

SUSTAINABLE TRANSPORT INFRASTRUCTURE

A CASE STUDY OF GUJARAT STATE HIGHWAY PROJECT-II

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Abstract - Sustainable highway infrastructure integrates environmental protection, economic efficiency, and social safety within a unified evaluation framework. This study presents a corridor-wise sustainability assessment of the Gujarat State Highway Project – Phase II (GSHP-II), covering approximately 775 km across five regional corridors. A quantitative multi-criteria evaluation model was developed using environmental, economic, and social indicators. Indicators were normalized to a 0–5 scale and aggregated using weighted scoring to compute a Sustainability Index (SI).

Results indicate regional variation in sustainability performance. South Gujarat achieved the highest Sustainability Index (4.63), reflecting balanced environmental safeguards, economic efficiency, and safety improvements. Kutch & Port Connectivity showed strong economic performance but lower environmental and safety ratings. The study demonstrates that weighted multi-criteria assessment provides an effective benchmarking framework for evaluating corridor-level sustainability in state highway projects.

Key words:- Sustainable Highways, GSHP-II, Sustainability Index, Road Safety, Life Cycle Cost, Green Infrastructure

1. INTRODUCTION

Transport infrastructure plays a critical role in economic growth and regional integration. However, conventional highway development often leads to environmental degradation, high energy consumption, and safety challenges. Sustainable highway infrastructure seeks to address these issues through integration of environmental resilience, economic viability, and social responsibility.

Gujarat, one of India's most industrialized states, depends heavily on road-based freight movement and port connectivity. The Gujarat State Highway Project – Phase II (GSHP-II) upgraded approximately 775 km of priority corridors to enhance connectivity, safety, and pavement performance.

This study evaluates GSHP-II using a structured sustainability framework to determine how effectively sustainability principles were integrated across environmental, economic, and social dimensions.

2. Literature Review

Environmental Sustainability

The concept of sustainable transport infrastructure has shifted from conventional planning to an integrated approach balancing environmental protection, economic efficiency, and social equity. Highways significantly affect land use, energy consumption, material extraction, and lifecycle emissions. Raja Rafidah (2018, 2013) developed structured evaluation models, including the Relative Importance Index, highlighting construction-stage activities, waste management, and quality control as key sustainability drivers. Xiaodong Zhang introduced multi-criteria decision tools for ranking green alternatives, while Asmalia Che Ahmad emphasized stormwater management and environmental interdependencies. Overall, sustainable highways require systematic, multi-criteria assessment frameworks to achieve measurable outcomes rather than isolated environmental interventions.

Sustainable Construction and Management Systems

Construction-stage activities strongly determine sustainability performance. Raja Rafidah (2018) found construction-phase criteria rank highest, showing that on-site execution matters more than policy intent. JunHua Cai (2020) proposed a structured green highway management framework integrating pollution control, resource efficiency, and energy-saving measures, stressing systematic oversight. Muhammad Akmal Hafiz Mohamad (2023) examined Building Information Modelling adoption, identifying policy gaps, limited resources, and skill deficits as barriers. Overall, sustainability depends not only on technology but also on institutional capacity, regulatory support, and effective management systems.

Environmental Sustainability in Highway Development

Environmental sustainability underpins green highway development, as materials, pavements, lighting, and drainage significantly affect lifecycle impacts. Mastura Bujang (2018) stressed sustainable material selection but noted implementation gaps. Asmalia Che Ahmad (2017)

highlighted stormwater and climate-resilient drainage as critical criteria. Marufa Yeasmin Mukta (2020) showed IoT-based adaptive lighting improves energy efficiency, while Li Ji (2022) demonstrated emission reductions through optimized scheduling. Vijay Laxmi Kalyani (2015) proposed renewable-powered smart highways. Overall, integrated application remains limited in large-scale state highway projects.

Social and Safety Sustainability

Environmental sustainability is fundamental to green highway development, as materials, pavements, lighting, and drainage drive lifecycle impacts. Mastura Bujang (2018) emphasized sustainable material selection but identified implementation gaps. Asmalia Che Ahmad (2017) highlighted stormwater management and climate-resilient drainage as key criteria. Marufa Yeasmin Mukta (2020) demonstrated energy savings through IoT-based adaptive lighting. Li Ji (2022) confirmed emission reductions via optimized scheduling, while Vijay Laxmi Kalyani (2015) proposed renewable-powered smart highways. However, integrated large-scale implementation remains limited.

Smart Infrastructure and Intelligent Service Systems

The future of sustainable highways depends on digital integration and smart infrastructure. Zhengkai Li (2019) proposed an intelligent service area model using GIS, image recognition, and internet technologies to enhance user convenience and operational efficiency while optimizing resources. Smart highway concepts also promote renewable energy integration and adaptive systems for emission reduction and resilience. However, large-scale adoption in developing regions remains constrained by financial and institutional barriers. Additionally, studies on heavy vehicle-bridge interaction emphasize durability and lifecycle performance, supporting sustainability through resilient design and reduced maintenance and rehabilitation demands.

Research Gap

Sustainable transport infrastructure has received growing academic attention, emphasizing the triple-bottom-line framework. However, most studies assess environmental or economic aspects separately, rely on qualitative reviews, and lack region-specific quantitative models. In Gujarat, no integrated sustainability evaluation exists for Gujarat State Highway Project – Phase II (GSHP-II), despite documented safeguards and upgrades. Corridor-level comparative analysis across diverse regions remains absent. This gap limits performance benchmarking and policy refinement. The present study addresses this by developing a structured, weighted multi-criteria framework to quantitatively assess and compare sustainability performance across GSHP-II corridors.

3. Objectives of the Study

To examine the principles of sustainable transport infrastructure in highway development

This objective examines the core principles of sustainable highway development based on the triple-bottom-line framework—environmental protection, economic efficiency, and social equity. Highways significantly influence land use, emissions, biodiversity, and regional connectivity, requiring a strong theoretical foundation before project evaluation. The study reviews global sustainability frameworks, green highway concepts, emission reduction strategies, stormwater management, life cycle cost analysis, durability, road safety, and stakeholder engagement. This establishes a structured benchmark to assess the Gujarat State Highway Project – Phase II (GSHP-II), implemented by the Roads and Buildings Department, Government of Gujarat with support from World Bank.

To analyse sustainability measures adopted under GSHP-II in Gujarat

The second objective evaluates sustainability measures implemented within the 775 km Gujarat State Highway Project – Phase II corridor. It assesses environmental actions such as plantation, stormwater drainage, recycled materials, and warm mix asphalt for emission reduction, along with climate-resilient design features. Economic aspects include optimized pavement design, durability, and cost efficiency, while social measures cover road safety audits, black spot improvements, signage, and stakeholder consultation. Region-wise analysis across North, Central, South Gujarat, Saurashtra, Kutch, and Port corridors identifies performance variation. This determines whether GSHP-II reflects conventional upgrading or integrated sustainable transport development.

To evaluate environmental, economic, and social impacts of GSHP-II

The third objective evaluates the multidimensional impacts of Gujarat State Highway Project – Phase II using a weighted sustainability scoring model. Environmental indicators include plantation density, drainage efficiency, recycled materials, and emission reduction technologies. Economic assessment examines cost per kilometre, traffic capacity, durability, and life cycle savings, while social evaluation measures accident reduction, safety features, and community impact management. Region-wise and before-after comparisons identify performance variations across corridors. This approach converts descriptive data into quantifiable outcomes, determining whether GSHP-II achieves balanced sustainability across environmental, economic, and social dimensions.

To assess long-term sustainability performance using selected indicators

The fourth objective assesses long-term durability and resilience of the Gujarat State Highway Project – Phase II (GSHP-II). As highways have 15–20-year design lives, sustainability requires reduced maintenance, structural stability, and climate adaptability. The study examines pavement technology, design life assumptions, drainage performance under extreme rainfall, and freight load impacts in port corridors. It also evaluates maintenance planning and monitoring capacity within the Roads and Buildings Department, Government of Gujarat. This objective determines whether sustainability was embedded as a lifecycle strategy rather than short-term compliance and identifies areas for strengthened monitoring and resilience planning.

To propose recommendations for improving sustainable highway development in Gujarat

The final objective converts analytical findings into actionable recommendations for the Gujarat State Highway Project – Phase II. Based on corridor-wise evaluation, it identifies strengths and performance gaps, proposing measures such as increased recycled material use, strengthened plantation in arid regions like Kutch, improved pedestrian safety in port corridors, and digital environmental monitoring. It also suggests adopting green highway rating systems, institutionalizing sustainability indices, conducting stage-wise audits, and incentivizing emission-reducing technologies. This objective ensures policy refinement and engineering improvements, supporting Gujarat's transition toward resilient, resource-efficient, and socially inclusive highway infrastructure.

4. Scope of Work

Geographic Scope – Coverage of 775 km GSHP-II Corridors

The study is geographically limited to approximately 775 km of upgraded corridors under GSHP-II in Gujarat. The analysis is regionally structured into North Gujarat, Central Gujarat, South Gujarat, Saurashtra, Kutch, and Port Connectivity corridors. This regional segmentation enables comparative evaluation of sustainability performance across different climatic, topographical, and traffic conditions.

The scope includes only the selected corridors covered under GSHP-II and does not extend to other phases of the Gujarat State Highway Project. By restricting the geographic boundary, the study maintains analytical depth and consistency while allowing region-wise comparison of environmental measures, economic efficiency, and safety improvements.

This limitation ensures focused and structured evaluation without dilution of data integrity.

Thematic Scope – Environmental, Economic, and Social Dimensions

The study evaluates sustainability using the triple-bottom-line framework:

- Environmental sustainability
- Economic sustainability
- Social and safety sustainability

Environmental scope includes plantation initiatives, stormwater management systems, recycled material use, emission reduction measures, and climate resilience features.

Economic scope includes cost-per-kilometre analysis, pavement durability, life cycle considerations, and traffic handling efficiency.

Social scope includes accident reduction, road safety audits, signage improvements, pedestrian facilities, and stakeholder engagement processes.

The study does not include unrelated infrastructure sectors such as railways or urban metro systems, maintaining focus strictly on highway sustainability.

Project Phase Scope – Focus on Design, Construction, and Post-Construction Outcomes

The scope covers sustainability integration during:

- Planning and design stage
- Construction stage
- Operational stage (performance indicators such as accident reduction and durability)

However, the study does not include real-time operational management or future expansion planning beyond GSHP-II. It primarily evaluates completed or implemented measures rather than proposing entirely new infrastructure systems.

This ensures practical, evidence-based assessment rather than speculative modelling.

Data Scope – Secondary Data-Based Analytical Study

The research relies primarily on:

- GSHP-II project reports
- Environmental Impact Assessment (EIA) documents

- Road safety audit reports
- Government publications
- World Bank project documentation

No primary traffic survey or field experimentation is conducted unless supplementary verification is required. The analysis is therefore documentary and analytical in nature, based on officially available technical data.

This ensures feasibility within academic time constraints while maintaining technical rigor.

Methodological Scope – Section-Wise and Weighted Sustainability Assessment

The study applies a structured methodology:

- Division of 775 km into regional corridors
- Collection of uniform sustainability indicators
- Application of weighted scoring model
- Comparative regional analysis

The scope includes development of a sustainability index but does not involve advanced simulation modelling or software-based predictive forecasting.

This ensures analytical clarity and journal-level evaluation quality.

Limitations within Scope

The study does not:

- Conduct laboratory material testing
- Perform structural load simulations
- Undertake long-term carbon life cycle inventory modelling
- Include private sector financial audits

5. CASE STUDY (GSHP-II)

Introduction to the Case Study

Sustainable transport infrastructure has emerged as a critical component of regional economic growth, environmental protection, and social well-being. To evaluate practical implementation of sustainability principles in highway development, the present study examines the Gujarat State Highway Project – Phase II (GSHP-II), implemented in the state of Gujarat.

GSHP-II represents a large-scale state highway upgradation initiative covering approximately 775 km across diverse geographic and economic regions. The project was undertaken to improve connectivity, enhance road safety, support industrial growth, and integrate climate-resilient engineering measures within transport infrastructure.

The project is supported under institutional frameworks involving the Gujarat State Road Development Corporation and financial/technical assistance from the World Bank. The integration of sustainability components such as plantation drives, recycled materials, warm mix asphalt, and improved drainage systems makes GSHP-II an appropriate case for evaluating sustainable transport development.

This case study therefore provides a structured assessment of sustainability dimensions—environmental, economic, and social—within the GSHP-II corridor network.

Rationale for Selecting GSHP-II as Case Study

The selection of GSHP-II is justified based on the following considerations:

1. Geographical Diversity – The 775 km corridor spans semi-arid northern regions, industrial central zones, coastal Saurashtra, desert areas of Kutch, and high rainfall southern districts. This allows comparative sustainability analysis under varied climatic conditions.
2. Economic Importance – Gujarat is one of India's most industrialized states, with significant port connectivity, freight corridors, and manufacturing hubs. Highway efficiency directly influences trade competitiveness.
3. Integrated Sustainability Measures – The project includes plantation programs, recycled material usage, drainage enhancement, and safety improvements, aligning with sustainable transport principles identified in the literature review.
4. Availability of Quantifiable Data – Traffic volume (AADT), accident statistics, cost per kilometer, and environmental parameters are measurable, enabling objective sustainability scoring.
5. Policy Alignment – GSHP-II reflects national and international efforts to incorporate environmental safeguards and climate resilience into infrastructure planning.

Thus, GSHP-II provides a balanced and data-supported framework for sustainability assessment.

Regional Classification of the 775 km Corridor

For analytical clarity, the 775 km network has been categorized into five regional corridors:

1. North Gujarat Corridor
2. Central Gujarat Corridor
3. Saurashtra Region
4. Kutch & Port Connectivity Corridor
5. South Gujarat Corridor

Each region exhibits distinct terrain, climate conditions, and traffic characteristics.

- North Gujarat – Semi-arid, rural connectivity, moderate traffic.
- Central Gujarat – Urban-industrial linkage, high vehicular density.
- Saurashtra Region – Coastal and agricultural belt with moderate rainfall.
- Kutch & Port Connectivity – Desert terrain with heavy freight movement.
- South Gujarat – High rainfall zone with strong industrial presence.

This regional segmentation enables comparative sustainability evaluation.

Project Objectives of GSHP-II

The primary objectives of GSHP-II include:

- Capacity enhancement of state highways.
- Improvement of pavement quality and riding comfort.
- Reduction in road accidents through geometric corrections and safety measures.
- Integration of environmental safeguards.
- Strengthening freight connectivity to ports and industrial clusters.
- Climate-resilient infrastructure through improved drainage design.

These objectives align with the triple bottom line approach—environmental protection, economic viability, and social safety.

Scope of Engineering Interventions

1) Pavement Strengthening and Rehabilitation:-

Upgradation of flexible pavement layers to achieve 15-year design life.

2) Drainage Improvement:-

Construction of cross-drainage structures, culverts, and longitudinal drainage to enhance climate resilience.

3) Plantation and Green Measures:-

Roadside plantation to reduce carbon footprint and mitigate environmental impact.

4) Use of Recycled Materials:-

Incorporation of recycled aggregates and reclaimed asphalt pavement in construction.

5) Warm Mix Asphalt (WMA):-

Adoption of WMA technology in selected corridors to reduce construction emissions.

6) Road Safety Enhancements:-

Installation of signage, crash barriers, reflective markings, and geometric corrections.

Pre-Project and Post-Project Scenario

Prior to intervention, several sections experienced:

- Pavement distress and reduced riding quality
- Inadequate drainage
- Higher accident frequency
- Capacity constraints under increasing traffic loads

Post-implementation improvements include:

- Enhanced pavement condition
- Improved drainage performance
- Reduction in accident rates
- Increased AADT handling capacity

These changes provide measurable indicators for sustainability evaluation in subsequent chapters.

Data Sources and Availability

Data utilized in this case study includes:

- Traffic volume (AADT) data
- Accident statistics (before and after project implementation)
- Cost per kilometer
- Environmental parameters (trees/km, recycled %, drainage structures)
- Project technical reports and sustainability compliance documents

The availability of quantitative data enables structured scoring and weighted sustainability assessment, which is detailed in the Methodology chapter.

6. METHODOLOGY

This study adopts a quantitative multi-criteria sustainability assessment framework to evaluate the Gujarat State Highway Project – Phase II (GSHP-II) covering 775 km of upgraded state highways in Gujarat. The approach is analytical and corridor-comparative.

Corridor Segmentation

The network was divided into five regions: North Gujarat, Central Gujarat, Saurashtra, Kutch & Port Connectivity, and South Gujarat, enabling sustainability benchmarking across varied terrain, rainfall, and traffic intensity.

Indicator Framework

Sustainability was assessed using measurable indicators under three dimensions:

Environmental:- trees/km, drainage density, recycled material (%), Warm Mix Asphalt adoption.

Economic:- cost/km, pavement design life, AADT.

Social & Safety:- accident frequency (pre- and post-project), accident reduction (%).

Data were obtained from GSHP-II technical reports, safety audits, environmental compliance documents, and traffic statistics.

Normalization and Weighting

Since indicators were measured in heterogeneous units, values were standardized to a 0–5 rating scale.

Accident reduction was calculated as

$$\frac{\text{Before} - \text{After}}{\text{Before}} \times 100$$

Weights were assigned to maintain triple-bottom-line balance:

$$\text{Environmental} = 0.35$$

$$\text{Economic} = 0.30$$

$$\text{Social \& Safety} = 0.35$$

Sustainability Index

The composite Sustainability Index (SI) was computed as:

$$SI = (E \times 0.35) + (Ec \times 0.30) + (S \times 0.35)$$

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where E, Ec, and S are normalized ratings (0–5).

The SI enables corridor ranking, identification of sustainability gaps, and objective benchmarking of GSHP-II performance.

7. RESULTS AND DISCUSSION

Environmental Sustainability Performance

Environmental performance was evaluated using plantation density (trees/km), drainage density, recycled material usage, and adoption of warm mix asphalt technology. Scores were normalized on a 0–5 scale from the calculated environmental score (out of 40).

Table 1 Environmental Rating of Corridors

Corridor	Environmental Score (40)	Environmental Rating (0-5)
North Gujarat	30	3.75
Central Gujarat	30	3.75
Saurashtra	36.7	4.59
Kutch & Port Connectivity	16.7	2.09
South Gujarat	40	5.00

South Gujarat achieved the highest environmental rating (5.00) due to higher plantation density (23 trees/km), maximum drainage structures (210), 20% recycled material usage, and adoption of warm mix asphalt. Saurashtra also demonstrated strong environmental performance. Kutch & Port Connectivity recorded the lowest rating (2.09), primarily due to limited plantation density and absence of

warm mix asphalt usage. The desert terrain and freight-focused structural priorities likely influenced this outcome.

Economic Sustainability Performance

Economic sustainability was assessed using cost per kilometre, pavement design life, and Average Annual Daily Traffic (AADT). Since all corridors adopted a 15-year design life, economic differentiation was primarily influenced by traffic capacity and cost efficiency.

Table 2 Economic Rating of Corridors

Corridor	Economic Rating (0-5)
North Gujarat	3.40
Central Gujarat	4.20
Saurashtra	3.20
Kutch & Port Connectivity	4.50
South Gujarat	4.10

Kutch & Port Connectivity achieved the highest economic rating (4.50) due to the highest AADT (20,500 vehicles/day) and strong freight movement linked to port activities.

Central Gujarat and South Gujarat also exhibited strong economic sustainability, supported by industrial connectivity and high commercial traffic.

Saurashtra demonstrated moderate economic performance due to comparatively lower traffic intensity despite cost efficiency.

Social and Safety Performance

Safety performance was evaluated using accident reduction percentage between pre-project and post-project conditions.

Table 3 Social & Safety Rating of Corridors

Corridor	Accident Reduction (%)	Social Rating (0-5)
North Gujarat	40.9%	4.65
Central Gujarat	33.9%	3.85
Saurashtra	44.0%	5.00

Corridor	Accident Reduction (%)	Social Rating (0-5)
Kutch & Port Connectivity	23.9%	2.72
South Gujarat	41.7%	4.75

Saurashtra recorded the highest accident reduction (44%), followed closely by South Gujarat (41.7%) and North Gujarat (40.9%).

Kutch & Port Connectivity demonstrated the lowest reduction (23.9%), likely due to continued exposure to heavy freight traffic.

The findings indicate that road safety audits, geometric improvements, signage enhancement, and crash barrier installations significantly contributed to safety outcomes across most corridors.

Final Sustainability Index

The final Sustainability Index (SI) was calculated using weighted aggregation:

- Environmental Weight = 0.35
- Economic Weight = 0.30
- Social & Safety Weight = 0.35

$$SI = (Env \times 0.35) + (Eco \times 0.30) + (Social \times 0.35)$$

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Table 4 Final Sustainability Index

Corridor	Environmenta l	Economi c	Socia l	Fina l SI
North Gujarat	3.75	3.40	4.65	3.93
Central Gujarat	3.75	4.20	3.85	3.94
Saurashtra	4.59	3.20	5.00	4.29
Kutch & Port Connectivit	2.09	4.50	2.72	3.02

Corridor	Environmental	Economic	Social	Final SI
y				
South Gujarat	5.00	4.10	4.75	4.63

South Gujarat achieved the highest Sustainability Index (4.63), indicating balanced integration of environmental safeguards, economic performance, and safety improvements.

Saurashtra ranked second (4.29), driven by strong environmental and safety performance.

Central and North Gujarat demonstrated moderate but stable sustainability performance (~3.9).

Kutch & Port Connectivity recorded the lowest overall sustainability score (3.02), despite strong economic performance, due to comparatively weaker environmental and safety outcomes.

8. CONCLUSIONS

This study assessed the sustainability of the Gujarat State Highway Project – Phase II using a weighted multi-criteria framework covering environmental, economic, and social dimensions across five corridors. Results show regional variation: South Gujarat ranked highest due to balanced safeguards, traffic capacity, and accident reduction, while Saurashtra performed strongly in environment and safety. Kutch-Port corridors showed high economic output but lower environmental and social scores, indicating trade-offs in freight-dominated areas. Plantation, drainage, recycled materials, warm mix asphalt, and safety measures improved resilience. The model offers a replicable tool for corridor-level sustainability benchmarking and policy refinement.

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