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Case Study

Integration of strategic environmental assessment (SEA) in motorway/highway planning and construction: A case study for sustainable infrastructure development in Pakistan

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Abstract

Pakistan has constantly prioritized the development of roads and motorways as they are they are reflective of nation's economic and physical condition. However, poor highway planning, design, and construction can have a negative impact on the environment and can lower the quality of life for inhabitants. Therefore, eco-friendly roadway/motorway planning, and construction approaches are crucial for reducing environmental, social, and economic damages. Currently, environmental impact assessment (EIA) is the prevalent method for assessing and evaluating the environmental impact of road infrastructure projects. Still, this conventional approach focuses primarily on development projects and lacks strategic insight. Hence, the world is now focusing on integrating and implementing SEA as a realistic approach for executing a sustainability plan in every area, including the infrastructure and transportation sector. Pakistan invests a considerable portion of its annual budget on infrastructure, particularly roadways; therefore, it must incorporate the changing trends and parameters into the planning and developing phase. thus, current research aims to incorporate SEA into the strategic planning of motorway/highway development by conducting a desktop study using secondary sources, including research articles and EIA reports, to analyze the environmental and socioeconomic effects of motorway/highway by identifying the direct, indirect, and commutative impacts. The alternatives are assessed using impact criteria and indicators to choose the best sustainable option for achieving the required objectives. our study is a pioneer work to integrate SEA into the planning process for highway construction, which would act as a baseline and an advisory tool for the decision-makers to incorporate SEA in Pakistan's strategic development planning.

Keywords: Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Motorway planning, Baseline Data, Alternative Assessment.

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Introduction

Motorways in Pakistan are multi-lane, high-speed, controlled access roadways crucial for economic development. Pakistan has consistently prioritized the development of roads and motorways [1], recognizing that well-developed roadways are vital indicators of a nation's economic and physical status. An efficient road/highway infrastructure network not only promotes economic development but also improves access to essential services like health, education, housing, and commerce [2]. However, poor planning, design, and construction of highways can leads to significant environmental degradation [3]. For instance, the development of highways can have several unintended consequences, the most obvious of which are destruction to physical surroundings, habitat, and biodiversity; damage to the cultural and historical components; generation of environmental pollution; noise and vibration stress; occupation of widely available land; soil and water loss; and simultaneous production of a series of ecological problems [4]. Moreover, given the extensive length of motorways, they intersect various ecological and socio-economic zones, resulting in complex impacts that need careful consideration [3]. Therefore, implementing environmentally friendly practices in highway planning and construction projects is of utmost importance to lessen the detrimental effects on the natural environment [1]. Historically, Environmental Impact Assessment (EIA) has been the standard method for evaluating the environmental impacts of road infrastructure projects [5]. However, EIA tends to focus narrowly on individual projects and lacks a strategic perspective, limiting its effectiveness in addressing broader sustainability goals [3]. EIA is primarily a 'decision support' tool rather than a 'decision-making' instrument, focusing on integrating environmental considerations into specific projects [6]. To address these limitations, Strategic Environmental Assessment (SEA) has emerged as a more comprehensive approach that integrates sustainability considerations at the policy, plan, and program levels [3, 7]. SEA can also be applied to a specific geographical area (e.g., national, regional, local), a particular sector (e.g., spatial planning, transport, agriculture, forestry, fisheries, energy, waste/water management, tourism), or to a specific issue (e.g., climate change, biodiversity)[8], implications of proposed plans and their alternatives [9]. Although SEA is still in its early stages, numerous states have made operational SEA systems obligatory or voluntary over the past years [10].

SEA covers the three pillars of sustainability in-depth and is utilized in various sustainability certification schemes, including road infrastructure. A road or highway is considered sustainable if it satisfies all three criteria. So, a sustainable motorway/highway or road is defined as one that provides essential access and future opportunities while aligning with social and environmental objectives. It supports various transportation modes and preferences for all age groups and abilities, remains cost-effective, operates efficiently, reduces emissions, and minimizes the use of exhaustible resources. These principles apply equally to urban, suburban, and rural areas and can also serve as a revenue source for local governments [1].

As Pakistan's economy has progressed, substantial investments have been made in infrastructure development, focusing on road construction. A considerable share of the annual budget is allocated to this sector [1]. For road development projects exceeding Rs. 50 million Environmental Impact Assessments (EIAs) are mandatory to address environmental concerns. While these assessments are essential for integrating environmental considerations, they often fail to address broader sustainability goals. Though crucial for economic stability and growth, developmental projects can have significant environmental impacts. In Pakistan, the national environmental legislation, specifically the Pakistan Environmental Protection Act (PEPA), does not mandate Strategic Environmental Assessments (SEA) [11], except in Khyber Pakhtunkhwa, Baluchistan, and Gilgit-Baltistan, but here, SEA implementation has not been brought into actual practice for development projects. This highlights a critical gap in integrating SEA into the planning and construction processes, which is vital for minimizing ecological damage and achieving sustainable development. Therefore, incorporating SEA into the planning and construction of highways is crucial for achieving sustainable infrastructure development.

While Strategic Environmental Assessment (SEA) remains theoretical, mainly in Pakistan, with little to no practical application, Environmental Impact Assessments (EIA) have been widely studied and implemented. Many studies have evaluated the EIA process regarding challenges, effectiveness, and decentralization. However, there is a significant gap in research on SEA for development projects in Pakistan. This study pioneers the integration of SEA into the 5 lanningg process for highway construction, establishing baseline environmental and socioeconomic data to identify sustainable alternatives for infrastructure projects. Moreover, it provides valuable insights for practitioners involved in Strategic Environmental Assessment, particularly in preparing the Environmental Report, which is a crucial element of the SEA process.

Materials and Methods

Figure 1 provides the overall methodology followed in this study.

Data collection and baseline study

To assess the environmental and socioeconomic impacts of motorway projects, a comprehensive desktop study

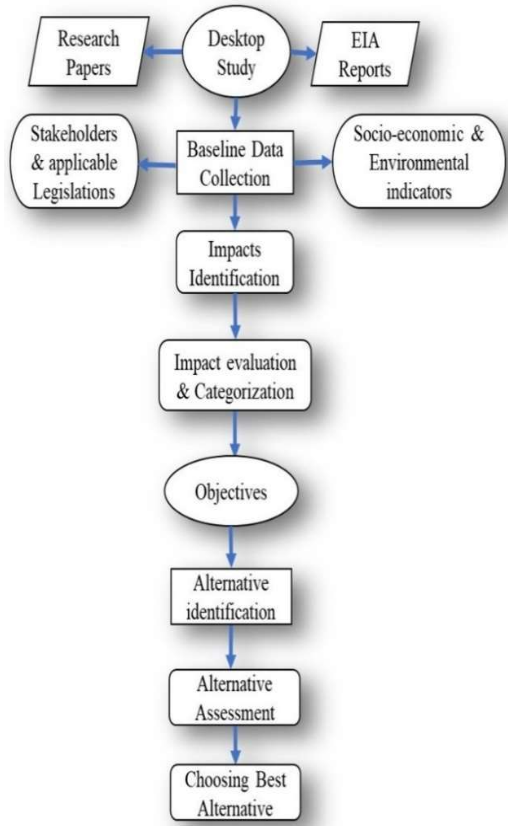

Figure 1: Methodology flowchart

was undertaken, focusing on collecting and analyzing baseline data from secondary sources. This study reviewed, EIA reports on Motorway M3 (Lahore–Abdul Hakeem), M4 (Pindi Bhattian–Multan), M5 (Multan–Sukkur), and M9 (Hyderabad–Karachi), including EIA reports on the subsections of these Motorways, i.e., Abdulhakeem – Lahore section III, Sukkur to Multan (375km long) section of Karachi-Lahore Motorway, from Yarak on N–55 to Hakla on M–1.

Baseline data collection process

Review of EIA reports: Systematic examination of EIA reports to gather comprehensive data on existing conditions, environmental impacts, and socioeconomic factors related to motorway construction.

Data extraction: Key data points, including environmental quality indicators (e.g., air and water quality, soil conditions) and socioeconomic indicators (e.g., economic activities, community infrastructure), were extracted from the reports.

Data processing and analysis

Documentation of baseline conditions and impact assessment: Recorded the current state of each socioeconomic and environmental factor to establish a reference point and evaluated the direct, indirect, and cumulative impacts of the motorway projects on these baseline conditions to develop strategic objectives.

Alternatives assessment: Conducted an assessment of alternatives based on established criteria and impact indicators to select the most sustainable options for highway/motorway planning and development.

Implementation of SEA

Strategic Environmental Assessment (SEA) assesses proposed plans or programs' ecological effects to ensure environmental problems are addressed early in strategic planning [12]. It is a stepwise process that includes baseline data collection to identify current and predicted issues, impact identification and analysis, setting objectives to address the possible solutions of impacts and issues, and alternatives considered to opt for the best possible option for achieving the best objectives [13].

Baseline data

The baseline data consists of the existing and expected future environments. The baseline environment data comes from a variety of places, such as official documents and websites from federal, state, and regional governments, academic institutions, NGOs, and other similar groups; historical maps that reveal patterns in land use; polls and surveys conducted among locals; and information that is known to experts but not officially documented. The process of collecting baseline data should be done in a progressive way, where the outcomes of the data collection are used to improve and modify the objectives, targets, and indicators of the SEA [14].

List of motorways in Pakistan

The Road network is essential to Pakistan's transportation system, making up 90% of passenger service and 96% of haulage movement. Within the last decade, passenger and freight traffic on the roads has grown much faster than the country's economic growth. The National Highway and Motorway system is 10,849 km long, making up 4.2% of the total transit system. They carry 90% of Pakistan's traffic [15]. Currently, 2816 km of motorways are open, and another 1213 km are being constructed or planned. Motorways in Pakistan were proposed in the 1990s. Since then, expanding the road network has connected much of the country, facilitated trade and travel, enhanced economic growth, and enabled planners to use Pakistan's geostrategic location for economic corridors. M-2 was the first motorway to link Lahore and Islamabad in 1997. Since then, roads have been developed. In 2014, highways were incorporated into the China-Pakistan Economic Corridor (CPEC) projects and the National Trade Corridor to facilitate travel between provinces and regions. These road projects attempt to connect Gwadar, Karachi, and Bin Qasim Port to the rest of Pakistan and the North with China, Afghanistan, and Central Asia [16]. Recent motorways like M-12 and M-13, completed or under construction in 2023, indicate ongoing infrastructure development to meet increasing transportation demands. Table 1 provides an overview of the motorway network in Pakistan, detailing the extent and development of the country's transportation infrastructure.

Trends and indicators

Indicator is a quantitative measure that simplifies and communicates complex phenomena, revealing trends and progress. Essentially, indicators help monitor the direction of a project, environment, or society [17]. Various indicators provide information about the potential or realized effects of human activities on phenomena of concern. Indicators can be used to assess both the socioeconomic and environmental conditions of a system, to monitor trends in conditions over time, or to provide an early warning signal of change [18].

Table 1: List of motorways in Pakistan

S/No	Name	Route	Length (km)	Lanes	Completion Year	Status
1	M-1 Motorway	Peshawar-Islamabad	155	6	2007	OP
2	M-2 Motorway	Islamabad-Lahore	367	6	1997	OP
3	M-3 Motorway	Lahore-Abdul Hakeem	230	6	2019	OP
4	M-4 Motorway	Pindi Bhattian-Multan	309	6-Apr	2019	OP
5	M-5 Motorway	Multan-Sukkur	392	6	2019	OP
6	M-6 Motorway	Sukkur-Hyderabad	306	6	Not yet started	PL
7	M-7 Motorway	Dadu-Hub	270	N/A	N/A	PL
8	M-8 Motorway	Ratodero-Gwadar	892	2	2022	PO & UC
9	M-9 Motorway	Hyderabad-Karachi	136	6	2018	OP
10	M-10 Motorway	Karachi Northern Bypass	57	2	2007	OP
11	M-11 Motorway	Lahore-Sialkot	103	4	2020	OP
12	M-12 Motorway	Sialkot-Kharian	70	4	2023	UC
13	M-13 Motorway	Kharian-Rawalpindi	117	4	2023	UC
14	M-14 Motorway	Islamabad-D. I. Khan	285	4	2022	OP
15	M-15 Motorway	Hasan Abdal-Thakot	180	4/6/2002	2020	OP
16	M-16 Motorway	Swabi-Chakdara	160	4	2020	OP

(OP = Operational, PL = Planned, UC = Under Construction, PO= Partially Operational)

Environmental indicators

An environmental indicator is a measurable feature that provides evidence of environmental and ecosystem quality or trends. In Strategic Environmental Assessment (SEA), these indicators demonstrate changes in environmental quality due to implemented plans and programs. They simplify complex data for decision-makers, such as using air or water quality indices to indicate pollution levels, which are based on detailed data about chemical concentrations [17].

The indicators obtained from the consulting reports are outdated, but the current trend is increasing, highly impacting the country's environmental conditions, as presented in Table 2. This table aggregates data on various environmental factors to illustrate the impact of motorway projects on the environment. The table highlights areas where environmental quality may be compromised by comparing actual values with targets and observing trends. For example, increasing air pollution and noise levels during construction can negatively affect human health and ecosystems. The decreasing number of species in both flora and fauna underscores the need for mitigation strategies to preserve biodiversity.

Table 2 provides a detailed overview of various environmental indicators related to motorway projects, highlighting both current conditions and trends. Air quality indicators, such as PM10, NO_2, SO_2, and CO, show increasing levels compared to target values, indicating a deterioration in air quality.

Table 2: Environmental indicators

AIR			
Indicators	**Quantified Data**	**Targets**	**Trends**
PM10	48-163	150	Increasing
NO2	0.01-56	80	
SO2	0.01-8.5	120	
CO	0.1-2.1	5	
WATER			
PH	6.5-7.9	10-Jun	Increasing
TDS	60-782	3500	
Turbidity	0.02-160	5	
NOISE			
Pre-construction	35.2-59.8	55-65db	Increasing
During construction	68.7-76.3		
BIODIVERSITY			
Flora	Kikar, Biloo, Neem, Khajoor, Beri, Ber, Peepal, Eucalyptus, Shisham, Dharek, AK, Karir, Lani, Naar		Effected/ Decreasing number of species
Fauna	Jackal, Mongoose, Squirrel, Mouse, Jungle cat, Porcupine, Hare, Wild Boar, Fox, Cobra, Indian Monitor, Viper, Gecko, Snake, Garden lizard, Krait, Egret, Heron, Sparrow, Duck, Crow, Black Myna.		Effected/ Decreasing number of species

Source : (NHA, 2014; NHA, 2015; NHA, 2017 NHA, 2012; NHA, 2014a, Rahman, 2007)

Water quality parameters, including pH, TDS, and turbidity, reflect an increasing trend in pH while other metrics remain within acceptable ranges. Noise levels have increased from pre-construction to during construction phases, exceeding target ranges and indicating heightened noise pollution. Biodiversity indicators reveal a decrease in the number of species of both flora and fauna, signifying adverse impacts on local ecosystems. These findings underscore the environmental challenges associated with motorway projects, including worsening air and noise pollution and declining biodiversity. These require targeted mitigation strategies to minimize ecological damage and maintain environmental quality.

Socio economic indicators

Socioeconomic indicators refer to various concepts used to measure and assess economic and social conditions. These include aspects such as ‘happiness,’ ‘quality of life,’ ‘well-being,’ ‘living conditions,’ ‘life situation,’ ‘social capital,’ ‘generalized and political trust,’ and environmental measures like ecological footprints. Frameworks such as Human Development, ‘Beyond GDP,’ and ‘How’s Life?’ also fall under this category, providing comprehensive tools to evaluate and understand complex socio-economic phenomena [19]. They are crucial in motorway planning and construction because they provide insights into how the project will affect and be affected by various aspects of the socio-economic environment, including industry growth, educational facilities, and cultural resources. These indicators help ensure that the project supports economic development and equitable access and minimizes adverse social and environmental impacts.

Table 3 summarizes the trends in key socioeconomic factors influenced by motorway projects, revealing positive and negative impacts. The increasing trends in industry, educational facilities, and health services indicate economic and infrastructural benefits resulting from improved connectivity. Enhanced connectivity from motorways supports industrial growth and expands access to education and healthcare. However, the table also highlights adverse effects on cultural and heritage resources and an increase in the displacement of indigenous populations. These negative effects underscore the need for careful planning to minimize damage to cultural assets and address social challenges. While motorway projects contribute to economic growth and improved public services, they also pose risks to cultural sites and local communities, necessitating targeted measures to support affected communities and mitigate the adverse effects of relocation.

Stakeholders

The comprehensive SEA evaluation includes the participation of stakeholders or facilitators because communication is essential for planning and making decisions correctly.

Table 3: Socioeconomic indicators

Indicators	Trends	Source
Industry & commercial activities	Increases	(AA ASSOCIATE & NHA, 2014; NHA, 2015; NHA & MMP, 2017; SGS PAK & NHA, 2014)
Educational Facilities, schools, colleges	Increases	
Health facilities	Increases	
Cultural & heritage Resources	Effected	
Indigenous People displacement	Effected/ Increases	

Table 4 outlines the key stakeholders involved in the planning and construction of motorways and highways in Pakistan, emphasizing the diverse roles and responsibilities crucial to the process. This table categorizes stakeholders into government bodies, private entities, and non-governmental organizations, each playing a specific role in ensuring effective project execution. Government stakeholders include national and regional authorities responsible for highway development, environmental protection, revenue collection, and forest and wildlife management. Private sector involvement includes consulting construction companies and funding agencies that contribute expertise & financial resources.

Table 4: Stakeholders involved in motorway planning & construction

Stakeholders	**Abbreviation**	**State**	**Type**
National Highway Authority	NHA	Pakistan	Government
Khyber Pakhtunkhwa Highways Authority	KPHA	KP	Government
Punjab Highways Authority	PHA	Punjab	Government
Sindh Highways Department	SHD	Sindh	Government
Gilgit-Baltistan Highway Department	GBHD	GB	Government
Pakistan Environmental Protection Agency	Pak-EPA	Pakistan	Government
Sindh Environmental Protection Agency	SEPA	Sindh	Government
Punjab Environmental Protection Department	EPD	Punjab	Government
Environmental Protection Agency, KPK	EPA-KP	KP	Government
Gilgit-Baltistan Environmental Protection Agency	GB-EPA	GB	Government
Federal Board of Revenue	FBR	Pakistan	Government
Khyber Pakhtunkhwa Revenue Authority	KPRA	KP	Government
Punjab Revenue Department	PRD	Punjab	Government
Sindh Revenue Board	SRB	Sindh	Government
Board of Revenue Gilgit Baltistan	BR-GB	GB	Government
Forest Department of Sindh	SFD	Sindh	Government
Punjab Forrest Department	PFD	Punjab	Government
Forestry, Environment & Wildlife Department, Khyber Pakhtunkhwa	FEWD-KP	KP	Government
Gilgit-Baltistan Forest, Wildlife & Environment Department	GBFWE	GB	Government
Wildlife Department, Government of Sindh	SWD	Sindh	Government
Punjab Wildlife Department	PWD	Punjab	Government
Planning & Development Department, Sindh	PPDS	Sindh	Government
Planning & Development Department Khyber Pakhtunkhwa	PDD-KP	KP	Government
Planning & Development Department, Gilgit-Baltistan	PDD-GB	GB	Government
Communication and Works Department, Government of Khyber Pakhtunkhwa	CWD-KP	KP	Government
Consulting Construction Companies	CCC	National	Private
Non-Governmental Organizations	NGOs	National & International	Private
Funding Agencies	FA	International	Private

NGOs and international funding agencies also play a vital role in addressing environmental and social impacts, ensuring that projects align with sustainable development goals. The participation of these varied stakeholders is essential for comprehensive planning, effective decision-making, and successful implementation of motorway projects, as their collaboration ensures that multiple perspectives and interests are considered, leading to more balanced and sustainable outcomes.

Stakeholder's interest and influence

The NHA manages most of Pakistan's national roadways, including motorways and major roads. [15]. The National Highway Authority (NHA) is responsible for the public highway network and the motorway system. These projects can only proceed with approval from Environmental Protection Agencies/ departments (EPA/EPD) [15]. Other departments and institutions are also involved directly and indirectly, which influences and interests in motorway planning.

Figure 2 categorizes stakeholders in Pakistan's motorway planning by their influence and interest. High-influence, high-interest groups like the National Highway Authority (NHA) and Environmental Protection Agencies (EPAs) are critical to project approval and must be managed closely. Influential but less directly interested stakeholders, like the Planning and Development Departments, should be consulted to maintain their satisfaction. Low-influence groups, including Public Works Departments and NGOs, require monitoring and information to ensure they remain informed and engaged according to their interest level. This approach ensures effective stakeholder management throughout the project.

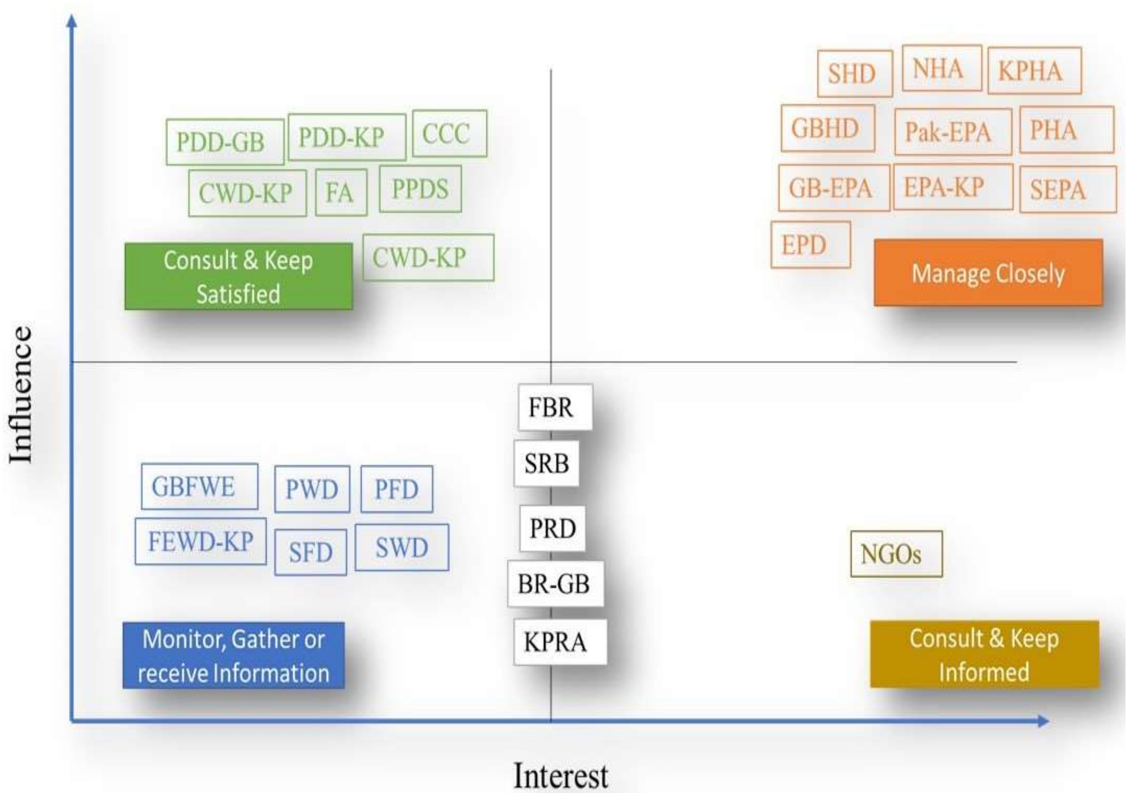

Figure 2: Stakeholder according to interest and influence

Applicable legislation

The legislation consists of numerous acts and ordinances that relate directly or indirectly to roadways' design, building, and operation. The existing environmental legal framework evaluates the Pakistani motorway construction projects. The most important national and international environmental laws influence Pakistan's highway development [20]. Pakistan is also a signatory to several international pollution control and biodiversity conventions, as presented in the Table 5 below.

Table 5 outlines the National and International legislation pertinent to Pakistan's motorway construction, emphasizing the comprehensive legal framework that governs these projects. These laws and conventions are designed to ensure that motorway construction adheres to environmental and conservation standards. The key point is that Pakistan's road infrastructure projects operate within a complex legal network, requiring careful adherence to national regulations and international commitments to achieve sustainable development objectives.

Table 5: Applicable legislation taken into consideration in motorway construction

National	International
1. Antiquity Act, 1975 2. Cutting of Trees (Prohibition Act), 1975 3. Forest Act, 1927 4. Highway safety ordinance, 2000 5. Land Acquisition Act, 1894 6. Motor vehicle rules, 1969 7. National Conservation Strategy, 8. National Environmental Policy, 2005 9. National Environmental Quality Standard (NEQS) 10. Pakistan Environmental Protection Act, 1997 11. Pakistan Environmental Protection Agency Review of IEE and EIA Regulations, 2000 12. Punjab Wildlife (Protection, Preservation, Conservation, & Management) Act 1974 13. Sindh Cultural Heritage (Preservation) Act, 1994 14. Sindh Wildlife Protection (Second Amendment) Ordinance, 2001 15. Canal and drainage act, 1873 16. Pakistan Penal Code, 1860 17. National Council for Conservation of Wildlife (NCCW)	1. World Bank Guidelines on Environment 2. Obligation under International Treaties and Convention 3. International Convention on Biodiversity 4. Convention on Wetlands of International Importance, (RAMSAR) 1971 5. International Union for Conservation of Nature and Natural Resources (IUCN) Red List 6. Kyoto Protocol 7. Convention on Biological Diversity 8. The Convention on Conservation of Migratory Species of Wild Animals, 1979 9. The Convention on Wetlands of International Importance, Ramsar 1971 10. Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 1973 11. Convention on Wetlands of International Importance especially as Waterfowl Habitat, Ramsar,1971 and its amending protocol, Paris,198 12. Convention concerning the Protection of World Culture and Natural Heritage (World Heritage Convention), 1972 13. International Plant Protection Convention, 1951

Impact assessment

The goal of impact assessments is to pinpoint the most important environmental concerns that must be considered when making decisions. The document must be sufficiently detailed to identify the most critical environmental issues efficiently. Converting the anticipated effects into important or significant statements is its goal. The significance of particular impacts and who benefits and loses as a result of these impacts are disclosed to the decision-maker [14].

Highways and motorways are essential to national, state, and local transportation systems. However, their construction degrades the natural environment and measuring the potential environmental ecosystems in the surrounding area, so impacts of projects is essential to ensure a safe and sustainable environment [21].

Table 6 provides a comprehensive approach to discuss the impacts of motorway/highway construction on the environment, the economy, and society.

Table 6: Potential environmental, economic, and social impacts

Indicator	Project Phase (C/O)	Negative Impact			Positive Impact		Geographical Extent of Impact (Local and Regional)	Impact Type (Direct/ Indirect)
		Short Term	Long Term	Reversible/ Irreversible	Short Term	Long Term		
ENVIRONMENTAL IMPACTS								
Water Resources	C/O	-	ü	Irreversible	-	-	Local to Regional	Direct
Air Quality	C/O	-	ü	Irreversible	-	-	Local to National	Direct
Land/ Soil Degradation (Waste Disposal)	C	ü	-	Reversible	-	-	Local	Direct
Natural Vegetation	C/O	ü	ü	Reversible/ Irreversible	-	-	Local to Regional	Direct/ Indirect
Noise	C/O	ü	ü	Reversible	-	-	Local	Direct
Nearby Flora and Fauna	C/O	ü	ü	Irreversible	-	-	Local to Regional	Direct/ Indirect
Visual Pollution	C	ü	-	Reversible	-	-	Local to Regional	Direct
ECONOMIC IMPACTS								
Employment Opportunities	C/O	-	-	-	ü	ü	Local	Direct
Pressure on Local Infrastructure	C	ü	-	Reversible	-	-	Local	Direct
Fertile Land Acquisition	C	-	ü	Irreversible	-	-	Local to Regional	Direct
Land Value Changes	O	-	-	-	-	ü	Local to Regional	Direct
Local Community Development	O	-	-	-	-	ü	Local	Direct

Indicator	Project Phase (C/O)	Negative Impact			Positive Impact		Geographical Extent of Impact (Local and Regional)	Impact Type (Direct/ Indirect)
		Short Term	Long Term	Reversible/ Irreversible	Short Term	Long Term		
ECONOMIC IMPACTS								
Traffic Congestion	C	ü	-	Reversible	-	-	Local	Direct
Travel Time and Fuel Usage	-	-	-	-	-	ü	Local to Regional	Direct
SOCIAL IMPACTS								
Community Disturbance	C	ü	-	Reversible	-	-	Local	Direct
Cultural and Language Barrier	C/O	-	ü	Reversible	-	-	Local to Regional	Direct/ Indirect
Local Residents Displacement	C	-	ü	Irreversible	-	-	Local	Direct
Public Health and Safety	C/O	ü	ü	Reversible/ Irreversible	-	-	Local to Regional	Direct/ Indirect
Religious or Cultural Heritage	**Site Specific Impacts**							
• High Adverse (Irreversible and Long term, Irreversible and Short term, Both phases C and O)								
• Medium Adverse (Reversible and Long term, Reversible and Short term, Both phases C and O)								
• Low Adverse (Reversible and Short term, Only in C Phase)								
• Beneficial (Positive long- or short-term impact, either during C or O Phase)								

C = Construction Phase, O = Operational Phase, (-) = Not Applicable

Additionally, the same table evaluates the impacts during the construction I and operational (O) phases based on developing an impact matrix, ranking them according to their significance. Indicating whether the impacts are negative or positive, their geographical extent, and their nature (short-term or long-term, reversible or irreversible, direct or indirect).

From the table it can be presumed that Environmental impacts can show significant concerns such as the irreversible effects on water resources and air quality observed during the construction and operational phases. These impacts can extend from local to regional, and in the case of air quality, even national levels. Land and soil degradation due to waste disposal during construction can be reversible, with effects mainly at the local level. The impact on natural vegetation is particularly concerning, as it can be reversible and irreversible, potentially affecting local and regional areas during all project phases. Noise pollution, while reversible, is also noted as a persistent issue throughout the project's lifecycle. The effects on nearby flora and fauna are highly adverse and largely irreversible, impacting local and regional ecosystems. Additionally, visual pollution during construction is identified as a reversible problem, though it extends from local to regional areas.

The Economic impacts are more varied, with both positive and negative outcomes. Employment opportunities, for example, present a clear benefit during both construction and operation, with positive impacts localized to the areas surrounding the project. However, the construction phase also increases pressure on local infrastructure, which is a reversible but still significant situation. The acquisition of fertile land for the project has an irreversible negative impact that affects local and regional areas. On the other hand, land value changes and local community development are expected to see positive outcomes during the operational phase, providing long-term benefits. Traffic congestion, a reversible issue, is primarily a concern during construction. At the same time, improvements in travel time and fuel usage during operation are noted as positive impacts with broader local to regional benefits.

Moreover, Social impacts address concerns such as community disturbance during construction, which, though reversible, affects local communities in the short term. The potential for cultural and language barriers is also noted, with these impacts being reversible but significant at both local and regional levels during all phases. The displacement of residents during construction is highlighted as an irreversible and direct negative impact on local communities. Public health and safety issues range from reversible to irreversible, with impacts spanning both the construction and operational phases and affecting local to regional areas. Additionally, the impact on religious or cultural heritage sites is noted as a site-specific issue requiring careful evaluation.

Cumulative impacts of highway construction

The highway construction also results in several cumulative impacts as depicted in Figure 3. For instance, such projects occupy cultivated and uncultivated land, resulting in land segmentation and decreasing land resources. Highway development and operation impairs natural soil structure and erosion resistance, damaging nearby vegetation, water, and soil. Many highway projects pass over mountainous terrain, requiring extensive slope excavation, embankment filling, tunnel excavation, and other methods to avoid violating landform constraints. These actions cause geophysical events like collapse, landslides, debris flows, and the loss of human life, property, water, and soil. Additionally, construction waste from the highway destroys the soil, water, and plants

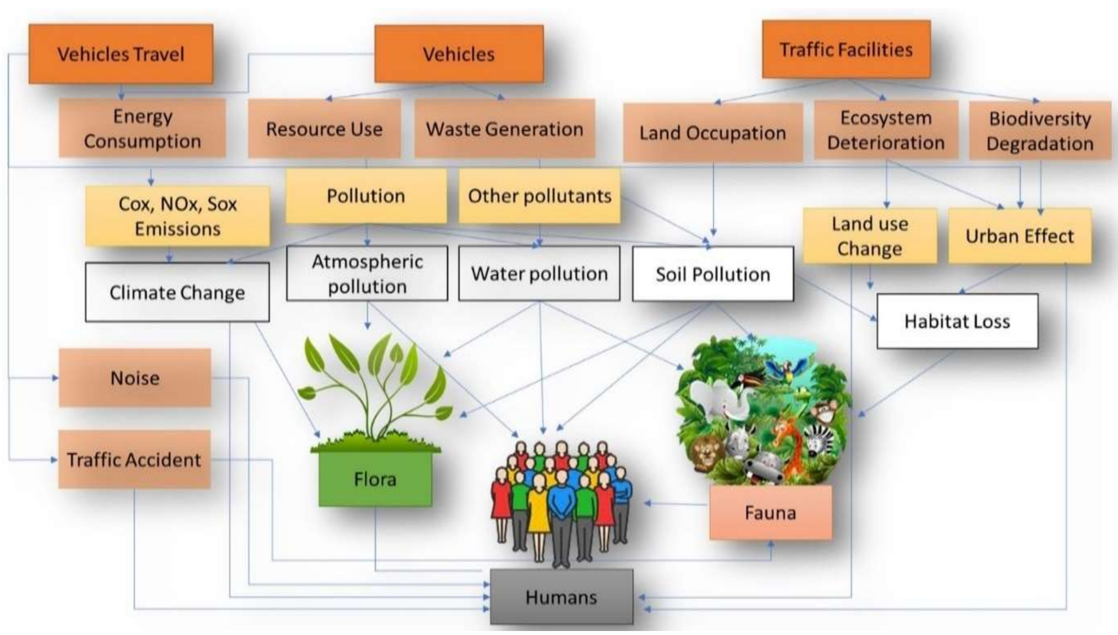

Figure 3: Cumulative impacts of motorway construction and operation.

Highway development affects the overland runoff, causing washing, silting, waterlogging, soaking, etc. Highway separation impacts the catchment area and runoff direction. When work is underway, multiple factors substantially impact the water quality of existing runoffs, waterways, freshwater bodies, and agriculture surrounding roads, including the construction company's sanitary sewage and heavy machinery oil disposal. Exhaust gas from construction machines and dust from construction materials are the primary sources of air pollution. A bituminous mixture amalgamator sends mine and fuel dust into the air, contaminating air and crops. During highway operations, vehicle emissions affect the atmosphere the most. Motor vehicle pollutants that impair human health include CO, NO_2, HC, and photochemical smog [3].

Objectives

In order to achieve sustainability objectives, the SEA Framework uses environmental indicators. There is no legal basis for creating objectives, but they are widely accepted to evaluate the environmental impact of a plan [22]. In this situation, the SEA Objectives facilitate the beginning of evaluating the alternatives for planning and building motorways in Pakistan.

The strategic objectives of motorway planning and construction in Pakistan are as follows: -

- Promote the use of sustainable motorway/highway construction equipment and structures for long-term use and minimum footprint.
- Use of advanced and creative technologies in automobiles to reduce greenhouse gas emissions to reduce climate change contributing aspects.
- Preserve, improve, and manage archaeological, historical, and cultural heritage-related features and regions during motorway/ highway construction.
- Enhance, protect, and manage the uniqueness and originality of the landscape and townscape, maintaining and enhancing distinctiveness and its specific traits.
- Reduce poverty and social exclusion and reduce the development gap between the country's most impoverished regions to contribute to the country's economic progress.

Results and Discussion

Alternatives

In the SEA process, considering alternatives is a crucial stage that follows screening, scoping, and baseline assessment and precedes impact assessment, mitigation, and monitoring. This stage leverages insights from scoping and baseline analysis to identify more effective solutions or mitigation strategies for potential adverse effects. It typically involves three steps: identification and development, assessment and comparison, and selection and documentation. To ensure a structured approach, alternatives can be organized based on their need, mode, location, and timing [9].

Alternatives with minimal adverse environmental impacts must be considered if the goals/objectives of the transportation plan or program are to be met sustainably. The development and analysis of alternatives should examine additional realistic solutions that will facilitate eradicating identified negative environmental impacts. This is a crucial stage in ensuring that the development is environmentally friendly. The following alternatives are identified.

- No further development" (A1)

- Sustainable infrastructure construction
- in environmentally sensitive and less sensitive areas (A2)
- Expansion of existing motorways/ highways (A3)
- Infrastructure development for other transport modes, i.e., rail and air transport (A4)

Alternatives assessment

In the SEA process, identifying environmental impacts and exploring alternatives is crucial. This requires analytical tools and techniques that help assess opportunities and risks for each planning decision. Essential methods include expert judgment, which relies on expert insights but may be biased; matrix-based assessments, which compare alternatives against environmental objectives and multi-criteria assessment (MCA), which ranks alternatives based on weighted environmental criteria. Additionally, environmental resource mapping and environmental sensitivity mapping use GIS to visualize and assess potential impacts, while modeling predicts future environmental conditions to evaluate the long-term feasibility of alternatives [9].

When considering SEA alternative options, they must meet four criteria: realistic, reasonable, viable, and feasible to implement. Furthermore, this study evaluates the environmental, economic, and social implications of each option. It assesses their overall impacts concerning impact indicators to identify the best possible highway/motorway construction solution. Table 7 presents the core criteria assessment of the proposed alternatives.

The table evaluates four alternatives for motorway development. Alternative A1 involves no further development in the motorway sector, which, while avoiding new environmental impacts, is deemed neither realistic nor reasonable as it fails to address current or future transportation needs. In contrast, Alternative A2 is positively assessed across all criteria. It is considered realistic, reasonable, viable, and implementable, focusing on sustainable infrastructure construction and careful site selection to minimize environmental impacts while balancing development with preservation. Alternative A3 is deemed realistic and implementable but is not considered reasonable or viable due to potential environmental and economic constraints. Expansion under this alternative may exacerbate environmental degradation and fail to address broader transportation needs. Alternative A4, which shifts focus from motorway construction to developing rail and air transport infrastructure, is neither realistic nor implementable. It is regarded as unreasonable and unviable given the specific requirements and challenges associated with motorway development. Ultimately, Alternative A2 was chosen because it effectively balances development with environmental preservation, addressing transportation needs in a sustainable manner.

Table 7: Alternatives assessment based on core criteria for alternative development

Identified Alternatives	Criteria			
	Realistic	Reasonable	Viable	Implementable
A1	-	-	✓	✓
A2	✓	✓	✓	✓
A3	✓	-	-	✓
A4	-	✓	-	-

Comparative analysis of alternatives

The comparative analysis of alternatives for transportation infrastructure development highlights varying impacts across environmental, economic, and social dimensions as presented in Table 8.

The above table shows that Alternative A1, which suggests no development, would result in continued road congestion, worsening air and noise pollution, and further deterioration of road conditions, exacerbating traffic issues and negatively affecting public health with increased medical costs. Economically, it impedes trade, foreign investment, and job creation while maintaining high transport costs and increasing traffic accidents. In contrast, Alternative A2, which proposes sustainable construction in less sensitive areas, offers an environmentally friendly approach with minimal impact on local ecosystems and reduced air emissions. Although initial costs are higher, the long-term economic benefits include reduced operational expenses and enhanced public health through sustainable practices. Alternative A3, focusing on expanding existing infrastructure, would lead to environmental drawbacks such as increased pollution and land clearance, along with significant costs for relocating structures.

Table 8: Alternative comparison analysis

IMPACTS			
Project Alternatives	**Environmental**	**Economic**	**Social**
A1 (No Development)	▪ Increase in congestion-related air and noise pollution on existing roads. ▪ More emissions of CO, CO_2, NO_X, SO_X, PM_{10}, and photochemical oxidants will adversely affect the environment and contribute to the global warming phenomenon. ▪ An increase in noise pollution will disrupt the nearby fauna diversity.	▪ Deterioration of existing roads due to increasing traffic loads. ▪ Hindrance in trade activities in-country different parts. ▪ The country's bad reputation for foreign visitors decreases foreign investment. ▪ No new job opportunities and high transport costs.	▪ Increase chances of traffic accidents. ▪ Negative impacts on commuters and drivers' health due to inhalation of polluted air. ▪ Increase in medical-related costs. ▪ Disruption to the current road network's users.
A2 (Sustainable Construction in less sensitive areas)	▪ Less to no negative impact on nearby flora and fauna hence conserving biodiversity. ▪ The utilization of environmentally friendly materials in constructing infrastructure will reduce air emissions. ▪ The use of pollution control technologies during the operation phase will limit damage to the natural and built environment. ▪ Better suited to withstand the effects of natural disasters.	▪ Sustainable technology may be expensive for a developing country like Pakistan at first, but if integrated, overall economic expenses could be decreased. ▪ Increase investments, profitability, and earning potential due to the choice for sustainable development to adapt to climate change. ▪ Less operational and maintenance costs as compared to traditional transport infrastructure.	▪ Improved public health due to fewer air pollutants emissions, less noise, and use of safer materials. ▪ Individuals who experience job contentment, health, and productivity will share their experiences with the community, impacting general wellness. ▪ Greater adoption of environmentally friendly products, community-wide design practices, and behavioral transformation.

<table>
<tr><th colspan="4">IMPACTS</th></tr>
<tr><th>Project Alternatives</th><th>Project Alternatives</th><th>Project Alternatives</th><th>Project Alternatives</th></tr>
<tr><td>A3 (Expansion of existing infrastructure)</td><td>▪ Increase in air pollution during construction and operation phases due to more greenhouse gas emissions.
▪ Increase in noise pollution due to heavy machinery during construction.
▪ Clearance of fertile land for expansion causes damage to nearby vegetation.</td><td>▪ High cost of relocating public and private structures and utilities.
▪ Additional re-development along the road and urban and suburban centers.
▪ Temporary employment opportunities during the construction phase and permanent employment modes can also be developed.</td><td>▪ Destruction of privately owned property, e.g., homes, shops, malls, etc.
▪ More displacement of people during land acquisition.
▪ The arising of social conflicts and cultural and/or linguistic barriers can lead to social disharmony.
▪ Acceptance among people on creating more job chances and developing their local area.</td></tr>
<tr><td>A4 (Rail Transport)</td><td>▪ More land clearance for railway tracks, railway stations, etc.
▪ The use of fossil fuels as a fuel source will further pollute the air and more pollution of water bodies.
▪ Contributes to soil erosion, land degradation, flooding, and habitat damage.</td><td rowspan="2">▪ Increased cost for the development of necessary infrastructure support. i.e., airports, railway stations, railway tracks.
▪ Employment opportunities for specialists in relevant fields to employ daily wage workers.
▪ Using efficient fuel either for trains or plains will be costly for developing countries like Pakistan.
▪ High maintenance cost and indirect cost in case of accidents.
▪ Facilitate foreign tourists, generate tax income, and promote the preservation of protected areas.</td><td>▪ Feasible as compared to air transport expenses.
▪ Railway tracks passing through nearby residential areas pose a safety hazard for the public.
▪ More nuisance to nearby residents due to trains noise.</td></tr>
<tr><td>A4 (Air Transport)</td><td>▪ More space to build runways and airports.
▪ Comparatively fewer negative impacts on the air with expensive, efficient fuel but create more noise.
▪ Air quality is impacted by airplane emissions, ground operations, road movement, and airport energy generation and heating.</td><td>▪ Not feasible for the average Pakistani due to the prohibitive cost of air travel.
▪ Safety issues and noise nuisance for the public residing near airports as in Pakistan airports are not constructed away from residential areas.
▪ Health issues in public living in the vicinity of airports.</td></tr>
</table>

However, it provides temporary construction jobs and potential permanent employment but may cause property destruction and displacement. Alternative A4, combining rail and air transport development, involves substantial land clearance and habitat disruption, with air and noise pollution from fossil fuels. It requires high initial investment and maintenance costs but creates jobs and supports tourism. However, it poses safety hazards and noise issues for residents near rail tracks and airports.

Alternative assessment in terms of impact indicators

The assessment of alternatives regarding impact indicators evaluates how each proposed solution affects critical environmental, economic, and social factors as shown in Table 9.

Table 9: Alternatives assessment in terms of impact indicators

Proposed Alternatives	INDICATOR						
	Air quality*	Water quality*	Biodiversity*	Noise*	Human Health*	Employment*	Economic Development*
A1 (No Development)	-	-	-	-	-	+	+
A2 (Sustainable Construction in less sensitive areas)	+	+	+	I	I	I	+
A3 (Expansion of existing infrastructure)	-	-	-	-	-	+	+
A4 (Rail Transport)	-	-	-	-	-	+	I
A4 (Air Transport)	-	-	-	-	-	+	I

Key: + = Positive impact; - = Negative Impact; I = Depends on implementation and further operation. * = Important indicators in the SEA process

The assessment reveals that Alternative A1, which entails no new development, maintains current conditions without significant changes to air quality, water quality, biodiversity, noise, or human health. It does, however, preserve existing employment and economic conditions without introducing new infrastructure or disruptions. Alternative A2, which focuses on sustainable construction in less sensitive areas, enhances air quality, water quality, and biodiversity through environmentally friendly practices. While its impacts on noise and human health vary depending on implementation, it supports long-term economic benefits and employment through sustainable development practices. Alternative A3, which involves expanding existing infrastructure, has generally negative effects on air quality, water quality, biodiversity, noise, and human health due to increased pollution and land clearance. Nevertheless, it offers economic development and job opportunities, reflecting the trade-offs of infrastructure expansion. Alternative A4, which includes both rail and air transport development, negatively impacts air quality, water quality, biodiversity, and noise, with similar health risks to rail transport. Despite these environmental and health challenges, it provides economic benefits and job opportunities, contingent on effective implementation and management of the transport systems.

In the context of the above-described alternatives criteria, comparison, and evaluation based on impact indicators, it may be inferred that some of the identified alternative possibilities are more sustainable. For example, "Alternative A2: Sustainable Infrastructure Construction in Environmentally sensitive and less sensitive areas." Opting for this alternative would have little to no impact on local flora and fauna, preserving biodiversity. Using eco-friendly materials to build infrastructure reduces air emissions, while pollution control systems prevent damage to the natural and built environment. If integrated, sustainable technology may be expensive for a developing country like Pakistan. Still, it could reduce total economic costs in the long run by increasing investments, profitability, and earning potential when considering sustainability for climate change adaptation. It would also save operational and maintenance expenditures and reduce air pollution; less noise and safer materials will benefit public health. Moreover, integrating academia, industry, and business professionals will create more job opportunities to contribute to the country's economic growth.

Considering stated factors, it is evident that integrating sustainable practices into motorway and highway planning and construction offers a comprehensive solution to addressing environmental, economic, and social challenges. By prioritizing environmentally sensitive construction methods, the project aligns with broader sustainability goals and contributes positively to the overall quality of life. This approach mitigates adverse impacts and enhances long-term environmental and societal benefits.

The significance of this study lies in its ability to inform decision-making processes with a clear, evidence-based framework for sustainable development. By systematically evaluating alternatives through detailed criteria and impact indicators, this study provides valuable insights into how best to achieve infrastructure goals while minimizing harm. It underscores the necessity of adopting innovative and environmentally friendly practices, especially in developing regions where such considerations are often overlooked. The findings of this study offer a strategic blueprint for future projects, ensuring that development efforts are both sustainable and resilient, ultimately guiding policymakers and stakeholders toward more informed and responsible infrastructure planning.

Conclusion

Strategic Environmental Assessment (SEA) is an effective way to plan, design, and implement policies and programs of a country and help achieve sustainable development goals (SDGs) faster. The status of SEA in Pakistan is relatively weak because environmental issues do not prioritize the country's politics, and there is a lack of SEA professionals with the right expertise in all sectors, including infrastructure development. For that reason, the inadequate planning and construction of highways cause adverse effects, including traffic congestion and pollution. Only environmental impact assessments (EIAs) are carried out for road infrastructure and motorway development projects, which lack strategic insight. Therefore, the integration of SEA is a practical way to achieve sustainability. SEA is a stepwise implementation approach in any sector's policy, plan, and program. Starting from the baseline data collection, impact identification, objectives formulation, and alternative assessment. According to various SEA frameworks and protocols, such as the EU directive and UNECE protocol, identifying the alternatives to reach the policy objectives and then shortlisting the most sustainable ones should be considered after evaluation. Unfortunately, no such direction is available by any authority at the national level in Pakistan. However, it is an adopted practice to identify and evaluate alternatives in the SEA process for any policy, plan, or program. In this study, for Pakistan's road/motorway planning and development, four alternatives were assessed based on impact indicators; alternative 2(A2) scored best in the criteria assessment and proved a sustainable option, fulfilling four criteria: realistic, reasonable, viable, and implementable.

Current study serves as an example of how SEA can be integrated into planning, explicitly focusing on highway planning through a desktop study. Future studies should go beyond desktop analyses by incorporating comprehensive field surveys and detailed project-specific data to expand knowledge and understanding of SEA. Additionally, efforts should be made to develop national SEA guidelines and provide cross-sectoral training for professionals to enhance environmental sustainability, protection, economic stability, and social well-being.

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