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Sustainable Road Indicators and Assessment Models for Supporting Sustainable Urban Infrastructure: A Systematic Literature Review

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Abstrak

Sustainable road infrastructure is essential for supporting urban mobility, environmental quality, safety, resilience, and long-term economic performance. However, existing road sustainability assessment models often emphasize environmental, technological, and economic aspects while providing limited attention to governance and climate resilience. This study aimed to identify dominant sustainability dimensions, compare major road rating systems, and develop an integrated framework for sustainable urban road assessment. A quantitative systematic literature review was conducted using Scopus-indexed publications from 2000 to 2026, following the PRISMA 2020 guidelines. From 202 retrieved records, 188 unique records were screened, and 134 documents were included for performance analysis, dimension-based content analysis, and keyword co-occurrence mapping. The results showed that the environmental dimension was the most frequently addressed aspect (56.0%), followed by innovation and technology (45.5%) and economics (37.3%). In contrast, governance (7.5%) and climate and disaster resilience (6.7%) were the least represented dimensions. A comparison of the Greenroads, INVEST, and Envision rating systems also indicated limitations in adapting these frameworks to developing-country contexts. The study concludes that sustainable road assessment requires a more balanced and context-sensitive framework integrating environmental, technical, social, safety, economic, resilience, governance, and innovation dimensions. Such an approach can better support sustainable urban infrastructure development, particularly in Indonesia, and provide a foundation for future empirical validation in Indonesian cities.

INTRODUCTION

Roads are the arteries of a city. They transport people to workplaces, goods to markets, and public services to communities; therefore, the performance of a road network provides important insights into the sustainability of an urban system (Arts, Leendertse, & Tillema, 2021). Challenges such as pavement deterioration, increased emissions from road construction activities, and persistent gaps in safety, accessibility, and climate resilience highlight the limitations of conventional condition-based road assessment approaches. These challenges indicate the need for broader, low-carbon, and inclusive indicator frameworks. Sustainability-oriented road indicators and rating systems that integrate environmental, technical, social, economic, resilience, governance, and innovation dimensions have increasingly been promoted as strategic tools for improving road infrastructure performance and supporting sustainable urban development.

In this article, road sustainability indicators and assessment models are conceptualized as structured criteria, indices, or rating systems that support the planning, design, construction, operation, and evaluation of road infrastructure across multiple performance dimensions. The broader literature on road sustainability encompasses material science, transportation engineering, and urban planning. However, this review specifically focuses on indicators, frameworks, and rating systems that assess road sustainability as a multidimensional construct rather than the mechanical or rheological properties of individual construction materials. Accordingly, the term “road sustainability” refers to indicator-based and model-based assessments of roads and road networks unless otherwise specified.

Efforts to establish more comprehensive road sustainability assessment frameworks are not new. Greenroads was developed to provide a systematic metric for sustainable road design and construction (Muench & Anderson, 2011) and has subsequently been evaluated through practical applications to determine its influence on real-world infrastructure practices (Lew, Anderson, & Muench, 2016; Zokaei Ashtiani & Muench, 2024). INVEST adopts a broader perspective by covering the entire lifecycle of transportation systems, from planning to operation, whereas Envision applies a credit-based verification approach to civil infrastructure across various sectors. However, these frameworks were initially developed within the institutional context of the United States, requiring further evaluation regarding their applicability in different geographical and socioeconomic settings. This issue has been addressed through contextual adaptations, such as the development of green road rating systems in South Korea (Park & Ahn, 2015), livability indicators for green road assessment in Taiwan (Tran, Yang, Tsai, Yang, & Chang, 2021), and the selection of appropriate rating systems for Hungarian road construction using the TOPSIS method (Szpotowicz & Tóth, 2020). Similar developments have occurred in developing countries. Dhakal and Oh (2011) developed a sustainability indicator toolkit for Michigan roads, Dokyi, Tookey, Rotimi, and Osei (2024) proposed an indicator framework for sustainable roads and highways in Ghana, and Devkota, Shakya, and Sudmeier-Rieux (2019) developed an eco-safe assessment framework for rural roads in Nepal’s hill districts. Collectively, these studies demonstrate that road sustainability assessment frameworks cannot be transferred directly across contexts without considering local characteristics and infrastructure conditions.

Similar limitations have been identified globally. Suprayoga, Bakker, Witte, and Spit (2020) found that many road infrastructure sustainability assessment approaches failed to comprehensively incorporate all sustainability criteria, with long-term risk considerations and intergenerational equity remaining among the least represented aspects. From another perspective, Vijayakumar, Mahmood, Gurmu, Kamardeen, and Alam (2024) reported that existing road sustainability assessment models remain heavily focused on environmental and economic dimensions, while social considerations receive comparatively less attention, despite identifying nine dimensions and 48 social indicators from 93 reviewed articles. From the triple bottom line perspective, Del Rosario and Traverso (2023) reached a similar conclusion, emphasizing that studies integrating environmental, social, and economic dimensions simultaneously remain limited. Furthermore, many assessment models continue to rely on expert judgment and subjective weighting methods with limited empirical validation (Yang, Tran, Chang, Tsai, & Yueh, 2026). These limitations become increasingly significant when sustainability rating systems developed in advanced economies are applied to developing countries characterized by tropical climates, flood risks, motorcycle-dominated transportation systems, and limited data availability (Aghimien & Ngcobo, 2022).

The novelty of this research lies in synthesizing fragmented road sustainability literature into an integrated eight-dimensional conceptual framework consisting of environment (ENV), engineering and asset performance (TEC), social inclusiveness (SOC), safety (SAF), economics (ECO), climate and disaster resilience (RES), governance (GOV), and innovation and technology (INO). Rather than focusing solely on environmental impacts, pavement engineering, or project-level green construction practices, the proposed framework conceptualizes road sustainability as a multidimensional phenomenon associated with broader sustainable urban infrastructure outcomes. This approach is distinctive because it explicitly incorporates governance and climate resilience into the analytical framework, despite these dimensions being among the least represented in existing studies, accounting for only 7.5% and 6.7% of the reviewed literature, respectively. Furthermore, the study differs from direct adoption of international rating systems by treating established frameworks as comparative references rather than universally applicable solutions. The synthesis provides an empirical foundation for the conceptual relationship SR = f(ENV, TEC, SOC, SAF, ECO, RES, GOV, INO), through which sustainable road performance can be linked with urban mobility, accessibility, livability, and resilience outcomes. Thus, the novelty of this research is both conceptual and contextual: conceptually, it integrates dimensions frequently examined separately in previous studies; contextually, it establishes a foundation for developing assessment models suitable for Indonesian urban road conditions.

Based on this background, this study aims to systematically identify, classify, and synthesize indicators, dimensions, and assessment models used to evaluate road sustainability and determine their relevance for supporting sustainable urban infrastructure, particularly in developing and tropical urban contexts such as Indonesia. Specifically, this research seeks to identify dominant and underrepresented sustainability dimensions in existing literature, compare the scope and limitations of major road sustainability rating systems, map intellectual and thematic trends in road sustainability research, and develop an integrated conceptual basis for future indicator validation and empirical model development. The study contributes theoretically by consolidating fragmented road sustainability concepts into a multidimensional framework; methodologically by applying a protocol-driven systematic literature review and structured dimensional mapping approach; and practically by providing planners, transportation agencies, policymakers, engineers, and infrastructure managers with evidence-based guidance for selecting indicators that represent environmental, technical, social, safety, economic, resilience, governance, and innovation priorities. The findings are expected to provide a more balanced foundation for future sustainable road assessment by reducing excessive dependence on imported rating systems and supporting the validation of locally appropriate indicators through expert evaluation and empirical implementation. Ultimately, this research aims to support the development of road infrastructure that not only achieves technical performance but also contributes to safer mobility, environmental responsibility, social accessibility, institutional accountability, climate resilience, economic efficiency, and long-term urban sustainability.

METHOD

This study applied a quantitative, protocol-driven systematic literature review to publications from 2000 to 2026 addressing road sustainability indicators and assessment models. The review followed the PRISMA 2020 guidelines (Page et al., 2021) to ensure transparent reporting and adopted a two-part analytical structure commonly used in bibliometric-style reviews (Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021): performance analysis to describe the characteristics of the literature corpus through publication trends, countries, institutions, authors, and sources, and content analysis to examine the dimensional structure of the research field. Unlike reviews that employ graded, multi-reviewer relevance assessments, such as the PERT-based approach applied in a recent systematic review of intelligent transportation systems for sustainable urban mobility (Fernando, Francisco, & Guillermo, 2026), this study used binary inclusion and exclusion criteria during title, abstract, and keyword screening. This approach was considered appropriate for the single-reviewer screening process; however, its limitations were acknowledged in Section 5.3.

Systematic Literature Search and Selection

The search and document selection protocol is summarized in Table 1.

Table 1. Search and document selection protocol

Stage	Description
Scope	Systematic review of road sustainability indicators and assessment models, 2000 to 2026
Database	Scopus
Search field	TITLE-ABS-KEY
Boolean query	("road infrastructure" OR "urban road" OR "highway" OR "pavement" OR "road network") AND ("sustainable" OR "green" OR "low carbon" OR "resilient" OR "climate resilient") AND ("model" OR "framework" OR "indicator" OR "criteria" OR "index" OR "assessment" OR "rating") AND ("urban" OR "city" OR "metropolitan" OR "sustainable infrastructure")
Time span	2000 to 2026
Language	English and Indonesian
Final screening	Manual screening based on titles, abstracts, and keywords against eight inclusion and eight exclusion criteria
Final corpus	134 documents
Processing	RIS export parsed and deduplicated programmatically; dimension coding and frequency analysis computed directly from title, abstract, and keyword fields

The search ran on the Scopus database on 10 August 2026 across four separate sessions, combining the four keyword groups shown in Table 1: the road object, sustainability, assessment models or indicators, and the urban context. Scopus was chosen as the sole source for this stage because it offers consistent metadata and full RIS export, which the analysis pipeline in this study depends on; broadening the search to Web of Science and ScienceDirect is flagged as a next step in Section 5.4. The four sessions together returned 202 bibliographic records. Deduplication based on DOI and title similarity left 188 unique records.

These 188 records then went through title, abstract, and keyword screening against eight inclusion criteria and eight exclusion criteria, listed in Table 2.

Table 2. Inclusion and exclusion criteria for title and abstract screening

Code	Inclusion criterion (I)
I1	Addresses the sustainability of roads, highways, pavements, or road networks
I2	Presents an indicator, variable, model, framework, assessment method, or rating system
I3	Addresses at least one sustainability dimension
I4	Has relevance to urban infrastructure
I5	Is a peer-reviewed journal article, conference paper, standard, or official technical report
I6	Published between 2000 and 2026
I7	Available in English or Indonesian
I8	Title and abstract accessible for screening

Code	Exclusion criterion (E)
E1	Discusses only vehicles, with no link to road infrastructure
E2	Discusses only public transport, with no road-related aspect
E3	Discusses only laboratory material performance, with no sustainability implications
E4	Presents no extractable indicator, method, model, or finding
E5	Is a conference entry, editorial, or presentation that is not a standalone study
E6	Duplicate publication
E7	Title and abstract not available
E8	Not relevant to the research question

The screening process identified 54 records for exclusion: 20 under E3 (primarily studies on asphalt or concrete mechanical or rheological performance without a sustainability assessment framework), 15 under E4 (primarily machine-learning traffic or crash prediction models without extractable sustainability indicators), 10 under E8 (off-topic records such as medical studies or non-road infrastructure captured via keyword overlap), 5 under E1 (vehicle technology without links to road infrastructure), and 4 under E5 (conference entries without substantive extractable content). The final set of 134 articles for the analysis in this review was left. The complete selection process is presented in the PRISMA 2020 style in Figure 2.

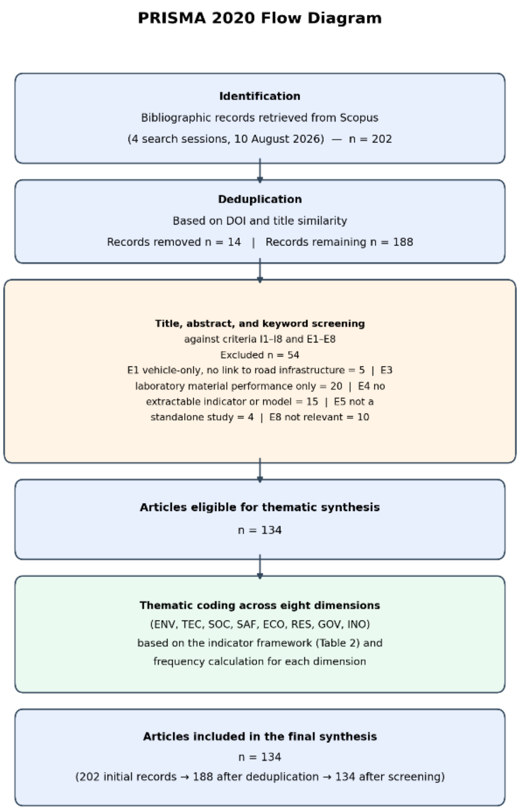

Figure 2. PRISMA 2020 flow diagram of the article selection process

Dimension Coding and Content Analysis

The 134 included articles were thematically coded, from title, abstract and keywords, into eight road sustainability dimensions derived from a synthesis of rating-system literature and previous academic models: environment (ENV), engineering and asset performance (TEC), social inclusiveness (SOC), safety (SAF), economics (ECO), climate and disaster resilience (RES), governance (GOV) and innovation and technology (INO), following the conceptual structure shown in Figure 1. Each dimension was divided into 10 to 14 groups of indexes, and the groups of indexes were used as a keyword dictionary to determine whether a certain dimension featured in a certain article. We classed an article as covering a dimension if at least one term representing the indicator groups of that dimension appeared in the title, abstract or keywords. The relative frequency of each dimension was calculated by:

$$F_i = (n_i / N) \times 100\% \qquad (1)$$

where F_i is the relative frequency of dimension i, n_i is the number of articles dealing with dimension i and N is the total number of included articles (N = 134). As a complementary step, a keyword co-occurrence network was generated directly from the author-keyword field of the 134 records following the co-word logic put out by Callon, Courtial, and Laville (1991) and codified for strategic diagrams by Cobo, López-Herrera, Herrera-Viedma, and Herrera (2011). terms were converted to lower case and only those terms appearing in at least four of the 134 articles were maintained, the same minimum-occurrence criteria employed in comparable reviews (Fernando, Francisco, & Guillermo, 2026). This left 54 keywords from a total of 1,246. An edge was created for each pair of kept keywords, weighted by the number of articles that share the pair, when the two terms appeared in the same article. Subsequently, clusters were identified using the greedy modularity algorithm from the Python NetworkX library and the network was plotted using the force-directed spring algorithm and rendered in a bubble-and-line style deliberately similar to VOSviewer's default network visualization, where node size reflects keyword frequency and node color denotes cluster membership. It is not the same as doing the review via VOSviewer or Biblioshiny itself (Aria & Cuccurullo, 2017), which use their own algorithms to cluster and report the centrality and density scores directly, but rather the network reported in Section 4.2.3 should be read as a close, independently built approximation of that output, not software-generated bibliometric output, a distinction revisited in Section 5.3.

This coding was carried out at the abstract and metadata level rather than on full text, so the result maps out the themes in broad strokes rather than delivering an in-depth methodological quality assessment of each article. Full-text quality assessment is planned as a subsequent stage of the dissertation, focused on the subset of articles that will anchor the final indicator set.

Corpus Characteristics

The final corpus of 134 documents was written by 422 unique authors, an average of 3.57 authors per document, with 7 single-authored documents. The articles carry 1,246 unique author keywords and split into 93 journal articles, 33 conference papers, and 8 book chapters. The main information about the corpus appears in Table 3.

Table 3. Main information about the corpus

Description	Value
Time span	2000 to 2026
Documents	134
Authors (unique)	422
Average authors per document	3.57
Single-authored documents	7
Author keywords (unique)	1,246
Document types	Journal articles 93; Conference papers 33; Book chapters 8

RESULTS AND DISCUSSION

This section presents the results of the performance and dimension-based content analyses conducted on the 134 selected studies. Frequency counts and percentage distributions were computed to identify the intellectual structure, priority dimensions, and rating-system practices within the literature, addressing RQ1 in this section and setting up the interpretation of RQ2 in Section 5.

Performance Analysis

Among the 134 included articles, the earliest was published in 2003 and the most recent in 2026, with a clear rise in publication volume from 2020 onward. Annual output never exceeded seven articles between 2003 and 2019, but from 2021 to 2026 it ranged between 11 and 19 articles a year, peaking at 19 in 2025 (Figure 3). This pattern matches Vijayakumar et al.'s (2024) observation that attention to the social sustainability of roads rose sharply after 2020, and it lines up with the growing urgency of the 2030 SDG targets pushing many countries to rethink their road infrastructure indicators (Dokyi, Tookey, Rotimi, & Osei, 2024). The lower count for 2026 is not a real decline; it reflects a search carried out partway through the year, which left 2026 incomplete.

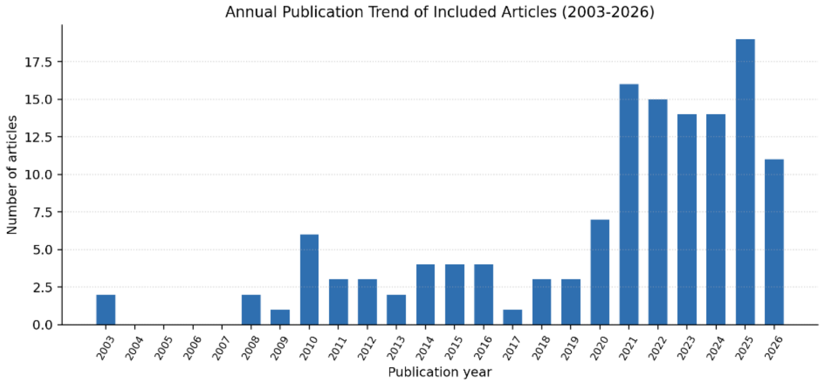

Figure 3. Annual publication trend of included articles (2003-2026)

Global Distribution by Country

Based on first-author affiliation, the included articles come from more than 30 countries. The United States contributes the most (14 articles), followed by Italy (11 articles), Indonesia (9 articles), India and Australia (7 articles each), and China, Canada, and the United Kingdom (6 articles each) (Figure 4). Indonesia's third-place ranking, ahead of many developed countries, stands out. Most of that domestic contribution, however, comes from single case studies on specific issues, such as road drainage (Yunianta & Setiadji, 2020), roadkill mitigation (Wulandari, Lestyana, & Tranggono, 2021), fund-based maintenance (Setyawan, Hermani, Yulianto, & Gravitiani, 2024), and district-level green road evaluation (Aidita, Masykuri, & Astuti, 2026), rather than a comprehensive indicator model spanning multiple dimensions at once.

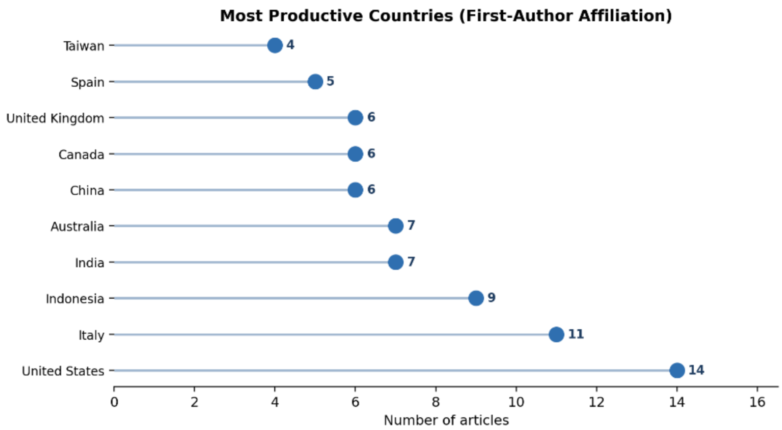

Figure 4. Most productive countries by first-author affiliation.

Most Productive Institutions

The corpus is not dominated by any single institution. Curtin University is the most productive institution with four documents followed by Federico II University of Naples, National Cheng Kung University, University of Saskatchewan, University of Palermo and University of Washington with three each and another group including Auckland University of Technology, Diponegoro University, Universiti Teknologi Malaysia and Deakin University with two each (Figure 5). The more active institutions include two Indonesian universities, Diponegoro University and Universitas Sebelas Maret, indicating that the local research base, while fractured in its focus, is not concentrated in a single place.

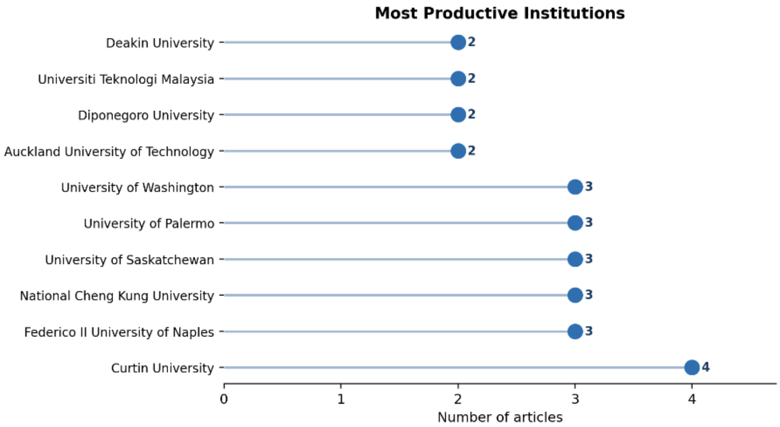

Figure 5. Most productive institutions by first-author affiliation

Most Productive Authors

The field has no single dominant author. Yang, S.-H. leads with four documents, all connected to the Taiwan green road rating system work discussed in Section 2 (Tran, Yang, Tsai, Yang, & Chang, 2021; Yang, Tran, Chang, Tsai, & Yueh, 2026). A wider group of authors follows with three documents each, including Veropalumbo, R., Oreto, C., and Viscione, N., who work together on pavement material and asset performance, Tran, N.H., a co-author on the Taiwan and cross-system comparison studies (Tran & Yang, 2021), and Muench, S., whose name recurs across the Greenroads literature cited throughout this review (Muench & Anderson, 2011; Zokaei Ashtiani & Muench, 2024) (Figure 6). These low, closely bunched counts, together with the number of common surnames in the corpus, call for some caution, since a handful of entries may combine distinct researchers who share a surname and initial.

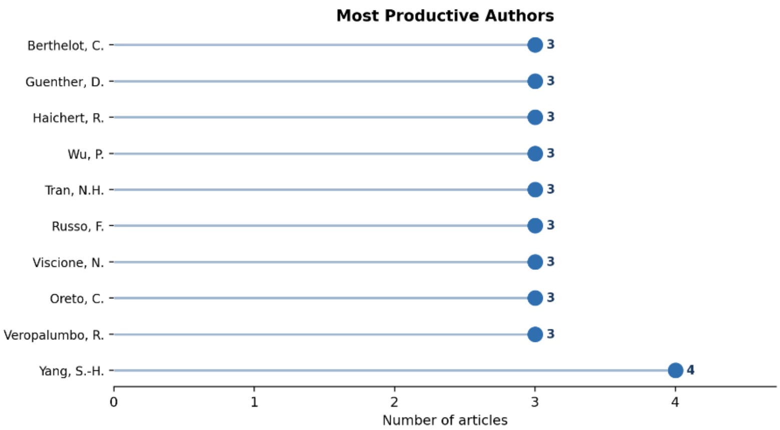

Figure 6. Most productive authors by number of documents

Source Analysis

The 134 articles are spread across more than 90 journal and conference titles. Sustainability (Switzerland) is the single largest contributor with 15 articles, followed by Journal of Cleaner Production (5 articles), IOP Conference Series: Earth and Environmental Science and Transportation Research Record (4 articles each), and Transportation Research Procedia, Transportation Research Part D: Transport and Environment, and Sustainable Cities and Society (3 articles each) (Figure 7). The ranking here reflects output volume only. The Scopus RIS export used for this review does not carry a citation-count field, so a citation-weighted measure such as a source h-index, of the kind reported in comparable bibliometric reviews (Thangavel & Chandra, 2023), could not be computed and is left for a follow-up analysis once citation data become available.

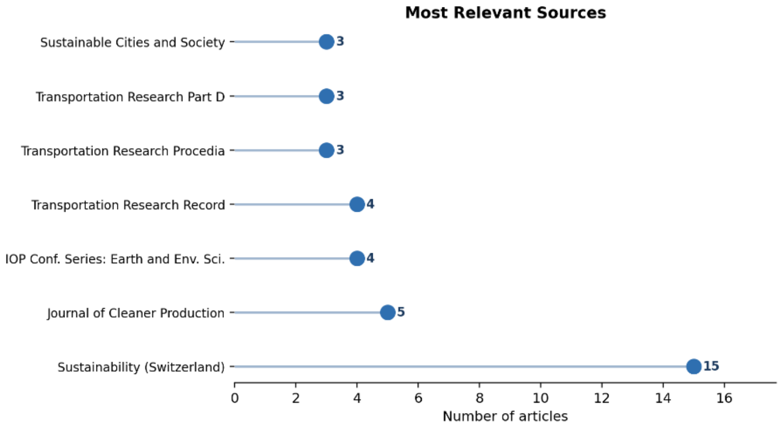

Figure 7. Most relevant sources by number of documents

Document Types and Keyword Profile

Of the 134 included articles, 93 are journal articles, 33 are conference papers, and 8 are book chapters. The ten most frequent author keywords are sustainable development (36 articles), roads and streets (32), sustainability (30), highway planning (25), motor transportation (18), road transport (13), highway administration and road infrastructures (12 each), and life cycle and environmental impact (11 each) (Figure 8). These terms track the dimension coding closely: environmental and planning vocabulary sits at the top, machine learning and rating system appear further down the list with seven and eight occurrences respectively, and terms tied to governance or climate resilience barely register.

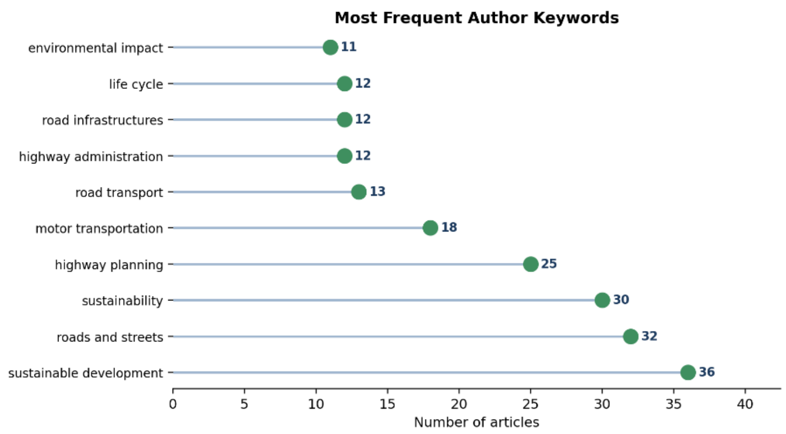

Figure 8. Most frequent author keywords

Dimension-Based Thematic Structure

1. Frequency of Road Sustainability Dimensions

Table 4 and Figure 9 present the frequency with which each of the eight road sustainability dimensions appears across the 134 included articles. The environmental dimension is the most common, appearing in 75 articles, or 56.0% of the corpus, followed by innovation and technology in 61 articles (45.5%) and economics in 50 articles (37.3%). Social inclusiveness appears in 38 articles (28.4%), engineering and asset performance in 25 articles (18.7%), and safety in 18 articles (13.4%). The two least discussed dimensions are governance, appearing in only 10 articles (7.5%), and climate and disaster resilience, appearing in 9 articles (6.7%).

Table 4. Frequency of road sustainability dimensions across 134 included articles

Dimension	No. of Articles (ni)	Percentage (Fi)	Category
Environment (ENV)	75	56.0%	Dominant
Innovation & technology (INO)	61	45.5%	Moderate
Economics (ECO)	50	37.3%	Moderate
Social inclusiveness (SOC)	38	28.4%	Moderate
Engineering & asset performance (TEC)	25	18.7%	Limited
Safety (SAF)	18	13.4%	Limited
Governance (GOV)	10	7.5%	Limited
Climate resilience (RES)	9	6.7%	Limited

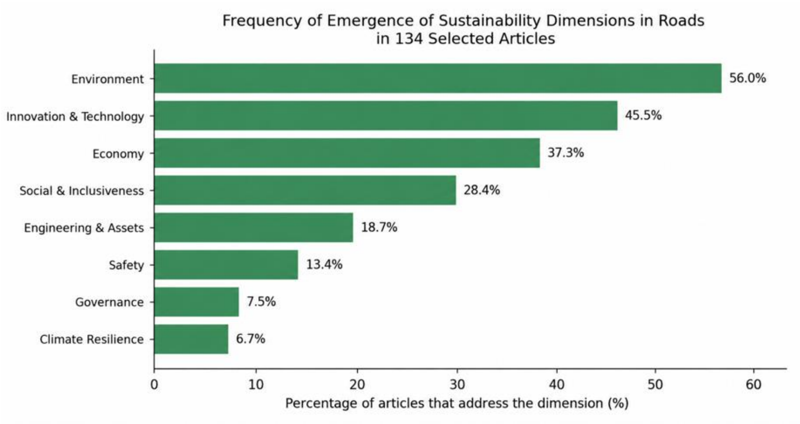

Figure 9. Frequency of the eight road sustainability dimensions

2. Comparison of Reference Rating Systems

Table 5 compares the three road sustainability rating systems most frequently cited in the corpus, expanding on the qualitative description in Section 2.2 with a structured side-by-side summary.

Table 5. Comparison of the three main reference road sustainability rating systems

Aspect	Greenroads	INVEST	Envision
Primary object	Road projects	Road transport programs and projects	Civil infrastructure broadly
Life-cycle coverage	Mainly design and construction	Planning through operation and maintenance	Planning through delivery
Assessment format	Requirements and credits	Self-evaluation criteria	Credits and verification
Strength	Road-specific	Covers the transport life cycle	Holistic across sectors
Initial limitation	Tied to a specific institutional setting	Built around US practice	Not road-specific

3. Keyword Co-occurrence Network

Figure 10 shows the author-keyword co-occurrence network built from the 134 included articles, following the procedure set out in Section 3.2. Fifty-four keywords met the minimum-occurrence threshold of four, and all of them fall inside a single connected network, which the greedy modularity algorithm split into three clusters, shown in red, teal, and blue.

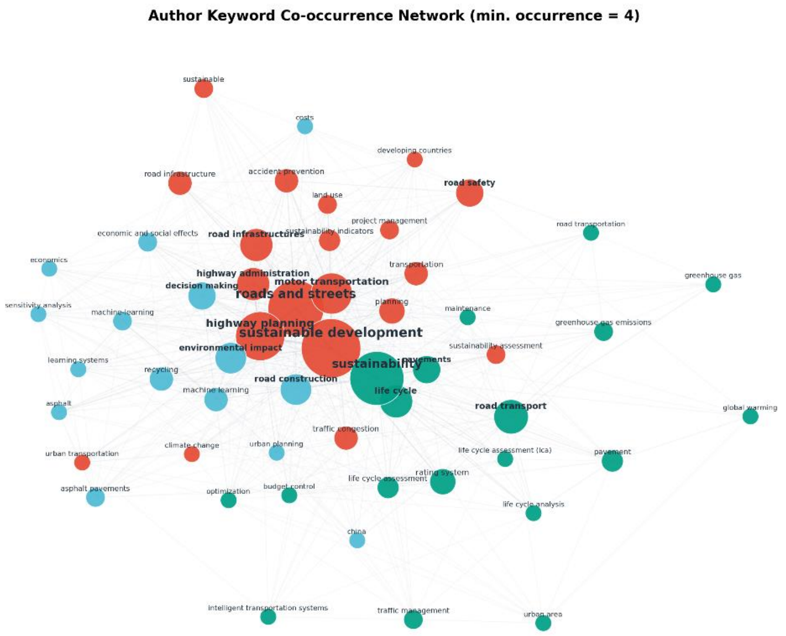

Figure 10. Author-keyword co-occurrence network (minimum occurrence = 4), clustered with the greedy modularity algorithm and rendered in a VOSviewer-style bubble map

The red cluster combines planning and safety vocabulary: sustainable development, roads and streets, highway planning, motor transportation, highway administration and road safety are at the core, with accident prevention and traffic congestion. The teal cluster emphasizes sustainability, life cycle, pavements, and rating system, including life cycle assessment, greenhouse gas emissions, and intelligent transportation systems, which together constitute the field's evaluation and rating-system lexicon. The blue cluster combines environmental effect, road construction, decision making, machine learning and recycling, a combination that suggests a more applied, technology and cost oriented strand of the literature. Sustainable development and sustainability are located in the densest part of the network, where dozens of links connect them to other terms, in line with their position as the two most frequent keywords in the corpus and confirming from an independent angle the dominance of the environmental and economic dimensions already reported in Table 4.

The three clusters correspond rather closely to the eight coded dimensions, although not in a one-to-one way. Neither governance nor climate resilience is mentioned in any of the three clusters. This confirms, with a totally independent methodology, the same imbalance discussed in Section 4.2.1 and returned to in Section 5.1, since both terms have a low frequency of coding (7.5% and 6.7%, respectively).

General Observations

The prevalence of the environmental feature, included in 56.0% of the papers, is not surprising. Emissions, energy use and recycled material content have long been the most obvious entrance point into road sustainability research and are also the most easily quantified in terms of their life-cycle assessment (Wibowo & Hatmoko, 2020; Hasan, Whyte, & AlJassmi, 2024). Yet this figure also verifies a tendency discovered by Suprayoga et al. (2020) a decade ago: socio-ecological integrity criteria have continually been the most generally embraced whereas precaution against long-term danger has hardly registered at all. That is, more than two decades into road sustainability research, academic attention has not moved substantially away from environmental issues to the harder-to-measure characteristics of resilience and governance.

The high frequency of the innovation and technology dimension (45.5%) should attract special attention as it is higher than the social dimension and traditional engineering. This implies a change in the conversation about road sustainability, with more and more conversation via monitoring sensors, building information modeling, predictive-maintenance artificial intelligence and digital twins (Habtu, A. Elsaigh, & Musonda, 2026; Antunes, Tan, Wanke, & Jabbour, 2023). That's understandable given how fast asset-monitoring tech has improved in the past five years, but it also creates a risk. Digitalization does not automatically translate into lower emissions or better access for vulnerable groups. "Innovation when discussed in isolation from environmental, social and governance indicators can lead to a technically sophisticated road that is not necessarily more sustainable."

The third studied topic is economics with 37.3%. The key topics are life-cycle cost, maintenance budget efficiency, and finance methods (Yang, Tran, Chang, Tsai, & Yueh, 2026; Antunes, Tan, Wanke, & Jabbour, 2023). However, the social dimension is fourth with a large gap of 28.4 per cent. This difference is in line with the results of Vijayakumar et al. (2024, 2025) (Vijayakumar, Mahmood, Gurmu, Kamardeen, & Alam, 2024; Vijayakumar, Mahmood, Gurmu, Kamardeen, & Alam, 2025) who showed that current road sustainability models have always been more focused on economic and environmental issues than social issues. However, this may not always be the case in studies that focus on social problems, such as Maelissa, Rohman, and Wiguna (2026) on social value creation in road projects, or Devkota et al. (2019) on rural road accessibility in Nepal.

The two least represented dimensions of these are governance at 7.5% and climate and disaster resilience at 6.7%, which are most relevant for the purposes of this dissertation. It should be a matter of concern for tropical cities grappling with extreme rainfall, flooding and rising surface temperature. However, only nine of 134 articles reviewed explicitly mention this issue . One of the more representative examples is Zhang, Lu, Wang, Yuan, and Huang's (2023) study of Chinese road transport resilience to emergencies, which was framed in terms of the pandemic rather than long-term climate risk. The governance is similarly patterned. Studies addressing interagency coordination, procurement transparency, or stakeholder participation, such as the environmental criteria framework for federal road procurement in Brazil (Giamberardino, Nagalli, Fernandes, & Garcias, 2022) or the review of policy instruments for sustainable road transport (Santos, Behrendt, & Teytelboym, 2010) discussed in Section 2.3, are far outnumbered by technical and environmental studies. Without clear governance arrangements, though, even the best technical and environmental indicators will only be applied as far as political will and institutional capacity allow, and that capacity is rarely measured.

The comparison of the three reference rating systems reinforces this picture. Greenroads is strong on road specificity, but its emphasis on design and construction means it captures less of the long-term dynamics of operation and maintenance (Lew, Anderson, &

Muench, 2016; Zokaei Ashtiani & Muench, 2024). INVEST addresses that gap by covering operation and maintenance, but its self-evaluation criteria leave room for assessor subjectivity. Envision is the most holistic across civil infrastructure sectors, but that breadth is also its weakness. All three also share a US institutional origin, so adapting them elsewhere has always required real adjustment, as seen in the work for South Korea (Park & Ahn, 2015), Taiwan (Tran, Yang, Tsai, Yang, & Chang, 2021), and Hungary (Szpotowicz & Tóth, 2020). No comparable adaptation effort has yet appeared for the Indonesian context; all nine Indonesian articles in this corpus are single case studies rather than an integrated indicator model covering all eight dimensions at once.

Answers to Research Questions

1. **Research Question 1: Dominant Dimensions and Rating-System Coverage**

The environmental, innovation and technology, and economic coverage dimensions are the most dominant themes in road sustainability research, attracting the bulk of the thematic attention, while governance and climate resilience are marginalized, despite their obvious importance for flood-prone and institutionally heterogeneous urban contexts, based on the dimension-frequency and rating-system comparison findings. This has an impact on the reference rating systems. The rating systems Greenroads, INVEST and Envision assess environmental, technical and economic criteria relatively well, but none of these systems was created with a developing country's governance capacity or climate exposure as a core issue. This answers RQ1: priority coverage areas are weighted both technically and environmentally, and current rating systems simply perpetuate the imbalance.

2. **Research Question 2: Contributions to Sustainable Urban Infrastructure**

The performance analysis and the dimension-based theme analysis combined indicate three items pertinent to RQ2 and to establishing a road sustainability model in support of sustainable urban infrastructure in Indonesia. First, a truly comprehensive model cannot be satisfied with environmental, technical and economic concerns, the pattern dominating the literature, but needs to deliberately bring governance and climate resilience into the frame, given how much more exposed Indonesian cities are to flooding and extreme weather than the countries where most existing rating systems originated. Secondly, the increasing emphasis on innovation and technology should be balanced by impact measures, rather than adoption indicators, for the road digitalization to contribute to sustainability goals rather than just technological modernization for its own sake. Third, the nine Indonesian studies and two Indonesian institutions found in this corpus, fragmentary as they are, give an empirical foothold that may be weaved into an integrated model, rather than beginning from scratch or adopting Greenroads, INVEST or Envision altogether. This review gives a relatively robust empirical foundation for the proposed model SR = f(ENV, TEC, SOC, SAF, ECO, RES, GOV, INO) in Figure 1, where all eight dimensions are weighted equally, and its relation to SUI = f(SR, MOB, ACC, LIV, RESU) in terms of road sustainability that feeds into mobility, accessibility, quality of life and urban resilience.

Limitations

This study has several limitations that should be acknowledged. First, the search was limited to studies indexed in the Scopus database and published in English or Indonesian between 2000 and 2026; relevant studies indexed in Web of Science, ScienceDirect, or published as domestic gray literature such as government reports and national technical standards may not have been included. Second, screening applied a binary set of inclusion and exclusion criteria rather than a graded, multi-reviewer relevance-scoring procedure of the kind used in comparable systematic reviews of transport technology research, appropriate for a single-reviewer process but less able to distinguish partially aligned contributions from highly aligned ones. Third, dimension coding was carried out at the title, abstract, and keyword level rather than on full text, so the results sketch a thematic map in broad strokes rather than delivering an in-depth methodological quality assessment of each article. Fourth, source-level rankings reflect output volume only, since the Scopus RIS export used in this review does not carry a citation-count field, so a citation-weighted measure such as a source h-index could not be computed. Fifth, the keyword co-occurrence network in Figure 10 was clustered with NetworkX's greedy modularity algorithm rather than the algorithm built into VOSviewer or Biblioshiny, and it does not report the centrality and density scores those tools would normally generate, so the three clusters should be read as a close approximation of a VOSviewer-style map rather than actual VOSviewer output. Finally, the low and closely bunched author-productivity counts mean that some entries may combine distinct researchers who happen to share a surname and initial.

A further limitation is the geographic skew in the available literature: contributions concentrate in the United States, Italy, and Indonesia, while many African, Latin American, and other Southeast Asian contexts are sparsely represented. The synthesized findings may therefore over-reflect the institutional and technological conditions of these better-studied regions and should be interpreted with caution when extrapolated to cities with different governance structures or infrastructure development levels.

Future Directions

The findings of this review suggest various avenues for future investigation. First, we need to expand the literature search to include Web of Science, ScienceDirect, and domestic gray literature, in addition to Scopus, to minimize database-coverage bias. Second, full text quality assessment should be conducted instead of the current abstract level coding for the subset of articles that will anchor the final indicator set. The keyword network in Figure 10 should be re-run in VOSviewer or Biblioshiny itself to see whether Callon centrality and density scores confirm the three clusters found here with NetworkX. Third, the eight dimensions and indicators need to be validated in a Delphi process with Indonesian road experts and practitioners, with special focus on governance and climate resilience given how infrequently either dimension appears in the existing literature. Fourth, more empirical work from underrepresented locations, particularly African and Latin American cities and less explored sections of Southeast Asia, is needed before any indicator model can be generalized beyond the geographic concentration in this review. Finally, once confirmed, the eight-dimension model should be empirically assessed as a measurement instrument for a sustainable urban road index, from a literature-based synthesis to an applied, context-sensitive assessment.

CONCLUSION

Out of the 202 Scopus records published between 2000 and 2026, 134 articles were evaluated and included in this systematic review. Road sustainability indicators and assessment models represent complex phenomena that extend beyond pavement condition and traffic capacity. Publication activity increased substantially after 2020, reflecting a geographically diverse research field without a dominant country, institution, or author. The United States, Italy, and Indonesia represented the three countries with the highest publication outputs. The eight sustainability dimensions coded in this review received uneven attention, with environmental, innovation and technology, and economic dimensions dominating the literature. This pattern was further supported by author-keyword frequency analysis. In contrast, climate resilience and governance dimensions remained substantially underrepresented despite their importance for tropical urban areas exposed to flooding and disaster risks.

The comparative analysis of three reference rating systems, namely Greenroads, INVEST, and Envision, demonstrated that none was originally developed specifically for the institutional and climatic conditions of developing countries. Therefore, adopting these systems without contextual adaptation may result in assessment frameworks that do not fully address local infrastructure priorities and sustainability challenges. The nine Indonesia-based articles and two Indonesian institutions identified in this corpus indicate growing domestic research interest in road sustainability; however, existing studies remain largely limited to individual case studies. This condition represents both a limitation and an opportunity for developing an integrated, Indonesia-specific indicator framework that considers all eight dimensions more comprehensively and assigns greater attention to governance and climate resilience.

Future research and practical implementation should therefore focus on developing more integrated, climate-responsive, and governance-oriented road sustainability frameworks that incorporate environmental, technical, social, economic, resilience, institutional, and technological objectives. Such frameworks should employ indicators that represent all sustainability dimensions rather than concentrating only on the most frequently assessed aspects. Furthermore, future models should remain aligned with sustainable urban infrastructure objectives before being transformed into validated measurement instruments for empirical application in Indonesian cities.

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