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Navigating the blue economy in Bangladesh: Strategic prospects, challenges and pathways toward sustainable maritime growth

Abrar Azizul Hasan Buhiyan ^{1,2,*}, Md. Fahim Al Muntasir ^{2,3} and Sabrina Hasan Orpa ^{2,4}

¹ Department of Economics, North South University, Dhaka, Bangladesh.

² Young's Organization of Urban Research (YOUR), Mirpur, Dhaka 1216, Bangladesh.

³ Computer Science and Technology, Harbin Institute of Technology, Shenzhen, China.

⁴ Department of Marketing, Independent University, Dhaka, Bangladesh.

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Abstract

The blue economy presents a transformative opportunity for Bangladesh to harness its vast marine and coastal resources for sustainable development. With an Exclusive Economic Zone (EEZ) of approximately 118,813 km² in the Bay of Bengal, Bangladesh stands at the cusp of unlocking significant economic, environmental, and social benefits. This paper critically assesses the current state, opportunities, and barriers to implementing a sustainable blue economy strategy in the country. Drawing on policy documents, sectoral data, and recent literature, the study highlights key sectors such as fisheries, marine transport, coastal tourism, renewable energy, and marine biotechnology that hold substantial potential to diversify the national economy, generate employment, and enhance resilience to climate change. Despite the promise, challenges persist, including institutional fragmentation, environmental degradation, inadequate scientific infrastructure, and limited access to finance and technology. The study proposes an integrated roadmap that aligns blue economy development with national priorities and the UN Sustainable Development Goals (SDGs). It emphasizes the need for robust governance frameworks, scientific innovation, regional cooperation (e.g., through BIMSTEC), and strategic investments to ensure ecological sustainability and inclusive growth. Bangladesh's transition to a blue economy will require harmonizing short-term economic goals with long-term environmental stewardship to build a resilient maritime future.

Keywords: Blue Economy; Exclusive Economic Zone (EEZ); Sustainable Development Goals (SDGs); Fisheries; Maritime Transport; Coastal Tourism; Renewable Energy; Marine Biotechnology; Water Governance; Integrated Roadmap; Regional Cooperation

1. Introduction

The blue economy is a buzz phrase that has gained traction as a transformative framework for sustainable development focusing on the ocean and coastal space for achieving simultaneous economic promotion with ecological resilience and social inclusion. More broadly conceived as the sustainable use of the ocean for economic growth, improved livelihoods, and jobs, but without causing harm to ocean ecosystem health, this model moves beyond the classic ocean economy by focusing on a regenerative and cross-sectorial collaborations [1]. Contradictory to traditional maritime activities based on extraction only, the blue economy includes fisheries, aquaculture, renewable energy, biotechnology, maritime transport and ecotourism along with the recognition of ecosystem services such as carbon sequestration, coastal defense and biodiversity preservation [1]. The ocean economy is worth \$1.5 trillion a year globally and is expected to reach \$3 trillion by 2030, which highlights its importance to human well-being [1]. But in maintaining sustainability, strict governance and oversight of risk to avoid over-harvesting, environmental damage and disparities in resource

* Corresponding author: Abrar Azizul Hasan Buhiyan

access is required. The blue economy will be successful to the extent that economic policies are aligned with ecological thresholds and the principles of inclusive growth [2].

Global and national development pathways are set upon maritime resources, which form the backbone of the global economy and international trade [3]. More than 80% of the volume of world trade is carried out by sea, the proportion being even higher for most developing countries [4, 5]. In addition to shipping, the oceans provide food security, energy, and livelihoods for billions. In the United States, just its coastal counties produce the same amount of economic output as the world's third largest economy, and marine fisheries and aquaculture support the livelihoods over 10% of the world's population [6]. The efficiency of maritime transport requiring only 214 British Thermal Units (BTU) per ton-mile against 292 for rail and nearly a 100 fold difference against trucks with 21,573 well explains its critical place as a means of decreasing trade costs and improving market access.

Despite this, variations remain, landlocked countries have an inherent logistical disadvantage, while coastal countries with strong port, digital and varied maritime sectors show greater economic resilience and the innovative capacity [4]. The urgency of good ocean stewardship is worsen by the climate crisis, where sea levels are rising and ecosystems being placed at risk, putting at risk US \$8 trillion of coastal assets globally [1]. Maritime Context Bangladesh's maritime ambience has undergone a fundamental transformation following resolution of its maritime boundary disputes with Myanmar (2012) and India (2014). Before these settlements, competing claims in the Bay of Bengal were encouraging and lack of investment off-shore, particularly for the exploitation of hydrocarbons, and increased concern for geopolitical activity [7]. The 2012 judgment of the International Tribunal for the Law of the Sea (ITLOS) gave Bangladesh not only equitable rights to the continental shelf but also proclaimed new paths in governance, for instance a 'Grey Area' wherein while Bangladesh leads over the seabed, Myanmar administers the overlying waters [7]. So when all was said and done, the law paved the way for 118,813 km² of sea that was to be Indonesia, a rich area in fishery, energy and shipping. Post settlement study done by researchers like Hussain et al. (2017) [2] underline how this shift has fueled investor optimism and prepared Bangladesh to unlock its blue potential. However, major challenges remain, such as fragmented governance, inadequate technologies, climate vulnerabilities like cyclones and sea-level rise and the requirement for cross-sectorial interventions to ensure ecological degradation from unregulated exploitation is mitigated [1, 7].

Discovering this nascent marine domain will require Bangladesh to incorporate science and technology, just and equitable sharing of benefits and climate adaptation if the country is to realize its version of a sustainable blue economy. This research discusses Bangladesh's strategic options to develop its maritime resources in the face of such complicate scenarios and offers holistic strategies to ensure growth inclusivity and ecological sustainability.

2. Exclusive Economic Zone (EEZ) in the Bay of Bengal

Bangladesh's EEZ in the Bay of Bengal is 118,813 km² between 17°51'N to 24°22'N latitude and 88°55'E to 92°25'E longitude and has become a 'transformative' geopolitical and economic asset, that was acquired through international legal settlements with India and Myanmar [8, 2]. This ocean space which is the very foundation of Bangladesh's Blue Economy aspirations is located in the Bay of Bengal Large Marine Ecosystem (BOBLME), one of the most productive marine zones in the world, producing more than 7% of fisheries catches worldwide [9].

The EEZ is a region of rich and diverse fishery resources with 475+ species of fish which include commercially important stocks of Hilsa shad, Indian Mackerel, and Tuna. Key habitats such as the Sundarbans mangroves, which act as nursery grounds for fisheries and absorb carbon, are highly degraded with mangrove loss of more than 20% since the 1980s attributed to expansion of aquaculture, pollution and coastal development [9]. The Swatch-of-No-Ground Marine Protected Area (MPA), the first MPA to be established in Bangladesh, harbors endangered cetaceans (e.g., Irrawaddy dolphins) and sharks; however, climate-induced ocean acidification and cyclones are threatening ecosystem resilience [10].

Transboundary complexities are the barrier for good governance. Migratory fish stocks including Hilsa and Indian Mackerel, move across national EEZs, and it ultimately requires cooperative management, which is still in the beginning stage [11]. Fisheries disputes continue, as evidenced by the imprisonment of 519 Indian fishers in Bangladesh's EEZ during a 65-day fishing moratorium in 2023 that shows loopholes in enforcement and failure to adhere to UNCLOS Article 73 on the repatriation of fishers [11]. Regional initiatives such as the BOBLME Phase II (2023-2028) seek to promote multilateral cooperation among the seven littoral states on sustainable fisheries and reduction of pollution [9]. Internally, competing interests (offshore energy, shipping lanes) need for integrated zoning and for MPAs to increase, both to accommodate growth yet protect. Yet, institutional fragmentation is a barrier to change.

Coastal living provides the livelihood for over 17 million people who depend on fish as a major source of dietary animal protein contributing to 60% of national animal protein consumption [10]. Small-scale fishers (comprising 90% of the sector) are increasingly vulnerable to falling stocks, the expansion of large scale industrial fishing and climate shocks [11]. Apart from the fisheries, the share of maritime trade is already handling more than 90% of the country's foreign trade through ports of call such as Chittagong and exports from aquaculture attracting over 500 million dollars [10]. But shrimp farming, a primary source of income, increases the salinity of the soil, degrading agriculture and freshwater supplies. Resilience initiatives (e.g., the World Bank coastal polders, GCF-funded women's livelihoods programs) are designed to diversify livelihoods and benefit over 333,000 people from protection against climate hazards [12].

Scaling the EEZs potential includes transboundary stock assessments, harmonized MPA networks to fulfill Aichi target 11 (10% marine protection) and nature-based solutions like mangrove restoration [13]. It is projected that the value of the marine sector can increase to \$72 billion within 25 years, but this will depend upon finding a balance between ecological integrity and sustainable development [9].

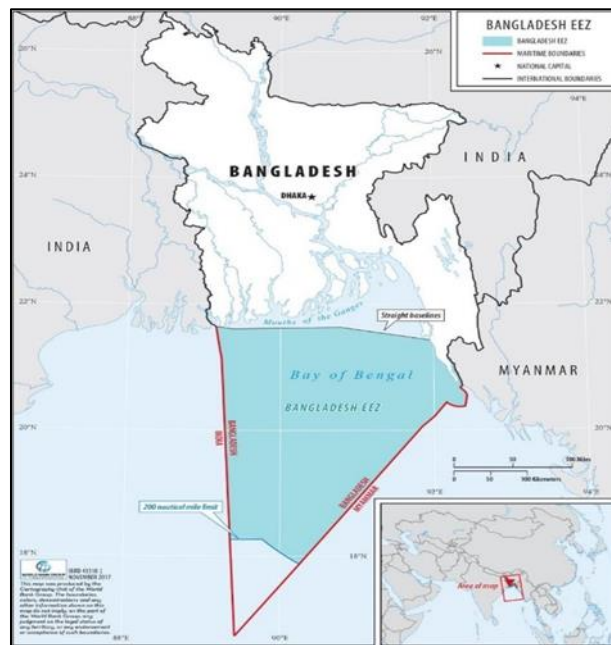


Figure 1 Bangladesh's Exclusive Economic Zone. [14]

3. Bangladesh's Blue Economy

The blue economy of Bangladesh, centred around its 118,813 km² exclusive economic zone (EEZ) in the Bay of Bengal, contains of numerous economic activities that are essential for the overall development of the nation, along with meeting the needs of food and energy security. The next section looks at six key sectors, their contribution to GDP, their strategic importance, problems and their inter-relationships.

3.1. Fisheries and Aquaculture

Bangladesh Blue Economy relies on fisheries and aquaculture as one of the forerunner sector with 3.6% of GDP, which supports hundreds of thousands employment but also their dependents employment as well [15]. Marine fish production constitutes around 20% of the country's total fish yield and the culturally, and economically important hilsa fishery is a major export item. But this sector, too is fraught with enormous challenges, such as overfishing of 40% of surveyed fish stocks, pollution-induced degradation of habitats, and climate change induced intrusion of saltwater into coastal aquaculture ponds [15]. Higher sea levels and cyclonic disturbances pose additional challenges for coastal fishing communities making them increasingly more vulnerable from social perspectives.

Aquaculture is the fastest growing subsector mainly due to the rising demand worldwide. Scientific projections indicate that climate-resilient polyculture practices linked with ecosystem restoration, such as mangroves, can result in 30-40% higher sustainable yields [15]. Five fish week programs by the government will also see investment in modernizing hatcheries and diversifying species to ease pressure on the wild and boost exports. Mangroves can be integrated

ecologically and economically with shrimp to restore and protect ecosystems in a way that respects the power of the market to encourage environmental stewardship.

Table 1 Aquaculture Growth Drivers & Constraints in Bangladesh

<i>Growth Drivers</i>	<i>Major Constraints</i>	<i>Sustainability Interventions</i>
Rising global seafood demand	Salinity intrusion in coastal ponds	Mangrove-integrated polyculture
Hatchery modernization	Disease outbreak	Biosecurity protocols
Species diversification	Feed cost volatility	Algae-based protein substitutes
Export market access	Market certification barriers	Organic/aquaculture certification

3.2. Offshore Oil, Gas, and Renewable Energy

Bangladesh's waters are rich in energy resources with 26 offshore blocks (11 shallow, 15 deep-sea) that have potential natural gas reserves and are vital for the country's energy security [16]. Exploration has been compared to neighboring countries which has awarded Myanmar 20 offshore blocks to foreign companies and Bangladesh has opened bidding rounds only in 2025 [16]. There are technical barriers and financial barriers in the way. Deep-sea based drilling would need \$1.5-2 billion per project investments in infrastructure, which is a financial hindrance [15]. The Payra oil terminal and the Matarbari deep-sea port (14m depth capacity) are the foundational actions to the offshore [16].

At the same time, renewable energy opportunities are being wasted. The Bay of Bengal, has a theoretical potential of 40 GW from offshore wind, tidal and waves energy [17]. Test cases for tidal turbines in the Maheshkhali channel reveal the possibility of hybrid systems. The Asian Development Bank (ADB) estimates a 25% reduction in dependency on fossil fuel by 2040 and the generation of 1,50,000 energy sector jobs by harnessing these resources [17]. Circular economy The circular economy chased by renewable investment in combination with oil-gas extraction, which is roused for example by solar powered drilling platforms, is also a promising approach to cutting carbon footprint in shipping activities.

3.3. Marine Biotechnology and Pharmaceuticals

Marine biotechnology is an emerging cross-cutting and high added value sector in the pharmaceuticals, nutraceuticals and industrial bio-products. The coastlines of Bangladesh contain more than 5,000 marine species, which include antibacterial producing bacteria in the mangrove sediments and anti-cancer compounds from the sea cucumbers [18]. However, commercialization is hindered by restricted R&D capacity. Among current efforts are bio-prospecting partnerships with, for example, the Ocean University of Chittagong, with research focusing on the isolation of enzymes from extremophiles in the Swatch-of-No-Ground submarine canyon [15].

The environmental and governance issues are represented by biodiversity access obligations according to the Nagoya Protocol and compensation to coastal communities. Development of marine natural product libraries could expedite the discovery of drugs maintaining genetic integrity. If the venture capital evolution and the legal framework protecting IP are initiated, the Norwegian model of public-private partnership and exploring the potential of marine biotech in generation of \$350 million annually in Norway can be followed by Bangladesh [19].

3.4. Shipping, Ports, and Maritime Trade

More than 90% (\$80 billion) of Bangladesh's trade passes through maritime shipment operations, which are concentrated in three ports: Chittagong (80% capacity), Mongla and Payra [17, 15]. Permanent poor infrastructure is restrictive (9m at Chittagong Vs.18M Global norms) result of vessel congestions and \$400 million/year demurrage costs [16]. The ADB estimates that an investment of \$1.5 billion in port modernization could triple the country's container capacity by 2035 and turn Bangladesh into a transshipment center between South and Southeast Asia' [17].

Key investments are directed at the Matarbari Deep-Sea Port (commissioned in 2016) which will cater to Panamax-size ships, complemented by the Sonadia Economic Zone. Connectivity at regional level include coastal shipping agreement with India and Myanmar which reduces transit time by 60% as compared to land routes [15].

Table 2 Port Infrastructure Development and Economic Impact

Port Project	Key Features	Trade Impact	Environmental Challenges
Chittagong Upgrade	16m dredging depth	Increase \$5B export capacity by 2030	Dredging sediment disposal
Matarbari Port	14m depth, Panamax Capability	Direct EU/US shipments	Mangrove clearance disposal
Payra Deep-Sea	LNG terminal integration	Energy import cost reduction	Coral relocation programs
Mongla Expansion	Chinese BRI investment	Gateway to north-east India & Myanmar	Sundarbans ecosystem monitoring

3.5. Coastal and Marine Tourism

Annual contribution to GDP from tourism in the coastline is estimated at \$ 6.2 billion (3% of GDP) but remains underutilized [20]. Bangladesh's 75 islands and landmarks, and the famous Cox's Bazar sea beach (longest in the world) coral reefs of Saint Martin's and the Sundarbans mangroves provide the eco-tourists with enough variety. The National Tourism Master Plan (2023-2047) features 255 locations in 11 raiding guilds, focusing on seven low impact resorts on 13 islands [20]. Collaborative UNDP-Bangladesh Tourism Board initiatives are concerned with "Blue Tourism" certification standards, tensions between touristic increase and sea grass/mangrove preservation [20].

Climate change vulnerabilities threaten existential risks which highlights that 20m of Saint Martin's Island might be under water by 2050 [21]. Community based efforts, like the one being run by women fishers to restore coral reefs, mix livelihoods with resilience. The cruise tourism collaborations with India earn foreign exchange but need to be managed for waste to avoid causing plastic pollution of the marine environment. 5,00,000 jobs could be added by 2040 by means of selected investments in eco-lodges and marine animal sanctuaries [20].

3.6. Deep-sea Mining and Seabed Resources

It's still exploratory, but deep-sea mineral extraction has the potential to change the world. Bangladesh's ECS harbors polymetallic modules, which are high in copper, nickel and cobalt, elements indispensable for electronics and renewable energy storage technology [15]. Exploratory studies report a reserve of 5.847 million tons of mineral sands 18T PER cubic meter to a depth of 20 meters, to a distance of 1,500 meters in the inner shelf, and 30m thickness to a distance of 1,600 meters at deeper depths, and 20 km long with a depth of 200m and 4 km width and 40m thickness; as well from static studies about 28 million ton of mineral behind the formed placers in the offshore in between 20 and 50 meters depth, having a value of \$210 billion [15]. But it confronts technology-related challenges like deep-sea mining technology is for depths exceeding 1,000m, while the country's EEZ is only 200m deep on average, calling for tailor-made solutions.

There are severe environmental governance gaps like unpoliced dredging could devastate marine ecosystems and fish spawning areas. The legal systems of the International Seabed Authority are instructive, but Bangladesh does not have specialized laws. The application of a precautionary approach including ecologically sensitive areas (for example: coral rich Swatch-of-No-Ground) with exclusion zones is warranted. Local collaborations with Japan's JOGMEC on seabed mapping and robotic mining methods provide options to reduce environmental impact, even as such projects could help maximize resource return [19].

The Blue Economy, one of the opportunities for transformation, in Bangladesh, still accounts for Fisheries and Maritime Trading. Delivering Sustainable Growth requires tackling sectorial challenges which include overfishing, energy mix, bio tech R&D, port re-modernization, resilient tourism and precautionary seabed resource management. Strategic investment, strong governance (for example: maritime policy integration), science-based conservation and international cooperation will be crucial to ensure that economic benefits are balanced with the long-term health of Bay of Bengal ecosystems [22].

4. Current Initiatives and Institutional Framework

The acceleration of Bangladesh's strategic adoption of the Blue Economy model represents an ever developing momentum, one that began following a series of key resolutions of maritime boundary disputes with both Myanmar (2012) and India (2014) which granted sovereign rights over 118,813 km² of Exclusive Economic Zone (EEZ) in the Bay

of Bengal, a body of water that mirrors the extent of accumulated territorial lands of all of Bangladesh [15]. The creation of a wide institutional and policy architecture to manage marine resources sustainably has been catalyzed by this geopolitical shift. The government's policy is indicative of an increasingly acknowledged understanding of the dependence of the future prosperity of the country upon sustainable management of the country's 'Blue Spaces,' an important assertion, especially since 32% of the terrestrial land is ecologically greatly influenced by the marine environment [23]. This section analyzes how the landscape of government plans, institutional configurations and international relationships have evolved to determine Bangladesh's Blue Economy growth path.

The trend of maritime resources being more and more integrated in national development programming is evident in the government's strategies and policies. The most important theme of Bangladesh Delta Plan is the Bangladesh Delta Plan 2100 (BDP 2100) passed in 2018 by the National Economic Council headed by the Prime Minister. This century-long program names "Advancing the Blue Economy" as one of its nine key themes, framing marine resource development as part of a larger climate resilience and water security agenda. It's a vision to attain a safe climate-resilient and prosperous delta positively connect the development of Blue Economy with poverty reduction, food security and disaster risk reduction [24]. Economic modelling based on BDP 2100 indicates that successful integration of these outcomes can maintain GDP growth above 8% until 2041 and reduce environmentally induced migration from susceptible coastal areas by 50% [24]. The Delta Plan of \$38 billion investment until 2030 on 65 infrastructure and 15 institutional projects is a clear commitment to establishing favorable conditions for sustainable maritime development [24]. Complementarities such as Perspective Plan 2021-2041, and proposed 8th Five-Year Plan (2020-2025) place high emphasis on maritime sector as an engine of economic diversification. These papers underscore sustainable fisheries development, port-based industrialization, ocean-based renewable energy, and coastal tourism recognizing the ecology constraints and climate vulnerabilities [15]. Government has specifically committed to goal of increasing MPA coverage to ten percent of EEZ waters by 2030, in accordance to SDG 14 (Life Below Water) but development of regulatory process and avenues of compliance remain ongoing [19].

Bangladesh's Blue Economy governance architecture follows a complex inter-organizational ecosystem of ministries and specialized agencies to reflect the cross-sectorial character of maritime development. The overall authority concern rests with the MoFA, which set up a specialized Blue Economy Cell in the wake of the maritime boundary decisions. This cell facilitates inter-ministerial policy making and is the hub for international maritime cooperation [25]. Marine fisheries are an extremely important natural resource that contribute 3.6% to GDP and provide livelihoods to millions of coastal people in Bangladesh [19]. At the same time, port infrastructure development is supervised by the Ministry of Shipping (MoS) through the Bangladesh Ports Authority, which promotes expansion projects in the three seaports: Chittagong, Mongla and Payra, so as to make the most of the country's strategically located ports on the key shipping lanes of the world [15]. MPEMR has jurisdiction over offshore hydrocarbon exploration and nascent marine renewable energy (MPEMR) whereas MoEFCC considers the ecological aspects of conservation [19].

Even with this wide institutional field, important coordination challenges remain. Studies by Failler et al. (2019) [26], examine institutional fragmentation and the existence of overlapping mandates as critical obstacles, with at least 17 government agencies working in ocean governance with no evident hierarchical order or single policy framework. This fragmentation, as described in the lead contribution, can generate competing priorities such as resource development objectives and conservation needs. To overcome these shortage, scholars and development partners are calling for the establishment of a separate Ministry for Maritime Affairs or creating a empowered Blue Economy Authority, which would have the authority for cross-sectorial coordination and a technical capability [15]. The BDP 2100 creates a Delta Governance Council, under the leadership of the Prime Minister and an inter-ministerial forum to set strategic direction, potentially a mechanism to better coordinate maritime affairs [24]. Moreover, academic institutes such as the Department of Oceanography of the University of Chittagong offer more specialized courses in response to a human resource shortage. However, skills of conducting deep sea resource assessment, marine spatial planning and offshore monitoring are in shortage [19].

International collaborations and obligations are a third dimension of Bangladesh's Blue Economy blueprint, bringing critically needed technical knowhow, funds and diplomatic backing. The World Bank has become a key partner, pledging around \$1.8 billion in delta-related infrastructure to support maritime growth, such as port upgrades, inland waterways, and climate resilient coastal embankments [24]. As part of its South Asia Water Initiative, the Bank supports the Bangladesh Water Platform which brings development partners together around the implementation of the Delta Plan, including Blue Economy elements [24]. Regional cooperation takes place primarily in the Bay of Bengal Initiative for Multi-Sectorial Technical and Economic Cooperation (BIMSTEC) for which Bangladesh pushes for combined efforts in marine safety, sustainable fish management and marine disaster management [19]. Regional cooperation within BIMSTEC can greatly enhance in maritime resource management, by lowering of geopolitical tensions in the Bay [15]. Bangladesh is also party to global ocean governance instruments like the United Nations Sustainable Development Goals

as well as the Convention on Biological Diversity and the UNCLOS Implementation Agreements. These commitments offer normative guidance for national policy although implementation deficits remain between international commitments and domestic regulations [27]. Knowledge transfer has been facilitated by academic partnerships such as between the Nicholas Institute for Environmental Policy Solutions in Duke University and support building evidence based policy options is evidenced in 2018 seminal report, “Toward a Blue Economy: A pathway for sustainable growth in Bangladesh” [23]. The ENR has started investigating interest in areas such as deep sea resource assessment and management (with Norway and Sweden), and integrated coastal zone management (with the Netherlands), where those countries have strength in areas of governance and technology [26].

The institutional and strategic landscape of Bangladesh’s Blue Economy is dynamic and evolving, in response to development imperatives, ecological imperatives and changing governance capabilities. Significant advances in policy thinking and institutional experimentation have taken place since the maritime boundary settlements, yet it is clear that implementation issues associated with interagency coordination, technical capacity, regulatory enforcement, etc. divert from the best possible outcomes. Prospects for future institutional development including strengthened legislative authority on integrated ocean governance; improved scientific capacities in resource assessment and monitoring; and more differentiated forms of international engagements that elevate technology transfer and capacity building on par with infrastructure finance. As Bangladesh grapples with these challenges that its experience is likely to offer lessons for other developing littoral states striving to adapt maritime economic ambitions with sustainability imperatives in a climate-uncertain world.

5. Opportunities and Potential Benefits

The Blue Economy offers a valuable economic opportunity to Bangladesh using the 118,813 km² of Exclusive Economic Zone (EEZ) in the Bay of Bengal [15]. According to World Bank estimates, the sustainable exploitation of marine resources will contribute to 4.5% of Bangladesh’s GDP by 2030, receiving about \$42 billion in value-added output [28]. The fishery sector alone already accounts for 3.6% of GDP and provides millions of livelihoods, directly and indirectly [15]. Strategic investment could increase that contribution even further from growing sectors like offshore renewable energy and marine biotechnology. According to the Bangladesh Centre for Advanced Studies (2024), Blue Economy has potential to create between 1 and 4 million jobs in coastal ecosystems and is expected to reduce underemployment in these vulnerable areas [28]. Commercial deep sea fishing could raise the annual production of fish from 95,000 tons now to above 500,000 tons, bringing the country up to the levels achieved by regional neighbors like India and Myanmar [29].

Table 3 Projected Economic Contributions of Blue Economy Sectors in Bangladesh

Sector	Current Contribution	Projection (2030)	Employment Potential
Fisheries & Aquaculture	\$585 million GDP (2019)	\$8-10 billion	2.1 million jobs
Marine Renewable Energy	<1% energy mix	30% of coastal energy demand	300,000 jobs
Coastal Tourism	\$129 million annually	\$1.5 billion	500,000 jobs
Ports & Shipping	90% of export volume	\$12 billion logistics hub	800,000 jobs

Source: [28, 15, 25]

Similarly, emergence of Blue Economy, particularly among the coastal communities comprising of more than 35 million populations, has been increasingly considered as potentially profitable to coastal community through diversification of livelihood and resilience building interventions [30]. Environmentally sound mariculture projects like shrimp farms, seaweed farms, and oyster reef restoration can provide alternatives to fishing for a living, which is threatened by depleted stocks. The nascent seaweed industry currently involves 2,500 fishers, and could grow tenfold with the help of technology [28]. Readily-available community ecotourism based on the Sundarbans and Cox’s Bazar alone could bring in \$500M per year, all the while protecting prime habitat [31]. They reduce the vulnerability to sea-level rise and salinity intrusion in coastal regions, and as a result, enhance food security in the coastal area [30]. Marine biotechnology, aquaculture processing and renewable energy installation skills development programmes would raise 1.2 million youth from underemployment to technical skilled jobs by 2040 [29].

Export structure of Bangladesh is still very much dependent on RMG which contributes to 84% of total export earnings [28]. The blue economy allows for a dramatic diversification due to the production of high valued marine products and service that is rich in knowledge. Exports of processed fish (e.g., Hilsa, tuna loin, and value-added pharmaceuticals, such

as omega-3 oils) could be worth \$5-6 billion per year, compared with the current \$1.4 billion [28, 29]. Biotechnology in sea -unexplored potential: spirulina based nutraceuticals, cosmeceuticals from corals and algal biofuels may engage small global markets but could make a value of \$200 billion [29]. Strategic development of deep-sea port hubs (Matarbari and Payra) would allow Bangladesh to act as a transshipment pivot between South and Southeast Asia, potentially commanding 15–20% of regional ocean-borne cargo [15, 31]. In addition, low cost labor in Bangladesh could be used in shipbuilding and repair to challenge Singapore and Dubai and increase exports by \$2 billion [29].

The Blue Economy requires transboundary technology collaboration and domestic innovation enablers. Public-Private Partnerships (PPPs) with nations such as Norway (aquaculture tech), Japan (offshore wind), and the Netherlands (coastal engineering) can also facilitate knowledge transfer and overcome R&D costs during the innovation phase [19, 29]. Fishery-monitoring with the help of Bangladesh Satellite-1 (BS-1) in the space era and its data processing by AI based stock assessment model have potentialities to optimize fish catch without any fear of overfishing [29]. Investment in marine biotech research institutions, which are modeled on Canada's marine biotechnology clusters, would foster innovation in bioprospecting and deep-sea mineral mining [19, 25]. Renewable energy sources such as off-shore wind farms and tidal energy converters alone have the potential to meet 30% of the country's energy demands by 2040 thereby minimising the requirement for imported fossil fuels [31]. Blockchain-enabled traceability certification on digital platform would also provide compliance to EU and US sustainability standards and premium prices under ecosystem friendly certificate seafood [15].

The convergence of these opportunities means that Bangladesh may be able to attain 12 out of 17 UN Sustainable Development Goals (SDGs), for instance, SDG 14 (Life Below Water), SDG 8 (Decent Work), and SDG 7 (Clean Energy) [19]. Despite this fact for benefits to be maximised, there is a need for stronger governance mechanisms and an institution such as a Blue Economy Authority to monitor aligning policy frameworks across fisheries, energy, and transportation sectors [15]. Protective measures such as marine protected areas (MPAs), mangrove restoration, and zero-discharge from industries have to be coincided with economic activities for sustaining ecological resilience [30]. BIMSTEC regional cooperation can help deal with common challenges such as IUU fishing and maritime security, in addition to sharing resources for deep-sea exploration. Requiring USD 15-20 billion of FDI over the next 10 years, Bangladesh should enact specific maritime FDI legislation and fiscal incentives in order to capture worldwide capital [29].

6. Challenges and Barriers

The search for a vibrant Blue Economy of Bangladesh is challenged through various dimensions like institutional, environmental, climatic, technological and security issues. Institutional weakness and policy gaps are evident through the lack of coherent governance architecture and inefficient regulatory functions. The country has no separate ministry or authority for its maritime activities, and its 17 ministries and agencies have overlapping responsibilities that hinder the coherence of policy formulation and implementation [15]. Institutional barriers despite recent positive moves, regulatory environments are still burdensome and described as bureaucratic, with very difficult registration requirements, and also arbitrary fees and costs not evidenced-based all barriers to investment, which also undermine compliance [32]. This diffusion of institutions is compounded by weak enforcement, little inter-agency co-operation and vulnerability to corruption, all of which contribute to the failure of transparent management of resources and environmental protection. These governance gaps are magnified through the lack of an integrated maritime spatial planning policy that would otherwise prevent limitless exploitation of the marine resources without any environmental inspection [15, 29].

Degradation of environment removes a lot of risk of marine ecosystems from a variety of vectors. Major river systems and coastal waters are polluted by industrial discharge, agricultural runoff, and untreated sewage, and this pollution results in more than 272,000 premature deaths per year and cost for the country an estimated 17.6% of the GDP in health and productivity losses [4]. The massive growth and expansion of the shrimp industry has led to the large-scale exposure of mangrove forests and the resultant increase in salinity of groundwater and removal of fish when illegal fishing methods and trawling were used, threatening the food security of coastal communities who rely on marine protein [15]. Plastic pollutants and other untreated garbage further compromise marine ecosystems, and country's key river Buriganga not only suffers from severe water quality degradation that endangers diversity and human health. These anthropogenic forces interact synergistically to create ecological tipping points that erode the natural capital, on which the Blue Economy is based [4].

The adverse effects of climate change, including the rise of sea levels pose as empirical challenges to the maritime endeavour of Bangladesh. Already with two-thirds of the country lying below 15 feet of sea level, the heightened in rise of the sea level (50 cm by 2050), would submerge 11% of Bangladesh's land, displace some 18 million coastal dwellers,

and raise soil salinity by 26% in that time [33]. This salinization has already spread to 105.6 million hectares of agricultural lands and fresh water, polluted drinking water and decreased rice yields in the coast [33]. Climate migration contributes to unregulated urban sprawl, and every year about 400,000 climate-migrants move into Dhaka, settling in informal settlement without basic amenities. Intensifying matters like strengthening cyclones, that have become more frequent and more severe, resulting in enormous financial damage. Due to cyclone Amphan in 2020, 176,007 hectares of cultivation's land under cultivation lost and its coastal infrastructure vital to marine industries perished [33, 34].

Limited capacity for research and technical deficiencies greatly restrict evidence-based policy and resource generation. Bangladesh has had a history of low investment in marine science, with only minimal state investment in oceanographic research and lack of lab facilities within universities [29, 15]. A number of information gaps remain for deep offshore hydrocarbon resources, pelagic fish resources, inventorying of marine biodiversity, and estimating renewable energy potential resources in the EEZ. In spite of RTI Act 2009, data availability is still an issue as researchers find it difficult to get primary data from government and private agencies making them depend on non-authentic secondary sources [29]. Human resource: The latter constraint is due to the lack of higher education programs designed to exploit the marine resources (university courses in marine biotechnology, offshore engineering, maritime law), human capital stock deficiency and lack of adequate technology for deep-sea resource exploitation and modern fishing. Bangladesh cannot perform effective inventory or sustainable management of its 118,813 km² maritime domain without substantial improvement of its marine scientific research infrastructure and international knowledge partnerships [29, 15].

There are traditional and non-traditional security and governance issues covering the bay of Bengal. The contest among India, China, and the United States is an integral source of sovereignty issues for Bangladesh, which the country tries to overcome with managing complex power structures and maintaining neutrality in the region, as it has been outlined in its Indo-Pacific Outlook [34]. Non-traditional security challenges include foreign vessels engaging in illegal, unreported, and unregulated (IUU) fishing activities; Drug smuggling through main channels originating from the Golden Triangle; Human traffickers capitalizing on the outflow of Rohingyas; and returning pirate threats to commercial sea lines of communication. Older regionalist mechanisms such as BIMSTEC continue to battle with conflicting national agendas, jurisdictional jealousies and weak information-sharing arrangements. Bangladesh is currently developing its naval capabilities and while strong investment in surveillance contributes to improved maritime domain awareness, comprehensive coverage over the full EEZ is challenging due to budgets restrictions [34]. Adding to this, climate induced displacement may further exaggerate vulnerabilities to human security that criminal networks exploit, resulting in intersecting governance crises along the coastal and maritime [33].

These multi-dimensional challenges combine to form complex trade-offs between development, sustainability and equity. Specifically, the increase in shrimp aquaculture may generate export income, but also accelerate the destruction of mangrove, which offer invaluable coastal protection services valued at around US \$250 million in avoided disaster damages annually [15]. And offshore hydrocarbon exploration could sustain energy security, though it may also lead to disastrous pollution in a region already under considerable environmental strain. Addressing such tensions calls for integrated governance approaches that harmonize between short-term economic imperatives and long-term ecological resilience, taking special care of climate adaptation actions in risk-exposed coastal communities [4, 15, 27].

7. Strategic Recommendations

If Bangladesh's potential of US \$6.2 billion of blue economy opportunity over an Exclusive Economic Zone of 118,813 km² in the Bay of Bengal is to be unlocked, multi-focal governance will need to amend institutional fragmentation through an unified National Blue Economy Authority endowed with constitutional powers that enables to coordinate the maritime policies across the present silos by 17 ministries and agencies [19, 15]. This apex body will develop MSPs and ensure the enforcement of standard environmental protocols, and develop together with a public-private data sharing the digital visible assets to fill in crucial regulatory gaps in marine biotechnology and seabed mining that at present discourage investment and lead to the extraction of resources in an unsustainable manner [19, 35]. Without the centralised coordination and the updated legal frameworks, the competing sectoral focus can prevail at the cost of sustainability goals even if resources exist for conservation as we have seen through overlapping governance in fisheries, energy, and transport sectors leading to predicament of enforcement among off shore surveillance [15].

Capacity development would mean increase national investment in marine research infrastructure by setting up dedicated institutions for oceanography at Chittagong, Khulna, and Barishal universities with technology transfer collaboration models from Norway and Japan with their sophisticated offshore know-how could serve to establish sustainable models for tropical marine science [19, 15]. Creation of a National Marine Data Repository with remote sensing technologies and AI analytics (ensuring completion of 73% knowledge gap representing benthic biodiversity to map) and 500 trained ocean professionals per annum through BIMSTEC academic exchanges in areas like Sustainable

Fisheries Management and renewable energy technologies [36, 15]. Empirically, a 10% rise in marine science investment translates to a 2.3% gain in GDP through the efficient utilization of resources, showing that the scientific capital directly leads to economic returns, of maritime resources and reduces ecological consequences due to unregulated trust [35].

Marine spatial planning should incorporate an ecosystem-based zoning via defining 30% of EEZ as MPAs alongside shipping corridors and renewable energy zones through a participatory GIS mapping with coastal communities that will provide a balance between economic activities and ecological resiliency against the climate vulnerabilities risking 40 million coastal inhabitants [19, 37]. Integrated coastal management requires the rehabilitation of 5,000 km² of Sundarbans adjacent mangroves with community-based adaptation funding, and enforcing climate-proof building standards for port infrastructure, to reduce the annual \$1.2 billion damage from cyclones, and protect essential habitats for commercially important species such as Hilsa shad, which provides 20% of marine catches [15]. This type of spatial governance discourages sectoral conflict (e.g., Offshore drilling's damaging of fishing grounds) through legally binding environmental impact assessments and real-time vessel monitoring, by aligning scale of economic production in space with estimates of carrying capacity of marine ecosystems [19]. The fragmentation of water governance in Bangladesh necessitates legal integration, as Ahmed et al. (2023) [38] argued, to streamline the mandates of overlapping institutions and create a cohesive regulatory framework.

Long-term financing requires blue bonds and debt-for-nature swaps by harnessing US \$700 million annual fisheries export earning of Bangladesh with the risk-sharing facility by the Bangladesh Bank to contribute 15% of its foreign exchange reserves support as a trade-off loan to offshore wind and mariculture projects certified by third-party sustainability standards [15, 35]. Public-private partnerships should work on the basis of 30-year build operate transfer contracts for the modernization of deep-sea ports at Matarbari and Payra, after increasing cold chain facilities to reduce post-harvest losses from 40% to 15%; doing so would unlock an additional US \$2.1 billion in investment at the same time promoting technology transfer and benefit-sharing with traditional fishers [19, 15]. Hybrid financing is an appropriate blend of philanthropic and commercial funding, where one can effectively use funding for risk minimization, for instance, an offshore wind farm or a blue carbon project, thus catalyzing private institutional investment, complemented by affordability derived from progressive tariff mechanisms and community ownership [35].

To break through recession, the region should push for greater regional cooperation (including more active Bangladesh leadership within BIMSTEC's Blue Economy sub-sector) with the creation of a Bay of Bengal Resource Management Council as a platform for joint surveillance against illegal fishing, and the establishment of harmonized customs procedures that lower by 25% the cost of sea-borne trade across member countries [36]. For cross-border management that constitutes mutual marine pollution possibility planning and climate-proof infrastructure interdependent on the BIMSTEC Coastal Resilience Initiative based on a regional adaptation levy on shipping containers to address shared vulnerabilities such as salinity intrusion that affects 12% of arable land [36, 37]. Bangladesh must actively advocate a Bay of Bengal Treaty to ensure fair and equitable exploration and sharing of hydrocarbon reserves to avoid geopolitical conflicts and to harness pooled expertise for deep-sea mining and offshore wind projects that are beyond the scope of individual nations and that could help transform the bay from being a contested periphery into an integrated economic corridor [36, 37].

8. Aligning with Sustainable Development Goals (SDGs)

The pursuit of a Blue Economy framework for Bangladesh is, therefore, a strategic commitment to the United Nations Sustainable Development Goals, with SDG 14 (Life Below Water) as a primary anchor. The country's Blue Economy with its maritime domain within the Bay of Bengal includes a 118,813 km² Exclusive Economic Zone EEZ and currently directly contributes to SDG 14 through sustainable fishery, ocean and marine pollution, and ecosystem conservation. Empirical analyses show that Bangladesh's Blue Economy is directly linked to 12 of the 17 SDGs; in addition to SDG 14, they include SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work), and SDG 13 (Climate Action). For example, SDG Target 14.4 End Overfishing mandate is also linked to a national program to restore hilsa population through locally managed fish sanctuaries. This initiative increased hilsa quantum by 85% from 2005 and currently supports 500,000 coastal households. However, IUU, plastic pollution 73,000 tons of marine plastic annually enter the Bay of Bengal, and habitat degradation, including through sand dredging are still pressing issues that require better governance such as the Joint Management Centre for vessel monitoring. SDG 14 is thus directly linked to other goals; for instance, the Blue-Green Revolution rice-fish farming systems boosted rice yields by 8-15% and fish production by 183,243 tonnes/year, contributing to SDG 2 (food security) and SDG 1 (poverty reduction) at the same time.

Moreover, the Blue Economy serves as a foundation for climate adaptation and green growth, allowing Bangladesh to address its high vulnerability to climate change. Offshore renewable energy facilities, including the 30 GW of planned wind capacity, fall under SDG 7 (Affordable Clean Energy). They decrease annual Carbon dioxide emissions by 78 million metric tons and reflect available instance using U.S. and Norwegian models. In addition, the Sustainable Forests and Livelihoods Project has already restored 255,000 hectares of coastal forests, which increases carbon sequestration as per SDG 13 and protects against storm surges the 19 million people dependent on forests. There are scientific and research data demonstrating this type of ecosystem-based adaptation lowers disaster risks by over 40% in cyclone-prone Kuakata. Other projects, such as the Sustainable Coastal and Marine Fisheries Project supported by the World Bank, ensure climate-resilient livelihoods to 60,000 poor coastal households. Impliedly, this helps reduce overfishing pressure through alternative income and supports SDG 8 (Decent Work). These areas of convergence validate the findings of Alam, (2017) [39] who argues that investment in the Blue Economy for LDCs should prioritize special and differential treatment.

Overall, SDG alignment is partially achievable without addressing institutional and technological barriers. Marine spatial planning, fragmented regulation, and limited enforcement compensated for reduced ecological sustainability, such as ongoing habitat loss in the Sundarbans. The 8th Five-Year Plan and Perspective Plan 2041 of the Government of Bangladesh proposed an integrated Blue Economy Authority and regional cooperation with BIMSTEC for transboundary resource management. Technology transfer, however, is still required. LDCs such as Bangladesh emphasized during the UN Ocean Conference in their national statement that they need remote sensing, bioprospecting, and oceanographic monitoring tools to achieve SDG Target 14.A. A technology bank dedicated to LDCs or coastal nations could assist, as Bangladesh lags behind developed economies in marine biotechnology, although it contains vast potential microbial biodiversity.

9. Conclusion

Bangladesh's marine area, secured through historic boundary agreements, including its extensive Exclusive Economic Zone (EEZ) in the bio-diverse Bay of Bengal, represents a strategic pathway to sustainable development, climate resilience, and inclusive economic progress. The main findings replicate the high promise that lies in this "Blue Gold", with fisheries and aquaculture today already making a great contribution to GDP and lives, and with new edges such as offshore renewable energy, marine biotechnology and deep-sea port logistics expected to lead the diversification of the economy beyond traditional sectors and to factor millions of jobs. Estimates suggest that the blue economy could bring in tens of billions of dollar receipts from the marine sector value and contribute substantially to national GDP as early as 2030, providing a critical engine for structural transformation. But tapping into that potential will require some hard work. This widespread institutional fragmentation throughout many ministries hinders integrated decision-making, and significant ecological challenges, for example: over-fishing, habitat loss, coastal retreat, and rising climate-related risks such as sea-level rise and cyclones, endanger not only ecological integrity but also economic viability. In addition, the low level of science and technology capacity, the shortage of oceanographic research, and lack of data to make rational decisions also restrict the capacity of the State to utilize the deep-sea resources and to manage the resources in an effective way.

An integrated and progressive road ahead for Bangladesh's sustainable maritime future requires strong governance, scientific innovation and regional cooperation. Creating a well-resourced Blue Economy Authority with robust cross-sectorial coordination powers is crucial in order to rationalize the overlap between policies, regulations and conflicting mandates, and to ensure coherent and coordinated delivery of national strategies such as the Bangladesh Delta Plan 2100. At the same time, significant investment in homegrown scientific and technical talent-building mandatory; this entails prioritizing the development of homegrown oceanographic research institutions, deploying state of the art monitoring technologies such as satellite surveillance and AI for stock assessments, and cultivating trained human resources for deep-sea exploration, marine spatial planning and biotechnology R&D. Strategic zoning of the EEZ to accommodate competing uses (fisheries, shipping lanes, energy extraction, conservation zones, and tourism) is important to avoid conflict and damage, and only possible with a thorough marine spatial planning exercise. Sustainable financing schemes Public-Private Partnerships (PPP), among others in addition to targeted incentives must be leveraged in order to secure the kind of foreign direct investment that both is necessary to modernize ports, fund renewable energy opportunities, or dictate resilient climate infrastructure. Inescapably, environmental stewardship will need to be integrated into all blue economy operations, with strict monitoring (to enforce marine protected area networks, high-risk mangrove restoration projects, and tough pollution regulations) and the activation of the precautionary procedure particularly in the case of emerging industries, such as deep-sea mining. Last but not least, acknowledging that the Bay of Bengal is a large marine ecosystem, deepening the existing regional cooperation under frameworks like the BIMSTEC is indispensable in dealing with the common transboundary issues including illegal fishing, maritime security, stock conservation, and disaster responses, and joint research and in transferring the benefits of the sustainable development

of the BoBLME to all littoral states. If it can pursue this integrated pathway with sustained determination, Bangladesh can navigate the complexities of its blue economy to turn its maritime heritage into a backbone of lasting prosperity, ecological vitality, and resilience to climate challenges of the 21st century.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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