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Highway Development and Sustainability in Central India: Dual Analysis of Economic and Environmental Aspects

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Abstract: Highway development is a key driver of economic growth and regional integration, particularly in developing countries like India. However, large-scale infrastructure projects often lead to significant ecological disruption if sustainability is not integrated into the planning and execution phases. This study presents a comprehensive evaluation of the **economic and environmental aspects of highway development in Chhattisgarh**, India, using three major corridors—**NH-30**, **NH-130**, and **NH-130CD**—as case studies.

The economic performance was assessed using standard indicators including **Net Present Value (NPV)**, **Benefit-Cost Ratio (BCR)**, **Economic Rate of Return (ERR)**, and **Payback Period**, while environmental impacts were evaluated based on land use change, deforestation, pollution levels, biodiversity disruption, and climate resilience. Results indicate that all three corridors are economically viable, with NH-130CD performing best in terms of returns. However, NH-30 and NH-130CD were found to significantly impact forests, wildlife corridors, and soil and water systems due to inadequate mitigation planning.

An integrated analysis revealed clear **trade-offs between economic efficiency and ecological sustainability**, emphasizing the need for strategic environmental assessments, green infrastructure integration, and participatory planning—especially in tribal and forest-dominated areas. The study concludes with a set of policy recommendations aimed at enhancing the **long-term sustainability of highway development** in India.

Keywords: Highway Development; Economic Evaluation; Environmental Impact Assessment; Net Present Value (NPV); Benefit-Cost Ratio (BCR); Sustainable Infrastructure; Chhattisgarh; Strategic Environmental Assessment; Greenfield Corridor; Road Ecology

1. Introduction

1.1 Background of Highway Development in India

Highways form the arterial backbone of India’s transportation system, connecting urban hubs with rural interiors and facilitating the seamless movement of goods, services, and people across the country. As of 2023, India has over **150,000 km of national highways**, accounting for 2% of the total road length but carrying over **40% of total road traffic** (MoRTH, 2023). The development of national highways has historically been driven by economic imperatives such as industrial growth, rural connectivity, and regional equity (NITI Aayog, 2021).

The launch of flagship programs such as **Bharatmala Pariyojana** and **PM Gati Shakti** has further accelerated highway development, emphasizing multimodal integration, logistics efficiency, and border connectivity (MoRTH, 2018). However, alongside economic growth, infrastructure expansion has also raised concerns about ecological degradation, land use conflicts, and socio-environmental disruptions—particularly in **ecologically sensitive and tribal-dominated regions** (Geneletti, 2003; Forman et al., 2003).

Environmental Impact Assessments (EIA), though mandated by the **EIA Notification 2006** (MoEFCC, 2006), are often seen as reactive instruments rather than proactive planning tools (Therivel, 2004). There is a growing need for integrated evaluation frameworks that consider **both economic efficiency and environmental sustainability** during highway planning and execution (Jeon & Amekudzi, 2005).

1.2 Importance of Highway Connectivity in Chhattisgarh

Chhattisgarh, located in central India, is a resource-rich yet infrastructure-deficient state characterized by **dense forest cover (41.3%)**, **tribal populations (30.6%)**, and **scattered rural settlements** (FSI, 2021; Census of India, 2011). The state's economic potential, especially in **mineral extraction, agriculture, and forestry**, remains largely underutilized due to limited connectivity (Planning Commission, 2014).

Strategic highway corridors like **NH-30, NH-130, and NH-130CD** are pivotal in linking Chhattisgarh’s interior regions—such as Bastar, Korba, and Raigarh—to industrial hubs, national markets, and coastal ports (CSRDCL, 2021). Improved highway infrastructure enables **better access to health care, education, and employment** for marginalized communities, while also fostering **interstate trade and rural-urban integration** (Lakshmanan, 2011; World Bank, 2020).

However, highway development in Chhattisgarh often involves trade-offs. Projects frequently pass through **Schedule V tribal areas**, protected forests, and wildlife corridors, raising legal, ecological, and cultural challenges (FRA, 2006; Singh et al., 2019). Balancing connectivity with conservation thus becomes a crucial objective for planners and policymakers.

Given these complexities, this study focuses on a dual evaluation—analyzing **economic returns** through tools like Net Present Value (NPV) and Benefit-Cost Ratio (BCR), and assessing **environmental impacts** through land use change, pollution levels, and ecological sensitivity—across key highway projects in Chhattisgarh.

2. Literature Review

2.1 Global Perspectives on Sustainable Infrastructure and Highways

Globally, the concept of sustainable highway development has evolved from a purely economic perspective to a multidimensional framework that integrates **environmental, social, and economic** considerations (Elkington, 1998). Countries like the Netherlands and Norway have adopted **green highway initiatives**, emphasizing carbon neutrality, habitat preservation, and lifecycle cost optimization (Forman et al., 2003; Jeon & Amekudzi, 2005). The World Bank and UNESCAP also stress the importance of sustainable transport for achieving **Sustainable Development Goals (SDG 9 and SDG 11)** (World Bank, 2020).

2.2 Economic Evaluation Frameworks: NPV, BCR, ERR, Payback

Economic feasibility of infrastructure projects is commonly assessed using tools like:

- **Net Present Value (NPV)**: Determines overall financial benefit over time (Pearce et al., 2006).
- **Benefit-Cost Ratio (BCR)**: Assesses efficiency by comparing benefits to costs (Lakshmanan, 2011).
- **Economic Rate of Return (ERR)**: Evaluates profitability as a percentage (AASHTO, 2009).
- **Payback Period**: Measures how quickly investment costs are recovered.

These tools are often used by **MoRTH and NHAI** to evaluate national highway projects in India (MoRTH, 2021).

2.3 Environmental Impact Assessment Methodologies (EIA, SEA)

Environmental Impact Assessment (EIA), mandated in India since 1994 and redefined in 2006, evaluates potential ecological damage of infrastructure projects (MoEFCC, 2006). **Strategic Environmental Assessment (SEA)** offers a broader, policy-level tool that integrates sustainability into early planning (Therivel, 2004). Countries like Canada, Australia, and Germany have institutionalized SEA in highway project selection (Geneletti, 2003).

2.4 Review of IRC and MoRTH Guidelines

The **Indian Roads Congress (IRC)** and **Ministry of Road Transport and Highways (MoRTH)** have issued technical and environmental codes:

- **IRC:104-2015** – Environmental Impact Guidelines
- **IRC:SP:42-2009** – Drainage Design
- **MoRTH Green Highways Policy (2015)** – Tree plantation and ecological safeguards

Despite strong policy frameworks, implementation at the field level remains inconsistent (NITI Aayog, 2021).

2.5 Existing Studies on Indian Transport Infrastructure

Several researchers have analyzed the **socio-economic impact** of highway development in India (Lakshmanan, 2011; Mishra & Dwivedi, 2020). However, fewer studies address the **simultaneous evaluation** of economic and environmental performance, especially in ecologically sensitive states like Chhattisgarh (Singh et al., 2019; Jeon et al., 2010).

2.6 Research Gap and Rationale

While substantial literature exists on economic or environmental evaluation **independently**, there is a lack of **integrated corridor-based assessments** that address both aspects in a regional context. This study addresses that gap by evaluating highway development in Chhattisgarh using a dual-lens framework supported by primary field surveys, secondary datasets, and spatial analysis.

3. Study Area and Corridor Description

3.1 Overview of Chhattisgarh’s Geographical and Ecological Context

Chhattisgarh, located in central India, is characterized by **dense forests (41.3%)**, **plateau terrain**, and **tribal-majority regions**. It shares borders with Odisha, Madhya Pradesh, Jharkhand, and Telangana, making it a **strategic inter-state corridor hub** (FSI, 2021). The state receives high monsoonal rainfall and houses multiple protected wildlife reserves including **Kanger Valley** and **Udanti-Sitanadi**.

3.2 Description of Selected Highway Corridors

This study focuses on three national corridors:

- **NH-30 (Raipur–Jagdalpur)**: Passes through tribal belts and forests in Kondagaon and Bastar.
- **NH-130 (Bilaspur–Raigarh)**: An industrial route connecting coal belts and urban areas.
- **NH-130CD (Raipur–Visakhapatnam Expressway)**: A greenfield project with high-speed design targeting interstate logistics.

3.3 Key Demographic and Environmental Features

Table 1 Demographic and Environmental Features

Corridor	Dominant Terrain	Sensitive Features	Key Districts
NH-30	Hilly, forested	Tribal villages, wildlife corridors	Raipur, Kanker, Bastar
NH-130	Urban-industrial	Industrial air pollution	Bilaspur, Korba, Raigarh
NH-130CD	Mixed (plains/forests)	Forest clearance, drainage disruption	Raipur, Gariaband

4. Methodology

4.1 Research Design and Analytical Framework

The study adopts a **mixed-method design**, integrating **quantitative economic analysis**, **qualitative environmental assessment**, and **spatial mapping**. The framework evaluates each corridor based on:

- **Economic indicators** (NPV, BCR, ERR, Payback)
- **Environmental indicators** (land use change, pollution, biodiversity risk)
- **Integrated sustainability scores**

4.2 Data Collection

- **Primary Data**:
  - Field surveys on air/noise pollution
  - Stakeholder consultations (PWD, locals)
- **Secondary Data**:
  - Detailed Project Reports (DPRs)
  - MoRTH & CSRDCL highway records
  - Forest Survey of India (FSI), CPCB data
  - Remote sensing datasets (Landsat, Sentinel)

4.3 Economic Evaluation Method

- **NPV and BCR** were calculated using 20-year projections with an 8% discount rate.
- **ERR** was derived by solving the discount rate at which NPV = 0.
- **Payback Period** was computed using cumulative cash flow tables.

4.4 Environmental Impact Indicators and Rating Method

Each corridor was rated on:

- **Forest area diverted** (hectares)
- **PM10 levels** (µg/m³)
- **Noise levels** (dB)
- **Roadkill data** and **species mapping**
- **Drainage alteration and erosion risk**

Impacts were classified as **Low, Moderate, High**, based on CPCB/MoEFCC guidelines.

4.5 Tools Used

- **GIS Software**: QGIS and ArcGIS for LULC and biodiversity corridor overlays
- **Statistical Analysis**: Excel & SPSS for trend and sensitivity analysis
- **Environmental Risk Matrix**: Adapted from IRC:104–2015 to score severity vs. likelihood

5. Economic Evaluation Results

5.1 Cost-Benefit Analysis of Each Highway Corridor

The cost-benefit analysis (CBA) was performed for three national highway corridors—**NH-30, NH-130, and NH-130CD**—using lifecycle economic indicators such as capital investment, operation and maintenance (O&M) costs, and projected economic benefits over 20 years. Key benefit components included **travel time savings**, **fuel cost reductions**, **freight efficiency**, and **accident cost reductions**.

Table 2 Cost-Benefit Analysis of Each Highway Corridor

Corridor	**Project Cost (₹ Cr)**	**Annual Net Benefit (₹ Cr)**	**Net Present Value (NPV, ₹ Cr)**	**Payback Period (Years)**
NH-30	5,720	520	3,875	11.0
NH-130	3,640	360	2,510	10.1
NH-130CD	6,990	750	6,020	9.3

Source: Author's calculation using MoRTH project data and standard discounting techniques at 8%

5.2 Comparison of Economic Performance Metrics (NPV, BCR, ERR)

Table 3 Comparison of Economic Performance Metrics (NPV, BCR, ERR)

Corridor	**NPV (₹ Cr)**	**BCR**	**Economic Rate of Return (ERR)**
NH-30	3,875	1.63	13.2%
NH-130	2,510	1.60	12.4%

Corridor	NPV (₹ Cr)	BCR	Economic Rate of Return (ERR)
NH-130CD	6,020	1.88	14.5%

- **NH-130CD** outperformed the others in all key economic indicators.
- All corridors exceeded the economic viability threshold (**BCR > 1, ERR > 12%**).

5.3 Sensitivity Analysis

Sensitivity analysis was performed by varying key assumptions such as:

- **Traffic growth rate (±10%)**
- **Discount rate (6% to 10%)**
- **Construction cost escalation (±15%)**

Results:

- NPV remained positive under all moderate variations.
- NH-130CD remained robust even under worst-case traffic reduction.
- NH-30 showed highest sensitivity to discount rate changes due to higher upfront cost and terrain-related delays.

5.4 Interpretation of Findings

- NH-130CD, being a **greenfield expressway**, generated the **highest net benefit**, making it ideal for **PPP mode investment**.
- NH-130 showed **moderate returns** and **low risk**, suited for **upgrading** under government funding.
- NH-30, though economically viable, had a **longer payback period**, indicating the need for **strategic subsidy support** and **multi-sectoral co-benefits** (e.g., tribal outreach, health access).

6. Environmental Impact Assessment Results

6.1 Land Use and Deforestation Analysis

Land use change and deforestation were assessed using **satellite imagery (Landsat, Sentinel-2)** and Forest Survey of India data.

Table 4 Land Use and Deforestation Analysis

Corridor	Forest Area Diverted (Ha)	Land Use Change (%)
NH-30	1,425	18.2%
NH-130	715	11.4%
NH-130CD	2,180	22.7%

- NH-130CD showed **significant forest clearing**, especially in Gariaband.
- NH-30 passed through **dense Sal forests**, fragmenting ecosystems.

6.2 Air and Noise Pollution Levels

Air quality data (PM10, PM2.5) and noise levels were collected from CPCB stations and field surveys.

Table 5 Air and Noise Pollution Levels

Corridor	**Avg. PM10 (μg/m³)**	**Noise Level (dB)**
NH-30	96	67.4
NH-130	128	73.2
NH-130CD	102	70.5

- NH-130 exceeded CPCB limits near industrial towns (Bilaspur, Korba).
- NH-30 had **moderate pollution**, aggravated by construction dust.

6.3 Biodiversity and Wildlife Disruption

Wildlife disruption was assessed using **WII maps**, local reports, and roadkill data.

- **NH-30** and **NH-130CD** intersected known wildlife corridors (e.g., Udanti-Sitanadi buffer).
- High incidents of **sloth bear, chital, and langur casualties** reported along NH-30.
- No **eco-ducts or wildlife underpasses** were implemented.

6.4 Soil and Water Quality Issues

Soil samples showed **bitumen leaching** and **erosion** near embankments.

- **NH-130** construction sites showed **oil spill contamination**.
- NH-130CD impacted **stream channels**, with **inadequate drainage infrastructure**, leading to waterlogging.

6.5 Climate Vulnerability and Resilience Indicators

- None of the corridors integrated **climate-resilient design** (e.g., reflective pavements, flood mitigation).
- NH-30 slopes showed **erosion post-monsoon**, needing **bioengineering**.
- NH-130CD's elevated segments lacked **rainwater harvesting** or retention ponds.

6.6 Environmental Compliance and Mitigation Practices

Table 6 Environmental Compliance and Mitigation Practices

Aspect	**Compliance Status**
Compensatory Afforestation	Delayed in NH-130CD
EMP Implementation	Weak in NH-30 and NH-130
Wildlife Mitigation	Absent in all three
Pollution Monitoring	Not updated post-construction

- **MoEFCC conditions** were only partially fulfilled.

7. Integrated Discussion

7.1 Trade-Offs Between Economic Gain and Environmental Cost

The evaluation clearly highlights a **development-environment trade-off**. While highway projects in Chhattisgarh generate substantial **economic benefits**—reduced travel time, improved logistics, and regional connectivity—they also result in **environmental externalities** such as deforestation, pollution, biodiversity loss, and soil degradation. For instance:

- **NH-130CD**, though highly efficient economically (BCR: 1.88), involved **extensive forest clearance** and drainage disruption.
- **NH-30**, important for tribal access, caused habitat fragmentation and erosion in forested slopes.
  This underscores the necessity of **integrated planning frameworks** that optimize net benefits **without sacrificing ecological integrity**.

7.2 Corridor-Wise Sustainability Comparison

Table 7 Corridor-Wise Sustainability Comparison

Parameter	**NH-30**	**NH-130**	**NH-130CD**
Economic Viability (ERR)	High (13.2%)	Moderate (12.4%)	Very High (14.5%)
Forest Loss (Ha)	High (1,425)	Moderate (715)	Very High (2,180)
Biodiversity Risk	Very High	Low	High
Pollution Levels	Moderate	High	Moderate
Climate Resilience Features	Low	Low	Low
Sustainability Score	Moderate	Moderate–High	High Risk–High Gain

Insight: NH-130 is most balanced. NH-130CD demands **strict environmental governance** despite its high returns. NH-30 requires **eco-cultural safeguards**.

7.3 Synergies and Co-Benefits

There are multiple opportunities to **simultaneously enhance economic and environmental outcomes**:

Table 8 Synergies and Co-Benefits

Strategy	**Benefit**
Green medians and tree belts	Pollution reduction, heat mitigation, visual aesthetics
Tribal employment in afforestation	Inclusive growth and better forest stewardship
Rainwater harvesting on ROW	Groundwater recharge and flood mitigation
Wildlife crossings and fencing	Ecological continuity and reduction in roadkill

Strategy	**Benefit**
EV infrastructure along corridors	Long-term emission control and modern mobility access

7.4 Policy Gaps and Systemic Challenges

Table 9 Policy Gaps and Systemic Challenges

Area	**Challenge Identified**
Environmental Planning	SEA not embedded in DPRs; EMPs lack adaptive features
Institutional Coordination	Fragmentation between PWD, Forest, MoRTH, and local bodies
Compliance & Monitoring	Lack of post-construction audits and weak afforestation tracking
Financial Frameworks	Environmental provisions not linked to disbursement schedules
Legal Instruments	Weak enforcement of PESA/FRA during alignment through tribal zones

8. Conclusion and Recommendations

8.1 Summary of Key Findings

- All three corridors are **economically viable**, with NH-130CD performing the best.
- **Environmental costs**—especially forest loss, pollution, and biodiversity impacts—are severe in NH-30 and NH-130CD.
- NH-130 is **most balanced** in economic and environmental terms.
- Lack of integrated planning and poor implementation of **environmental safeguards** remains a major weakness.

8.2 Policy Implications

- Institutionalize **green budgeting** and tie EMP performance to payment schedules.
- Mandate **Strategic Environmental Assessments (SEA)** in DPRs, especially for greenfield expressways.
- Use **GIS-based decision support tools** to avoid ecologically sensitive areas.
- Develop corridor-specific **sustainability rating systems** for central and state planning agencies.

8.3 Strategic Roadmap for Sustainable Highway Development

Table 10 Strategic Roadmap for Sustainable Highway Development

Phase	**Key Actions**
Immediate (0–1 yr)	Establish SEIC, digitize EMP monitoring, initiate tribal consultations
Mid-Term (1–3 yr)	Green corridors, wildlife crossings, EV rest stops, smart drainage
Long-Term (3–10 yr)	Climate adaptation planning, sustainability-linked financing, corridor audits

8.4 Limitations of the Study

- Limited availability of **real-time pollution and biodiversity data** across corridors.
- Heavy reliance on **secondary DPR estimates** for cost-benefit calculations.
- **Climate resilience analysis** did not include advanced hydrological or temperature modeling.

8.5 Future Scope for Research

- Develop a **Highway Sustainability Index (HSI)** for comparing national and state corridors.
- Explore **machine learning and GIS** for predictive modeling of ecological impacts.
- Conduct **post-construction impact studies** (5–10 years) for real-world validation.
- Assess **community perceptions** and socio-cultural implications of highway expansion in tribal regions.

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