

CPEC AND MARINE ENVIRONMENTAL SUSTAINABILITY: ASSESSING THE ECOLOGICAL IMPACT OF PORT AND SHIPPING DEVELOPMENT IN GWADAR

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ABSTRACT

The China–Pakistan Economic Corridor (CPEC), a flagship project of the Belt and Road Initiative, has transformed Gwadar into a strategic maritime hub. While this development promises economic growth through trade, industrialization, and employment, it simultaneously threatens Pakistan’s fragile coastal ecosystems. This paper provides the first integrated legal ecological assessment of Gwadar’s port expansion, critically examining the environmental consequences of dredging, shipping traffic, and industrial activity. It situates these impacts within Pakistan’s national legislation, including the Pakistan Environmental Protection Act (1997), and international obligations under UNCLOS, MARPOL, and the Convention on Biological Diversity. The analysis reveals persistent gaps in enforcement, institutional capacity, and stakeholder participation, underscoring the tension between economic ambition and ecological responsibility. The study concludes that sustainable port development under CPEC requires stronger regulatory compliance, regional cooperation, and the embedding of environmental safeguards into broader economic planning, positioning Gwadar as a test case for balancing Belt and Road growth with marine sustainability.

Keywords: CPEC, Gwadar Port, Marine Environmental Law, Sustainable Development, MARPOL, UNCLOS, Coastal Ecology

1. Introduction

From a modest fishing town to a deep-sea port at the heart of the China–Pakistan Economic Corridor (CPEC), Gwadar epitomizes the promise and peril of rapid maritime development. Strategically located near the Strait of Hormuz, Gwadar offers Pakistan unprecedented access to global shipping routes and regional markets, positioning it as a cornerstone of the Belt and Road Initiative. Yet this transformation has come

at a steep ecological cost. Dredging, reclamation, and intensified shipping traffic have disrupted mangrove forests, degraded water quality, and threatened marine biodiversity along the fragile Makran coast.

These ecological risks are compounded by weak environmental governance. Although Environmental Impact Assessments (EIAs) are legally required under the Pakistan Environmental Protection Act (1997), they are often superficial,

poorly enforced, and disconnected from cumulative ecological realities. At the same time, Pakistan's obligations under international conventions—including UNCLOS, MARPOL, and the Convention on Biological Diversity—demand stronger measures to prevent marine pollution and conserve biodiversity. The tension between economic ambition and ecological responsibility thus lies at the heart of Gwadar's development trajectory.

This paper critically evaluates the ecological implications of port and shipping expansion in Gwadar within the framework of CPEC. It examines the extent to which Pakistan's legal and policy structures support marine environmental sustainability, identifies regulatory and institutional gaps, and proposes reforms. By adopting a multidisciplinary approach that integrates environmental law, maritime policy, and sustainable development theory, the study aims to provide practical recommendations for reconciling economic growth with ecological stewardship.

2. Conceptual Framework: Marine Environmental Sustainability and Coastal Ecology

Marine environmental sustainability refers to the responsible use, management, and preservation of oceanic and coastal resources to ensure ecological integrity, biodiversity conservation, and long-term human well-being (Sun et al., 2020). Within the context of CPEC, this concept encompasses the sustainable development of ports, shipping, fisheries, and coastal infrastructure along Pakistan's Arabian Sea. Gwadar Port, as the central hub of CPEC, provides a critical case study for examining the intersection of economic development and environmental management.

Marine sustainability rests on three interconnected dimensions: ecological, economic, and social (Jattak et al., 2023a). Ecologically, it requires safeguarding habitats, species diversity, and ecosystem functions. Economically, it demands that port activities, shipping, and trade be pursued in ways that do not deplete resources for future generations. Socially, it emphasizes protecting the livelihoods of coastal communities,

particularly those dependent on fisheries and traditional practices. Together, these dimensions align with the principles of sustainable development articulated in the United Nations Sustainable Development Goals (SDGs), especially SDG 14: *Life Below Water*, which emphasizes the conservation and sustainable use of marine resources (Whittingham et al., 2023).

CPEC presents both challenges and opportunities for marine sustainability. On one hand, large-scale infrastructure projects, industrial zones, and deep-sea port expansion threaten coastal ecosystems through dredging, reclamation, intensified shipping traffic, and industrial effluents. These activities risk altering sediment patterns, degrading mangrove forests, and jeopardizing marine biodiversity (Butt et al., 2024a). On the other hand, CPEC also provides an opportunity to adopt modern environmental management practices, such as green port technologies, advanced marine monitoring systems, and stricter compliance with international environmental conventions. In this sense, Gwadar's development can either exacerbate ecological fragility or serve as a platform for embedding sustainability into economic growth.

A comprehensive framework for evaluating marine sustainability under CPEC must integrate law, policy, ecology, and socio-economic considerations. National legislation, such as the Pakistan Environmental Protection Act (1997), and provincial coastal management authorities provide the domestic legal foundation, while international commitments under UNCLOS, MARPOL, and other multilateral agreements establish global obligations (Rothwell & Stephens, 2023a). Environmental Impact Assessments (EIAs) must be conducted rigorously, not only at the project level but also through cumulative evaluations that capture broader ecosystem risks (Lonsdale et al., 2020). Equally important is the engagement of local fishing communities, NGOs, and maritime experts in decision-making, ensuring that development does not marginalize traditional livelihoods (Khalid et al., 2022a). Finally, technological innovation—ranging from pollution control systems to marine surveillance technologies—offers practical tools for monitoring

and mitigating ecological harm (Hassan et al., 2022).

Marine environmental sustainability under CPEC is therefore not merely a policy objective but a multidimensional process that requires the integration of legal frameworks, ecological science, and socio-economic realities. With this conceptual foundation established, the following section examines Pakistan's legal and policy context to determine whether existing frameworks adequately support marine environmental protection in Gwadar.

3. Legal and Policy Context: Marine Environmental Law in Pakistan

Marine environmental governance in Pakistan is shaped by a complex interplay of national legislation, provincial policies, and international commitments. These frameworks are intended to regulate maritime activities, prevent pollution, and promote the sustainable use of coastal and marine resources. Yet the rapid expansion of Gwadar Port under CPEC has exposed significant weaknesses in implementation and enforcement, raising doubts about the adequacy of existing legal structures (A. Khan et al., 2022).

At the domestic level, the Pakistan Environmental Protection Act (PEPA) of 1997 remains the cornerstone of environmental regulation. It mandates Environmental Impact Assessments (EIAs) for major development projects, including ports and shipping facilities, and assigns compliance responsibilities to the Pakistan Environmental Protection Agency (Pak-EPA) and provincial agencies (Staudt et al., 2021). While provincial initiatives such as the Sindh Coastal Zone Management Policy (2016) provide guidance on habitat preservation and industrial regulation, Balochistan—home to Gwadar—still lacks a comprehensive coastal management policy. This absence limits its ability to address the ecological challenges posed by port expansion and industrialization (Zainb et al., n.d.).

Pakistan's international commitments further underscore its obligations to protect marine ecosystems. As a party to UNCLOS (1982), Pakistan is required to prevent marine pollution and manage its Exclusive Economic Zone

sustainably. MARPOL (1973/78) obligates the regulation of shipping activities to minimize oil spills, waste disposal, and chemical discharges. The Convention on Biological Diversity (CBD, 1992) requires conservation of marine biodiversity, while the London Convention (1972) prohibits the dumping of hazardous substances at sea. Despite ratifying these instruments, Pakistan struggles with enforcement due to limited technical capacity, weak monitoring infrastructure, and overlapping jurisdictions between federal and provincial authorities (Butt et al., 2024b).

Beyond legislation, policy instruments have been introduced to strengthen marine sustainability. The Environmental Impact Assessment Guidelines (2020) aim to standardize ecological risk evaluation for coastal projects, while the National Climate Change Policy (2012) addresses coastal erosion, mangrove conservation, and pollution control. More recently, blue economy initiatives have sought to promote sustainable fisheries, renewable marine energy, and environmentally responsible port management (Ahmed et al., 2023a). However, the pace of industrial and maritime growth in Gwadar often outstrips the capacity of regulatory bodies, resulting in ineffective EIAs, limited community consultation, and weak compliance with environmental safeguards.

The challenges are significant. Fragmented governance creates regulatory ambiguity, limited technical expertise hampers effective monitoring, and weak enforcement mechanisms discourage compliance. Moreover, economic development and environmental sustainability are rarely coordinated, leaving cumulative ecological impacts unaddressed. These gaps highlight the urgent need for legal and institutional reforms to ensure that CPEC-related maritime projects do not compromise Pakistan's coastal ecology. With this governance context established, the next section turns to the direct environmental impacts of Gwadar Port development on coastal ecosystems and biodiversity.

4. Environmental Impacts of Gwadar Port Development on Coastal Ecology

The rapid expansion of Gwadar Port under the China–Pakistan Economic Corridor (CPEC) has profoundly reshaped the coastal landscape of Balochistan. While port development carries undeniable economic and strategic significance, it has simultaneously introduced multiple ecological pressures that threaten the sustainability of Pakistan’s marine environment (A. A. Khan, 2024a).

One of the most visible impacts is habitat alteration and coastal erosion. Port construction requires extensive dredging, reclamation, and shoreline modification. Dredging operations, designed to deepen shipping channels, disturb benthic communities, resuspend sediments, and alter seabed topography (Rashid et al., 2024). These changes destabilize adjacent coastlines, accelerate erosion, and contribute to the loss of mangrove forests—critical ecosystems that provide fish nurseries and natural coastal defenses (A. Khan & Ullah, 2024). The Makran coast and Indus Delta, ecologically linked to Gwadar, are particularly vulnerable to such disturbances.

Water pollution represents another pressing challenge. Industrial activities associated with port operations—such as ship repair, cargo handling, and oil storage—pose significant risks of marine contamination. Oil spills, lubricants, and hazardous chemicals degrade water quality and bioaccumulate in aquatic species (Al Arif & Ershadul, 2013a). Ballast water discharge from international vessels introduces invasive species, further disrupting local ecosystems. Despite Pakistan’s commitments under MARPOL, monitoring and enforcement remain weak, particularly in remote regions like Gwadar (Arslan et al., 2018).

Marine biodiversity has also been adversely affected. Gwadar’s coastal waters host diverse marine life, including commercially important fish, mollusks, crustaceans, and endangered species such as sea turtles and marine mammals. Port expansion and increased shipping traffic fragment habitats, generate underwater noise, and disrupt migratory patterns (Khalid et al., 2022b). The decline of mangrove forests reduces breeding

and feeding grounds, leading to diminished fish stocks and threatening the livelihoods of local fishing communities (Rafique, 2018).

The socio-ecological impacts of environmental degradation are equally significant. Traditional fishing communities face declining catches and reduced income due to biodiversity loss (Jattak et al., 2023b). Industrial expansion and port-related displacement exacerbate socio-economic vulnerabilities, underscoring the need for compensation, livelihood restoration, and community participation in development planning.

Mitigation measures are therefore essential to balance economic growth with ecological protection. Strategic Environmental Assessments (SEAs) should complement project-specific EIAs by evaluating cumulative ecosystem impacts. Mangrove restoration programs can offset habitat loss, while strict pollution control protocols—including compliance with MARPOL, effluent treatment, and ballast water management—are necessary to safeguard water quality. Establishing marine monitoring stations to track biodiversity, sedimentation, and pollution levels would further strengthen compliance and accountability (Jattak et al., 2023b). These measures are critical not only for environmental protection but also for ensuring the long-term economic viability of CPEC projects in Gwadar.

5. Ecological Impacts of Shipping and Maritime Traffic under CPEC

The expansion of Gwadar Port has led to a significant increase in shipping and maritime traffic along Pakistan’s Arabian Sea coast. While this growth supports economic integration and trade, it has simultaneously introduced multiple ecological hazards that undermine marine sustainability (Butt et al., 2024c). The cumulative effects of pollution, noise, accidents, and emissions highlight the urgent need for comprehensive management strategies.

Water pollution remains one of the most pressing concerns. Shipping activities contribute to contamination through oil spills, bilge water release, ballast water discharge, and operational waste. Oil spills are particularly destructive,

coating the sea surface, disrupting food webs, and harming sensitive species such as plankton, fish, and seabirds (Ullah et al., 2022). Ballast water introduces invasive species that compete with native organisms, destabilizing ecological balance. Despite Pakistan's obligations under MARPOL and the Ballast Water Management Convention, compliance remains weak due to limited monitoring and enforcement capacity (Zhang & Yang, 2024).

Noise pollution is another critical issue. Increased maritime traffic generates underwater noise from ship engines and propellers, which interferes with the navigation, communication, and feeding behaviors of marine mammals such as dolphins and whales (Rako-Gospić & Picciulin, 2019). Chronic exposure to acoustic disturbance can reduce reproductive success, alter migratory routes, and pose long-term risks to biodiversity (Ahmed et al., 2023b). These impacts are often overlooked in environmental assessments, despite their profound implications for marine ecosystems.

The risk of accidents and habitat damage also rises with intensified traffic. Large vessels navigating congested shipping routes increase the likelihood of collisions, groundings, and accidental spills (A. Khan et al., 2023). Dredging and seabed modification to accommodate container ships destroy benthic habitats and spawning grounds, while coastal erosion and turbidity degrade coral reefs and mangrove ecosystems—key sources of ecological resilience.

Maritime traffic further contributes to air pollution and climate change. Emissions of nitrogen oxides, sulfur oxides, and particulate matter exacerbate ocean acidification and regional climate impacts, reducing fisheries productivity and intensifying the environmental footprint of port operations (Russo et al., 2023). These emissions highlight the global dimension of Gwadar's ecological challenges, linking local port development to broader climate concerns.

The socio-ecological consequences of shipping are equally significant. Declining fish stocks reduce catches for small-scale fishers, while shipping-related accidents threaten livelihoods and increase social vulnerability (Dahey et al., 2023).

Addressing these effects requires integrating community resilience into maritime management strategies, ensuring that local populations are not marginalized by industrial expansion.

Mitigation measures are therefore essential to align Gwadar's role as a regional shipping hub with international standards of marine environmental sustainability. Strict ballast water treatment protocols can prevent invasive species introduction, while the designation of Emission Control Areas (ECAs) would reduce sulfur and nitrogen emissions in sensitive coastal zones. Routing measures and speed restrictions can minimize habitat disruption and collision risks, while quieter ship technologies can mitigate acoustic pollution. Finally, robust emergency response plans are needed to contain oil spills and maritime accidents swiftly (Aslam et al., 2023). Together, these measures underscore the importance of embedding ecological safeguards into the governance of maritime traffic under CPEC.

6. Compliance with Environmental Law (National & International)

Ensuring marine environmental sustainability under CPEC requires strict adherence to both domestic legislation and international legal obligations. While Pakistan has established a framework for regulating port development and shipping, the rapid industrialization of Gwadar has revealed significant gaps in compliance and enforcement (Ismail et al., 2023b).

At the national level, the Pakistan Environmental Protection Act (PEPA, 1997) is the primary instrument governing environmental regulation. It mandates Environmental Impact Assessments (EIAs) for large-scale projects such as ports and industrial zones, with approvals and monitoring overseen by the Pakistan Environmental Protection Agency (Pak-EPA) and provincial authorities (Cares et al., 2023). In practice, however, compliance in Gwadar has been inconsistent. Many CPEC projects have been criticized for superficial EIAs, limited public consultation, and inadequate consideration of cumulative ecological risks (A. A. Khan, 2024b). Monitoring challenges further weaken

enforcement, as Pak-EPA and provincial agencies face resource constraints, overlapping jurisdictions, and limited technical expertise (Zahid & Khan, 2024). Moreover, unlike Sindh, Balochistan lacks a comprehensive coastal management policy, creating ambiguity in regulating port and industrial activities.

Internationally, Pakistan is bound by several conventions that directly address marine environmental protection. UNCLOS (1982) requires states to prevent, reduce, and control marine pollution, manage resources sustainably, and protect vulnerable ecosystems (Mega Jaya et al., 2024b). MARPOL (1973/78) establishes standards for controlling ship-generated pollutants, including oil, sewage, and garbage. The Convention on Biological Diversity (CBD, 1992) obligates conservation of biodiversity and sustainable use of marine resources, while the London Convention (1972) prohibits the dumping of hazardous wastes into the sea. Despite ratification, Pakistan's implementation remains weak due to insufficient monitoring infrastructure, lack of enforcement mechanisms, and fragmented governance (Durlík et al., 2025). These shortcomings reveal several compliance gaps. Fragmented governance between federal and provincial agencies creates inefficiency, while limited technical capacity undermines marine surveillance and pollution monitoring. Weak enforcement mechanisms, including minimal penalties, fail to deter violations, and the absence of integrated planning means cumulative ecological impacts of port development, shipping, and industrialization are rarely assessed together. Strengthening compliance requires a multi-pronged approach. Institutional capacity building is essential to enhance technical expertise, monitoring infrastructure, and inter-agency coordination. EIAs and Strategic Environmental Assessments (SEAs) must be conducted rigorously, with meaningful stakeholder participation to ensure ecological risks are properly addressed. Legal harmonization is also critical, aligning PEPA and provincial laws with international obligations under UNCLOS, MARPOL, and CBD. Finally, Pakistan should establish a comprehensive marine policy that unifies port development, shipping

regulation, and coastal protection under a single framework (Ahmed et al., 2023c). Effective compliance is not only vital for environmental protection but also for the long-term economic sustainability and international credibility of CPEC projects in Gwadar.

7. Sustainable Development Measures and Policy Recommendations

The development of Gwadar Port under CPEC has generated immense ecological and socio-economic challenges. To ensure that economic growth does not compromise marine sustainability, Pakistan must adopt a comprehensive set of reforms that integrate law, policy, technology, and community participation. These recommendations draw on national experience, international best practices, and principles of environmental law (Zeewaqr, 2024). Strengthening the legal and regulatory framework is a critical first step. Pakistan requires a specialized Marine Environmental Protection Act to unify federal and provincial laws, ensuring consistency in port operations, shipping regulation, and coastal industrial activities (Ismail et al., 2023c). Existing legislation, such as PEPA (1997), should be reinforced through stricter penalties, frequent audits, and effective compliance checks (Afridi, 2025). Domestic laws must also be harmonized with international obligations under UNCLOS, MARPOL, and CBD, so that CPEC projects meet global environmental standards (Rothwell & Stephens, 2023b).

Environmental planning and assessment must move beyond project-specific EIAs toward Strategic Environmental Assessments (SEAs) that evaluate cumulative impacts along the Makran coast. Adaptive management approaches should be incorporated into project design, allowing flexibility to respond to new ecological data. Public participation is equally vital: NGOs, local communities, and stakeholders must be engaged in environmental decision-making, particularly in relation to port expansion and industrial development (Asim & Bakar, 2025).

Technological and operational reforms can further reduce ecological risks. The adoption of green port technologies—such as energy-efficient

infrastructure, renewable energy systems, and low-emission equipment—would minimize environmental footprints. Effective ballast water treatment, oil spill prevention systems, and industrial effluent management are essential to control marine pollution. Noise mitigation measures, including quieter ship engines, speed limits in sensitive zones, and designated shipping routes, can protect marine mammals from acoustic disturbance (Alahmari et al., 2023).

Conservation and habitat restoration must also be prioritized. Mangrove reforestation and coastal ecosystem rehabilitation programs can offset habitat loss caused by dredging and reclamation. Establishing marine protected areas (MPAs) would safeguard biodiversity hotspots, while sustainable fisheries management would prevent overexploitation and support the livelihoods of coastal communities. These measures would not only restore ecological balance but also strengthen socio-economic resilience.

Institutional reforms and capacity-building are indispensable. Stronger inter-agency coordination between federal and provincial authorities, Pak-EPA, Balochistan EPA, and port authorities is needed to overcome fragmented governance. Technical capacity must be enhanced through training programs for marine scientists, auditors, and policymakers in monitoring, risk assessment, and enforcement. Long-term ecological monitoring programs should be established to track biodiversity, pollution levels, and climate impacts, ensuring that policy decisions are informed by reliable data.

Finally, regional and international cooperation is essential. Gwadar's strategic location near the Strait of Hormuz places it at the heart of global shipping routes, making transboundary collaboration indispensable. Pakistan should strengthen partnerships with neighboring states to coordinate pollution monitoring, share ecological data, and establish joint emergency response mechanisms for oil spills and maritime accidents. Engagement with international organizations such as the International Maritime Organization (IMO) can provide technical expertise, training, and financial support for sustainable port operations. Adopting global best practices—such as green port

initiatives, emission control areas, and marine protected zones—would further align Gwadar's development with international standards. Regional research collaborations on biodiversity, climate impacts, and sustainable fisheries would also enhance ecological resilience.

Taken together, these measures highlight the pathways through which Pakistan can reconcile economic growth with ecological protection. They underscore that Gwadar's future as a maritime hub depends not only on infrastructure and trade but also on embedding sustainability into the very fabric of CPEC's development.

8. Conclusion: Balancing CPEC Growth with Marine Environmental Sustainability

The transformation of Gwadar Port under the China–Pakistan Economic Corridor (CPEC) illustrates the complex interplay between economic ambition and ecological responsibility. While the corridor offers unparalleled opportunities for trade, industrialization, and regional integration, it simultaneously threatens fragile coastal ecosystems, marine biodiversity, and the livelihoods of local communities. The analysis has shown that Pakistan's existing legal and policy frameworks, though formally aligned with international conventions such as UNCLOS and MARPOL, remain fragmented, weakly enforced, and insufficient to address the cumulative impacts of port expansion and maritime traffic.

Achieving sustainable development in Gwadar requires more than incremental reforms. Pakistan must strengthen its domestic legal and regulatory structures, improve environmental planning and assessment, adopt green technologies, and prioritize conservation and habitat restoration. Institutional reforms, capacity-building, and meaningful stakeholder engagement are equally critical to ensure that ecological concerns are integrated into economic planning. At the same time, Gwadar's strategic position within global shipping routes demands robust regional and international cooperation. Collaborative efforts with neighboring states, engagement with international organizations, and the adoption of global best practices will be essential to harmonize economic growth with ecological protection.

Ultimately, the success of CPEC and Gwadar Port will not be measured solely by economic output, but by the ability to safeguard marine ecosystems for future generations. Embedding sustainability into the very fabric of CPEC's development is therefore not only an environmental necessity but also a prerequisite for long-term economic resilience and international credibility. Gwadar thus stands as a test case for the Belt and Road Initiative: its trajectory will demonstrate whether large-scale infrastructure projects can reconcile economic ambition with ecological stewardship in a rapidly changing global order.

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