.2.1.5	Disposal Costs	No	Non-Applicable	0	
			EC.2.1.6	Maintenance Costs.	No	Non-Applicable	0	

TABLE 5.2
RISE Scores by Sustainability Indicators.

Pillar	Code	Indicator	Computed Score	Max Score	Weight	Weighted Score	Difference
Environmental	E.1.1	Energy Conservation	1	4	2.08%	0.52%	75.00%
	E.1.2	Resource Efficiency	1	4	2.63%	0.66%	75.00%
	E.1.3	Water Efficiency	0	4	2.53%	0.00%	100.00%
	E.2.1	Material Selection	0	4	2.63%	0.00%	100.00%
	E.2.2	Local Sourcing	0	4	2.44%	0.00%	100.00%
	E.3.1	Waste Reduction and Recycling	0	4	2.56%	0.00%	100.00%
	E.3.2	Environmental Impact of Waste	3	4	2.02%	1.51%	25.00%
	E.4.1	Habitat Fragmentation and Connectivity	4	4	1.90%	1.90%	0.00%
	E.4.2	Land Use Management	3	4	2.08%	1.56%	25.00%
	E.5.1	Air Pollution Control	2	4	2.30%	1.15%	50.00%
	E.5.2	Light and Noise Pollution	7	8	2.21%	1.93%	12.50%
	E.5.3	Dust Management	4	4	2.96%	2.96%	0.00%
	E.6.1	Green Gas Emission	2	4	2.34%	1.17%	50.00%
	E.6.2	Adaptation to Climate Impacts	4	4	2.03%	2.03%	0.00%
	E.6.3	Water Management	4	4	2.16%	2.16%	0.00%
Social	S.1.1	Comprehensive Health and Safety Measures at Work	1	4	3.28%	0.82%	75.00%
	S.1.2	Promoting Employee Well-being and Equity	0	4	2.44%	0.00%	100.00%
	S.1.3	Ensuring Workplace Integrity and Fair Practices	0	4	2.93%	0.00%	100.00%
	S.1.4	Active and Inclusive Stakeholder Involvement	12	12	2.93%	2.93%	0.00%
	S.2.1	Improvement Measures in Mobility and Accessibility	6	8	2.87%	2.15%	25.00%
	S.3.1	Quality of Life Improvements	2	4	2.35%	1.17%	50.00%
	S.3.2	Community Safety and Risk Reduction	3	4	3.11%	2.33%	25.00%
	S.4.1	Societal Well-being and Equity for Vulnerable Groups	4	4	2.15%	2.15%	0.00%
	S.5.1	Cultural Preservation and Integration with Local Character	4	4	2.65%	2.65%	0.00%
	S.6.1	Compensation and Relocation Practices that Preserve Dignity	4	4	2.35%	2.35%	0.00%
	S.6.2	Socioeconomic Impacts of Projects	4	4	2.29%	2.29%	0.00%
	S.7.1	Governance Compliance and Transparent Decision-Making	8	8	3.17%	3.17%	0.00%
Economic	EC.1.1	Net Present Value (NPV)	0	4	7.24%	0.00%	100.00%
	EC.1.2	Internal Rate of Return (IRR)	0	4	7.44%	0.00%	100.00%
	EC.1.3	Payback Period	0	4	8.01%	0.00%	100.00%
	EC.2.1	Overall Project Costs	4	8	9.95%	4.97%	50.00%
					RISE FINAL SCORE	44.53%	

economic benefits. Land use conversion—approximately 17.4% of the total right-of-way—was well documented. Air pollution mitigation is partially addressed through emissions controls for mobile sources and diesel equipment, but without detailed strategies or follow-up monitoring, their effectiveness may be limited. A more proactive approach—such as real-time emissions tracking and feedback mechanisms—could further enhance air quality outcomes.

5.6.2 Social Pillar

The I-69 Finish Line project demonstrates several commendable efforts aligned with social sustainability objectives, particularly in areas related to stakeholder engagement, accessibility improvements, cultural preservation, and equitable governance. One of the strongest aspects is the project's approach to stakeholder involvement. Consultations began more than 12 months prior to project implementation, and engagement was active and sustained throughout the planning process. As a result, the project achieved an 85% stakeholder approval rating, indicating strong public support. Ongoing communication is also prioritized, with updates consistently provided through the project website at least once per month, reinforcing transparency and responsiveness.

The project also exhibits measurable success in improving mobility and accessibility. Documented accessibility analyses indicate enhanced connections to essential destinations such as schools, universities, healthcare facilities, religious institutions, and emergency services. Notably, travel time is projected to decrease by 8% to the Indianapolis Airport, 22% to downtown Indianapolis, and 19% to the I-69 Northeast corridor, with an average reduction of 16%. These improvements support both regional mobility and economic opportunity. Furthermore, a fully integrated universal accessibility framework has been adopted, ensuring barrier-free mobility for all user groups, including those in historically underserved communities. This aligns with social goals and strengthens the project's community value.

Cultural and historical integration is another key strength. The final design reflects the architectural and cultural heritage of Morgan, Johnson, and Marion counties, preserving local identity and enhancing public appreciation of place. In terms of safety, the project is expected to reduce crash rates involving property damage and fatalities by 17.2%, with a 21.4% reduction in crash-related costs. These projected outcomes indicate a clear prioritization of public health and safety.

From an institutional perspective, the project demonstrates strong adherence to governance and human rights standards. It complies fully with relevant legal and regulatory frameworks and follows a transparent and accountable procurement process. Independent oversight, audit trails, and public disclosures ensure integrity throughout the project lifecycle. Additionally, land acquisition and resettlement activities were conducted in alignment with the Uniform Act and INDOT's relocation assistance programs (FHWA, 2014), ensuring fair compensation, livelihood restoration, and post-relocation support.

Despite these strengths, the project shows room for improvement in certain areas. The construction contractors which include Milestone, manage general workforce safety (Henry, 2023). However, there is no dedicated, project-specific health and safety plan detailing on-site measures. Similarly, although ethical practices and anti-corruption training are reported, the project lacks defined efforts to recruit and upskill local labor—an opportunity that could further amplify its social value. Moderate improvements such as pedestrian facilities are in place to support social cohesion, but co-designed public spaces or initiatives promoting community interaction were not documented. Future projects could benefit from more deliberate strategies in these areas to further strengthen long-term social outcomes.

5.6.3 Economic Pillar

The economic sustainability performance of the I-69 Finish Line project reflects both the complexities inherent in large-scale public infrastructure delivery and opportunities for enhanced transparency in financial evaluations. Although the detailed application of traditional investment appraisal methods such as NPV, IRR, and Payback Period was not explicitly found in the documentation reviewed, it is important to acknowledge that such analyses are typically conducted for major publicly funded infrastructure projects. Their absence from the reviewed materials does not necessarily imply omission but highlights the limitations of relying solely on publicly available project documentation for sustainability assessments.

Cost evolution over the project lifecycle has been significant. According to the 2024 Financial Plan Annual Update, the total estimated cost of the project increased by $428.93 million since the initial 2018 estimate, representing a 26.2% rise in investment requirements (INDOT, n.d.b). Despite this upward adjustment, the project has achieved substantial cost efficiencies through mechanisms such as integrated planning, optimized construction phasing, value engineering, and strategic contracting approaches. These efforts have not only controlled expenditures but have also ensured high-quality execution, indicating a commitment to financial stewardship even in the face of complex and dynamic delivery conditions.

5.6.4 RISE Score

The final RISE score for the I-69 Finish Line project is 44.53%, placing it within the "Good Practice" category on the RISE rating scale. This classification indicates that the project demonstrates a meaningful commitment to sustainability, with several evaluation criteria actively addressed across all three pillars. While the score reflects a solid baseline of sustainability integration—particularly in social governance, environmental protection during construction, and stakeholder engagement—it also highlights clear opportunities for enhancement. Targeted improvements in economic appraisal methods, local labor policies, renewable energy adoption, and lifecycle material reuse could elevate future sustainability outcomes for similar RIDPs.

5.7 Summary

This chapter demonstrated the practical application of the RISE framework by evaluating the I-69 Finish Line project during its ongoing construction phase. The I-69 project, a large-scale RIDP of statewide and regional significance, provided an ideal case to test the framework's flexibility and comprehensiveness. After identifying the relevant indicators and evaluation criteria, the project was assessed using RISE's structured rating scales and the weighting scheme developed specifically for the construction phase. Evaluation results showed strong performance in several environmental and social indicators, including habitat connectivity, stakeholder engagement, universal accessibility, cultural integration, and transparency in governance. Economic sustainability, while addressed through cost oversight, lacked formal financial return metrics such as NPV or IRR. The final RISE score of 44.53% placed the project in the "Good Practice" category, indicating a solid foundation of sustainability integration with clear areas for improvement. The chapter illustrates how RISE could offer a transparent, multicriteria approach to evaluating sustainability in RIDPs, providing insights into performance across dimensions while helping agencies identify targeted strategies to improve future infrastructure outcomes.

6. ADVANCING SUSTAINABILITY WITHIN INDOT

This chapter presents the findings of a web-based survey conducted under an exempt IRB protocol (IRB#2024-1450) approved by Purdue University's Institutional Review Board. To protect participant privacy and ensure ethical rigor, no personally identifiable information was collected, and all responses remained strictly anonymous.

A total of 45 INDOT professionals, representing roles in planning, design, construction, and maintenance, were invited to participate. Of those, 20 completed the survey, yielding a 44 % response rate. Respondents brought a wide range of experience levels and prior exposure to sustainability concepts, making their collective input especially valuable for shaping and weighting the RISE sustainability indicators.

The survey instrument comprised eight sequential sections designed to introduce respondents to the study, establish a common conceptual framework, and then delve progressively deeper into their professional experience and perspectives. It began with an informed-consent section outlining the study's objectives, benefits, and risks, followed by a concise glossary of key terms—such as "Sustainable Development"—to ensure consistent interpretation. Next, participants answered screening questions about their current roles at INDOT, years of service, and prior training in sustainability; some of these demographics were summarized in Table 4.2, underscoring the relevance of their expertise for the RISE tool's weighting procedure.

In the middle sections, respondents assessed their own knowledge and attitudes toward sustainability, rated organizational and technical barriers as well as facilitators to adopting sustainable practices, and evaluated the applicability of specific measures—such as the use of recycled materials or enhanced stormwater management—across each phase of roadway development (planning, design, construction, and operation). In Section 7, professionals ranked 31 candidate sustainability indicators by phase; those rankings directly informed the weight-setting methodology for our RISE framework. Finally, open-ended questions invited participants to share reflections and suggestions to strengthen INDOT's sustainability initiatives.

The remainder of this chapter is organized around three overarching themes that emerged from the survey data: respondents' awareness and confidence in sustainability concepts, the barriers impeding implementation within INDOT's organizational context, and priority initiatives—including targeted training—that can accelerate the agency's transition to more sustainable road-infrastructure development. Each section integrates quantitative results, illustrative excerpts from qualitative feedback, and a discussion of implications for both the RISE tool and INDOT's long-term strategic objectives in sustainability.

6.1 Sustainability Awareness

Survey respondents reported that their professional duties intersect most frequently with the planning phase of road-infrastructure development, with 85 % indicating active involvement in planning tasks (Figure 6.1). Maintenance activities followed at 50 %, and operations at 40 %. Design responsibilities accounted for 35 % of respondents' work, while monitoring comprised 25 %. Only 5 % cited construction as their primary phase, and one individual (5 %) noted their focus lies in environmental assessment rather than a standard RID phase.

Despite this broad engagement across project stages, formal education in sustainability appears limited: 80 % of participants indicated they have received no structured training in sustainable road-infrastructure development, whereas 20 % reported some form of formal coursework or certification Figure 6.2). Instead, respondents rely heavily on

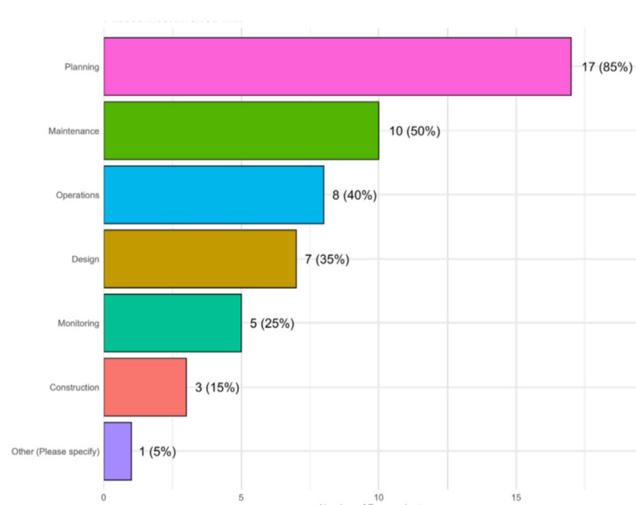

Figure 6.1 Distribution of Respondents by RID Phase Involvement.

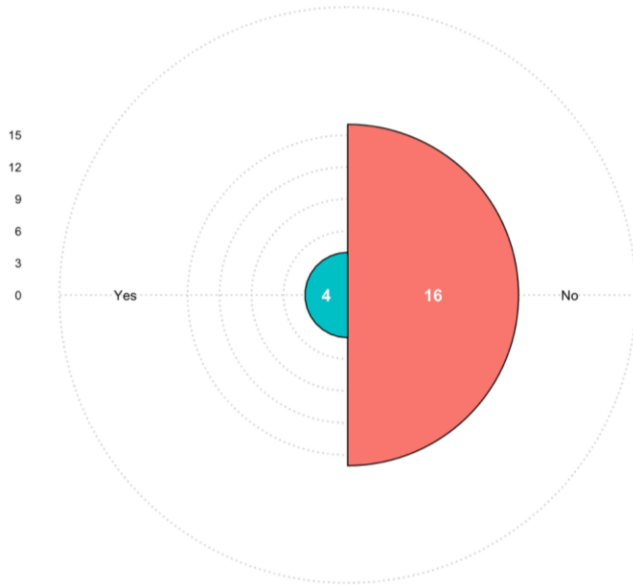

Figure 6.2 Formal Training in Sustainable RID Practices.

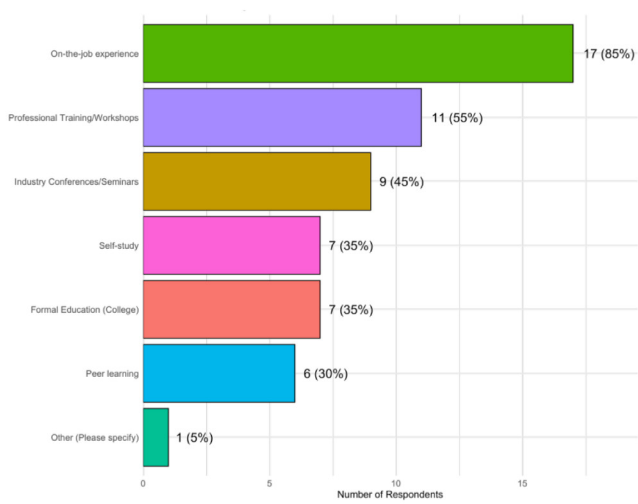

Figure 6.3 Sources of Sustainability Knowledge.

experiential learning—85 % attributed their sustainability knowledge to on-the-job experience. Other common sources include workshops and professional training (55 %), industry conferences (45 %), self-study (35 %), traditional academic programs (35 %), and peer-to-peer exchanges (30 %; Figure 6.3).

When asked how frequently they integrate sustainability considerations into their decision-making, 45 % of professionals said "most of the time," 40 % "sometimes," and 5 % "about half the time," while 10 % admitted they "never" factor sustainability into their daily work Figure 6.4). Confidence in applying sustainable practices mirrors this pattern: only 25 % of respondents described themselves as "very confident," 40 % as "moderately confident," 25 % as "slightly confident," and 10 % as "not confident at all" Figure 6.5).

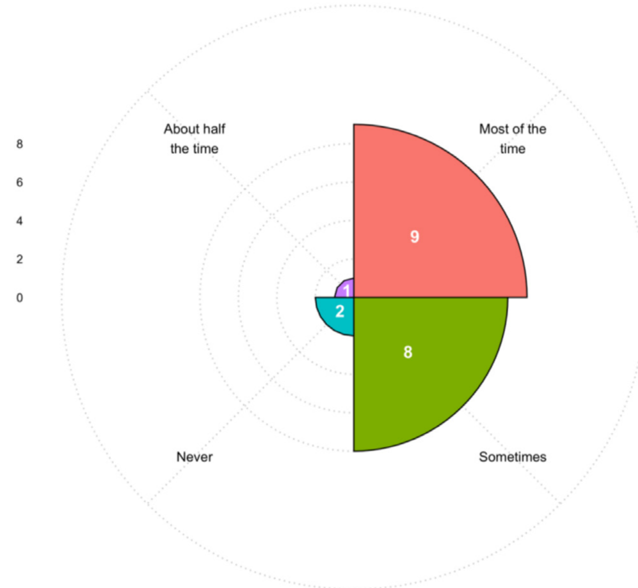

Figure 6.4 Frequency of Sustainability Consideration.

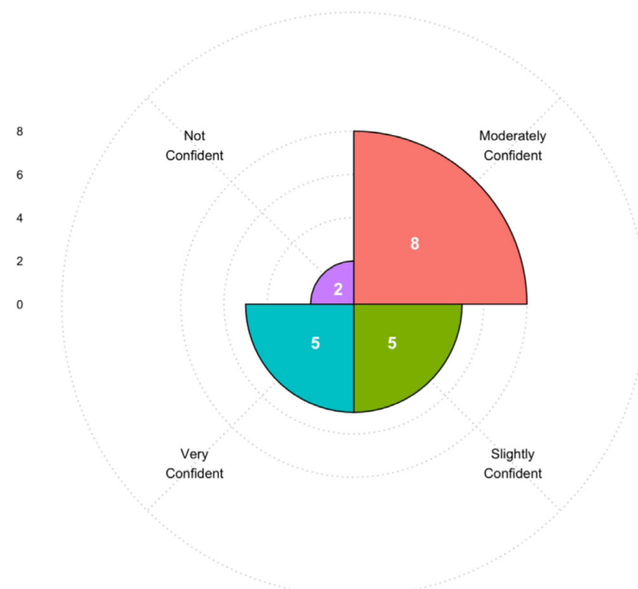

Figure 6.5 Confidence in Implementing Sustainable Practices.

Finally, participants self-rated their level of knowledge across four critical RID phases—Planning and Design; Construction; Operations and Maintenance; and End-of-Life Management (Figure 6.6). The strongest comfort level appeared in Planning and Design, where 35 % of respondents claimed high expertise, followed by 20 % in both Construction and Operations and Maintenance. However, the distribution of responses reveals that the majority in every phase fall into a "moderate" knowledge category. Notably, 60 % rated their construction-phase knowledge as low or very low, and 70 % did so for End-of-Life Management, underscoring clear gaps in later-stage sustainability competencies.

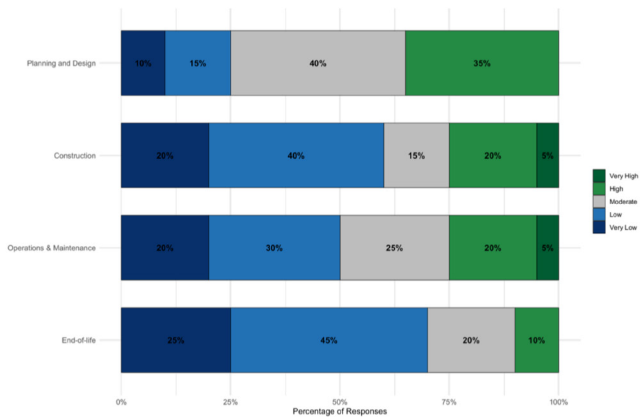

Figure 6.6 Self-Rated Knowledge by RID Phase.

Together, these findings illustrate a workforce deeply engaged in the earliest stages of project delivery but lacking comprehensive formal training in sustainability. While many practitioners feel capable of integrating green practices—particularly in planning and design—significant opportunities exist to bolster confidence and expertise in construction, operations, and end-of-life phases. These insights will guide the development of targeted training modules and priority initiatives introduced later in this chapter.

6.2 Principal Barriers to Sustainable Practices Integration

To uncover the obstacles hindering the uptake of sustainable practices at INDOT, respondents were asked to identify which factors most impede integrating green measures into road-infrastructure development. As illustrated in Figure 6.7, high upfront costs emerged as the primary concern, cited by 75 % of participants. Following closely, 60 % of professionals pointed to a lack of knowledge about sustainability techniques, while limited organizational resources, insufficient awareness of available practices, and inadequate training were each identified by 55 %. Half of the respondents also noted cultural resistance to change as a significant barrier. Additional comments highlighted doubts about product quality and performance—specifically that some environmentally friendly alternatives fail to meet INDOT's established durability and efficiency standards.

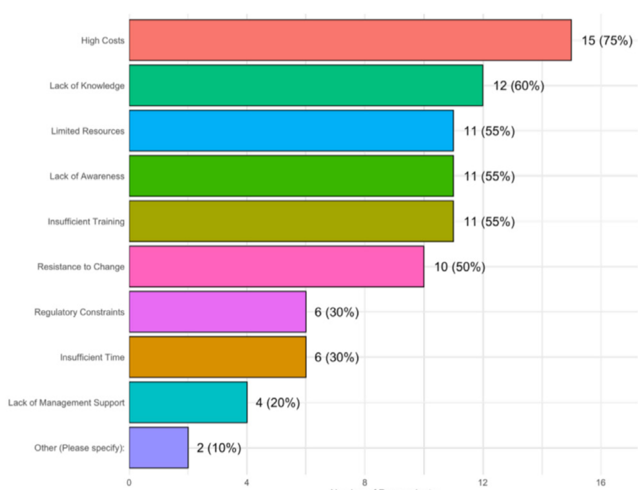

Figure 6.7 Identified Barriers to Implementation.

To further quantify the relative impact of each barrier, participants ranked all nine factors on a scale from "1 = most impactful" to "9 = least impactful." The aggregated ranking (Figure 6.8) reaffirms that high costs pose the greatest challenge, followed by knowledge gaps and a general lack of awareness. Notably, insufficient training was the only barrier consistently placed among the top four concerns by all respondents, underscoring a clear demand for structured educational programs. This ranking exercise not only validates the frequency-based findings but also highlights the urgent need to address both financial and capacity-building dimensions in order to advance INDOT's sustainability agenda.

6.3 Priority Initiatives and Channels

To identify the most promising avenues for accelerating sustainable practices at INDOT, survey participants evaluated a suite of potential initiatives and ranked them by perceived impact. When asked to select all measures that could facilitate the adoption of green approaches, 75 % of respondents highlighted increased training and education as the top priority (Figure 6.9). This was followed by integration of sustainability into performance metrics (65 %), incentives for sustainable practices (60 %), improved funding and budget allocation (60 %), awareness campaigns (55 %), and clearer regulatory guidance (50 %). Lesser-cited ideas included partnerships with academic institutions and pilot-project programs.

To deepen this analysis, participants then ranked the same initiatives from "most" to "least" effective in driving change. Here, improved funding and budget allocation emerged as the single most influential initiative, with 40 % of professionals placing it at the top of their list (Figure 6.10). Increased training and education maintained a strong showing—25 % ranked it as the highest-value intervention—while integration of sustainability into performance metrics also featured prominently among top choices. Notably, collaboration with external partners was the least favored initiative, suggesting that internal capacity and resource alignment take precedence over external coordination in INDOT's current context.

Understanding how practitioners prefer to receive new information is equally critical for designing effective capacity-building programs. As shown in Figure 6.11, online courses and webinars received the strongest endorsement (70 %), reflecting the convenience and flexibility of virtual learning. In-person workshops (65 %) and internal training sessions (60 %) were also popular, indicating continued value in face-to-face engagement and organization-specific curricula. Industry conferences and seminars (50 %) and online toolkits or resource libraries (45 %) rounded out the top five, underscoring the importance of both structured events and self-paced reference materials.

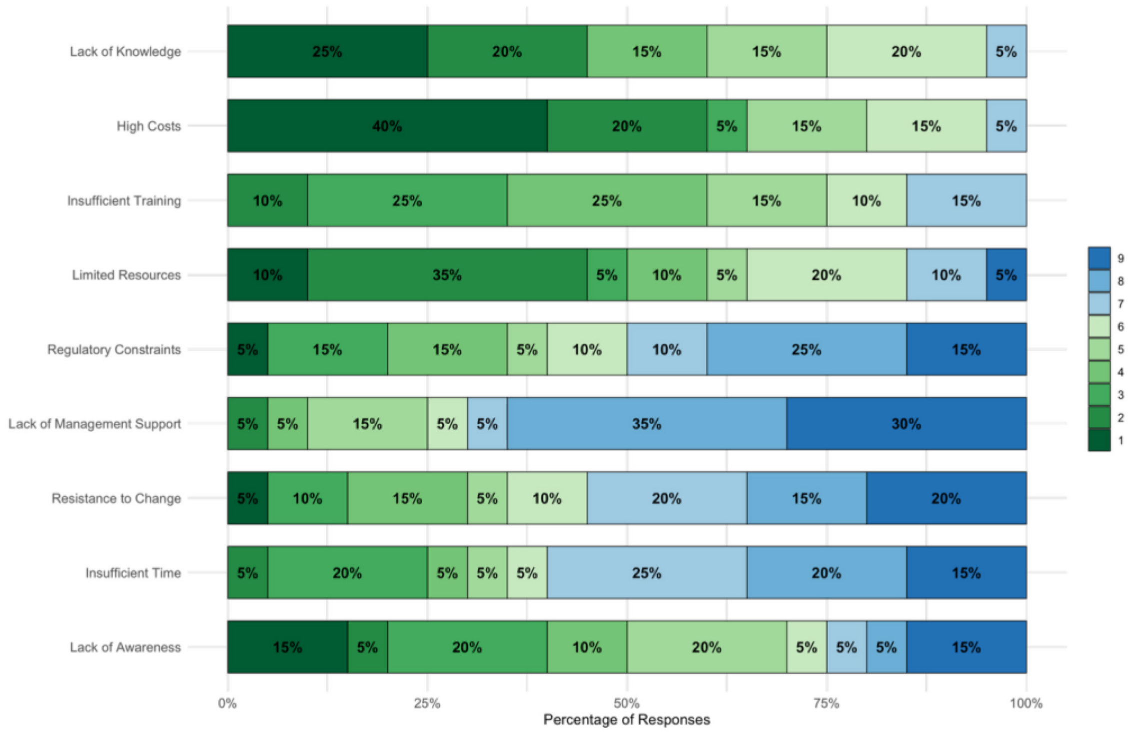

Figure 6.8 Ranked Impact of Barrier.

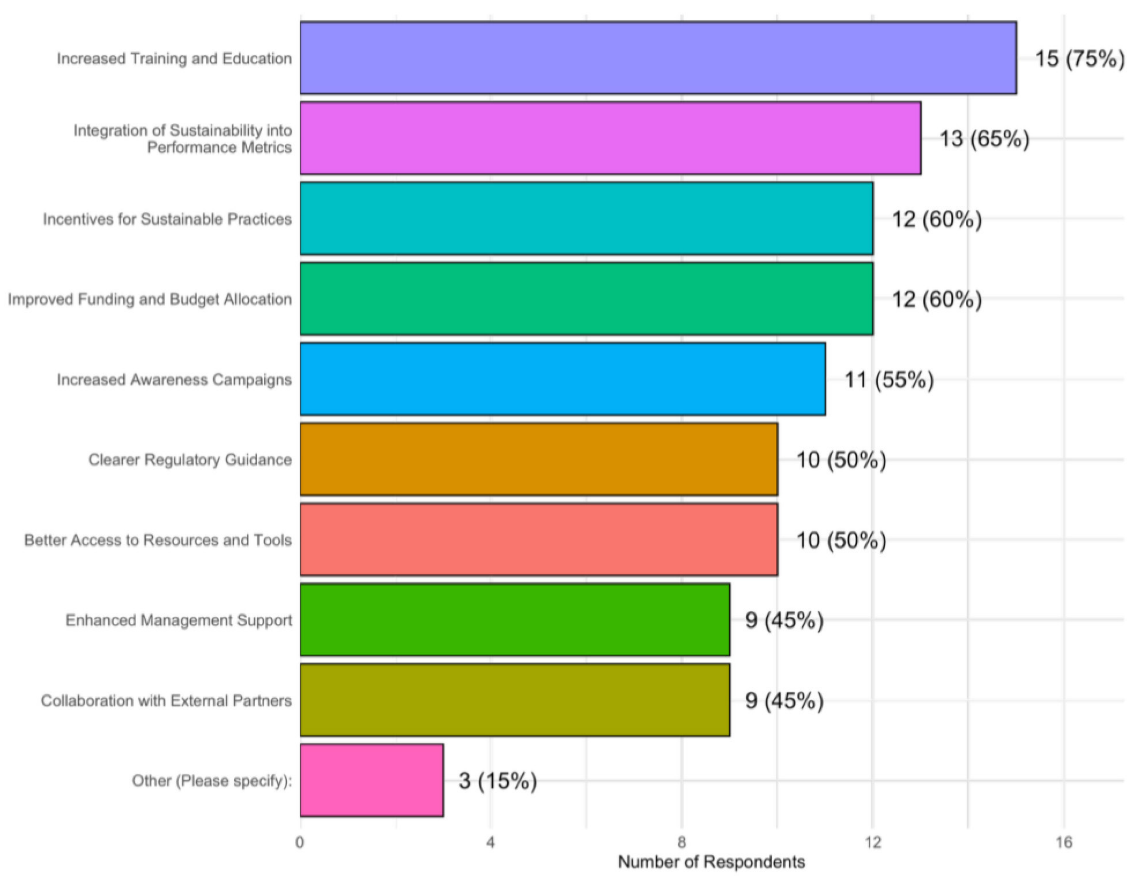

Figure 6.9 Recommended Initiatives.

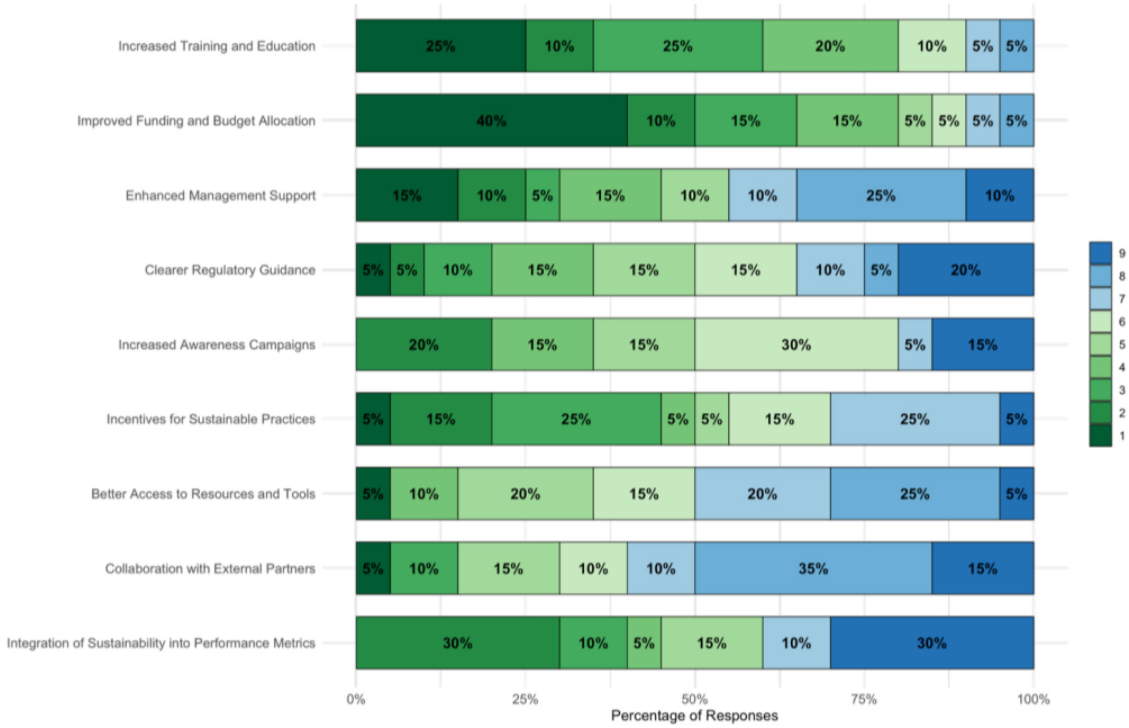

Figure 6.10 Ranked Effectiveness of Initiatives.

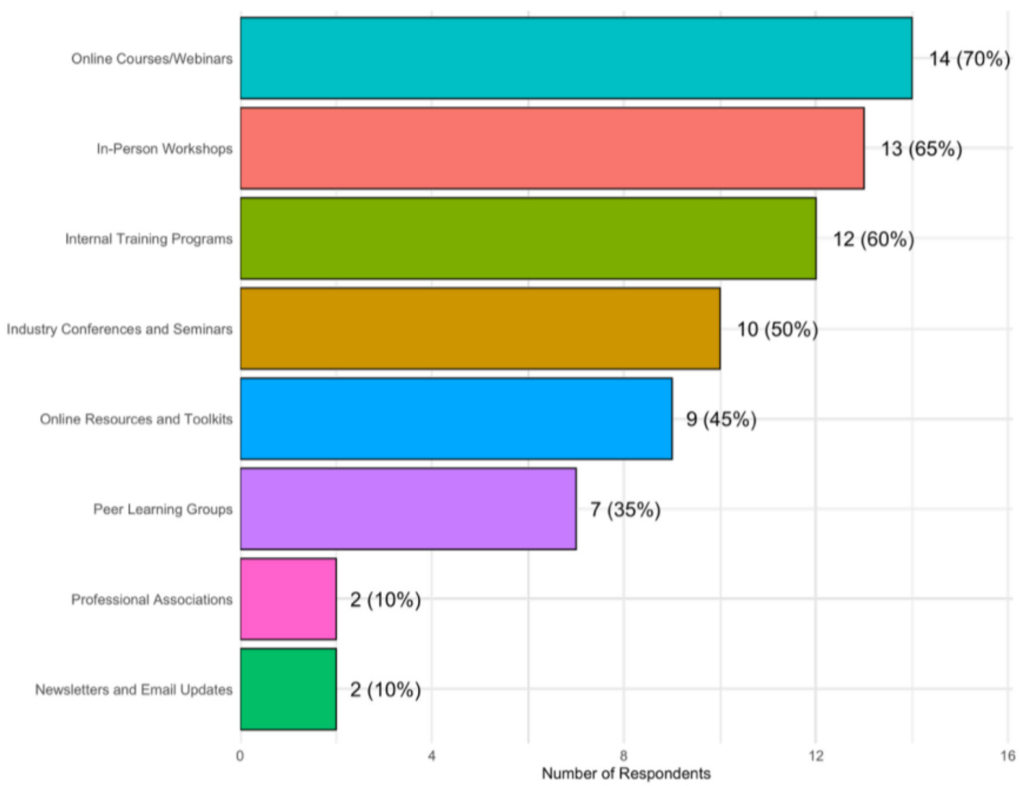

Figure 6.11 Preferred Training Channels.

6.4 Recommendations for implementation

Taken collectively, the survey findings suggest that INDOT can advance sustainability most effectively through a structured, multilayered implementation approach. Strengthening internal capacity through targeted training, increasing awareness of sustainable practices, and improving access to tools and guidance will help address identified knowledge gaps across project phases. At the same time, adequate funding support and integration of sustainability into performance metrics and incentive systems can reduce cost barriers and reinforce adoption behaviors. By sequencing these actions as practical implementation steps, INDOT can build sustained momentum toward agency-wide sustainability integration. The implementation recommendations for fostering a sustainability culture within INDOT are summarized below:

6.4.1 Capacity Building and Training

1. Expand structured sustainability training programs for staff, particularly in construction, operations, and end-of-life phases.
2. Offer recurring training through LTAP, internal offices, and academic partners, utilizing online courses, workshops, and targeted sessions aligned with key project stages.
3. Increase access to professional development through webinars, interactive modules, and in-house knowledge-sharing sessions.
4. Develop targeted training to address phases where confidence and technical understanding are comparatively low.

6.4.2 Awareness and Knowledge Enhancement

1. Launch agency-wide sustainability awareness campaigns to strengthen familiarity with emerging practices.
2. Deliver periodic sustainability-focused communication such as case studies, thematic briefs, and best-practice highlights, through newsletters, CEPDS sessions, LTAP events, and Road School programs.

6.4.3 Funding and Resource Strategy

1. Improve budget mechanisms to support sustainable design, material selection, and innovation pilots.
2. Address high upfront cost barriers by implementing dedicated sustainability funding lines and pilot allocation programs.

6.4.4 Performance Integration, RISE Embedding and Accountability

1. Integrate sustainability performance metrics into employee evaluations and project delivery expectations across all RID phases.
2. Embed phase-specific RISE tool checklists and scorecards into routine processes, enabling systematic tracking of usage, outcomes, and cost-effectiveness.

6.4.5 Incentivization and Adoption Culture

1. Introduce incentives to recognize and reward implementation of sustainable techniques and innovations.
2. Promote a culture of adoption to reduce resistance to change, encourage experimentation, and scale successful practices.

6.4.6 Regulatory and Procedural Support

1. Provide clearer regulatory guidance to improve consistency in compliance and implementation.
2. Embed sustainability expectations into planning documents, design reviews, and approval workflows.

6.4.7 Knowledge Sharing & Learning Systems

1. Strengthen peer-to-peer learning through internal communities of practice and collaborative knowledge exchanges.
2. Use insights from open-ended survey responses to refine training needs, improve implementation planning, and adapt sustainability strategies over time.

7. CONCLUSIONS

7.1 Report Summary

This report has developed a comprehensive business case for embedding sustainability into INDOT practices. Chapter 1 laid the foundation by defining the role of sustainability in road-infrastructure development, articulating the study's objectives and scope, and guiding readers through the structure of the document. In Chapter 2, we explored the multifaceted nature of sustainability within civil engineering, ranging from economic dimensions at the project level to systemic considerations at the agency and statewide scales. This discussion highlighted strategic plans, sustainability programs, and institutional challenges that shape how sustainability actions are conceived and executed—from long-term agency operations down to field-level practices.

Building on this conceptual groundwork, Chapter 3 shifted focus to measurement. We reviewed established exposure metrics and existing sustainability rating systems, then delved into the mechanics of multicriteria decision making: selecting performance criteria, assigning weights, normalizing scores, and amalgamating results. Supplementary methods for sustainability assessment were surveyed, and key lessons learned from each approach were distilled to inform our own framework development.

Chapter 4 introduced the RISE tool, which operationalizes the business case by offering 31 carefully chosen indicators and 96 corresponding evaluation criteria. Drawing on survey responses from INDOT practitioners, we calibrated indicator weights to reflect real-world priorities and preferences. A robust normalization and amalgamation procedure then enables the calculation of a single RISE score, allowing objective comparison of project sustainability performance.

To demonstrate RISE in action, Chapter 5 presented a detailed case study of the I-69 Finish Line project in Indiana. Focusing on the construction phase, the analysis translated complex sustainability data into a clear performance score. The case study revealed strong results in stakeholder engagement, habitat connectivity, and transparent governance, while also identifying opportunities for improvement in local sourcing, material reuse, emissions reduction strategies, and integration of financial sustainability metrics.

Finally, Chapter 6 turned inward to INDOT itself, analyzing survey feedback from twenty professionals across diverse roles. We assessed current levels of sustainability awareness, diagnosed the primary barriers to adoption—such as high up-front costs and training gaps—and identified priority initiatives, including enhanced funding mechanisms and targeted education programs. Together, these findings offer a roadmap for strengthening INDOT's capacity to plan, design, build, and operate more sustainable road-infrastructure projects.

7.2 Study Conclusions

7.2.1 The Need for a Triple-Bottom Line Paradigm

The dramatic rise in U.S. road and highway spending—from \$196 billion in 2002 to over \$233 billion in 2021 (inflation-adjusted)—underscores the vital role of highway infrastructure in driving economic growth and social connectivity. Yet, these investments carry substantial hidden costs: embodied carbon in construction materials alone generates nearly 12–13 Mt of carbon dioxide annually, and traditional project delivery often overlooks long-term impacts on communities and ecosystems. Chapter 1 showed that conventional lifecycle management, with its singular focus on cost efficiency and engineering performance, fails to account for the full spectrum of economic, environmental, and social outcomes. Although existing sustainability rating systems (CEEQUAL, GreenLITES, Envision) have advanced greener practices, they leave critical gaps in phase-specific measurement, local adaptability, and end-of-life accountability. The findings in Chapter 1 thus make clear the imperative for a purpose-built, lifecycle approach—one that embeds quantifiable, phase-targeted indicators and decision-support tools directly into agencies' standard workflows.

7.2.2 Embedding Sustainability Across Scales and Phases

Chapter 2 illuminated how sustainability must be woven into policies and practices at every level. At the agency scale, strategic plans and dedicated programs (e.g., ODOT's Sustainability Plan, ADOT's Complete Transportation Guidebook) prove that mission statements, performance measures, and transparent reporting can institutionalize environmental, social, and economic objectives. Tools like FHWA's INVEST translate high-level aspirations into actionable checklists for planning, project development, and operations, fostering cross-departmental alignment. Meanwhile, diversified funding—from formula grants to performance-based contracting and public-private partnerships—underpins long-term fiscal resilience, and advanced digital-twin platforms promise predictive maintenance and resource optimization. At the project level, interventions range from programmatic needs assessments and value-for-money analyses in Planning to recycled materials, resilience-rated pavements, and digital modeling in Design; lean logistics, local procurement, and low-emission equipment in Construction; flock electrification, outcome-based maintenance contracts, and on-site renewables in Operations; and full-depth reclamation and circular material flows at End-of-Life. Although these tools form a robust toolbox, siloed governance, capacity constraints, and outdated incentives often stymie their adoption, revealing the need for integrated metrics, cross-functional councils, and academy-industry partnerships to make sustainability a core—rather than peripheral—driver of infrastructure delivery.

7.2.3 Rigorous Measurement for Balanced Outcomes

As Chapter 3 stressed, rigorous measurement is the keystone of genuine sustainability. Exposure metrics such as vehicle miles traveled, traffic volumes, and GHG emissions provide the necessary baselines but, without balanced weighting, risk tilting decisions toward environmental factors at the expense of social equity and economic viability. Our review of major rating systems found that environmental indicators constitute about 45 % of criteria, social about 37 %, and economic merely 18 %—an imbalance that can undervalue long-term cost efficiency, financial risk management, and stakeholder well-being. MCDA offers a transparent framework for integrating diverse quantitative and qualitative criteria through weighting methods (AHP, BWM, Delphi), normalization techniques (linear, vector, logarithmic), and amalgamation methods (WSM, TOPSIS, VIKOR, PROMETHEE). Complementary approaches—Lifecycle Assessment (E-LCA, LCCA, S-LCA), Cost-Benefit Analysis, and data-driven tools like DEA and SD—allow practitioners to tailor the depth of analysis to project complexity and data availability. Nonetheless, the lack of standardized weighting protocols and local customization underscores the need for a context-sensitive tool, designed with direct stakeholder engagement.

7.2.4 Introducing the RISE Framework

Chapter 4 presented the RISE framework as a comprehensive, practitioner-informed method that closes the gaps left by existing systems. RISE defines 31 sustainability indicators—spanning environmental, social, and economic pillars—and operationalizes them via 96 measurable criteria. Indicator weights are derived from a structured survey of INDOT professionals using the RII, producing distinct weightings for each phase of the project lifecycle. During Planning and Design, economic feasibility leads with 36 % of weight, closely followed by social engagement at 34 %; in Construction and Operations and Maintenance, environmental controls dominate at 35 %; and at End-of-Life, financial stewardship resurges to 35 %. By applying a consistent 0–4 achievement scale and a weighted-sum amalgamation method, RISE generates an intuitive percentage score that agencies can use to compare alternatives or integrate alongside traditional metrics. Its flexibility—allowing indicator subsets and phase-specific recalibration—ensures adaptability to local priorities, while explicitly including the often-neglected End-of-Life stage sets RISE apart.

7.2.5 Case Study Insights: I-69 Finish Line

In Chapter 5, applying RISE to the I-69 Finish Line during its construction phase yielded a 44.5 % score, placing the project in the "Good Practice" category. The case study highlighted several strengths: 100 % completion of wildlife crossings, comprehensive erosion and stormwater controls, full implementation of dust suppression and noise mitigation, strong stakeholder engagement (85 % approval), universal accessibility enhancements, and transparent governance in procurement and resettlement. Nevertheless, gaps emerged: absent project-specific energy conservation or renewable-energy plans, no formal recycled-materials or local-sourcing strategies, and a lack of documented NPV, IRR, or payback analyses in public records. These findings underscore RISE's value both as a diagnostic tool—revealing where sustainability is strong and where it falls short—and as a roadmap for continuous improvement, guiding future projects toward "Leading Practice."

7.2.6 Building Organizational Capacity

Chapter 6's survey of INDOT professionals revealed a workforce deeply engaged in Planning & Design, yet limited in formal sustainability training (only 20 %) and lacking confidence in Construction and End-of-Life phases. High upfront costs, technical knowledge gaps, and resource constraints surfaced as the most impactful barriers, with inadequate training consistently ranking among the top concerns. Practitioners prioritized improved funding and budget allocation as the single most effective intervention, followed closely by expanded training and education delivered through online courses, in-person workshops, and agency-specific sessions. Embedding sustainability objectives into performance metrics and incentive structures, alongside clear guidance and awareness campaigns, will be essential to translate RISE's theoretical rigor into everyday practice.

Across these six chapters, this study demonstrates that truly sustainable road infrastructure requires a holistic, life-cycle perspective; rigorous, balanced measurement; phased weighting and evaluation; and robust organizational capacity. The RISE framework delivers on these imperatives, translating abstract triple-bottom-line goals into a clear, flexible, and practitioner-validated tool. When combined with targeted funding reforms, capacity-building initiatives, and governance realignments, RISE offers agencies like INDOT a concrete, data-driven pathway to deliver resilient, equitable, and fiscally sound road networks for the 21st century.

7.3 Study Limitations

While this research delivers a structured, multi-phase framework for assessing the sustainability of road infrastructure projects, several overarching limitations must be acknowledged. First, the study relies heavily on secondary data drawn from publicly available reports, technical guidelines, and peer-reviewed literature. Many critical project details—such as contractor-level energy consumption, proprietary material performance data, and post-construction social outcomes—are either unpublished or held in internal agency archives. This scarcity of granular data constrains the depth of our case study analyses and may understate both innovative practices and unintended impacts.

Second, the expert judgments that underpin our indicator-weighting and framework validation stem from a single web-based survey of 20 INDOT professionals. Although these respondents represent a range of roles and experience levels, the modest sample size and the exclusive focus on one state agency limit the ability to generalize findings across different institutional, geographic, or regulatory contexts. Self-selection bias and the absence of external stakeholders—such as contractors, community advocates, or private-sector engineers—further narrow the spectrum of perspectives reflected in the RII and may overemphasize INDOT's organizational priorities.

Third, by design, the RISE framework was applied to a single, large-scale case—the I-69 Finish Line project—which offers a valuable but inherently localized illustration of tool functionality. Project-specific factors (e.g., Indiana's regulatory environment, corridor geography, funding structures) shaped both the available documentation and the project outcomes. As such, the lessons drawn from I-69 may not map directly to urban arterials, rural low-volume roads, or jurisdictions with different funding mechanisms or community dynamics.

Fourth, the methodological backbone of this study—MCDA—carries its own limitations. As indicator counts increase, normalization and weighting procedures become more complex, raising the risk of evaluator fatigue and inconsistent judgment. Moreover, WSM and the RII approach, while transparent, assume linear utility and equal interval scales that may not capture nonlinear trade-offs or threshold effects inherent in sustainability outcomes.

Finally, the rapidly evolving nature of sustainability science, material technologies, and policy frameworks means that any static set of indicators or criteria risks becoming dated. New approaches to low-carbon materials, community co-design, and digital monitoring continue to emerge, suggesting that frameworks like RISE must be periodically revisited, expanded, and recalibrated to remain fit for purpose.

Taken together, these limitations underscore the need for ongoing data collection, broader stakeholder engagement, and iterative refinement of both the RISE tool and the underlying sustainability indicators. Future work should seek to incorporate richer project datasets, expand survey participation across multiple agencies and sectors, test the framework in varied infrastructure contexts, and explore advanced decision-support algorithms to enhance the robustness and applicability of sustainability assessments in road-infrastructure development.

7.4 Opportunities for Future Research and Implementation

This study lays the groundwork for a comprehensive approach to sustainability assessment in road-infrastructure development projects, yet several avenues remain open for deepening its impact and broadening its applicability. Foremost among these is the expansion of stakeholder engagement beyond agency professionals. Future research should deliberately include contractors, design-build teams, local community representatives, environmental NGOs, and policymakers in the indicator-weighting and validation processes. Such active co-creation not only enriches the relevance and legitimacy of the framework's priorities but also fosters shared ownership of sustainability goals across the entire project delivery chain.

To facilitate consistent application in diverse real-world settings, it will be crucial to develop more detailed, phase-specific guidance for each evaluation criterion. This could take the form of annotated scorecards, case-based examples, and recommended data-collection protocols that reduce ambiguity and evaluator bias. Embedding these resources within an interactive digital platform—complete with dashboards, automated scoring calculators, and built-in help tools—would lower the barrier to adoption for agencies and consultants with limited MCDA experience. Such a tool could also log project data over time, creating a growing repository of benchmarks to inform continuous improvement.

On the methodological front, advancing the decision-support capabilities of the framework will require exploring more sophisticated weighting, normalization, and aggregation techniques. Research into machine-learning approaches for pattern recognition in past project performances, or optimization algorithms that can suggest indicator bundles based on agency priorities and resource constraints, could streamline evaluations and surface hidden trade-offs. Likewise, integrating quantitative methods—such as LCA, social-LCA, and CBA—would anchor the largely qualitative RISE scoring in empirical evidence, yielding richer insights into environmental footprints, social welfare impacts, and economic value.

Finally, to ensure that sustainability assessments keep pace with evolving technologies, policies, and societal expectations, the indicator set and scoring thresholds should be revisited periodically. Longitudinal studies that track the performance of completed projects against their RISE scores would validate and refine both the framework's structure and its calibration. By pursuing these research and implementation pathways, transportation agencies can transform sustainability from a static checklist into a dynamic, learning-oriented process—ultimately driving more resilient, equitable, and fiscally responsible infrastructure outcomes.

7.5 The Future of Sustainability: Technology, Pandemics, and Ethics

Technological innovations are rapidly reshaping the future of sustainable transportation and infrastructure, offering powerful tools to address environmental, social, and economic challenges. In the realm of materials engineering, the development of electrically conductive asphalt concrete (ECAC) exemplifies this evolution. ECAC not only enables snow and ice melting through embedded heating capabilities but also opens possibilities for real-time traffic detection and structural health monitoring (Lu et al., 2023). As such technologies become mainstream, sustainability evaluation frameworks must increasingly emphasize indicators related to infrastructure adaptability, operational resilience, and energy efficiency in construction materials. Similarly, advancements in pervious concrete (Zhong et al., 2018), bio-asphalt (Z.-j. Dong et al., 2019), and the recycling of plastics such as PET into asphalt mixtures (Leng et al., 2018) underscore the growing importance of indicators focused on material lifecycle impacts, resource circularity, and waste minimization. Future infrastructure will be judged not only by its immediate functionality but also by its contributions to circular economy practices and its embedded environmental footprint over the lifecycle.

Parallel shifts are occurring in the mobility sector, where EVs, alternative fuels, and connected and autonomous vehicles (CAVs) promise transformative impacts (Labi & Sinha, 2022). EVs, by eliminating tailpipe emissions, offer significant potential for reducing transportation-related GHG, provided that electricity grids transition toward renewable energy sources (Gkritza, 2015; Ibanez et al., 2016; Moras et al., 2024). This technological shift will make indicators measuring renewable energy integration, carbon footprint reduction, and energy sourcing sustainability even more pivotal. However, the sustainability performance of EVs also raises new concerns regarding the ethical sourcing of battery materials, end-of-life recycling, and the environmental implications of large-scale electrification (H. Chen et al., 2024; Hawkins et al., 2013). Thus, sustainability frameworks must account for supply chain responsibility and resource efficiency, ensuring that technological adoption does not inadvertently create new vulnerabilities or inequities. Alternative fuels such as green hydrogen and advanced biofuels add further dimensions to the sustainability landscape. Green hydrogen holds promise for decarbonizing heavy-duty transport and energy-intensive sectors, while biofuels offer opportunities to utilize waste streams for fuel production (IEA, 2024). However, each pathway brings associated risks: hydrogen production remains energy-intensive, and biofuels can trigger land-use conflicts or ecological degradation if not managed carefully (Bailis et al., 2015; Hassan et al., 2023). Consequently, evaluation criteria related to emissions across the full fuel lifecycle, land-use impacts, and energy conversion efficiency must become more prominent as these technologies are deployed.

The rise of CAVs further illustrates how emerging technologies necessitate a reassessment of sustainability metrics. While automation offers potential benefits such as increased traffic efficiency, reduced crashes, and enhanced mobility access (Gkartzonikas & Gkritza, 2019; Metz, 2018), it also poses risks of induced travel demand, greater energy consumption, and worsened congestion if poorly managed (Othman, 2022). This dynamic emphasizes the critical need to embed indicators that evaluate system-wide efficiency, vehicle occupancy rates, urban density support, and mobility as a service integration within sustainability frameworks. Additionally, the cybersecurity vulnerabilities introduced by connected infrastructure require the future inclusion of digital resilience and data security considerations in comprehensive evaluations of sustainable infrastructure systems (J. Dong et al., 2022).

While technological innovation creates new opportunities, the COVID-19 pandemic served as a sobering reminder that resilience is equally indispensable for sustainable development. Pandemic-induced disruptions exposed the vulnerabilities of transportation systems overly reliant on singular modes and rigid operational patterns (Amekudzi-Kennedy, Labi, Woodall, Chester, & Singh, 2020). The ability of communities to pivot toward telework, digital services, and multimodal transportation alternatives became a critical determinant of system resilience. Accordingly, indicators that measure infrastructure redundancy and multimodal integration must be prioritized when assessing future projects. Moreover, the pandemic sharply illuminated pre-existing social inequities within transportation access and service provision (Amekudzi-Kennedy, Labi, Woodall, Marsden, & Grubert, 2020). Vulnerable and marginalized populations were disproportionately impacted, underscoring the reality that sustainability without social aspects is incomplete and ultimately fragile. Thus, indicators pertaining to equitable access to transportation, community engagement, and protection of vulnerable groups must be more deeply integrated into sustainability evaluation frameworks.

Taken together, these technological and societal shifts affirm that sustainability evaluation must be a living process, evolving in tandem with emerging challenges and opportunities. The framework proposed in this thesis establishes a foundation for this evolution, but it must remain dynamic, with particular attention to indicators that are gaining prominence in a world shaped by electrification, automation, alternative energy, pandemics, and social movements. Continuous refinement — recalibrating indicator weights, introducing new evaluation dimensions, and reexamining assumptions — will be necessary to ensure that sustainability frameworks remain effective, relevant, and ethically grounded. Ultimately, the future of sustainable transportation and infrastructure lies not solely in adopting new technologies, but in how thoughtfully, and ethically these innovations are implemented. Achieving this vision will require synthesizing technical ingenuity with social responsibility, ensuring that advances in materials, vehicles, and systems enhance resilience, reduce inequities, and minimize environmental impacts. In this context, sustainability emerges not as a static destination, but as an ongoing ethical commitment—one that demands foresight, adaptability, and an unwavering focus on building infrastructure to serve both present and future generations.

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APPENDICES

Appendix A. List of Acronyms

Appendix B. Carbon Credit Markets and Their Future Role in RID Sustainability

Appendix C. Survey

Appendix D. RISE – Sustainability Evaluation Criteria

Appendix E. Details of MCDA Analysis

Appendix A. List of Acronyms

AHP	Analytic Hierarchy Process
ASCE	American Society of Civil Engineers
BWM	Best-Worst Method
CBA	Cost-Benefit Analysis
CEEQUAL	Civil Engineering Environmental Quality Assessment and Awards Scheme
DEA	Data Envelopment Analysis
DOT	Department of Transportation
EVs	Electric Vehicles
FHWA	Federal Highway Administration
INDOT	Indiana Department of Transportation
IRB	Institutional Review Board
IRR	Internal Rate of Return
LCA	Life Cycle Assessment
LCCA	Life-Cycle Cost Analysis
MCDA	Multicriteria Decision Analysis
NPV	Net Present Value
ODOT	Ohio Department of Transportation
OMM	Operations, Monitoring, & Maintenance
RID	Road Infrastructure Development
RIDP	Road Infrastructure Development Projects
RII	Relative Importance Index
RISE	Road Infrastructure Sustainability Evaluation
S-LCA	Social Life Cycle Assessment
TBL	Triple Bottom Line
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
WSM	Weighted Sum Method

APPENDIX B. Carbon Credit Markets and Their Future Role in RID Sustainability

A key mechanism for achieving sustainable road infrastructure is the utilization of carbon credit markets. These markets have emerged as a key mechanism to mitigate climate change by placing a price on carbon emissions and incentivizing reductions across various sectors. These markets allow companies, governments, and individuals to purchase carbon credits that represent verified reductions or removals of greenhouse gases (GHGs), typically measured in metric tons of carbon dioxide equivalent (tCO_2e) (Digitemie & Ekemezie, 2024). The credits are generated through projects that either reduce emissions—such as renewable energy initiatives—or enhance carbon sequestration—such as reforestation or soil carbon management programs (Hodgman et al., 2012; Digitemie & Ekemezie, 2024).

There are two primary types of carbon credit markets: compliance carbon markets and voluntary carbon markets (Lovell, 2010). Compliance carbon markets are established by regulatory frameworks at national, regional, or international levels, requiring entities to meet legally mandated emission reduction targets. Under cap-and-trade systems, for example, authorities set an emissions cap, and regulated entities can either reduce their own emissions or purchase allowances or carbon credits to remain in compliance. When allowances become scarce, their price increases, thereby incentivizing further emission reductions. Some important examples include the European Union Emissions Trading System (EU ETS) and California's cap-and-trade program in the United States (Lovell, 2010; United Nations Environment Programme, 2021).

In contrast, voluntary carbon markets (VCM) have seen substantial growth as organizations and individuals seek to offset emissions beyond regulatory requirements (United Nations Environment Programme, 2021). Projects listed in voluntary markets are often certified by independent standards like the Verified Carbon Standard (VCS) or the Gold Standard, which verify the quality and authenticity of reductions (Lovell, 2010; Pudasaini et al., 2024). These certification bodies ensure that projects meet criteria such as "additionality," meaning the project's emissions reductions would not have occurred without the incentive provided by carbon credit financing (Pudasaini et al., 2024).

Another emerging approach is Personal Carbon Trading (PCT), which assigns each individual a specific carbon budget covering transport, heating, and energy use. If an individual stays below the limit, they can sell surplus credits, whereas those exceeding it must purchase additional allowances (Tang et al., 2023). A related concept, Personal Carbon Allowances (PCAs), operates similarly but focuses on government-regulated individual carbon limits to ensure fair distribution of emissions rights (Raux et al., 2015).

Studies indicate that PCT schemes encourage behavior change by reinforcing accountability and social norms surrounding emissions reductions (Fuso Nerini et al., 2021).

Despite their potential, carbon credit markets, including PCT, face challenges related to measurement, reporting, and verification (MRV), as well as ensuring that projects deliver verifiable climate benefits without causing unintended social or ecological impacts. Stakeholders are increasingly recognizing the need for robust governance structures, transparent methodologies, and standardized protocols to validate emissions reductions consistently. Additionally, concerns about “double counting”—where the same emissions reduction is claimed by multiple entities—underline the importance of tracking and registry systems with technologies like blockchain (Christiansen, 2024; Gillenwater, 2012; Woo et al., 2021).

Looking ahead, carbon credit markets are expected to continue evolving, playing a growing role in scaling global climate ambition by enabling cost-effective emissions reductions and reinvestment in deeper mitigation efforts (Piris-Cabezas et al., 2023). However, persistent challenges, such as the need for stronger governance and more transparent monitoring systems, underscore the importance of improving market mechanisms (Chen, 2023; Woo et al., 2021). In this context, expanding market frameworks, particularly for nature-based solutions, could significantly help bridge the emissions gap while ensuring credibility and effectiveness in climate action (Chen, 2023; Piris-Cabezas et al., 2023).

B.1 Global Carbon Credit Markets

Globally, while compliance markets dominate in terms of traded volume and financial value, voluntary markets have come under increasing scrutiny regarding their credibility and effectiveness (Procton, 2024; World Bank, 2024). In 2014, compliance-based carbon pricing policies covered only 7% of global emissions. As of April 1, 2024, operational emissions trading systems (ETSs) and carbon taxes encompassed nearly 24% of global greenhouse gas (GHG) emissions, as illustrated in Figure B1. In this context, the total value of global carbon pricing instruments reached a record high of approximately $104 billion in 2023, representing a real term increase of approximately 4% compared to the previous year. This growth is attributed to the expansion of carbon pricing mechanisms, with 75 instruments implemented worldwide (World Bank, 2024).

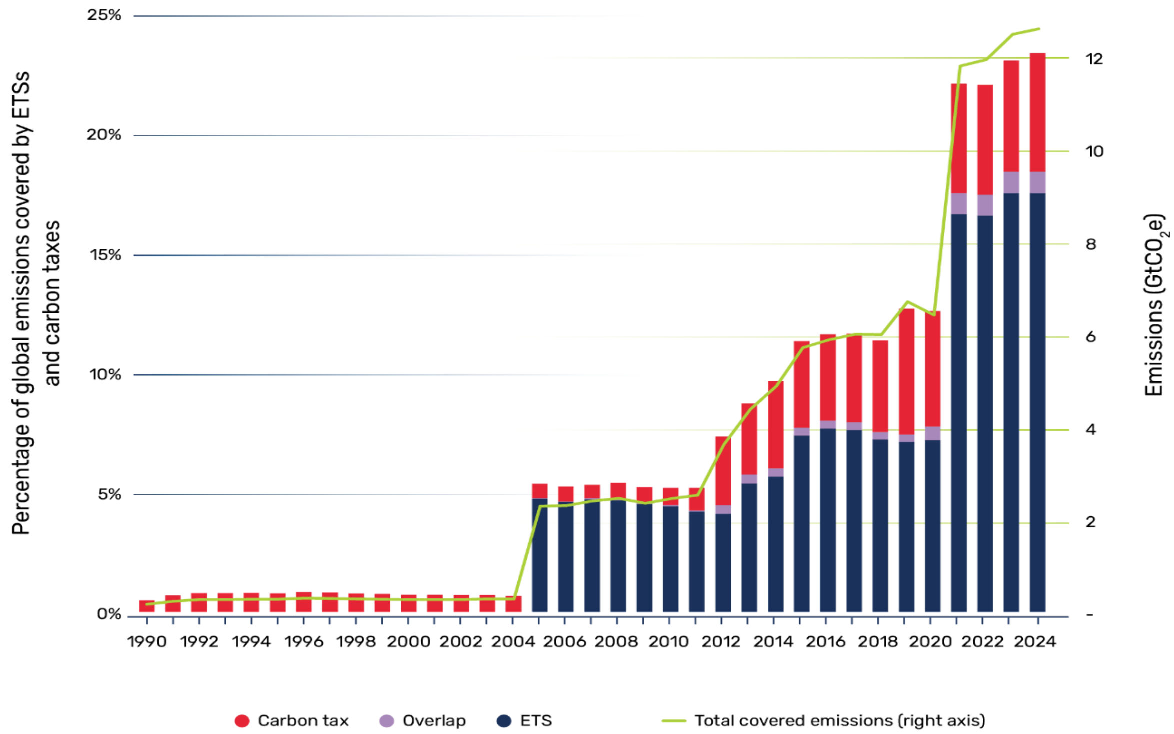

Figure B1. Global GHG Emissions Covered by ETS and Carbon Taxes (World Bank, 2024).

The European Union Emissions Trading System (EU ETS) is the most developed carbon market, serving as a benchmark for carbon pricing. It covers all 27 EU member states, along with Norway, Iceland, and Liechtenstein. In early 2023, the EU implemented key reforms under the "Fit for 55" package to align with its 2030 climate target of at least a 55% emissions reduction from 1990 levels. These reforms extended coverage to maritime transport and introduced a separate ETS for buildings, road transport, and other sectors (International Carbon Action Partnership [ICAP], 2024; World Bank, 2024). Similarly, Germany expanded its national ETS, launched in 2021, to include coal emissions in 2023 and waste incineration fuels in 2024. However, a late 2023 court ruling reduced its budget, triggering an unexpected CO_2 price increase in early 2024 (ICAP, 2024). Additionally, the CitiCAP project in Lahti, Finland, piloted an urban-level Personal Carbon Trading (PCT) scheme, demonstrating how localized trading initiatives can complement national cap-and-trade systems by encouraging individual emissions reductions through incentives and digital tracking (Kuokkanen et al., 2020).

Meanwhile, China, in addition to its national carbon market—the world's largest by emissions covered—continues to operate regional pilot ETSs to refine market mechanisms. It has also relaunched its Certified Emissions Reduction Scheme, allowing companies to offset compliance obligations. Recent regulations, including stricter penalties for non-compliance and market manipulation, further strengthen its long-term development. Other compliance markets, such as South Korea's Emissions Trading Scheme (K-ETS) and California's cap-and-trade program, continue to evolve, with growing regional initiatives exploring the possibility of integrating carbon pricing mechanisms across jurisdictions (ICAP, 2024; World Bank, 2024).

Despite this progress, the voluntary carbon market faced challenges in 2023, experiencing a 56% year-on-year decline in the volume of reported transactions. Additionally, the total reported transaction value of the VCM fell to $723 million USD, representing a 61% decrease compared to the previous year (Procton, 2024). In response, the ISO 14068-1 standard, introduced in November 2023, provides a science-based, transparent framework for achieving and demonstrating carbon neutrality, prioritizing GHG reductions over offsetting. By aligning carbon neutrality with net zero goals, it ensures credibility and consistency across organizations, products, and services (Kreibich, 2024).

In general, regional trends reflect varying levels of engagement with carbon pricing mechanisms. In North America, California's cap-and-trade program remains the most significant, while Canada has implemented both federal and provincial-level carbon pricing systems. In the Asia-Pacific region, countries such as China, South Korea, and New Zealand have operational emissions trading schemes, with some other nations exploring regional frameworks to facilitate cross-border carbon trading, considering that almost 75% of the potential credit volume is based in Asia. Latin America has seen a rise in carbon pricing initiatives, with countries like Colombia, Mexico, and Chile implementing carbon taxes and piloting emissions trading systems. Meanwhile, Africa has emerged as an important player in nature-based carbon credit generation although participation in markets remains limited (ICAP, 2024; World Bank, 2024).

B.2 Carbon Credit Markets in the United States

The United States has developed a network of compliance and voluntary carbon credit markets, offering diverse mechanisms for emissions reduction. While lacking a national carbon pricing system, various state-level initiatives and voluntary programs provide pathways for entities to engage in carbon trading and offset strategies (World Bank, 2024).

Among the most established compliance markets, California's Cap-and-Trade Program is the most comprehensive, covering approximately 75% of the state's greenhouse gas (GHG) emissions. Established in 2012, the program operates under the authority of the California Air Resources Board (CARB) and is linked with Québec's carbon market through the Western Climate Initiative (WCI). The program has generated over $26.97 billion in revenue since its inception in 2012, including $4.72 billion in 2023 alone. In 2022, the CARB established a new goal of reducing emissions by 48% below 1990 levels by 2030, exceeding the initial target of a 40% reduction. California's program covers a broad spectrum of sectors, including power generation, industry, buildings, and transportation (ICAP, 2024), making it particularly relevant to sustainable road infrastructure development.

Another key initiative is the Regional Greenhouse Gas Initiative (RGGI), launched in 2009 as a cooperative effort among twelve northeastern and mid-Atlantic states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia. Virginia, which joined RGGI in 2021, repealed its ETS regulation in 2023 and ceased participating at the end of that year (ICAP, 2024; RGGI, 2018). This program focuses primarily on the power sector and operates under a cap-and-trade model, requiring power plants to purchase allowances equivalent to their carbon emissions. Since its inception, the initiative has successfully reduced greenhouse gas emissions while generating significant revenue. These funds have been reinvested into clean energy development, energy efficiency programs, and support for economically disadvantaged communities, amplifying the program's environmental and social impact (RGGI, 2018).

More recently, Washington State's Cap-and-Invest Program, which began operation in 2023, has introduced another economy-wide ETS. Covering approximately 70% of the state's emissions, the program shares structural similarities with California’s system and has begun evaluating potential market linkage with California and Québec. The state has also approved offset credit registries, allowing compliance through certified offset projects (ICAP, 2024).

Colorado has also developed an ETS, primarily targeting industrial emissions. The Greenhouse Gas and Energy Management for Manufacturing Regulation (GEMM), which came into effect in 2024, covers large in-state manufacturers, with a trading system for GHG credits set to launch by the end of the year. The program establishes emissions reduction targets and compliance mechanisms, with plans to facilitate bilateral credit trading and auctions (ICAP, 2024).

While compliance markets remain central to emissions trading in the U.S., voluntary carbon trading has gained traction as a flexible mechanism for offsetting greenhouse gas emissions. These markets, primarily driven by organizational commitments to sustainability, have seen growth in sectors like renewable energy and forestry projects, which account for a significant portion of credits issued. However, their development has been uneven, with persistent concerns regarding credit quality and market transparency (Miller & Ramseur, 2024).

Recent efforts, such as the guidance issued by the Commodity Futures Trading Commission (CFTC) in December 2023, aim to address these challenges by enhancing transparency, standardizing methodologies, and ensuring robust validation processes. The guidance highlights critical aspects like additionality and permanence while advocating for mechanisms to prevent double-counting and enhance accountability in transactions (Miller & Ramseur, 2024).

In parallel, federal initiatives outlined in the Voluntary Carbon Markets Joint Policy Statement emphasize the need for high-integrity markets that align with ambitious decarbonization pathways. These efforts focus on fostering market confidence, ensuring equitable participation, and leveraging VCMs as a tool to complement broader climate strategies (U.S. Department of the Treasury, 2024).

As infrastructure plays a critical role in decarbonization efforts, carbon credit programs can incentivize the integration of sustainable practices in transportation projects. For example, the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) encourage investments in reducing greenhouse gas emissions through tools like the Carbon Reduction Program, which supports initiatives such as active transportation infrastructure and clean vehicle technologies (U.S. Department of Energy et al., 2023; White House, 2022). By leveraging market-based mechanisms, road projects can secure additional financing while aligning with emissions reduction goals, positioning carbon markets as a strategic tool for advancing sustainable transportation infrastructure.

B.3 Carbon Credit Markets and Opportunities in Indiana

B.3.1. Policy and Regulatory Landscape in Indiana

The transportation sector in Indiana is a major contributor to carbon dioxide (CO_2) emissions, accounting for approximately 22% of the state's total emissions. This high percentage is primarily due to Indiana’s reliance on coal for electricity generation, which increases the carbon footprint of electric vehicles and other transportation-related energy consumption (Indiana Department of Transportation, 2023). As the state seeks to reduce emissions and transition to more sustainable infrastructure, carbon credit markets present a significant opportunity to support clean transportation initiatives and encourage investment in low-carbon technologies.

To address emissions in the transportation sector, the Indiana Department of Transportation (INDOT) has developed a Carbon Reduction Strategy (CRS) that aligns with the federal Bipartisan Infrastructure Law (BIL). The CRS serves as a roadmap for reducing on-road transportation emissions by prioritizing low-carbon infrastructure projects and encouraging the use of sustainable construction materials such as recycled asphalt and low-emission concrete (Indiana Department of Transportation, 2023).

In parallel, the Indiana Department of Environmental Management (IDEM) has established protocols for generating emission credits, particularly for criteria air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), and volatile organic compounds (VOC). These credits allow businesses and entities to offset their emissions by investing in reduction projects, promoting accountability and transparency in emission management (Indiana Department of Environmental Management, 2020). While Indiana does not yet operate a state-specific carbon trading system, these initiatives create a regulatory framework that could enable future participation in broader carbon credit markets.

At the federal level, Indiana can benefit from Section 45Q of the U.S. Tax Code, which provides financial incentives for the capture and sequestration of carbon dioxide. The 45Q tax credit supports projects that store CO_2 in underground formations or utilize it in industrial applications, encouraging investment in carbon capture and storage (CCS) technologies. The amount of credit varies based on the method of sequestration and the deployment timeline, making it a critical tool for states like Indiana that are exploring low-carbon energy solutions. By providing long-term financial incentives, Section 45Q facilitates the development of infrastructure necessary for large-scale CCS deployment, helping industries and transportation sectors reduce their carbon footprint and potentially participate in carbon credit markets (Jones & Marples, 2023).

Indiana has also taken legislative action to facilitate carbon capture and sequestration projects at the state level. Senate Bill 442 (SB 442), passed in 2019, officially recognizes carbon storage as a public benefit and supports the development of CCS infrastructure. A key provision of SB 442 is its support for a $450 million pilot project at a West Terre Haute ammonia production facility, which aims to capture and store CO_2 in underground geological formations (Great Plains Institute, 2020). This project serves as a proof-of-concept for large-scale CCS deployment in Indiana. By designating CCS as a matter of public interest, SB 442 provides legal clarity for future carbon sequestration projects, making it easier for companies and institutions to invest in long-term emission reduction strategies.

Beyond this initial investment, SB 442 also paves the way for further research into statewide carbon storage potential and economic feasibility studies for future CCS projects. It emphasizes the importance of conducting detailed assessments of geological storage capacity and the long-term economic viability of carbon sequestration in Indiana (Great Plains Institute, 2020). These legislative actions, coupled with federal tax incentives, position Indiana as an emerging player in the carbon capture and credit markets, with potential applications in both industrial and transportation sectors. As the state continues to explore policies that encourage carbon reduction and trading mechanisms, Indiana may further integrate into national and international carbon credit markets, leveraging both regulatory frameworks and financial incentives to support a sustainable, low-carbon future.

B.3.2. Existing Programs in Indiana

Indiana is actively engaged in initiatives to reduce carbon emissions. Since 2023, INDOT has been allocated $156 million over five years through the federal Carbon Reduction Program (CRP). Of these funds, 65% is designated for urbanized areas, while the remainder offers flexibility in distribution. The CRP primarily focuses on reducing CO_2 emissions from on-road highway sources. Additionally, INDOT is exploring strategies to minimize lifecycle emissions from transportation infrastructure materials, such as concrete and asphalt (Indiana Department of Transportation, 2023).

In the agricultural sector, despite the development of carbon markets in other parts of the country, they have not yet reached Indiana due to various factors that remain to be determined. However, at present, landowners can apply to the NCX and Forest Carbon Works programs. These programs often require adherence to specific protocols and long-term commitments but offer financial incentives for sustainable land management practices (Indiana Forestry & Woodland Owners' Association, 2021).

Overall, carbon mitigation programs—particularly carbon credit markets—are still in a very early stage of development in Indiana. This presents a significant opportunity for the state to establish itself as a leader in carbon reduction initiatives, leveraging emerging policies, technological advancements, and financial incentives to accelerate its participation in sustainable markets.

B.3.3. Opportunities for Indiana's Transportation Sector

Indiana has a significant opportunity to integrate carbon credit mechanisms into its transportation infrastructure by leveraging regulatory frameworks, funding resources, and institutional expertise. One key strategy involves establishing a detailed emissions registry in collaboration with the Indiana Department of Environmental Management (IDEM). A robust emissions tracking system would provide the necessary data to monitor transportation-related carbon outputs, facilitating the prioritization of low-carbon infrastructure projects. Utilizing Indiana Department of Transportation (INDOT) resources, the state can implement sustainable roadway projects while setting a precedent for future carbon reduction initiatives.

Incorporating carbon capture and sequestration (CCS) technologies into transportation infrastructure presents another promising opportunity. Indiana has multiple facilities eligible for 45Q carbon capture tax credits, including cement plants, steel manufacturing sites, and refineries, which are integral to road construction and maintenance. Facilities such as Lone Star Industries in Greencastle and Lehigh Cement in Speed have been identified as economically feasible candidates for carbon capture, reducing the carbon footprint of essential materials used in infrastructure projects (Great Plains Institute, 2020). By integrating CCS into roadway material production, Indiana could generate high-quality carbon credits while aligning transportation infrastructure with sustainable development goals.

Indiana also benefits from strong institutional support for clean transportation transitions, particularly through the adoption of electric vehicles (EVs) and alternative fuel technologies. Research institutions such as Purdue University are actively engaged in expanding EV charging infrastructure, developing grid integration strategies, and optimizing traffic systems to enhance transportation efficiency (Joint Transportation Research Program, n.d.). Expanding EV charging networks along major highways and incorporating low-carbon public transit options could significantly reduce on-road emissions, opening further opportunities for carbon credit generation.

Given Indiana's policy landscape and its ongoing efforts to reduce transportation-related emissions, integrating PCT into state-level carbon markets presents an opportunity to complement existing regulatory frameworks. By using digital platforms similar to CitiCAP, Indiana could pilot a voluntary PCT initiative targeting urban commuters and heavy vehicle users.

Additionally, Indiana's geographical and geological advantages support the development of carbon sequestration infrastructure, including underground storage sites in formations such as the Mt. Simon Sandstone. The state's coal-fired and ethanol facilities could be integrated into a broader CCS strategy, aligning with roadway infrastructure projects that prioritize low-carbon construction materials and emissions reduction techniques (Great Plains Institute, 2020).

By combining detailed emissions tracking, sustainable material use, transportation electrification, and carbon capture technologies, Indiana can establish itself as a leader in low-carbon road infrastructure. Strengthening partnerships between IDEM, INDOT, research institutions, and private industry will be crucial to ensuring that Indiana’s transportation sector aligns with emerging carbon credit opportunities, fostering both economic and environmental benefits for the state.

B.3.4. Challenges and Future Directions

Despite ongoing initiatives, Indiana faces challenges in fully integrating into carbon credit markets. The lack of a state-specific carbon trading system limits in-state credit trading opportunities, while the evolving nature of carbon markets requires robust measurement, reporting, and verification (MRV) systems to ensure credit integrity.

A significant challenge arises from shifts in federal regulations, which impact emissions tracking and sustainability initiatives. The repeal of the Greenhouse Gas Measurement Rule, which required state transportation departments to set CO_2 reduction targets for federally funded highways, removes a key framework for emissions accountability (U.S. Department of Transportation, 2025). Without standardized federal guidance, Indiana may face difficulties aligning infrastructure projects with carbon credit market requirements, potentially limiting investment in low-carbon transportation solutions.

Additionally, regulatory adjustments that deprioritize climate-focused programs could reduce funding opportunities for sustainability-driven projects. This creates uncertainty in long-term planning and may slow efforts to integrate carbon credit mechanisms within the state's transportation and industrial sectors.

To navigate these challenges, Indiana can strengthen participation in voluntary carbon markets, leverage public-private partnerships, and advocate for state-led policies that incentivize emissions reduction. Expanding data-driven solutions and engaging industry stakeholders will be essential in maintaining progress toward carbon credit market integration, despite evolving regulatory conditions.

Appendix C. Survey

The Business Case for Sustainable Road Infrastructure Development

IRB Research Project Number: IRB-2024-1450
Samuel Labi, Ph.D., Konstantina "Nadia" Gkritza, Ph.D.
Lyles School of Civil and Construction Engineering
Purdue University

Consent Form

Key Information:

You are being asked to participate or be a part of a research study. Your participation is voluntary which means that you may choose not to participate at any time. Please read this form and ask any questions before you agree to be in the study. If you decide to take part in the study, you will be asked to sign this form. Be sure you understand what you will do and any possible risks or benefits.

This study seeks to explore and addressed sustainable practices for road infrastructure development in the state of Indiana that the Indiana Department of Transportation (INDOT) could implement to enhance the sustainability of projects in the state. The project length is of two years starting in August of 2023, and finishing in July of 2025.

Please take time to review the rest of the information. This will give you more information about this study to help you decide if you want to participate.

What is the purpose of the study?

Purdue University and INDOT are conducting a study to develop the business case for sustainable road infrastructure development under the JTRP project SPR 4812. This survey has been designed with 3 main objectives: 1) to collect preferences and professional opinions from INDOT personnel on sustainable practices in different road infrastructure development phases; 2) to determine the extent to which sustainability is currently applied by personal at INDOT; and 3) to enhance the business case for sustainable road infrastructure development.

You are being asked to participate as a key participant of the decision-making process in road infrastructure development for INDOT. As part of the study, we expect to enroll as many people as possible that currently work directly or indirectly with sustainability practices.

What will I do if I choose to be in this study?

If you choose to participate in this study, you will be asked to answer questions related to your professional experience with sustainability and sustainable development practices in different phases of road infrastructure development (Planning, Design, Construction, Operations, Maintenance, and End-of-life). You will state your preference among different categories of commonly used sustainability indicators of road infrastructure projects, as well as your professional opinion on sustainable practices that INDOT could implement. The responses of all participants will be stored and analyzed by our team of researchers to understand the categories with more impact on sustainability assessment. No individual analysis will be carried out.

How long will I be in the study?

The survey is designed to take approximately 20 to 30 minutes to complete.

What are possible risks or discomforts?

Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section. No other major risks or discomforts should be encounter during your participation in this study.

Are they any potential benefits?

There are no anticipated direct benefits for the participants in this study.

Are they costs to me for participation?

There are no anticipated costs to participate in this research.

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by the study sponsor/funding agency Indiana Department of Transportation (INDOT), US DHHS Office for Human Research Protections, and by departments at Purdue University responsible for regulatory and research oversight. Only Professor Samuel Labi, Ph.D., Professor Konstantina "Nadia" Gkritza, Ph.D., and Graduate Research Assistant David Holguin-Mejia, will have access to the data. All data from the surveys will be coded and entered into a computerized data file that will be stored in password-protected computers accessible only to the research study personnel. Although all research carries the risk of breach of confidentiality which means that someone outside of our study could figure out that you were in the study or information was yours. In order to reduce this risk and protect your privacy, we will take the following actions:

- No identifying information will be collected in this survey, ensuring that your responses will remain completely confidential and anonymous.
- We will not collect any sensitive information as your exact age, ethnicity, income, employment records, etc.
- Survey responses will be securely stored on a university computer, with access restricted to study personnel.
- The results of this study will be presented in aggregate form, ensuring that no individual participant's responses can be identified.

Will I receive payment or other incentives?

Participants will be asked to volunteer their time to complete the questionnaire for no compensation.

What are my rights if I take part in this study?

Your participation in this study is voluntary and you can withdraw your participation at any time without any penalty or loss of benefits to which you are otherwise entitled. The decision to participate or not in the research will have no effect on the participant's relationship with INDOT or Purdue University.

Who can I contact if I have questions about the study?

If you have questions, comments, or concerns about this research project, please contact one of the researchers: David Holguin-Mejia at (765) 418-1069 or dholguin@purdue.edu, Samuel Labi at (765) 637-6038 or labi@purdue.edu, or Konstantina "Nadia" Gkritza at (765) 494-4597 or nadia@purdue.edu. If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University

Ernest C. Young Hall, Room 1010

155 S. Grant St.

West Lafayette, IN 47907-2114

Documentation of Informed Consent

By clicking the arrow at the bottom of the page, you confirm that you have had the opportunity to read this consent form and have the research study explained. You also confirm that you have had the opportunity to ask questions about the research study, the questions have been answered and that you are prepared to participate in the research study described above. Please print this information sheet for your records.

Section 2: Terminology and Concepts

Introduction to Terminology and Concepts

As a steward of Indiana's transportation infrastructure, the Indiana Department of Transportation (INDOT) holds the responsibility for the construction and maintenance of interstate highways, U.S. routes, and state roads throughout Indiana. This includes the upkeep of adjacent overpasses, ramps, traffic control devices such as signs and traffic signals. INDOT should ensure that these responsibilities are met by constructing, operating, and maintaining the road infrastructure in a manner that promotes sustainable development (SD).

Sustainable Development (SD) is a key principle that ensures road infrastructure development (RID) has minimal negative impacts on economic, social, and environmental resources, and maximizes positive impacts on these three pillars of sustainability.

Road Infrastructure Development (RID) involves several phases:

- **Planning and Design:** Creating plans and designs for new roads or upgrades.
- **Construction:** Building the road infrastructure.
- **Operations and Maintenance:** Keeping roads in good condition and operating efficiently.
- **End-of-Life:** Managing the end-of-life of infrastructure, including recycling or disposing of materials.

The importance of incorporating sustainability concerns at every phase of INDOT's infrastructure development is growing due to increased human activity, the ongoing demand for transportation infrastructure, and the need to preserve our natural resources. Sustainable practices in RID directly relate to human well-being and the resilience of our environment.

Screening Questions

Which of the following best describes your current role in the process of sustainable development within Road Infrastructure Development (RID)?

- Project Manager
- General Manager
- Sustainability Manager
- Contractor
- Executive
- Site Engineer
- ITS Engineer
- Design Engineer
- Environmental Engineer
- Planning Engineer
- Policy Analyst
- Other (Please Specify)

What is you higher level of academic qualification?

- High school diploma
- Associate Degree
- Bachelor's Degree
- Master's Degree
- Doctoral Degree

What was your major field of study? (Select all that apply)
- Civil Engineering
- Environmental Engineering
- Transportation Engineering
- Urban Planning
- Construction Management
- Environmental Science
- Policy Studies
- Other (Please Specify)

How many years of experience do you have in the field of RID?
- Less than 1 year
- 1 to 3 years
- 4 to 6 years
- 7 to 9 years
- More than 10 years

Which phase(s) of RID are you most involved in? (Select all that apply)
- Planning
- Design
- Construction
- Operations
- Maintenance
- Monitoring
- Other (Please specify)

Do you have any formal training or certification related to sustainable practices in RID?
- Yes
- No

What is the primary source of your knowledge on sustainability practices in RID? (Select all that apply)
- Formal Education (College)
- Professional Training/Workshops
- On-the-job experience
- Self-study
- Peer learning
- Industry Conferences/Seminars
- Other (Please specify)

General knowledge and attitudes towards sustainability

How would you rate your knowledge of sustainability practices in the following phases of Road Infrastructure Development (RID)?

Phase	Very Low	Low	Moderate	High	Very High
Planning and Design	☐	☐	☐	☐	☐
Construction	☐	☐	☐	☐	☐
Operations and Maintenance	☐	☐	☐	☐	☐
End-of-life	☐	☐	☐	☐	☐

How important do you think sustainability is in the following phases of RID?

Phase	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Planning and Design	☐	☐	☐	☐	☐
Construction	☐	☐	☐	☐	☐
Operations and Maintenance	☐	☐	☐	☐	☐
End-of-life	☐	☐	☐	☐	☐

Which phase of RID do you think has the most potential for integrating sustainability practices? (Rank the phases considering 1 the one with the most potential, and 4 the one with the least potential)

- Planning and Design
- Construction
- Operations and Maintenance
- End-of-life

How do you stay informed about sustainability practices in RID? (Select all that apply)
- Industry Publications
- Professional Associations
- Conferences and Workshops
- Online Courses/Webinars
- Internal Training
- Peer Discussions
- Other (Please specify):

How frequently do you consider sustainability in your decision-making process for RID?
- Never
- Sometimes
- About half the time
- Most of the time
- Always

How confident are you in your ability to implement sustainable practices in RID?
- Not Confident
- Slightly Confident
- Moderately Confident
- Very Confident
- Extremely Confident

Barriers and Facilitators for implementing Sustainable Practices

In this section, we aim to identify potential barriers to the implementation of sustainable practices within INDOT and explore possible ways to overcome these barriers. Additionally, we want to understand how INDOT personnel prefer to learn more about sustainability practices.

What do you perceive as the main barriers to implementing sustainable practices in Road Infrastructure Development (RID) at INDOT? (Select all that apply)
- Lack of Knowledge
- High Costs
- Insufficient Training
- Limited Resources
- Regulatory Constraints
- Lack of Management Support
- Resistance to Change
- Insufficient Time
- Lack of Awareness
- Other (Please specify):

Please rank the following barriers in order of their impact on the implementation of sustainable practices at INDOT (1 being the most impactful):

- Lack of Knowledge
- High Costs
- Insufficient Training
- Limited Resources
- Regulatory Constraints
- Lack of Management Support
- Resistance to Change
- Insufficient Time
- Lack of Awareness

What measures do you think could facilitate the implementation of sustainable practices at INDOT? (Select all that apply)

- Increased Training and Education
- Improved Funding and Budget Allocation
- Enhanced Management Support
- Clearer Regulatory Guidance
- Increased Awareness Campaigns
- Incentives for Sustainable Practices
- Better Access to Resources and Tools
- Collaboration with External Partners
- Integration of Sustainability into Performance Metrics
- Other (Please specify):

Please rank the following measures in order of their potential effectiveness in facilitating the implementation of sustainable practices at INDOT (1 being the most effective)

- Increased Training and Education
- Improved Funding and Budget Allocation
- Enhanced Management Support
- Clearer Regulatory Guidance
- Increased Awareness Campaigns
- Incentives for Sustainable Practices
- Better Access to Resources and Tools
- Collaboration with External Partners
- Integration of Sustainability into Performance Metrics

How would you prefer to receive information and training about sustainability practices?

- Online Courses/Webinars
- In-Person Workshops
- Industry Conferences and Seminars
- Internal Training Programs
- Peer Learning Groups
- Newsletters and Email Updates
- Online Resources and Toolkits
- Professional Associations
- Other (Please specify):

Definition of Sustainable Practices

Please read the following definitions of sustainable practices before answering the questions in this section. Understanding these definitions will help you provide informed responses about the suitability and applicability of these practices in the context of INDOT.

In-House Opportunities:

- **Carbon Pollution-Free Electricity (CFE):** Using electricity that does not emit carbon dioxide during generation, typically from renewable sources like wind, solar, or hydroelectric power.
- **Near-zero emission fleet:** Operating a fleet of vehicles that emit very low levels of pollutants, often through electric or hybrid vehicles.
- **Net-zero emission buildings, campuses, and installations:** Designing and operating buildings and facilities to balance the amount of emitted greenhouse gases with an equivalent amount removed from the atmosphere.
- **Reducing waste and pollution:** Implementing practices to minimize the generation of waste and pollutants through recycling, reuse, and efficient resource use.
- **Sustainable procurement:** Purchasing goods and services that have a reduced environmental impact and promote social and economic sustainability.
- **Climate- and Sustainability-focused federal workforce:** Training and engaging the workforce to prioritize and implement sustainable practices in their roles.
- **Incorporation of Environmental Justice:** Ensuring fair treatment and meaningful involvement of all people in environmental policies and practices, regardless of race, color, national origin, or income.
- **Accelerating progress through partnerships:** Collaborating with various stakeholders, including government agencies, private sector, and community groups, to advance sustainability goals.

Field Opportunities:

Infrastructure Planning and Design:

- **Framework for sustainable technologies:** Developing guidelines and standards for incorporating sustainable technologies into infrastructure projects.
- **Responsible water use:** Implementing strategies to use water efficiently and protect water resources during planning and design.

- **Active and eco-friendly design:** Designing infrastructure to promote active transportation (walking, cycling) and to minimize environmental impact.
- **Sustainable pavement and materials:** Using materials that are durable, recyclable, and have a lower environmental footprint.
- **Intended end-of-life:** Planning for the end-of-life phase of infrastructure to facilitate recycling and minimize waste.

Infrastructure Construction:

- **Reducing GHG emissions:** Implementing practices to reduce greenhouse gas emissions from construction activities.
- **Optimization of construction equipment usage:** Using construction equipment more efficiently to minimize fuel consumption and emissions.
- **Renewable energy and alternative fuel use:** Utilizing renewable energy sources and alternative fuels during construction to reduce reliance on fossil fuels.
- **Innovative work zone management:** Applying advanced techniques to manage construction zones safely and efficiently while minimizing environmental impact.
- **Enhanced sustainable procurement practices:** Procuring construction materials and services that meet sustainability criteria.

Infrastructure Operations & Maintenance:

- **Electrification of maintenance equipment:** Using electric-powered maintenance equipment to reduce emissions.
- **Renewable energy for operations:** Powering operations with renewable energy sources.
- **Sustainable snow and ice management:** Implementing methods for snow and ice removal that minimize environmental impact.
- **Smart infrastructure for maintenance:** Using advanced technologies to optimize infrastructure maintenance and reduce resource use.

Infrastructure End-of-life:

- **Pavement Full-depth Reclamation (FDR):** A recycling method where the full depth of the pavement is reused in the rehabilitation process.
- **Material recycling and reuse:** Reusing and recycling materials from decommissioned infrastructure to minimize waste.
- **Biodegradable and eco-friendly materials:** Using materials that break down naturally without harming the environment.

In-house and field opportunities

In-House Opportunities

How applicable do you think the following in-house sustainable practices are to the context of the DOT?

Practice	Not applicable	Slightly applicable	Moderately applicable	Very applicable	Extremely applicable	Not sure
Carbon Pollution-Free Electricity (CFE) at INDOT buildings	☐	☐	☐	☐	☐	☐
Near-zero emission fleet	☐	☐	☐	☐	☐	☐
Net-zero emission buildings, campuses, and installations	☐	☐	☐	☐	☐	☐
Reducing waste and pollution	☐	☐	☐	☐	☐	☐
Sustainable procurement	☐	☐	☐	☐	☐	☐
Climate- and Sustainability-focused federal workforce	☐	☐	☐	☐	☐	☐
Incorporation of Environmental Justice	☐	☐	☐	☐	☐	☐
Accelerating progress through partnerships	☐	☐	☐	☐	☐	☐

Field Opportunities

How applicable do you think the following sustainable practices are during the Infrastructure Planning and Design phase?

Practice	Not applicable	Slightly applicable	Moderately applicable	Very applicable	Extremely applicable	Not sure
Framework for sustainable technologies	☐	☐	☐	☐	☐	☐
Responsible water use	☐	☐	☐	☐	☐	☐
Active and eco-friendly design	☐	☐	☐	☐	☐	☐
Sustainable pavement and materials	☐	☐	☐	☐	☐	☐
Intended end-of-life	☐	☐	☐	☐	☐	☐

How applicable do you think the following sustainable practices are during the Infrastructure Construction phase?

Practice	Not applicable	Slightly applicable	Moderately applicable	Very applicable	Extremely applicable	Not sure
Reducing GHG emissions	☐	☐	☐	☐	☐	☐
Optimization of construction equipment usage	☐	☐	☐	☐	☐	☐
Renewable energy and alternative fuel use	☐	☐	☐	☐	☐	☐
Innovative work zone management	☐	☐	☐	☐	☐	☐
Enhanced sustainable procurement practices	☐	☐	☐	☐	☐	☐

How applicable do you think the following sustainable practices are during the Infrastructure Operations & Maintenance phase?

Practice	Not applicable	Slightly applicable	Moderately applicable	Very applicable	Extremely applicable	Not sure
Electrification of maintenance equipment	☐	☐	☐	☐	☐	☐
Renewable energy for operations	☐	☐	☐	☐	☐	☐
Sustainable snow and ice management	☐	☐	☐	☐	☐	☐
Smart infrastructure for maintenance	☐	☐	☐	☐	☐	☐

How applicable do you think the following sustainable practices are during the Infrastructure End-of-life phase?

Practice	Not applicable	Slightly applicable	Moderately applicable	Very applicable	Extremely applicable	Not sure
Pavement Full-depth Reclamation (FDR)	☐	☐	☐	☐	☐	☐
Material recycling and reuse	☐	☐	☐	☐	☐	☐
Biodegradable and eco-friendly materials	☐	☐	☐	☐	☐	☐

Indicators to Assess Sustainability

Please rate the relevance of each indicator in addressing sustainability during different phases of the road infrastructure development (RID) process. (Check if applicable to the phase)

Environmental

Indicator	Planning and Design Phase	Construction Phase	Operations and Maintenance Phase	End-of-life Phase
Energy Conservation through Renewable Sources and Energy-Saving Technologies	☐	☐	☐	☐
Resource Efficiency in Machinery and Construction Material Use	☐	☐	☐	☐
Water Efficiency via Reuse and Management Techniques	☐	☐	☐	☐
Sustainable Material Selection and Recycling	☐	☐	☐	☐
Local Sourcing and Procurement of Sustainable Materials	☐	☐	☐	☐
Waste Reduction, Recycling, and Reuse Techniques	☐	☐	☐	☐
Quantifying Environmental Impact of Waste	☐	☐	☐	☐
Reducing Habitat Fragmentation and Enhancing Connectivity	☐	☐	☐	☐

Optimal Land Use and Minimization of Productive Land Conversion	☐	☐	☐	☐
Comprehensive Air Pollution Control from Vehicular Emissions	☐	☐	☐	☐
Mitigation of Light and Noise Pollution from Infrastructure	☐	☐	☐	☐
Solid Waste and Dust Management during Construction	☐	☐	☐	☐
Greenhouse Gas Emission Reduction Strategies	☐	☐	☐	☐
Adaptation to Climate Impacts through Landscaping and Disaster Risk Reduction	☐	☐	☐	☐
Advanced Water Resilience Measures	☐	☐	☐	☐

Social

Indicator	Planning and Design Phase	Construction Phase	Operations and Maintenance Phase	End-of-life Phase
Comprehensive Health and Safety Measures at Work	☐	☐	☐	☐
Promoting Social Equity and Employee Well-being	☐	☐	☐	☐
Ensuring Workplace Integrity and Fair Practices	☐	☐	☐	☐
Active and Inclusive Stakeholder Involvement	☐	☐	☐	☐
Improving Mobility and Accessibility through Reduced Travel Time and Costs	☐	☐	☐	☐
Quality of Life Improvements through Environmental and Social Enhancements	☐	☐	☐	☐
Community Safety and Risk Reduction Measures	☐	☐	☐	☐
Societal Well-being and Equity for Vulnerable Groups	☐	☐	☐	☐
Cultural Preservation and Integration with Local Character	☐	☐	☐	☐

Compensation and Relocation Practices that Preserve Dignity	☐	☐	☐	☐
Monitoring and Enhancing Socioeconomic Impacts of Projects	☐	☐	☐	☐
Governance Compliance and Transparent Decision-Making	☐	☐	☐	☐
Integrative and Sustainable Planning Practices	☐	☐	☐	☐

Economic

Indicator	**Planning and Design Phase**	**Construction Phase**	**Operations and Maintenance Phase**	**End-of-life Phase**
Net Present Value (NPV) Analysis	☐	☐	☐	☐
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐
Investment Payback Period Assessment	☐	☐	☐	☐
Project Rate of Return Evaluation	☐	☐	☐	☐
Comprehensive Management of Project Costs	☐	☐	☐	☐

Other Indicators

Indicator	Planning and Design Phase	Construction Phase	Operations and Maintenance Phase	End-of-life Phase
Technological Utilization for Impact Mitigation	☐	☐	☐	☐
Adaptive and Inclusive Design Implementation	☐	☐	☐	☐

Additional Comments

Do you have any additional comments or suggestions on how INDOT can better implement sustainable practices?

What do you think are the most critical areas for INDOT to focus on to enhance sustainability in Road Infrastructure Development?

AHP Experiment Introduction

Analytic Hierarchy Process for Sustainability Assessment

In the following section, you have the option to participate in an Analytic Hierarchy Process (AHP) experiment. This experiment involves making pairwise comparisons to help determine the relative importance of different sustainability categories and subcategories during various phases of Road Infrastructure Development (RID). Your responses will contribute to understanding which factors are most critical in achieving sustainable outcomes.

Note: This section is optional, and you can choose whether or not to participate.

Would you like to participate in the AHP experiment to help identify the most important sustainability factors during RID?

- Yes, I would like to participate.
- No, I would like to skip this section.

For each pair of items, please indicate which item is more important and by how much. Use the following scale to indicate the importance level:

1: Equal importance

3: Moderate importance of one over the other

5: Strong importance of one over the other

7: Very strong importance of one over the other

9: Extreme importance of one over the other

Comparison Major categories

Phase: Infrastructure Planning and Design

Category	9	7	5	3	1	3	5	7	9	Category
Environmental	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social
Environmental	☐	☐	☐	☐	☐	☐	☐	☐	☐	Economic
Social	☐	☐	☐	☐	☐	☐	☐	☐	☐	Economic

Phase: Infrastructure Construction

Category	9	7	5	3	1	3	5	7	9	Category
Environmental	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social
Environmental	☐	☐	☐	☐	☐	☐	☐	☐	☐	Economic
Social	☐	☐	☐	☐	☐	☐	☐	☐	☐	Economic

Phase: Infrastructure Operations & Maintenance

Category	9	7	5	3	1	3	5	7	9	Category
Environmental	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social
Environmental	☐	☐	☐	☐	☐	☐	☐	☐	☐	Economic
Social	☐	☐	☐	☐	☐	☐	☐	☐	☐	Economic

Phase: Infrastructure End-of-life

Category	9	7	5	3	1	3	5	7	9	Category
Environmental	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social
Environmental	☐	☐	☐	☐	☐	☐	☐	☐	☐	Economic
Social	☐	☐	☐	☐	☐	☐	☐	☐	☐	Economic

Comparison within Environmental Subcategories

Phase: Infrastructure Planning and Design

Category	9	7	5	3	1	3	5	7	9	Category
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Sustainable Materials and Resources
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Waste Management
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Waste Management
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Habitat and Biodiversity Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Habitat and Biodiversity Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Pollution Control	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience

Phase: Infrastructure Construction

Category	9	7	5	3	1	3	5	7	9	Category
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Sustainable Materials and Resources**
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Waste Management**
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Habitat and Biodiversity Management**
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Pollution Control**
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Climate Resilience**
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Waste Management**
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Habitat and Biodiversity Management**
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Pollution Control**
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Climate Resilience**
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Habitat and Biodiversity Management**
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Pollution Control**
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Climate Resilience**
Habitat and Biodiversity Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Pollution Control**
Habitat and Biodiversity Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Climate Resilience**
Pollution Control	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Climate Resilience**

Phase: Infrastructure Operations & Maintenance

Category	9	7	5	3	1	3	5	7	9	Category
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Sustainable Materials and Resources
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Waste Management
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Waste Management
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Habitat and Biodiversity Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Habitat and Biodiversity Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Pollution Control	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience

Phase: Infrastructure End-of-life

Category	9	7	5	3	1	3	5	7	9	Category
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Sustainable Materials and Resources
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Waste Management
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Resource Utilization Efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Waste Management
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Sustainable Materials and Resources	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Habitat and Biodiversity Management
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Habitat and Biodiversity Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pollution Control
Habitat and Biodiversity Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience
Pollution Control	☐	☐	☐	☐	☐	☐	☐	☐	☐	Climate Resilience

Comparison within Social Subcategories

Phase: Infrastructure Planning and Design

Category	9	7	5	3	1	3	5	7	9	Category
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Mobility and Accessibility
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Community Health and Safety
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Community Health and Safety
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions

Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Governance and Human Rights**
Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**
Socioeconomic Repercussions	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Governance and Human Rights**
Socioeconomic Repercussions	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**
Governance and Human Rights	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**

Phase: Infrastructure Construction

Category	9	7	5	3	1	3	5	7	9	Category
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Mobility and Accessibility
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Community Health and Safety
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Community Health and Safety
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Cultural and Heritage	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and

Integration										**Human Rights**
Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**
Socioeconomic Repercussions	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Governance and Human Rights**
Socioeconomic Repercussions	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**
Governance and Human Rights	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**

Phase: Infrastructure Operations & Maintenance

Category	9	7	5	3	1	3	5	7	9	Category
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Mobility and Accessibility
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Community Health and Safety
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Community Health and Safety
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Cultural and Heritage	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and

Integration										**Human Rights**
Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**
Socioeconomic Repercussions	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Governance and Human Rights**
Socioeconomic Repercussions	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**
Governance and Human Rights	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**

Phase: Infrastructure End-of-life

Category	9	7	5	3	1	3	5	7	9	Category
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Mobility and Accessibility
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Community Health and Safety
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Employment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Community Health and Safety
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Mobility and Accessibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Equity
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Community Health and Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cultural and Heritage Integration
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and Human Rights
Equity	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrative Planning and Decision-Making
Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	Socioeconomic Repercussions
Cultural and Heritage	☐	☐	☐	☐	☐	☐	☐	☐	☐	Governance and

Integration										**Human Rights**
Cultural and Heritage Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**
Socioeconomic Repercussions	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Governance and Human Rights**
Socioeconomic Repercussions	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**
Governance and Human Rights	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Integrative Planning and Decision-Making**

Comparison within Economic Subcategories

Phase: Infrastructure Planning and Design

Category	9	7	5	3	1	3	5	7	9	Category
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Internal Rate of Return (IRR) Calculation**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Investment Payback Period Assessment**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Investment Payback Period Assessment**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Investment Payback Period Assessment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Investment Payback Period Assessment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Project Rate of Return Evaluation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**

Phase: Infrastructure Construction

Category	9	7	5	3	1	3	5	7	9	Category
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	Internal Rate of Return (IRR) Calculation
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	Investment Payback Period Assessment
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	Project Rate of Return Evaluation
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	Comprehensive Management of Project Costs
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	Investment Payback Period Assessment
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	Project Rate of Return Evaluation
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	Comprehensive Management of Project Costs
Investment Payback Period Assessment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Project Rate of Return Evaluation
Investment Payback Period Assessment	☐	☐	☐	☐	☐	☐	☐	☐	☐	Comprehensive Management of Project Costs
Project Rate of Return Evaluation	☐	☐	☐	☐	☐	☐	☐	☐	☐	Comprehensive Management of Project Costs

Phase: Infrastructure Operations & Maintenance

Category	9	7	5	3	1	3	5	7	9	Category
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Internal Rate of Return (IRR) Calculation**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Investment Payback Period Assessment**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Investment Payback Period Assessment**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Investment Payback Period Assessment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Investment Payback Period Assessment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Project Rate of Return Evaluation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**

Phase: Infrastructure End-of-life

Category	9	7	5	3	1	3	5	7	9	Category
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Internal Rate of Return (IRR) Calculation**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Investment Payback Period Assessment**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Net Present Value (NPV) Analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Investment Payback Period Assessment**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Internal Rate of Return (IRR) Calculation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Investment Payback Period Assessment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Project Rate of Return Evaluation**
Investment Payback Period Assessment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**
Project Rate of Return Evaluation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Comprehensive Management of Project Costs**

Final Thoughts

Thank you for your time and insights. Your feedback is invaluable in helping Purdue team and INDOT understand better and enhance the application of sustainable practices in Road Infrastructure Development.

APPENDIX D. RISE – Sustainability Evaluation Criteria

This section outlines the evaluation criteria for each sustainability parameter, enabling consistent, transparent interpretation of project performance. By applying a structured scoring framework, results are quantified and translated into meaningful performance bands. These classifications support clear comparison across projects and guide decision-making toward improved sustainability outcomes.

D.1 Environmental Sustainability Evaluation Criteria

E.1 – RESOURCE UTILIZATION EFFICIENCY

E.1.1 – Energy Efficiency and Renewable Energy

E.1.1.1 – Adoption of renewable energy sources (e.g., solar, wind)

Assesses the extent to which the project is powered by renewable energy sources.

- 0% – No renewable energy usage.
- 25% – Up to 25% of energy from renewable sources.
- 50% – 26%-50% of energy from renewable sources.
- 75% – 51%-99% of energy from renewable sources.
- 100% – Entire project runs on renewable energy.

E.1.1.2 – Implementation of energy-saving technologies and practices

Evaluates whether energy-efficient technologies and practices are applied in lighting, signage, and facilities.

- 0% – No plan or consideration for energy-saving technologies.
- 25% – Basic awareness with minimal implementation (e.g., partial LED lighting but no broader strategy).
- 50% – A general plan exists, and some energy-saving measures are in place across key areas.
- 75% – A comprehensive plan is developed and actively being implemented, covering most operational facilities.
- 100% – A fully detailed plan is implemented with continuous monitoring and optimization of energy-saving measures.

E.1.1.3 – Promotion of energy consumption monitoring plan

Assesses whether energy monitoring is planned and implemented across project phases.

- 0% – No energy monitoring or reporting plan.
- 25% – Basic energy tracking in some phases but no formal plan.
- 50% – Partial monitoring in multiple phases, but lacks structured reporting.
- 75% – Comprehensive monitoring in most phases with periodic reporting.
- 100% – Fully integrated monitoring and reporting plan for all phases.

E.1.2 – Energy-Efficient Construction Practices

E.1.2.1 – Use of energy-efficient machinery and vehicles

Evaluates the proportion of construction equipment and vehicles that meet energy efficiency standards.

- 0% – No energy-efficient machinery or vehicles used.
- 25% – Up to 25% of machinery and vehicles meet efficiency standards.
- 50% – 26%-50% of machinery and vehicles meet efficiency standards.
- 75% – 51%-99% of machinery and vehicles meet efficiency standards.
- 100% – All construction machinery and vehicles meet energy efficiency standards.

E.1.2.2 – Efficient use of construction materials to reduce waste

Assesses whether the project uses materials efficiently, reducing overall waste generation.

- 0% – No waste reduction measures in place; significant material waste generated.
- 25% – Some efforts to optimize materials, but waste reduction is minimal (e.g., basic recycling efforts).
- 50% – Moderate material waste reduction strategies in use, with some reuse and recycling programs active.
- 75% – Strong waste minimization efforts, with extensive reuse and recycling reducing waste significantly.
- 100% – Less than 5% of total construction materials used result in waste which is achieved through rigorous optimization, reuse, and recycling initiatives.

E.1.3 – Water Resource Management

E.1.3.1 – Grey water reuse

Assesses whether the project reuses greywater for construction, landscaping, or maintenance to reduce potable water demand.

- 0% – No greywater use.
- 25% – Limited greywater use for minor activities.
- 50% – Moderate greywater use in some construction and maintenance areas.
- 75% – Significant greywater use covering most activities.
- 100% – Full reliance on greywater for all applicable processes.

E.1.3.2 – Control of water use

Evaluates the existence and quality of a water management plan aimed at reducing water consumption across the project lifecycle.

- 0% – No water management plan.

- 25% – Basic water-saving efforts with no structured plan.
- 50% – A developed plan with partial implementation of water-saving measures.
- 75% – A comprehensive water management plan covering most aspects of the project.
- 100% – A fully integrated plan with active monitoring and maximum water conservation.

E.1.3.3 – Storm water runoff management

Assesses the project's ability to control runoff volume and prevent flooding through stormwater management best practices.

- 0% – No stormwater management plan in place.
- 25% – Basic stormwater management with limited best practices or partial compliance.
- 50% – Moderate stormwater management plan, partially meeting best practices.
- 75% – Comprehensive stormwater plan, following most best management practices.
- 100% – Fully integrated stormwater management plan, exceeding compliance with best practices.

E.1.3.4 – Rainwater harvesting

Evaluates integration of rainwater harvesting systems for non-potable use during construction and operations.

- 0% – No rainwater harvesting plan.
- 25% – Limited rainwater harvesting for specific applications.
- 50% – Partial integration of rainwater harvesting in construction or operation phases.
- 75% – Significant integration of rainwater harvesting for most non-potable uses.
- 100% – Full integration of rainwater harvesting systems for all non-potable applications throughout the project.

E.2 – Sustainable Materials and Resources

E.2.1 – Resource Selection and Reuse

E.2.1.1 – Recyclable materials

Evaluates whether materials used in the project can be recycled at the end of their lifecycle.

- 0% – No recyclable materials.
- 25% – Less than 10% of materials are recyclable.

- 50% – 10%-25% of materials are recyclable at the end of life.
- 75% – 25%-50% of materials are recyclable.
- 100% – At least 50% of materials are recyclable at the end of the project's life.

E.2.1.2 – Use of natural resources (soil, wood, bamboo, etc.)

- Assesses whether natural resources are sourced from certified sustainable sources.
- 0% – No natural resources from certified sustainable sources.
- 25% – Less than 10% of natural resources are from certified sustainable sources.
- 50% – 10%-25% of natural resources are sourced sustainably.
- 75% – 25%-50% of natural resources are sustainably sourced.
- 100% – At least 50% of natural resources are from certified sustainable sources.

E.2.1.3 – Durable material resources

Evaluates the durability of materials used, aiming for a minimum lifespan of 30 years.

- 0% – No durability standards or materials with short lifespans.
- 25% – Some materials meet durability standards but many fall short.
- 50% – At least 50% of materials meet durability standards.
- 75% – Most materials meet durability standards, with a few exceptions.
- 100% – All materials meet or exceed durability standards, ensuring a lifespan of at least 30 years.

E.2.1.4 – Re-use of pavement materials for construction

Assesses the extent to which pavement materials from existing roadways are reused in the project.

- 0% – No repurposed materials used for pavement.
- 25% – Up to 10% of pavement materials are repurposed.
- 50% – 10%-25% of pavement materials are repurposed.
- 75% – 25%-50% of pavement materials are repurposed.
- 100% – 50% or more of pavement materials are repurposed from existing roadways.

E.2.1.5 – Virgin material consumption

Assesses the percentage of virgin materials used, encouraging reduced dependence on non-renewable resources.

- 0% – More than 60% of materials are virgin materials.
- 25% – 50%-60% of materials are virgin materials.
- 50% – 40%-50% of materials are virgin materials.

- 75% – 30%-40% of materials are virgin materials.
- 100% – Less than 30% of materials are virgin materials.

E.2.2 – Sustainable Procurement

E.2.2.1 – Sustainable procurement of materials (Locally available)

Assesses the extent to which the project prioritizes sourcing materials locally to reduce emissions and support local economies.

- 0% – No procurement plan prioritizing local materials.
- 25% – Basic efforts to prioritize some locally sourced materials.
- 50% – A general procurement plan with partial prioritization of local materials.
- 75% – Procurement plan heavily favors local materials with some exceptions.
- 100% – A comprehensive procurement plan fully prioritizing locally available materials.

E.3 – Waste Management

E.3.1 – Waste Reduction and Recycling

E.3.1.1 – Waste collection

Evaluates whether the project includes a structured waste management plan with organized collection and segregation.

- 0% – No waste management plan in place.
- 25% – Basic waste management with limited segregation and collection methods.
- 50% – Partial waste management plan, with some segregation and disposal strategies.
- 75% – Comprehensive waste management plan with clear segregation, collection, and disposal methods.
- 100% – Full waste management plan with optimized segregation, collection, disposal, and sustainability practices.

E.3.1.2 – Recycling and reuse of waste

Measures how much construction waste is diverted from landfills through reuse or recycling.

- 0% – No diversion from landfills or minimal diversion efforts.
- 25% – 25%-40% of construction waste is diverted.
- 50% – 41%-60% of construction waste is diverted.
- 75% – 61%-79% of construction waste is diverted.
- 100% – 80% or more of construction waste is diverted from landfills.

E.3.2 – Environmental Impact of Waste

E.3.2.1 – Ozone depletion

Assesses whether construction materials and refrigerants used contribute to ozone layer depletion.

- 0% – No use of materials or refrigerants without ozone-depleting substances.
- 25% – Some materials or refrigerants meet zero ozone-depleting standards, but not all.
- 50% – 50% of materials and refrigerants used meet zero ozone-depleting standards.
- 75% – 75% of materials and refrigerants meet zero ozone-depleting standards.
- 100% – All materials and refrigerants used have zero ozone-depleting substances.

E.3.2.2 – Eutrophication

Assesses the project's contribution to nutrient enrichment in local water bodies—particularly due to runoff containing phosphates, nitrates, or deicing chemicals (e.g., road salt). This criterion considers both the design and operational measures to minimize pollutant discharges that may lead to algae blooms, oxygen depletion, and water quality degradation.

- 0% – No measures in place to control nutrient or deicing-related runoff; runoff directly discharges to surface water without treatment.
- 25% – Basic mitigation in place (e.g., vegetated buffers), but not specifically designed to meet nutrient loading targets; some effort to manage salt use or organic material.
- 50% – Partial treatment or detention systems implemented to reduce nutrient-rich runoff; deicing practices are improved but not optimized; measurable but moderate impact reduction.
- 75% – Strong design features including infiltration basins, constructed wetlands, or vegetated swales; salt application is optimized (e.g., calibrated spreaders, pre-wetting); monitoring shows reduced runoff nutrient load.
- 100% – Comprehensive runoff management system with engineered treatment (e.g., biofiltration, extended detention), optimized winter maintenance practices, and monitoring data confirming minimal nutrient discharge into nearby water bodies.

E.4 – Habitat and Biodiversity Management

E.4.1 – Habitat Fragmentation and Connectivity

E.4.1.1 – Barrier effect reduction for wildlife movement

Assesses whether wildlife crossings, underpasses, or green bridges are implemented in key ecological corridors.

- 0% – No wildlife crossings, underpasses, or green bridges implemented.

- 25% – Wildlife crossings or underpasses implemented in some identified corridors.
- 50% – Wildlife movement corridors partially addressed with crossings or underpasses.
- 75% – Most identified wildlife corridors are addressed with appropriate crossings or green bridges.
- 100% – All identified wildlife movement corridors have appropriate crossings, underpasses, or green bridges.

E.4.1.2 – Habitat connectivity enhancement

Measures the project's ability to maintain or improve pre-construction ecological connectivity.

- 0% – No habitat connectivity maintained or improved.
- 25% – 25%-40% of pre-construction habitat connectivity is maintained or improved.
- 50% – 41%-60% of pre-construction habitat connectivity is maintained or improved.
- 75% – 61%-79% of pre-construction habitat connectivity is maintained or improved.
- 100% – 80% or more of pre-construction habitat connectivity is maintained or improved.

E.4.1.3 – Protection of valuable habitats and natural (ecological) areas

Assesses whether ecologically significant areas are preserved or restored within the project scope.

- 0% – No preservation or restoration of ecologically significant areas.
- 25% – Limited preservation or restoration of ecologically significant areas.
- 50% – Partial preservation or restoration of significant areas, but many are not addressed.
- 75% – Most ecologically significant areas preserved or restored, with a few exceptions.
- 100% – All ecologically significant areas are fully preserved or restored within the project scope.

E.4.2 – Land Use Management

E.4.2.1 – Density of land use

Evaluates whether the project promotes compact development and minimizes conversion of undeveloped land.

- 0% – Project causes high land use change; more than 50% of land converted was previously undeveloped, natural, or agricultural.

- 25% – 40%-50% of land converted was previously undeveloped, natural, or agricultural.
- 50% – 30%-40% of land converted was previously undeveloped, natural, or agricultural.
- 75% – 10%-30% of land converted was previously undeveloped, natural, or agricultural.
- 100% – Less than 10% of land converted was previously undeveloped, natural, or agricultural; project makes efficient use of already urbanized land or brownfield sites.

E.4.2.2 – Minimization of productive land conversion

Assesses how much of the project area overlaps with high-productivity agricultural or ecological zones.

- 0% – More than 50% of land comes from high-productivity agricultural or ecological zones.
- 25% – 40%-50% of land comes from such zones.
- 50% – 30%-40% of land comes from high-productivity agricultural or ecological zones.
- 75% – 10%-30% of land used comes from such zones.
- 100% – Less than 10% land used from high-productivity agricultural or ecological zones.

E.5 – Pollution Control

E.5.1 – Reduction of Vehicle Emissions

E.5.1.1 – Reduction of vehicular emissions (specify pollutants like NOx, CO, PM10, CO_2)

Assesses whether the project includes a strategy to reduce pollutants from traffic via cleaner fuels, low-emission zones, or traffic management.

- 0% – No emissions reduction strategy in place.
- 25% – Basic efforts to reduce emissions, with limited measures or unclear strategy.
- 50% – Partial emissions reduction strategy with some measures in place for traffic management or cleaner fuels.
- 75% – Comprehensive emissions reduction strategy with most measures implemented.
- 100% – Fully integrated emissions reduction strategy with clear and active measures to lower pollutants.

E.5.2 – Light and Noise Pollution Control

E.5.2.1 – Decrease in light pollution from roadways

Assesses how effectively the project limits environmental light pollution through best practices in roadway lighting design and implementation. Emphasis is placed on measurable outcomes such as use of full cut-off fixtures, adaptive lighting controls, color temperature of lamps, and minimization of excessive or misdirected lighting. The use of dark-sky principles is encouraged but not required.

- 0% – No consideration of light pollution. High mast or overpowered lighting used without shielding, dimming, or cutoff controls.
- 25% – Basic efforts made to reduce lighting impact, such as partial shielding or basic lighting layout, but over-illumination and glare remain prevalent.
- 50% – Moderate reduction measures implemented, such as full cutoff fixtures and lower color temperature lighting in some areas, but without widespread adaptive controls or integrated planning.
- 75% – Strong efforts across the corridor: includes full cutoff fixtures, 3000K or lower lighting, minimized pole height and spacing, and some use of dimming or motion-based controls.
- 100% – Comprehensive strategy applied: full cutoff and directional lighting used corridor-wide, all luminaires, adaptive/dimming systems installed, and total light output minimized per unit area (lumens/m2). Audit or simulation shows measurable reduction in sky glow or environmental impact.

E.5.2.2 – Noise and vibration levels control during construction and operation

Assesses compliance with WHO noise guidelines and implementation of noise mitigation in sensitive areas.

- 0% – No measures taken to meet WHO noise guidelines, or no noise barriers or low-noise pavement used.
- 25% – Basic measures in place to meet noise guidelines, with limited use of noise barriers or low-noise pavement.
- 50% – Partial compliance with noise guidelines, with some noise barriers or low-noise pavement in sensitive areas.
- 75% – Most sensitive areas meet or exceed WHO guidelines, with significant use of noise barriers or low-noise pavement.
- 100% – Full compliance with WHO noise guidelines, with noise barriers or low-noise pavement implemented in all sensitive areas.

E.5.3 – Dust Control

E.5.3.1 – Dust suppression measures during construction phases

Assesses whether dust control strategies such as water spraying or material covering are consistently used on-site.

- 0% – No dust suppression techniques implemented on construction sites.
- 25% – Limited dust suppression techniques in use, not consistently applied.

- 50% – Dust suppression techniques used in some construction sites, but not universally applied.
- 75% – Most construction sites implement dust suppression techniques, with some exceptions.
- 100% – All construction sites fully implement dust suppression techniques.

E.6 – Climate Adaptation and Resilience

E.6.1 – Green Gas Emissions

E.6.1.1 – GHG emissions reduction strategies

Assesses whether the project includes a strategy to reduce both direct and indirect greenhouse gas (GHG) emissions throughout its lifecycle.

- 0% – No GHG reduction strategy or effort in place.
- 25% – Basic GHG reduction efforts or partial strategy addressing only direct emissions.
- 50% – Partial GHG reduction strategy that addresses both direct and indirect emissions but lacks comprehensive measures.
- 75% – Strong GHG reduction strategy addressing both direct and indirect emissions, with significant actions in place.
- 100% – Fully integrated GHG reduction strategy addressing direct and indirect emissions, with continuous monitoring and optimization efforts.

E.6.2 – Adaptation to Climate Impacts

E.6.2.1 – Integration of climate-adaptive landscaping (e.g., heat-resilient plant species)

Evaluates whether native, drought-resistant, and climate-resilient vegetation is used in landscaping plans.

- 0% – No landscaping plan with native or climate-adaptive species.
- 25% – Basic landscaping plan with limited use of native or drought-resistant species.
- 50% – Partial landscaping plan with a mix of native and drought-resistant species, but not fully climate-adaptive.
- 75% – Comprehensive landscaping plan with most areas covered by native, drought-resistant, and climate-adaptive plants.
- 100% – Full landscaping plan with native, drought-resistant, and climate-adaptive species used throughout the project.

E.6.2.2 – Disaster risk reduction in design (addressing erosion, landslides, floods)

Assesses whether erosion, flooding, and other natural hazards are addressed in the project design through a dedicated risk reduction plan.

- 0% – No disaster risk reduction plan in place.

- 25% – Limited disaster risk reduction measures addressing one or two risks (e.g., erosion or flooding).
- 50% – Moderate disaster risk reduction plan, covering some risks but lacking full integration into the design.
- 75% – Strong disaster risk reduction plan addressing most major risks (erosion, landslides, flooding) in the design.
- 100% – Fully comprehensive disaster risk reduction plan integrated into the design, addressing erosion, landslides, and flooding.

E.6.3 – Sustainable Stormwater Management

E.6.3.1 – Stormwater runoff management to reduce volume and peak flow

Evaluates whether low-impact development (LID) and green infrastructure practices are used to reduce runoff and improve water quality.

- 0% – No stormwater management practices beyond standard vaults or pipes; minimal consideration of runoff quantity or quality.
- 25% – Project includes one basic LID feature (e.g., vegetated swales, disconnected downspouts) or some treatment of runoff, but no major infiltration measures.
- 50% – Project uses a combination of LID elements (e.g., rain gardens, planters, permeable pavements) and treats a moderate portion of runoff with green infrastructure.
- 75% – Stormwater plan includes extensive use of natural drainage systems, multiple LID strategies, and provides on-site treatment for both quantity and quality control.
- 100% – Comprehensive stormwater strategy prioritizes infiltration and natural hydrology, minimizes use of underground vaults, and treats nearly all runoff using integrated LID and green infrastructure approaches.

D.2 Social Sustainability Evaluation Criteria

S.1 – Employment

S.1.1 – Comprehensive Health and Safety Measures at Work

S.1.1.1 – Working conditions

Assesses overall compliance with labor laws and occupational health and safety standards.

- 0% – No compliance with labor laws or safety standards.
- 25% – Some compliance, but significant gaps remain in labor laws and safety adherence.
- 50% – Partial compliance, with moderate adherence to labor laws and safety standards.
- 75% – Mostly compliant, with minor deviations or areas needing improvement.
- 100% – Full compliance with all labor laws, occupational health, and safety standards.

S.1.1.2 – Health and safety training

Measures the extent to which workers receive mandatory training before engaging in work activities.

- 0% – No workers receive mandatory health and safety training.
- 25% – 1%-25% of workers receive health and safety training.
- 50% – 26%-50% of workers receive health and safety training.
- 75% – 51%-99% of workers receive health and safety training.
- 100% – All workers receive mandatory health and safety training before starting work.

S.1.1.3 – Provision of personal protective equipment (PPE)

Evaluates access to appropriate certified personal protective equipment for workers.

- 0% – No provision of certified PPE.
- 25% – 1%-25% of workers have appropriate and certified PPE.
- 50% – 26%-50% of workers have appropriate and certified PPE.
- 75% – 51%-99% of workers have appropriate and certified PPE.
- 100% – All workers have appropriate and certified PPE at all times.

S.1.1.4 – Onsite medical services

Assesses the availability of medical support at construction sites.

- 0% – No onsite medical services available.
- 25% – Limited medical services available, but not 24/7.
- 50% – Medical services available during work hours but not round-the-clock.
- 75% – Medical services available 24/7 at most major construction sites.

- 100% – Medical services available 24/7 at all major construction sites.

S.1.1.5 – Safety measures (e.g., site hoarding, safety warnings)

Assesses whether project sites include physical safety precautions and emergency protocols.

- 0% – No safety measures in place.
- 25% – 1%-25% of project sites include clear safety measures.
- 50% – 26%-50% of project sites include clear safety measures.
- 75% – 51%-99% of project sites include clear safety measures.
- 100% – All project sites include clear safety measures such as signage, barriers, and emergency protocols.

S.1.1.6 – Traffic accident rates involving personal injury or death

Evaluates the existence and implementation of a plan to reduce work-related fatalities and traffic accidents.

- 0% – No plan for reducing fatalities or traffic accidents.
- 25% – Basic plan exists but with minimal implementation and impact.
- 50% – Partial plan with some safety measures in place, moderate progress in accident reduction.
- 75% – Strong plan with effective safety measures and significant reduction in traffic accidents.
- 100% – Fully implemented plan achieving zero fatalities and at least a 50% reduction in traffic accidents.

S.1.2 – Promoting Employee Well-being and Equity

S.1.2.1 – Employment of local labor

Evaluates the extent to which the project promotes and facilitates the hiring of local workforce.

- 0% – No initiatives to hire local labor; workforce entirely sourced externally.
- 25% – Minimal efforts to promote local hiring; local labor used only in minor roles or through subcontractors.
- 50% – Project includes some local hiring or partnerships with community job programs; partial documentation of workforce origin.
- 75% – Project has a structured local labor hiring plan, engages with local employment offices or training institutions, and can demonstrate moderate success in hiring locally.
- 100% – Strong local hiring strategy in place with transparent reporting; significant local workforce involved across roles; project contributes to long-term local job development and/or skills training.

S.1.2.2 – Employee well-being and benefits

Assesses the extent to which the project ensures access to benefits like healthcare, paid leave, and social security.

- 0% – No employees receive benefits.
- 25% – 1%-25% of employees receive benefits.
- 50% – 26%-50% of employees receive benefits.
- 75% – 51%-99% of employees receive benefits.
- 100% – All employees receive benefits, including healthcare, paid leave, and social security.

S.1.2.3 – Equal rights and opportunities across diverse groups

Evaluates whether a diversity and inclusion plan exists to ensure equitable opportunities for underrepresented populations.

- 0% – No diversity and inclusion plan in place.
- 25% – Basic plan exists but with limited implementation.
- 50% – Moderate efforts toward diversity and inclusion, with some hiring practices adjusted.
- 75% – Strong inclusion plan with significant hiring and employment equity measures in place.
- 100% – Comprehensive diversity and inclusion plan with equal employment opportunities ensured for underrepresented groups.

S.1.3 – Ensuring Workplace Integrity and Fair Practices

.1.3.1 – Job stability and security

Evaluates whether the project promotes long-term employment opportunities for contracted workers.

- 0% – No effort to support long-term employment; workers are hired temporarily with no provisions for continued work.
- 25% – Short-term hiring dominates; limited or informal efforts to promote employment beyond the project period.
- 50% – Project includes some employment continuity practices (e.g., contract extensions, hiring workers across phases); partial documentation available.
- 75% – Project promotes longer-term work through formal agreements, partnerships with contractors that offer continuing employment, or career development efforts.
- 100% – Strong commitment to employment stability: structured practices to ensure long-term or transitional employment, integration with workforce development programs, and tracking of post-project employment outcomes.

S.1.3.2 – Non-discriminatory hiring practices

Assesses whether anti-discrimination policies are established and monitored during recruitment and employment.

- 0% – No anti-discrimination hiring policy in place.
- 25% – Policy exists but no compliance audits are conducted.
- 50% – Policy exists with occasional audits, but gaps remain.
- 75% – Strong anti-discrimination policy with regular audits ensuring compliance.
- 100% – Fully enforced anti-discrimination policy with frequent audits and corrective measures.

S.1.3.3 – Anti-corruption measures

Evaluates whether the project has a corruption prevention framework and training for all stakeholders.

- 0% – No corruption prevention framework or training in place.
- 25% – Basic framework exists with limited training for stakeholders.
- 50% – Moderate framework with some stakeholders trained on ethical practices.
- 75% – Strong corruption prevention framework with most stakeholders trained.
- 100% – Fully developed framework with all stakeholders trained on ethical practices.

S.1.3.4 – Fair remuneration and reasonable workload

Assesses compliance with national labor laws related to fair wages and working hours.

- 0% – No compliance with labor laws.
- 25% – Limited compliance, with some adherence to fair wages and working hours.
- 50% – Moderate compliance, but some gaps remain.
- 75% – High compliance, with minor deviations.
- 100% – Full compliance with national labor laws ensuring fair wages and reasonable working hours.

S.1.3.5 – Knowledge and skills transfer

Assesses the presence of worker training or upskilling opportunities within the project.

- 0% – No training or upskilling opportunities provided.
- 25% – 1%-10% of workers receive upskilling opportunities.
- 50% – 11%-20% of workers receive upskilling opportunities.
- 75% – 21%-29% of workers receive upskilling opportunities.
- 100% – At least 30% of workers receive upskilling opportunities.

S.1.4 – Stakeholder Engagement and Participation

S.1.4.1 – Stakeholder acceptability

Measures the extent to which stakeholders approve of the project based on consultation or survey results.

- 0% – No stakeholder consultation or approval below 40%.
- 25% – 40%-59% approval from stakeholders.
- 50% – 60%-74% approval from stakeholders.
- 75% – 75%-79% approval from stakeholders.
- 100% – At least 80% approval from stakeholders based on consultation and survey results.

S.1.4.2 – Early involvement of stakeholders

Assesses the timing of stakeholder engagement relative to project development.

- 0% – No stakeholder engagement before project initiation.
- 25% – Stakeholder engagement begins less than 3 months before project initiation.
- 50% – Stakeholder engagement begins 3–6 months before project initiation.
- 75% – Stakeholder engagement begins 6–11 months before project initiation.
- 100% – Stakeholders are engaged at least 12 months before project initiation.

S.1.4.3 – Timely and relevant information sharing

Evaluates the regularity and transparency of updates shared with stakeholders.

- 0% – No project updates shared with stakeholders.
- 25% – Updates shared sporadically, less than twice a year.
- 50% – Updates shared at least twice a year but not quarterly.
- 75% – Updates shared consistently, at least three times a year.
- 100% – All project updates are planned to be shared transparently with stakeholders at least quarterly.

S.1.4.4 – Freedom of participation in decision-making

Assesses whether the community has meaningful opportunities to participate in the planning and design process.

- 0% – No public forums or community participation.
- 25% – Limited public meetings with minimal community input.
- 50% – Regular public meetings, but with limited impact on decision-making.
- 75% – Strong community participation with frequent open forums influencing project design.

- 100% – Fully transparent process with extensive community participation and feedback incorporation.

S.2 – Mobility, Accessibility, and User Benefits

S.2.1.1 – Project achieves measurable travel time savings for users

Evaluates the extent to which the project reduces travel time for users compared to pre-project conditions.

- 0% – No reduction in travel time (current conditions remain unchanged or worsened).
- 25% – 1%–10% reduction in travel time.
- 50% – 11%–20% reduction in travel time.
- 75% – 21%–30% reduction in travel time.
- 100% – More than 30% reduction in travel time for the majority of users or key corridors.

S.2.1.2 – Project reduces Road User Costs (RUCs) compared to pre-project conditions

Assesses the economic benefit to road users through decreased travel costs as a result of the project.

- 0% – No reduction in road user costs; costs remain unchanged or increase.
- 25% – 1%–10% reduction in road user costs.
- 50% – 11%–20% reduction in road user costs.
- 75% – 21%–30% reduction in road user costs.
- 100% – More than 30% reduction in road user costs, based on robust analysis or modeling of user benefits.

S.2.1.3 – Enhancement of service levels

Measures improvements in user experience and operational performance of transport services.

- 0% – No measurable improvement in service levels; conditions remain the same or worsen.
- 25% – Minor improvements observed (e.g., small delay reductions, improved signage, or minor frequency adjustments), but no shift in official service rating.
- 50% – Moderate improvement with clear evidence of better user experience (e.g., reduced delays, increased vehicle throughput, marginally improved headways) nearing a higher service level.
- 75% – Improvement sufficient to elevate service levels in some but not all corridors, times of day, or user groups.

- 100% – Documented improvement of at least one full-service level (e.g., LOS E → D, or transit frequency tier upgrade) across the majority of affected segments or users.

S.2.1.4 – Project increases passenger throughput along road corridors or transit systems
Evaluates the project's ability to move more passengers efficiently through the corridor or system.

- 0% – No measurable increase in passenger volumes; conditions remain unchanged or worsen.
- 25% – 1%–10% increase in passenger volumes or localized/small-scale gains.
- 50% – 11%–25% increase in passengers, suggesting moderate growth or partial modal shift.
- 75% – 26%–40% increase in passengers, representing substantial ridership gains across the corridor or network.
- 100% – More than 40% increase in passengers; strong modal shift or capacity utilization driven by significant infrastructure or service improvements.

S.2.1.5 – Project improves access to essential public services for the community
Assesses how well the project improves community access to healthcare, education, government services, or other essential destinations.

- 0% – No expected improvement in access to public services; project does not consider community access needs.
- 25% – Project acknowledges service access but has only basic or conceptual measures with limited local impact.
- 50% – Project includes specific design features or route changes that improve access to some services for some users.
- 75% – Project demonstrates substantial improvement in access to multiple essential services for a significant portion of the local population, supported by evidence (e.g., maps, surveys, catchment areas).
- 100% – Project provides clear, measurable improvements in access to multiple essential services, with documented outcomes or accessibility analysis.

S.2.1.6 – Project enhances transit accessibility through improved infrastructure, connectivity, and last-mile solutions
Assesses how effectively the project improves access to transit through integrated station design, multimodal connections, and last-mile strategies.

- 0% – No enhancements to transit accessibility; project does not address transit users' needs.
- 25% – Minor or isolated improvements (e.g., a new stop or partial sidewalk extension), with limited impact on overall accessibility.
- 50% – Moderate enhancements such as new connections, shelter upgrades, or improved signage that benefit some users or corridors.
- 75% – Significant accessibility improvements, including physical infrastructure (e.g., stations, ramps), enhanced multimodal integration, and better last-mile access for a wide range of users.
- 100% – Comprehensive and inclusive transit accessibility strategy implemented, featuring multiple integrated measures (e.g., new stations, universal design, bike/ped access, real-time info, and last-mile options), with demonstrated improvement in user access and connectivity.

S.2.1.7 – Promotion of Active Mobility (Walking and Cycling)
Evaluates the extent to which the project actively supports walking and cycling as viable, safe, and attractive transportation options, through infrastructure and policy.

- 0% – No plan or measures to support walking or cycling; active mobility needs are not addressed.
- 25% – A basic plan exists, but implementation is limited or informal; minimal infrastructure or outreach included.
- 50% – The project includes a moderate set of measures such as sidewalks, bike lanes, or traffic calming in selected areas; some supporting policies or signage are introduced.
- 75% – A strong active mobility approach is integrated into project design, with significant infrastructure (e.g., protected bike lanes, wide sidewalks), policies (e.g., reduced speed limits), and community engagement (e.g., workshops, feedback loops).
- 100% – A comprehensive and inclusive active mobility strategy is fully implemented, combining high-quality infrastructure, enabling policies, and sustained public engagement to promote walking and cycling as primary modes of transport.

S.2.1.8 – Traffic Flow Optimization and Disruption Minimization
Assesses how well the project improves traffic operations and reduces congestion using strategies such as signal timing, design modifications, and intelligent systems.

- 0% – No strategies or technologies implemented to reduce traffic disruptions.

- 25% – Basic or isolated interventions (e.g., minor signal timing changes) with limited measurable impact.
- 50% – Moderate improvements targeting specific congestion points (e.g., optimized intersections, queue jump lanes) but without corridor-wide integration.
- 75% – Strong implementation of coordinated traffic flow strategies (e.g., adaptive signal control, dynamic signage), showing noticeable performance gains across multiple segments.
- 100% – Comprehensive system of traffic flow optimization measures in place, using real-time data, ITS, and smart mobility solutions to maintain efficient and reliable traffic movement across the project area.

S.2.1.9 – Multimodal Integration

Evaluates how well the project enables seamless transitions between transportation modes—walking, cycling, transit, and private vehicles—through coordinated infrastructure, services, and design.

- 0% – No multimodal integration; modes operate in isolation without coordination.
- 25% – Some connections exist but are informal, poorly coordinated, or lack infrastructure support.
- 50% – Moderate integration between key modes (e.g., shared stops, bike racks at stations), but coverage is incomplete or inconsistent.
- 75% – Strong multimodal connectivity with physical and service integration (e.g., co-located transfer points, schedule coordination, unified wayfinding).
- 100% – Fully integrated multimodal transport system with cohesive physical design, policy support, real-time information, and inclusive infrastructure ensuring easy and seamless transfers between modes.

S.3 – Community Health and Safety

S.3.1 – Quality of Life Improvements

S.3.1.1 – Emission impact reduction on human health

Evaluates the degree to which the project implements strategies to reduce transportation-related emissions that negatively impact public health, including both direct mitigation (e.g., cleaner vehicles, traffic reduction) and monitoring efforts.

- 0% – No emission reduction or air quality monitoring measures are included in the project.
- 25% – Basic initiatives in place, such as limited air quality monitoring or isolated emission controls (e.g., low-sulfur fuel use in fleet vehicles).

- 50% – Moderate implementation of emission reduction strategies (e.g., partial traffic rerouting, limited green infrastructure) and some localized air quality data collection.
- 75% – Strong project-wide actions including coordinated emission control strategies (e.g., congestion pricing, low-emission zones), supported by expanded air quality monitoring and reporting.
- 100% – Comprehensive emission reduction framework in place, combining real-time air quality monitoring, multiple integrated mitigation strategies (e.g., electrification, mode shift, green infrastructure), and long-term public health tracking.

S.3.1.2 – Promotion of art, culture, and community values

Evaluates the degree to which the project reflects, protects, and enhances local cultural identity through public art, heritage preservation, and engagement with the affected community.

- 0% – No cultural, artistic, or heritage-related measures included in the project.
- 25% – Basic incorporation of cultural elements (e.g., murals, signage) with minimal community involvement or contextual relevance.
- 50% – Moderate integration of cultural and heritage elements into the design (e.g., traditional materials, localized design themes) with some public consultation.
- 75% – Strong emphasis on cultural preservation, including dedicated public spaces, heritage site protection, or commissioned public art developed through community engagement.
- 100% – Comprehensive integration of cultural, artistic, and heritage elements, co-developed with local stakeholders, fully embedded in the project’s design, spatial layout, and public experience.

S.3.1.3 – Improvement in social cohesion and aesthetics

Evaluates the extent to which the project incorporates urban design elements or programs that promote social interaction, inclusion, and visual quality in the public realm.

- 0% – No features or initiatives related to urban aesthetics or social cohesion are included in the project.
- 25% – Basic aesthetic improvements (e.g., landscaping, lighting upgrades) with minimal influence on community interaction or public life.
- 50% – Moderate enhancements such as improved sidewalks, gathering areas, or recreational spaces that support occasional social interaction or community use.

- 75% – Strong design integration promoting social cohesion (e.g., plazas, shaded seating areas, community gardens), with attention to inclusivity and well-being.
- 100% – Comprehensive and inclusive approach to urban design and social cohesion, combining aesthetics, functionality, and public programming to create active, accessible, and inviting public spaces co-designed with the community.

S.3.1.4 – Educational opportunities

Evaluates whether the project incorporates educational or outreach initiatives to inform, engage, and empower the public on topics related to transportation, sustainability, or environmental awareness.

- 0% – No educational or outreach activities included in the project.
- 25% – Basic outreach efforts (e.g., informational materials or announcements) with limited structure and low community impact.
- 50% – A moderately structured program addressing at least one key topic (e.g., transportation awareness, sustainable travel behavior, environmental stewardship), with some public engagement.
- 75% – A well-developed educational or outreach initiative with strong community involvement, such as workshops, campaigns, or school programs tailored to local needs.
- 100% – A comprehensive and inclusive educational or outreach program fully embedded in the project, combining multiple formats (e.g., events, learning materials, participatory activities) to actively engage the public and promote long-term awareness of sustainability and transportation issues.

S.3.2 – Community Safety and Risk Reduction

S.3.2.1 – Accident rate reduction

Evaluates the project's ambition and strategy to reduce crash rates through engineering, education, or enforcement interventions.

- 0% – No specific accident reduction goal or related safety strategies.
- 25% – Basic safety measures with limited scope; expected accident reduction <10%.
- 50% – Moderate safety strategies expected to reduce accident rates by 10%–20%.
- 75% – Strong and targeted interventions expected to yield a 21%–29% reduction in accident rates.
- 100% – Comprehensive and multi-faceted safety measures in place, with a realistic and evidence-based goal of at least a 30% reduction in accident rates.

S.3.2.2 – Risk of accidents per output unit

Assesses whether the project includes a formal safety risk assessment and uses it to guide the design and implementation of risk-reducing measures.

- 0% – No risk assessment conducted and no mitigation strategies in place.
- 25% – Basic or informal risk assessment with minimal mitigation planning.
- 50% – Moderate risk assessment process with some targeted interventions to address identified hazards.
- 75% – Thorough risk assessment with clearly defined and well-prioritized mitigation strategies integrated into the project design.
- 100% – Comprehensive, data-informed risk assessment and mitigation strategy fully embedded in the planning and design process, addressing all major safety risks along the corridor or site.

S.3.2.3 – Safety-related expenses

Evaluates the degree to which the project prioritizes safety through dedicated funding.

- 0% – No budget allocated specifically for safety enhancements.
- 25% – Minimal budget allocated, covering only basic or regulatory-required measures.
- 50% – Moderate budget allocation enabling implementation of some key safety features.
- 75% – Strong financial commitment covering a broad range of safety interventions.
- 100% – Dedicated and sufficient budget fully ensures the implementation of a comprehensive safety plan, including pedestrian, cyclist, and motorist protection elements.

S.3.2.4 – Immediate impact on road safety

Measures whether the project incorporates quick-impact, high-visibility safety features that enhance safety from the outset.

- 0% – No immediate or visible safety measures implemented.
- 25% – One safety measure (e.g., lighting, signage, calming) included in the design.
- 50% – Two immediate safety measures included.
- 75% – Three safety measures included but with limited coverage or effectiveness.
- 100% – At least three well-placed and fully implemented immediate safety measures (e.g., traffic calming, improved lighting, signage), ensuring a demonstrable improvement in road user safety.

S.4 – Societal Well-being

S.4.1 – Societal Well-being and Equity for Vulnerable Groups

S.4.1.1 – Equitable environmental quality for vulnerable groups

Evaluates whether the project addresses environmental disparities affecting low-income or historically marginalized communities.

- 0% – No actions to address environmental inequities.
- 25% – Basic consideration of disadvantaged areas, with limited action or implementation.
- 50% – Moderate efforts improving environmental conditions in affected communities.
- 75% – Strong targeted interventions resulting in noticeable environmental improvements for marginalized groups.
- 100% – Comprehensive and equitable environmental strategy ensuring improved quality for all communities, particularly the most vulnerable.

S.4.1.2 – Economic development enhancement

Measures the project's role in stimulating local commerce and economic growth, particularly for small businesses and underserved areas.

- 0% – No initiatives to support local economic activity.
- 25% – Limited actions with minimal impact on commerce or connectivity.
- 50% – Moderate initiatives that facilitate business activity or improve access to commercial areas.
- 75% – Strong strategies supporting business development and economic opportunity in the project area.
- 100% – Comprehensive interventions (e.g., access improvements, commercial zoning, small business programs) with clear, positive impact on local economies.

S.4.1.3 – Reduction of pollution impacts on vulnerable groups

Evaluates targeted efforts to protect at-risk populations (e.g., children, the elderly, low-income residents) from pollution-related harm.

- 0% – No pollution mitigation measures included.
- 25% – General mitigation measures, not focused on vulnerable groups.
- 50% – Moderate strategies aimed at reducing exposure in sensitive areas (e.g., schools, hospitals).
- 75% – Strong, location-specific actions protecting vulnerable populations from emissions or noise.

- 100% – Comprehensive and well-monitored mitigation plan ensuring long-term protection of vulnerable groups from pollution exposure.

S.4.1.4 – Enhancement of physical and social mobility for all

Assesses whether the project enhances mobility for diverse user groups, including people with disabilities, older adults, and other underserved populations.

- 0% – No improvements in mobility or accessibility.
- 25% – Basic features benefiting a limited group (e.g., curb ramps only).
- 50% – Moderate improvements across multiple groups (e.g., tactile paving, audible signals, wider sidewalks).
- 75% – Design enabling safe and comfortable access for a broad range of users.
- 100% – Fully integrated universal accessibility approach, ensuring barrier-free mobility for all population groups across the project area.

S.5 – Cultural and Heritage Integration

S.5.1 – Cultural Preservation and Integration with Local Character

S.5.1.1 – Protection of archaeological and historical sites

Evaluates whether the project includes specific strategies to protect, conserve, or enhance historical or archaeological assets in or near the project area.

- 0% – No consideration or plan to protect historical or archaeological sites.
- 25% – Basic protective measures (e.g., avoidance zones) with limited scope or enforcement.
- 50% – Moderate plan ensuring partial preservation or enhancement of relevant sites.
- 75% – Strong and proactive measures integrated into the project to protect and enhance historical/archaeological value.
- 100% – Comprehensive and site-sensitive plan in place, with clear implementation, monitoring, and enhancement strategies for full protection of cultural heritage sites.

S.5.1.2 – Enhancement of local identity and global reputation

Assesses how well the project reflects and promotes local cultural identity through design and branding, contributing to place recognition at both local and broader scales.

- 0% – No consideration of local cultural identity or branding in project design.
- 25% – Minimal or symbolic inclusion of local elements in design.
- 50% – Moderate integration of local themes or branding strategies that reflect the project's cultural setting.

- 75% – Strong and intentional incorporation of local identity through design, signage, materials, and branding efforts with regional visibility.
- 100% – Comprehensive strategy integrating local cultural identity and branding, elevating the project's recognition and sense of place at local, national, or international scales.

S.5.1.3 – Design integration with local character

Evaluates the project's consistency with local design traditions, materials, and aesthetics that reflect architectural or cultural heritage.

- 0% – No alignment with local architectural or cultural styles.
- 25% – Basic consideration of cultural or architectural cues in selected design elements.
- 50% – Moderate integration of local architectural characteristics (e.g., façade treatment, materials, spatial organization).
- 75% – Strong design alignment with local traditions and cultural context, creating visual and functional continuity.
- 100% – Full and thoughtful integration of architectural and cultural heritage in design, resulting in a project that authentically reflects local character.

S.5.1.4 – Expertise in managing cultural heritage

Assesses the involvement of qualified cultural heritage experts throughout the project lifecycle to ensure that cultural values are preserved and appropriately integrated.

- 0% – No cultural heritage expertise consulted during the project.
- 25% – Limited or one-time consultation with cultural specialists.
- 50% – Moderate involvement of specialists during project planning or assessment phases.
- 75% – Strong involvement of cultural experts in planning and implementation.
- 100% – Continuous and integrated participation of cultural heritage specialists in all project phases, from planning to execution and monitoring.

S.6 – Socioeconomic Repercussions

S.6.1 – Compensation and Relocation Practices that Preserve Dignity

S.6.1.1 – Fair compensation strategies

Evaluates the level and quality of compensation provided to displaced individuals, including whether it goes beyond market value to support recovery and resettlement.

- 0% – No compensation provided to displaced individuals.
- 25% – Compensation provided is below market value.
- 50% – Compensation matches current market value for lost assets or land.

- 75% – Compensation exceeds market value and includes additional support (e.g., moving costs, advisory services).
- 100% – Compensation exceeds market value and includes comprehensive relocation assistance, livelihood restoration, and post-relocation support.

S.6.1.2 – Dignity preservation during displacement
Assesses whether displaced individuals are resettled in a manner that preserves their dignity, strengthens social cohesion, and promotes long-term well-being.

- 0% – No resettlement plan or dignity preservation efforts in place.
- 25% – Basic relocation logistics provided, with minimal social or community integration support.
- 50% – Moderate resettlement efforts with some support for dignified transition and community ties.
- 75% – Strong measures ensuring social and cultural integration, access to services, and preservation of community identity.
- 100% – Comprehensive and participatory resettlement plan ensuring dignity, social inclusion, housing adequacy, and long-term stability of relocated individuals and communities.

S.6.1.3 – Management of land acquisition and involuntary resettlement
Evaluates the project's adherence to globally recognized resettlement principles and frameworks, such as those outlined by the World Bank, IFC, or UN-Habitat.

- 0% – No compliance with international resettlement policies or principles.
- 25% – Limited alignment with international best practices.
- 50% – Partial compliance with key international standards or guidance.
- 75% – Strong alignment with most principles of internationally recognized resettlement policies (e.g., FPIC, livelihood restoration).
- 100% – Full compliance with all applicable international resettlement standards, including rights-based approaches, stakeholder engagement, and long-term monitoring.

S.6.2 – Socioeconomic Impacts of Projects
S.6.2.1 – Socioeconomic benefits at regional and national levels
Evaluates the extent to which the project is expected to generate positive and measurable economic outcomes at broader geographic scales.

- 0% – No measurable economic benefits expected.
- 25% – Limited and localized economic impacts with minimal broader relevance.

- 50% – Moderate economic benefits with evidence of some regional influence.
- 75% – Significant contributions to regional or national economic growth, supported by modeling or projections.
- 100% – Major long-term economic benefits at the regional and national level, including productivity gains, investment attraction, or value chain development.

S.6.2.2 – Promotion of social marketing opportunities

Assesses the presence and effectiveness of campaigns that encourage public adoption of sustainable travel choices (e.g., public transit, walking, cycling).

- 0% – No awareness or behavior change initiatives implemented.
- 25% – Basic or isolated outreach efforts with minimal public engagement.
- 50% – Moderate campaigns reaching a portion of the population with targeted messaging.
- 75% – Strong, well-designed campaigns with broad reach and high community participation.
- 100% – Comprehensive, multi-platform campaigns that are inclusive, sustained, and demonstrably influence travel behavior across a wide user base.

S.6.2.3 – Monitoring of project impacts on local economies

Evaluates whether the project has a system in place to track and assess its economic outcomes over time.

- 0% – No mechanisms to monitor economic impact.
- 25% – Basic tracking with limited or one-time data collection.
- 50% – Moderate monitoring system covering key indicators and periodic assessments.
- 75% – Strong monitoring framework with structured reporting and stakeholder feedback.
- 100% – Comprehensive and long-term economic monitoring plan using robust indicators, time-series data, and impact evaluations.

S.6.2.4 – Transport cost analysis for cars and freight

Assesses whether the project conducts a thorough cost analysis of different transport modes to inform planning, equity, and efficiency.

- 0% – No transport cost analysis performed.
- 25% – Basic or high-level cost estimates with limited detail or comparison.
- 50% – Moderate analysis covering key modes (e.g., car, bus, freight), with some disaggregation.

- 75% – Detailed mode-based cost analysis providing comparative insights for users and planners.
- 100% – Comprehensive transport cost analysis with disaggregated data, sensitivity analysis, and actionable policy or design recommendations.

S.6.2.5 – Tourism enhancement strategies

Evaluates whether the project includes elements designed to improve accessibility, infrastructure, or services that support tourism growth.

- 0% – No initiatives to enhance tourism.
- 25% – Limited improvements near tourist areas with minimal effect.
- 50% – Moderate efforts to improve access or services for tourism (e.g., signage, road conditions, wayfinding).
- 75% – Strong initiatives with targeted investments in tourism infrastructure or accessibility.
- 100% – Comprehensive tourism strategy integrated into the project, with demonstrated or expected impact on visitor experience and regional attractiveness.

S.7 – Governance and Human Rights

S.7.1 – Governance Compliance and Transparent Decision-Making

S.7.1.1 – Adherence to anti-discrimination norms

Evaluates the project's adherence to national and international frameworks that prohibit discrimination in hiring, participation, and service delivery.

- 0% – No compliance with anti-discrimination regulations; discriminatory practices may be present.
- 25% – Limited or superficial adherence to national or international standards.
- 50% – Partial compliance with key anti-discrimination policies, with some safeguards in place.
- 75% – Strong compliance with most national and international standards, including clear procedures and reporting mechanisms.
- 100% – Full compliance with all applicable anti-discrimination regulations, backed by active enforcement, inclusive practices, and grievance redress mechanisms.

S.7.1.2 – Compliance with governmental rules and regulations

Assesses the project’s overall alignment with applicable legal frameworks, including environmental, labor, safety, and land-use regulations.

- 0% – No evidence of legal or regulatory compliance.

- 25% – Partial compliance with major gaps or unresolved legal issues.
- 50% – Moderate compliance with key requirements across relevant domains.
- 75% – Strong adherence to most legal and regulatory standards, with routine documentation and oversight.
- 100% – Full and demonstrable compliance with all relevant regulations, including permits, audits, and review procedures.

S.7.1.3 – Transparency in contractor selection

Evaluates whether the project employs fair and transparent procedures for selecting contractors, suppliers, and consultants.

- 0% – No transparency or fairness in contractor selection; process is undocumented or opaque.
- 25% – Limited transparency; selection influenced by unclear criteria or potential conflicts of interest.
- 50% – Moderate transparency; selection based on defined criteria but with limited accountability.
- 75% – Strong transparency supported by public documentation, stakeholder involvement, and conflict-of-interest safeguards.
- 100% – Fully transparent, accountable, and fair procurement process, with independent oversight, audit trails, and public disclosure of selection outcomes.

S.7.1.4 – Allocation of adequate resources for long-term social sustainability

Evaluates whether the project includes financial mechanisms or institutional plans to sustain social sustainability components beyond the construction or implementation phase.

- 0% – No funding or mechanisms for sustaining social sustainability initiatives.
- 25% – Short-term or temporary funding with no provisions for continuity.
- 50% – Moderate support mechanisms for limited sustainability elements, but without long-term commitment.
- 75% – Strong strategies in place to fund or institutionalize social sustainability efforts beyond the project timeline.
- 100% – Long-term, secured funding or institutional mechanisms (e.g., trust funds, local government partnerships) ensuring durable impact and continuity of social sustainability measures.

D.3 Economic Sustainability Evaluation Criteria

EC.1 – Investment Return Metrics

EC.1.1 – Net Present Value (NPV)

EC.1.1.1 – Net Present Value (NPV) Performance

This criterion evaluates whether the project delivers a positive economic return, as measured by Net Present Value — the difference between the present value of benefits and the present value of costs.

- 0% – NPV is negative; the project's total discounted costs exceed its discounted benefits. Or, no NPV analysis is carry out.
- 25% – NPV is near zero or slightly negative; project is close to breakeven.
- 50% – NPV is positive but modest, representing less than 10% of total project costs.
- 75% – NPV is significantly positive, equivalent to 10%–50% of total project costs.
- 100% – NPV is highly positive, exceeding 50% of total project costs, indicating strong economic performance.

EC.1.2 – Internal Rate of Return (IRR)

EC.1.2.1 – Internal Rate of Return (IRR) Performance

This criterion evaluates whether the project's internal rate of return exceeds the discount rate used in the economic analysis — indicating the project's capacity to generate returns above the opportunity cost of capital.

- 0% – IRR is lower than the discount rate; project is not economically viable.
- 25% – IRR is equal to or only marginally above the discount rate (0–1% higher); viability is uncertain or marginal.
- 50% – IRR is 1%–2% higher than the discount rate; project shows modest economic desirability.
- 75% – IRR is 3%–5% above the discount rate; project demonstrates strong economic performance.
- 100% – IRR exceeds the discount rate by more than 5%, indicating very high economic returns relative to cost of capital.

EC.1.3 – Payback Period

EC.1.3.1 – Payback Period Performance

This criterion evaluates the length of time required for the project's cumulative benefits to recover its initial investment costs. A shorter payback period indicates faster economic returns and lower investment risk.

- 0% – Payback period exceeds 30 years; economic return is delayed or uncertain.

- 25% – Payback period is between 21–30 years; benefits accrue slowly.
- 50% – Payback period is between 16–20 years, moderate return timeframe.
- 75% – Payback period is between 11–15 years; economically efficient.
- 100% – Payback period is 10 years or less; rapid return on investment.

EC.2 – Cost Management

EC.2.1 – Overall Project Costs

EC.2.1.1 – Operation Costs

This criterion evaluates whether the project includes a structured approach to identifying, managing, and reducing long-term operational and maintenance costs, contributing to the project's financial sustainability.

- 0% – No strategies or considerations in place to manage or reduce long-term operational costs.
- 25% – Basic cost-minimization measures considered (e.g., low-maintenance materials) but with limited coverage or planning depth.
- 50% – Moderate operational cost mitigation strategy addressing key cost drivers (e.g., energy use, maintenance frequency) with some supporting actions.
- 75% – Strong and well-documented cost-reduction strategy with defined measures, such as energy-efficient systems, durable infrastructure materials, or maintenance optimization.
- 100% – Comprehensive, life-cycle-based cost minimization plan in place, integrated into design and implementation, ensuring long-term financial sustainability and reduced operational burden.

EC.2.1.2 – Investment Cost

This criterion evaluates how effectively the project manages capital expenditures through proactive budget control and risk mitigation strategies.

- 0% – Project experienced major cost overruns (>20%) with no mitigation or cost control mechanisms.
- 25% – Basic budget tracking in place, but cost overruns (>10%) occurred and mitigation was limited.
- 50% – Moderate cost control measures implemented; minor overruns occurred (5%–10%) due to manageable risks.
- 75% – Strong budget management with defined cost-control procedures and active risk mitigation; project remained within ~5% of budget.
- 100% – Project remained fully within planned budget, supported by robust risk identification, contingency planning, and cost control throughout the project lifecycle.

EC.2.1.3 – Unit Cost of Construction, Maintenance, Rehabilitation, and Reconstruction
This criterion evaluates whether the project incorporates cost-efficient design principles and life-cycle cost analysis to optimize capital and future expenditures for construction, maintenance, rehabilitation, and reconstruction.

- 0% – No consideration of cost-efficiency or life-cycle costs in design or planning.
- 25% – Basic cost-saving ideas mentioned (e.g., material choice), but not systematically applied or analyzed.
- 50% – Moderate integration of cost-efficiency measures and some use of life-cycle considerations (e.g., maintenance intervals, durable materials).
- 75% – Strong application of cost-efficient design strategies, supported by a structured life-cycle cost analysis for key components (e.g., pavement, bridges).
- 100% – Comprehensive optimization strategy that integrates cost-efficient design and full life-cycle cost analysis to minimize total costs across construction, maintenance, and reconstruction phases.

EC.2.1.4 – Installation Costs
This criterion evaluates the extent to which the project minimizes short-term installation and deployment costs (e.g., labor, assembly, on-site setup), while ensuring durable and high-performing infrastructure components.

- 0% – No strategies to reduce installation costs; inefficient or ad-hoc deployment methods used.
- 25% – Basic cost-saving practices (e.g., bundled procurement, local labor use) applied, but with limited cost or quality impact.
- 50% – Moderate installation cost reductions achieved through standardization, prefabrication, or scheduling optimization, without compromising performance.
- 75% – Significant cost savings achieved via integrated planning, efficient contracting, or rapid deployment techniques, with verified performance quality.
- 100% – Installation phase fully optimized using best practices (e.g., modular construction, lean techniques, smart logistics), achieving both minimized costs and superior installation quality/performance.

EC.2.1.5 – Disposal Costs
This criterion evaluates whether the project includes strategies to responsibly manage end-of-life materials (during construction or future decommissioning), focusing on reducing waste generation and minimizing long-term disposal costs.

- 0% – No disposal or end-of-life material management strategies included.
- 25% – Basic disposal practices followed, minimal sustainability or cost consideration.
- 50% – Moderate measures for reuse, recycling, or sustainable disposal of some materials.
- 75% – Strong disposal strategy in place, emphasizing material separation, on-site reuse, or low-impact disposal methods.
- 100% – Comprehensive waste management plan targeting near-zero waste through reuse, recycling, circular economy principles, and cost-effective disposal across the project lifecycle.

EC.2.1.6 – Maintenance Costs

This criterion evaluates whether the project includes a structured and cost-conscious long-term maintenance plan to ensure infrastructure performance, durability, and sustainability.

- 0% – No maintenance planning or cost projections in place.
- 25% – Basic consideration of maintenance needs, with no strategies to control long-term costs.
- 50% – Moderate maintenance plan that includes schedules, material choice, and some cost-saving features (e.g., longer-wear surfaces).
- 75% – Strong and proactive maintenance strategy integrated into project design, with clear cost estimates, condition monitoring, or preventive maintenance.
- 100% – Comprehensive life-cycle maintenance strategy that balances long-term cost efficiency, performance, and sustainability goals (e.g., predictive maintenance, asset management tools, climate-resilient materials).

APPENDIX E. Details of MCDA Analysis

This appendix presents the detailed analytical framework used for the Multi-Criteria Decision Analysis (MCDA) undertaken in this study. It outlines the weighting, normalization, and amalgamation techniques applied to evaluate sustainability indicators, ensuring a transparent and replicable assessment process. By documenting each methodological component, this appendix supports clarity in interpretation and strengthens the validity of the decision-making outcomes derived from the MCDA.

E.1 Weighting Methods

E.1.1 Equal Weighting

The equal weighting approach assigns the same weight to all decision criteria, meaning each criterion is considered equally important in the evaluation process. This method is simple, intuitive, and requires no subjective judgments from decision-makers, making it an attractive option for data-driven decision environments where preferences are uncertain or undefined (Sinha et al., 2009). Equal weighting is particularly useful when there is insufficient information to justify assigning different levels of importance to various criteria. For example, in early-stage infrastructure assessments, decision-makers may lack sufficient data to determine whether environmental impact should be weighted more heavily than economic feasibility, leading them to apply equal importance to all indicators.

However, the main drawback of equal weighting is that it fails to capture the true importance of criteria, potentially leading to suboptimal decisions. In sustainability assessments, environmental, social, and economic indicators often have varying degrees of significance depending on stakeholder priorities, project location, and funding policies (Li, 2003). For example, in road infrastructure projects, construction cost and carbon emissions may not carry the same level of importance for decision-makers, yet equal weighting treats them as equivalent. While easy to implement, this method should be used cautiously, particularly when some criteria are demonstrably more important than others in achieving sustainability objectives (Sinha & Labi, 2007).

E.1.2 Direct Weighting

Direct weighting methods allow decision-makers to explicitly assign weights to criteria based on their perceived importance. This approach is more flexible than equal weighting and can be applied using several techniques, including point allocation, categorization, and ranking (Odu, 2019; Patidar, Labi, Sinha, & Thompson, 2007).

Point Allocation: Decision-makers distribute a fixed number of points among criteria according to their relative importance. For example, if given 100 points, they might allocate 40 points to environmental impact, 30 to economic feasibility, and 30 to social factors, reflecting perceived priorities . This technique provides a quantifiable representation of preferences and enables simple mathematical operations, such as normalization and aggregation.

Categorization: Criteria are grouped into predefined categories (e.g., "high," "medium," and "low" importance), with assigned numerical values. This method is useful when decision-makers are uncomfortable with assigning precise numbers but can differentiate importance levels qualitatively (Patidar, Labi, Sinha, & Thompson, 2007).

Ranking: Decision-makers arrange criteria in descending order of importance. For instance, carbon footprint may be ranked as the most important, followed by construction cost, safety, and accessibility (Keeney & Raiffa, 1993). Although ranking provides a clear hierarchy, it does not indicate the magnitude of differences between criteria (e.g., whether the most important criterion is twice or three times as important as the next).

A key advantage of direct weighting is its ease of implementation, as decision-makers can assign values quickly and intuitively. However, a notable limitation is that respondents may struggle to express precise numerical judgments, leading to inconsistencies and potential bias (Fischer, 1995). Additionally, in cases where a large number of criteria are involved, direct weighting can become cognitively demanding, making it less effective for complex decision problems.

E.1.3 Regression-Based Weighting

Observer-derived weighting methods estimate implicit criteria weights based on how decision-makers rate or rank alternatives rather than requiring them to assign weights explicitly. This method is particularly useful in situations where decision-makers may not be able to articulate their preferences numerically but can provide judgments on different alternatives (B. Hobbs & Meier, 2000; Patidar, Labi, Sinha, & Thompson, 2007). In this approach, decision-makers are asked to:

1) Assign values or scores to each criterion based on perceived benefits.
2) Rate a set of alternatives on a scale (e.g., 0 to 100).
3) Use statistical regression analysis to determine the weights that best explain the provided ratings.

This method is advantageous because it reduces subjective biases by using empirical data to derive weights. However, it requires large datasets and advanced statistical modeling, which may not be feasible in every decision-making scenario. Additionally, since decision-makers often focus on a few key attributes while ignoring others, regression-based weights may overemphasize certain factors, leading to biased assessments (Hobbs & Meier, 2000).

E.1.4 Gamble Weighting

Gamble weighting is a risk-based weighting technique where decision-makers compare a "sure thing" (guaranteed best outcome for one criterion) against a "gamble" (potential for all criteria to achieve their best or worst outcomes) (Li, 2003; Sinha et al., 2009). The key steps involve:

1) Ranking criteria in order of importance (least to most).
2) Presenting a hypothetical choice between:
    - A "Sure Thing," where one criterion is optimized while others remain at their worst levels.
    - A "Gamble," where all criteria have a probability p% of achieving their best outcomes and (1−p)% of achieving their worst.
3) Increasing p incrementally until the respondent prefers the gamble over the sure thing. The value of p becomes the assigned weight.

This method is particularly useful for decisions involving high uncertainty, as it captures risk preferences effectively. However, it is also cognitively complex, requiring respondents to process hypothetical risk scenarios. It may not be suitable when outcome probabilities are unknown or when criteria have uncertain worst/best values (Sinha et al., 2009).

E.1.5 Pairwise Comparison: AHP and BWM

Pairwise comparison-based methods, such as the Analytic Hierarchy Process (AHP) and the Best-Worst Method (BWM), are broadly used in Multicriteria Decision Analysis (MCDA) because they allow systematic and structured weighting of multiple decision criteria. These methods help decision-makers quantify their preferences by making comparisons between pairs of criteria, ensuring that the relative importance of each criterion is clearly established (Rezaei, 2015; Saaty, 1977). While AHP provides a comprehensive and widely accepted methodology, BWM was developed as an improved version of AHP that reduces the number of required comparisons while increasing consistency in weight estimation.

The Analytic Hierarchy Process (AHP), developed by (Saaty, 1988), is one of the most commonly used methods for deriving criteria weights in MCDA. It structures complex decision-making problems into a hierarchical framework, allowing for a systematic comparison of alternatives based on decision-maker preferences. AHP is particularly useful for infrastructure sustainability assessments, where criteria may involve both quantitative and qualitative dimensions (Bukhsh et al., 2017; Patidar et al., 2007; Torres-Machi et al., 2019). AHP is widely used because it allows decision-makers to handle both tangible and intangible criteria, making it useful for complex sustainability evaluations (Patidar, Labi, Sinha, Thompson, et al., 2007). However, one major limitation is that the number of comparisons grows exponentially as more criteria are introduced. If n criteria are considered, the number of required comparisons is n*(n-1)/2, which can become cognitively overwhelming for decision-makers when dealing with a large number of criteria (Sinha & Labi, 2007). Additionally, the reliance on subjective pairwise judgments introduces the risk of inconsistencies, which must be checked using the Consistency Ratio. The consistency ratio is used in MCDA techniques such as AHP, where pairwise comparison methods are employed. The primary function of the Consistency Ratio is to check for inconsistency in the weights assigned to decision criteria. When decision-makers use AHP, they make subjective pairwise judgments to determine the relative importance of criteria. The role of the consistency ratio is to mathematically verify whether these subjective judgments are consistent

The Best-Worst Method (BWM), developed by (Rezaei, 2015) addresses some of AHP's limitations by reducing the number of required comparisons and improving consistency in weight estimation. While still a pairwise comparison-based method, BWM simplifies the process by requiring decision-makers to only compare the most and least important criteria against all others, instead of conducting all possible pairwise comparisons (Xiaomei et al., 2019). BWM significantly reduces the number of required comparisons, as decision-makers only evaluate the Best and Worst criteria rather than comparing every pair of criteria (Rezaei, 2015). This makes it more efficient while still producing consistent and reliable weights. Studies have shown that BWM improves judgment consistency by eliminating redundant comparisons, leading to higher accuracy in weight assignments (Xiaomei et al., 2019).

However, one potential limitation is that BWM assumes decision-makers can reliably identify the most and least important criteria, which may not always be straightforward in complex decision problems. Additionally, while it reduces comparisons, BWM still relies on subjective input, meaning that biases can influence the weighting process.

E.1.6 Delphi Method

The Delphi Method is a structured expert consultation technique used in MCDA to derive consensus-based weights for decision criteria. Originally developed by Dalkey & Helmer (1963), the Delphi method is particularly valuable when empirical data are limited or unavailable, and when decision-makers seek to integrate diverse expert perspectives to establish robust weight assignments (Sinha & Labi, 2007). Unlike mathematical approaches such as AHP and BWM, which rely on numerical pairwise comparisons, the Delphi method is based on an iterative process of expert judgment, where a panel of professionals provides feedback on sustainability criteria weights over multiple rounds until a convergence of opinions is achieved (Cavalli-Sforza & Ortolano, 1984). By ensuring anonymity among participants, the Delphi method eliminates group pressure and dominance effects, fostering an environment where experts can express their views objectively and independently (Sourani & Sohail, 2015).

The Delphi process consists of several sequential rounds of expert feedback, beginning with the distribution of structured questionnaires where participants assign initial weights to the decision criteria under evaluation. After each round, responses are aggregated and analyzed, and statistical summaries (such as the mean, standard deviation, and interquartile range) are shared anonymously with the panel (Dalkey & Helmer, 1963). Experts then review their previous responses in light of the aggregated feedback, adjusting their weight assignments in subsequent rounds to reflect a more informed consensus. This iterative process continues until a stable agreement is reached, where the variation in responses becomes negligible across rounds (de la Cruz et al., 2008). The advantage of this structured feedback mechanism is that it allows experts to refine their judgments progressively, ensuring that weight assignments reflect broadly accepted and well-justified decision priorities (Sinha & Labi, 2007).

One of the main advantages of the Delphi method is its ability to integrate the knowledge of multiple stakeholders, ensuring that the weighting process accounts for diverse perspectives in infrastructure sustainability assessments. Additionally, since it is not constrained by mathematical consistency checks, the Delphi approach offers greater flexibility when applied to decision-making contexts involving qualitative or emerging sustainability criteria (Mullen, 2003). However, the method also has notable limitations. The iterative nature of Delphi can be time-consuming, particularly when multiple rounds are required to reach agreement, making it less efficient than pairwise comparison-based methods like AHP or BWM (Sinha & Labi, 2007). Furthermore, the reliability of results depends on expert participation and retention across rounds—if key experts drop out mid-process, the study may suffer from reduced validity and potential bias. Additionally, since the Delphi method relies solely on subjective expert judgment, it does not include a mathematical verification process to assess the consistency of weight assignments, which may lead to conservative or overly cautious estimates (Bendaña et al., 2008).

Despite these limitations, the Delphi method remains a powerful tool for weighting sustainability criteria in MCDA, particularly in infrastructure planning and policy evaluations where expert knowledge is crucial for decision-making. When combined with other MCDA techniques, such as AHP for pairwise comparisons or BWM for consistency optimization, Delphi can serve as a valuable preliminary step in establishing well-grounded weight assignments before applying mathematical modeling techniques (Rezaei, 2015). Its ability to capture expert consensus while reducing bias and group influence makes it an essential tool in sustainability assessment frameworks, particularly for complex and multi-stakeholder decision-making processes.

E.2 Normalization Methods

E.2.1 Direct Rating

The Direct Rating Method is a simple and intuitive approach where decision-makers directly assign a normalized utility value to each level of a decision criterion (B. Hobbs & Meier, 2000; Sinha & Labi, 2007). This method is particularly useful when dealing with criteria that have a small number of discrete levels, such as qualitative assessments of sustainability performance. Typically, decision-makers assign values between 0 and 100 based on their subjective judgment, which are then rescaled into a [0,1] range for consistency. Although this method is easy to implement, it relies heavily on expert judgment, which may introduce subjectivity and reduce comparability across different cases.

E.2.2 Mid-Value Splitting

Mid-Value Splitting is an advanced normalization technique that seeks to capture decision-maker preferences more systematically by dividing a criterion's value range into intervals that represent equal levels of satisfaction (Keeney & Raiffa, 1993; Sinha & Labi, 2007). The method involves a stepwise approach:

1) Define upper and lower bounds for a criterion, where v(X_L) = 0 and v(X_U) = 100.
2) Identify the value X_{50}, which represents the point at which an improvement from X_L to X_{50} is equally desirable as an improvement from X_{50} to X_U.
3) Repeat the process for X_{25} and X_{75} to refine the value function.
4) Conduct a consistency check to verify that the assigned values properly reflect the respondent's preference structure.

This method is particularly useful when decision-makers have strong preferences for certain performance thresholds, as it incorporates subjective indifference points into the normalization process. However, it requires careful respondent engagement, making it more time-consuming than basic linear scaling methods.

E.2.3 Vector Normalization

Vector Normalization, also known as Euclidean Normalization, converts raw criteria values into unit-free scores by dividing each value by its norm (Nijkamp, 1977). This technique preserves the proportional differences between values, ensuring that criteria with large numerical ranges do not dominate the decision-making process. However, a major drawback is that maximum and minimum values are not stable across time or location, making comparisons across different decision-making scenarios more challenging (Hwang & Yoon, 1981).

E.2.4 Linear Scale Transformation

One of the most widely used normalization techniques, Linear Scale Transformation (Max-Min Method), adjusts values based on the minimum and maximum observed values in the dataset (Hwang & Yoon, 1981). The normalized score for a benefit criterion is calculated as:

$$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \tag{1}$$

For cost criteria, the transformation is reversed:

$$r_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \tag{2}$$

This method ensures that all values fall within [0,1], making it easy to interpret and computationally simple. However, it is highly sensitive to outliers, as extreme values can distort the normalized scores and introduce bias in decision-making (Talukder et al., 2017).

E.2.5 Logarithmic Normalization

Logarithmic normalization is particularly useful when criteria values differ significantly in magnitude, such as in cases where sustainability indicators range from small percentages to large absolute values (Zavadskas & Turskis, 2008). The logarithmic normalization for a benefit criterion is given by:

$$r_{ij} = \frac{\ln(x_{ij})}{\ln(\prod_{i=1}^{n} x_{ij})} \tag{3}$$

For cost criteria, the transformation is:

$$r_{ij} = 1 - \frac{\ln(x_{ij})}{\ln(\prod_{i=1}^{n} x_{ij})} \tag{4}$$

This method reduces the impact of extreme values but may produce infinite or undefined values when handling zeroes or negative numbers (Vafaei et al., 2018).

E.3 Amalgamation Methods

E.3.1 Weighted Sum Method

The Weighted Sum Method (WSM) is one of the simplest and most widely used amalgamation techniques in MCDA. It calculates an overall performance score for each alternative by summing the weighted and normalized values of all decision criteria (Hazelrigg, 2019; Li, 2003). The formula for WSM is as follows:

$$V_i = \sum_{j=1}^{n} w_j * r_{ij} \quad (5)$$

where:

- w_j is the weight of criterion j,
- r_{ij} is the normalized value of alternative i for criterion j,
- V_i is the final performance score for alternative i.

The alternative with the highest V_i value is considered the most preferred. WSM is straightforward to implement and provides easily interpretable results, making it a popular choice for sustainability assessments in infrastructure projects. However, its simplicity comes with limitations. WSM assumes linear relationships between criteria, meaning that a small improvement in one criterion is always equivalent to the same small improvement in another, regardless of their nature. This assumption may not hold in complex sustainability assessments, where trade-offs between environmental, economic, and social factors require nonlinear evaluation techniques (Hazelrigg, 2019). Additionally, WSM does not consider interactions between criteria, potentially oversimplifying the decision-making process in cases where criteria are interdependent.

E.3.2 TOPSIS

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a method based on the concept that an ideal solution exists and that the best alternative is the one closest to the ideal solution while being farthest from the least ideal solution (Hwang & Yoon, 1981). The methodology consists of the following steps:

1) Determine the Ideal and Negative-Ideal Solutions:

- The ideal solution consists of the best values for each criterion (highest values for benefit criteria and lowest for cost criteria).
- The negative-ideal solution consists of the worst values for each criterion (lowest values for benefit criteria and highest for cost criteria).

2) Calculate the Distance of Each Alternative from the Ideal and Negative-Ideal Solutions:

- The distance of each alternative from the ideal solution is calculated using the Euclidean distance formula:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(r_{ij} - r_j^+\right)^2} \qquad (6)$$

- The distance from the negative-ideal solution is:

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(r_{ij} - r_j^-\right)^2} \qquad (7)$$

3) Compute the Relative Closeness to the Ideal Solution:

$$C_i = \frac{S_i^-}{S_i^2 + S_i^-} \qquad (8)$$

The alternative with the highest C_i value is considered the most preferable.

TOPSIS is particularly useful in decision-making scenarios where trade-offs between criteria are essential, such as sustainability assessments where decision-makers must balance environmental, economic, and social impacts (Papathanasiou & Ploskas, 2018). Unlike WSM, TOPSIS considers both the best and worst possible performance levels, making it a more balanced approach. However, one limitation of TOPSIS is that it does not explicitly account for correlations between criteria (Bai et al., 2008) which may lead to biased rankings when interdependencies exist among sustainability indicators.

E.3.3 VIKOR

The VIKOR method, developed by (Opricovic, 1998), is particularly useful for decision problems involving conflicting criteria, where decision-makers seek a compromise solution. Unlike TOPSIS, which focuses on distance to an ideal solution, VIKOR ranks alternatives based on their proximity to a compromise solution that balances multiple conflicting objectives. The key steps of VIKOR include:

1) Identify the Ideal and Negative-Ideal Solutions, similar to TOPSIS.
2) Calculate the Utility and Regret Measures:

- The utility measure S_i evaluates the overall performance of each alternative across all criteria:

$$S_i = \sum_{j=1}^{n} w_j (r_j^+ - r_{ij}) \tag{9}$$

- The individual regret measure R_i captures the worst performance of each alternative in any single criterion:

$$R_i = \max w_j (r_j^+ - r_{ij}) \tag{10}$$

3) Compute the VIKOR index Q_i:

$$Q_i = v\left(\frac{S_i - S^*}{S^- - S^*}\right) + (1 - v)\left(\frac{R_i - R^*}{R^- - R^*}\right) \tag{11}$$

Where v is a weight indicating the decision-maker's preference for compromise between utility and regret.

4) Rank the alternatives based on Q_i, where the lowest $Q_i$value represents the best alternative.

VIKOR is particularly useful when decision-makers are hesitant to assign strict weightings to certain criteria. However, its reliance on the compromise distance approach means that results may not always align with real-world stakeholder preferences, requiring further validation through expert consultation (Gul et al*.,* 2016).

E.3.4 PROMETHEE

The PROMETHEE method uses pairwise comparisons to determine a preference index for ranking alternatives (Brans & Vincke, 1985). Unlike WSM and TOPSIS, which rely on weighted summation and distance measures, PROMETHEE ranks alternatives based on outranking relationships: an alternative is considered superior if it dominates others across multiple criteria. The methodology involves:

1) Defining a Preference Function for each criterion, which assigns a preference value to pairwise comparisons of alternatives.
2) Computing the Outranking Flows, including:
- Leaving Flow ϕ^+: Measures how much an alternative dominates others.
- Entering Flow ϕ^-: Measures how much an alternative is dominated by others.
3) Ranking the Alternatives based on the net outranking flow $\phi = \phi^+ - \phi^-$.

PROMETHEE is effective in rank-ordering alternatives without requiring strong assumptions about decision-maker preferences. However, it requires careful selection of preference functions, which may introduce complexity in sustainability assessments (Pohl & Geldermann, 2024).

E.3.5 ELECTRE

The ELECTRE method, developed by Roy (1991), is a dominance-based approach where alternatives are evaluated based on their concordance and discordance relationships. It is particularly useful when decision-makers need to eliminate poor-performing alternatives rather than select a single best alternative.

1) Calculate the Concordance Index, which measures how much an alternative dominates another.
2) Calculate the Discordance Index, which identifies where an alternative performs significantly worse than another.
3) Construct an Outranking Matrix, where alternatives that fail dominance conditions are eliminated.

ELECTRE is well-suited for complex problems with many conflicting criteria but may be computationally demanding when handling large datasets.

E.3.6 MOORA

MOORA ranks alternatives using a ratio-based approach, where each alternative's score is calculated by comparing its benefit and cost attributes (Brauers & Zavadskas, 2006). This method is computationally efficient and particularly useful for sustainability assessments where decision-makers need a fast, reliable ranking of alternatives.

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About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at docs.lib.purdue.edu/jtrp/.

Further information about JTRP and its current research program is available at engineering.purdue.edu/JTRP.

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