Open Access

Contemporary Research Analysis Journal

e-ISSN: 3050-5909
p-ISSN: 3050-5895

Volume 02 Issue 05 May 2025
CrossRef DOI: 10.55677/CRAJ/09-2025-Vol02I05

Page no: 312-317

Renewable Energy in the Marine Environment: An Environmental Imperative, Awareness, and Action Towards a Greener Maritime Sector

Phan Trung Hai[1], Dang Thi Minh Nguyet[2]
[1,2]Class QL2301, University of Transport Ho Chi Minh City

Corresponding Author: Phan Trung Hai

ABSTRACT: As marine ecosystems increasingly face pressure from climate change and fossil fuel dependency, offshore renewable energy emerges as a crucial pathway toward sustainable development. This paper explores the vast potential of marine renewable energy sources—offshore wind, wave, tidal, ocean thermal, and solar—in reducing greenhouse gas emissions, enhancing energy security, and promoting a green maritime economy. The study emphasizes the importance of ecological assessment, integrated spatial planning, and community engagement in developing Vietnam's marine energy sector. Notably, Vietnam's offshore wind potential exceeds 1,000 GW within its Exclusive Economic Zone, offering transformative opportunities for decarbonizing maritime industries and meeting global climate goals. Case studies such as the Thăng Long offshore wind project (600 MW) exemplify the synergy between environmental awareness and actionable transition. While challenges remain, including high investment costs and ecological risks, the paper proposes solutions involving cross-sectoral cooperation, green technology deployment, and inclusive policy design. Ultimately, marine renewable energy is not only a technological necessity but also an ethical commitment to a cleaner and more resilient future.

KEYWORDS: Marine renewable energy, offshore wind, sustainable development, Vietnam, energy transition.

1. INTRODUCTION

In the context of depleting energy resources and the negative environmental impacts of fossil fuels, renewable energy has emerged as a sustainable and essential pathway. Among renewable energy sources, marine energy stands out due to its vast potential, diversity, and minimal pollution. Marine energy sources such as offshore wind, tides, waves, and ocean thermal energy offer significant benefits for sustainable development, reducing greenhouse gas emissions, and promoting a green economy. The exploitation and utilization of marine energy not only diversify national energy supplies but also create new opportunities for innovative technologies and sustainable development, paving the way for a cleaner and safer future for the planet. This article focuses on renewable energy in the marine environment, not only as a technological solution but also as an integral part of raising awareness about planetary responsibility and taking concrete actions toward a green lifestyle, highlighting the critical role of renewable energy in advancing the maritime industry.

2. CONTENT

2.1. Theoretical Basis of Renewable Energy in the Marine Environment

Concept:

Renewable energy in the marine environment refers to energy derived from continuous and inexhaustible natural elements in the marine environment, such as: Offshore Wind Energy: Harnessing the kinetic energy of wind blowing over the sea using wind turbines mounted on fixed or floating structures; Wave Energy: Converting the kinetic energy of ocean waves into electricity through floating, submerged, or shore-based devices; Tidal Energy: Utilizing the kinetic energy of tidal flows to drive turbines, similar to river hydropower. This can involve tidal barrages or submerged tidal stream turbines; Ocean Thermal Energy Conversion (OTEC): Exploiting the temperature difference between warm surface water and cold deep water to operate a thermal cycle and generate electricity; Ocean Current Energy: Harnessing the kinetic energy of stable ocean currents using submerged turbines. Marine Biomass Energy: Using seaweed or other marine plants to produce biofuels; Salinity Gradient Energy: Extracting energy from the difference in salt concentration between seawater and freshwater at river mouths

Characteristics:

Sustainability: These energy sources are naturally replenished and inexhaustible over time; Immense Potential: Oceans cover much of the Earth's surface, providing abundant energy resources; Reduced Greenhouse Gas Emissions: Emits little to no

greenhouse gases compared to fossil fuels; Energy Security: Helps coastal nations reduce reliance on imported energy; New Economic Opportunities: Creates new industries, jobs, and investment opportunities.

2.2. Theoretical Framework for Marine Renewable Energy Research and Environmental Actions

Role of Marine Renewable Energy in Achieving Sustainable Development Goals (SDGs):

SDG 7: Ensure access to affordable, reliable, sustainable, and modern energy for all:

Enhancing Clean Energy Supply: Marine renewable energy, including offshore wind, wave, tidal, and ocean thermal energy, provides clean and sustainable energy sources, reducing dependence on polluting fossil fuels; Diversifying Energy Mix: Integrating marine renewable energy into the energy system diversifies supply sources, enhances energy security, and mitigates risks from fossil fuel price volatility; Powering Remote Areas: Marine renewable energy solutions can provide electricity to coastal and island communities where access to the national grid is challenging, contributing to poverty alleviation and improved quality of life (related to SDG 1).

SDG 13: Take urgent action to combat climate change and its impacts:

Reducing Greenhouse Gas Emissions: Marine renewable energy generates little to no greenhouse gas emissions during operation, significantly contributing to carbon emission reduction and slowing climate change; Enhancing Climate Resilience: Developing sustainable marine renewable energy systems helps coastal nations achieve energy autonomy and mitigate climate-related risks.

SDG 14: Conserve and sustainably use the oceans, seas, and marine resources for sustainable development:

Reducing Marine Pollution: Compared to fossil fuel extraction and transportation, marine renewable energy has the potential to cause less marine pollution if managed effectively; Sustainable Use of Natural Resources: Marine renewable energy harnesses natural and renewable ocean resources, contributing to their sustainable use; Supporting; Conservation Goals: Transitioning to clean energy can reduce pressure on marine ecosystems caused by unsustainable resource extraction; Green Economy: An economic model aimed at minimizing environmental risks and ecological scarcity while promoting sustainable development. Marine renewable energy is a key component of the green economy.

2.3. Multidisciplinary Theoretical Foundation for Marine Renewable Energy

Marine Environment: Marine Ecosystem: The marine ecosystem is a complex environment with high biodiversity, encompassing benthic organisms, fish, marine mammals, phytoplankton, and migratory species; Ecological Impacts: The deployment of marine energy projects (wind, wave, tidal) may alter the physical and chemical conditions of the marine environment, such as underwater noise, currents, sediments, electromagnetic fields, temperature, and light; Risk of Biological Disruption: These factors can affect the migration, reproduction, foraging, and behavior of marine species.

Technology and Engineering: Offshore Wind Technology: Includes fixed or floating wind turbines connected to the grid via underwater cables, which may generate noise and electromagnetic fields; Wave and Tidal Energy Conversion Devices: Typically located underwater, affecting currents, seabed topography, and sediment; Marine Grid Technology: Involves power transmission and energy integration systems, related to electromagnetic impacts on sensitive marine species (e.g., sharks, rays).

Marine Economy and Sustainable Development: Reducing Fossil Fuel Dependence: Marine renewable energy is a key solution to reducing greenhouse gas emissions and reliance on fossil fuels; Green Growth: Contributes to job creation, the development of clean energy industries, and synergies with related marine economic sector; Environmental Cost-Benefit Analysis: Balancing economic benefits with environmental costs is essential for optimizing sustainable development policies.

Law, Planning, and Marine Policy: Marine Spatial Planning (MSP): Coordinates marine activities to minimize conflicts between energy development, fisheries, maritime transport, and ecological conservation; International and Domestic Policies: Commitments to emission reductions (e.g., Paris Agreement), marine environmental protection laws, and Environmental Impact Assessment (EIA) regulations form the mandatory legal framework.

Social Sciences and Coastal Communities: Environmental Justice: Ensuring benefits for coastal communities, especially vulnerable ones, affected by changes in the marine environment. Science Communication and Education: Raising community awareness of the benefits and risks of marine renewable energy fosters social support.

Application of Digital Technology and Artificial Intelligence; Marine Environment Simulation: Using hydrodynamic, geophysical, and ecological models to predict the impacts of marine energy projects; AI and Big Data Applications: Analyzing data from sensors, satellites, and monitoring devices to optimize operations and minimize environmental risks.

2.4. Impacts of Marine Renewable Energy

Positive Impacts:

Reduced Greenhouse Gas Emissions: Reduces CO2 and other greenhouse gases, mitigating climate change impacts on marine ecosystems, such as ocean acidification and rising sea temperatures; Biodiversity Protection: Offshore wind energy, widely used in wind turbines, creates artificial reefs, providing habitats for marine species; Reduced Oil and Chemical Pollution: Renewable energy minimizes oil and chemical spills, protecting water quality and marine life.

Negative Impacts:

Impacts on Marine Ecosystems: Noise and Vibration: Installing wind turbines, anchoring piles, or wave energy devices can generate underwater noise, affecting species that rely on sound for navigation, such as whales and dolphins; Changes to Environmental Currents: Natural currents may be altered by turbines, impacting the migration and reproduction of marine species; Collision Risks: Turbine and cable installations pose risks to seabirds and migratory animals (e.g., sea turtles, whales), causing injuries or fatalities from collisions; Impacts on the Seabed: Infrastructure such as anchoring piles or seabed cables can disturb sediments, destroying habitats of benthic species. Additionally, materials like anti-corrosion paint may leak toxic substances into the environment; Impacts on Fishing and Coastal Communities: Renewable energy installation areas may restrict fishing zones, affecting fishermen's livelihoods. Changes to the marine landscape can also impact coastal tourism and traditional cultural activities.

Solutions to Mitigate Negative Impacts: Careful Site Selection: Conduct thorough Environmental Impact Assessments (EIAs) to avoid ecologically sensitive areas or migration routes of marine species; Environmentally Friendly Technology: Use non-toxic materials, design low-noise turbines, and implement monitoring technologies to detect and minimize collisions with wildlife; Community Engagement: Collaborate with fishermen and coastal communities to ensure projects minimally impact livelihoods and local culture; Long-Term Research: Monitor the impacts of marine renewable energy projects to refine and improve technologies, minimizing environmental harm.

2.5. Awareness – Action

The Call from the Environment: Climate change is causing severe issues for the marine environment, including rising sea levels, ocean acidification, and biodiversity loss. The maritime industry contributes approximately 2-3% of global CO2 emissions, equivalent to about 1 billion tons of CO2 annually (International Maritime Organization (IMO), 2020, Fourth IMO GHG Study 2020). Vietnam has offshore wind energy potential exceeding 1,000 GW in its Exclusive Economic Zone (EEZ), particularly in areas like Bình Thuận, Ninh Thuận, and Bà Rịa - Vũng Tàu, helping reduce reliance on fossil fuels and protect marine ecosystems. Awareness: Understanding and recognizing the importance of renewable energy, the role of the ocean in the global ecosystem, and how to utilize it responsibly to avoid negative impacts on the marine environment. The ocean is a vital natural resource, regulating climate, absorbing CO2, and maintaining biodiversity. Improper exploitation can lead to adverse impacts on marine ecosystems. Renewable energy offers immense potential but requires awareness and appropriate technological approaches, implemented in coordination with relevant sectors to minimize negative environmental impacts.

Connecting Individual and Collective Awareness: Each individual is a vital link in the chain of sustainable development toward a green lifestyle. Examples of awareness demonstrate that individuals and communities are contributing to a greener future; Social media and media campaigns, such as Tạp chí Năng lượng Việt Nam, have spread information about the Thăng Long offshore wind project (600 MW) in Bình Thuận, raising awareness of the potential of marine renewable energy in reducing pollution; Educational programs and workshops organized by the Ministry of Industry and Trade have emphasized the role of renewable energy in meeting sustainable development goals, particularly in the maritime sector.

Action:

For Individuals and Consumers: Save energy, prioritize products from clean energy sources, support marine environmental protection policies, and report harmful behaviors.

For Communities and Organizations:

Enhance education and share knowledge about the marine environment in schools, social organizations, and communities.

Participate in activities to clean and protect the marine environment, such as waste collection and preserving coastal ecosystems that support marine species.

Develop ecotourism and sustainable fisheries models, balancing conservation and livelihoods.

For Governments, Scientists, and Businesses:

Invest in environmentally friendly marine energy technologies to minimize impacts on marine life.

Develop rational marine spatial planning policies with stakeholder involvement.

Ensure transparency in environmental impact assessments, applying scientific tools (GIS, AI, ecological modeling) in project development.

Encourage businesses to transition to clean energy, providing financial support for small and medium-scale green energy models.

Examples:

Individuals: Reducing single-use plastic waste (e.g., plastic bags, straws) to protect the marine environment where renewable energy projects are implemented. Campaigns like "For a Plastic-Free Ocean" have attracted thousands to clean beaches; Using green maritime transport services, such as solar or hybrid electric tourist boats, being tested in areas like Phú Quốc; Participating in mangrove planting or coral reef protection to support marine ecosystems, mitigate climate change impacts, and facilitate renewable energy projects.

Collectives, Agencies, and Businesses: Government: Decision 500/QĐ-TTg (2023) by the Vietnamese Government prioritizes offshore wind development to supply energy to various sectors, including maritime, targeting 15-20% renewable energy in the

primary energy supply by 2030; Businesses: PetroVietnam Technical Services Corporation (PTSC) collaborates with Ørsted to develop offshore wind projects in Bà Rịa - Vũng Tàu, supplying energy to ports and maritime infrastructure; Green Ports: Cái Mép - Thị Vải Port is testing solar and wind energy to power cargo handling and shore power systems (cold ironing), reducing emissions from docked ships; Research and Innovation: The Vietnam Petroleum Institute is researching hybrid energy vessels and green hydrogen-powered ships, using offshore wind energy to produce clean fuels (Nguyễn Ngọc, 2022).

In the Maritime Sector; Testing hybrid energy vessels using solar panels or electric batteries for short routes and fishing boats in Vietnam, reducing fossil fuel consumption; Using offshore wind energy to power lighthouses, navigation buoys, and marine research stations, especially in remote areas like Trường Sa; Implementing shore power systems (cold ironing) using renewable energy at major ports to reduce air pollution and noise from docked ships.

Linking Awareness and Action: Awareness of IMO's goal (reducing maritime emissions by 50% by 2050) has driven Vietnamese companies like PTSC to invest in offshore wind projects, such as Thăng Long (600 MW), to provide clean energy; Social media posts about the Thăng Long project and Ørsted collaboration have inspired communities, encouraging actions like reducing plastic waste and supporting green policies.

Challenges and Solutions:

Challenges: High investment costs for marine renewable energy projects, such as offshore wind turbines, pose difficulties for small businesses; Limited awareness among fishermen about the benefits of marine renewable energy, leading to conflicts over marine space with wind farms; Environmental impacts from turbine installation, such as noise and sediment disturbance, require thorough assessments.

Solutions: Provide subsidies and tax incentives to support marine renewable energy projects; Enhance communication and training campaigns to raise coastal community awareness; Conduct Environmental Impact Assessments (EIAs) before project implementation to protect marine ecosystems.

Renewable energy in the marine environment offers significant opportunities for the maritime industry to mitigate environmental impact, achieve long-term cost savings, and meet international requirements for sustainable development. However, substantial investment and close coordination among stakeholders are essential to overcome challenges and optimize benefits; Marine Renewable Energy Projects in Vietnam's Maritime Sector

With over 3,260 km of coastline and significant marine renewable energy potential, Vietnam is gradually implementing renewable energy projects in the maritime sector. Below are key projects and potentials in this field: Offshore Wind Projects: Immense Potential: Vietnam has up to 600 GW of offshore wind potential, particularly in areas like Bà Rịa - Vũng Tàu, Bình Thuận, and Ninh Thuận. Offshore wind projects not only supply energy to the mainland but also support ports and maritime activities; Collaboration with Ørsted: PetroVietnam Technical Services Corporation (PTSC) has partnered with Ørsted (Denmark), a global leader in offshore wind, to develop projects in Bà Rịa - Vũng Tàu. These projects focus on supplying energy to ports and maritime infrastructure while advancing green technology for the sector; Thăng Long Wind Project: One of Vietnam's largest offshore wind projects, with a planned capacity of 600 MW, is being developed off the coast of Bình Thuận. This project can supply electricity to ports and vessels in the region.

Renewable Energy Applications in Ports: Green Ports: Major ports like Cái Mép - Thị Vải (Bà Rịa - Vũng Tàu) are exploring solar and wind energy to power cargo handling, lighting, and shore power systems (cold ironing), reducing emissions from docked ships; Pilot Projects: Some smaller ports in central Vietnam are testing solar panels to power maritime equipment like navigation buoys and signal lights.

Vessels Using Renewable Energy; Hybrid Energy Vessels: Research projects in Vietnam are developing hybrid vessels using solar and electric power to reduce fuel consumption, particularly for fishing boats or coastal passenger vessels; Green Hydrogen: Although in early stages, some Vietnamese maritime companies are collaborating with international partners to pilot green hydrogen-powered vessels, using renewable energy to produce hydrogen.

Transitional Renewable Energy Projects: According to EVN, as of August 2024, 29 transitional renewable energy projects (mainly wind and solar) have generated over 3,475 billion kWh to the grid. Part of this capacity supports maritime activities, especially in major port areas; These projects also help reduce energy costs for the maritime sector, optimizing operational costs for ports and shipping companies.

Challenges: High Investment Costs: Offshore wind projects and green vessel technologies require significant capital, while Vietnam is still developing its infrastructure and technology; Legal Barriers: A Delphi method study indicates that incomplete legal frameworks and lack of supportive policies are major barriers to adopting renewable energy in the maritime sector; Environmental Impacts: Offshore wind farm construction can affect marine ecosystems, necessitating careful environmental impact assessments.

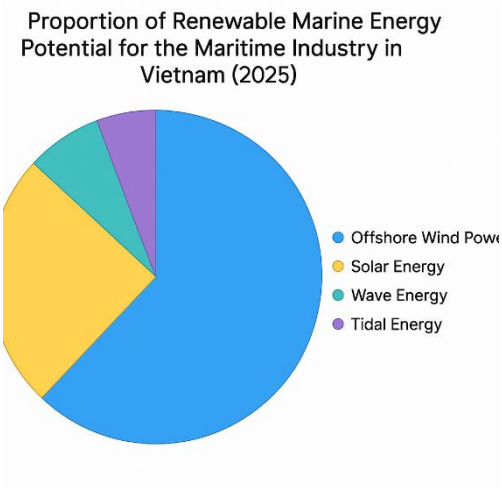

Figure 1: Chart Illustrating the Potential of Marine Renewable Energy for Vietnam's Maritime Sector

Offshore Wind (65%): The largest share, reflecting its superior potential in Vietnam. According to The Investor (2025), Vietnam's Exclusive Economic Zone (EEZ) has offshore wind potential exceeding 1,000 GW, particularly in areas like Bình Thuận, Ninh Thuận, and Bà Rịa - Vũng Tàu.

Maritime Applications: Offshore wind can power ports (e.g., Cái Mép - Thị Vải), shore power systems (cold ironing), and hybrid clean-energy vessels. Projects like Thăng Long (600 MW) exemplify this potential.

Trend: The high share (65%) highlights offshore wind as the dominant marine renewable energy source, prioritized for its high efficiency, scalability, and international support from partners like Ørsted.

Solar Energy (20%): A significant but smaller share compared to offshore wind, mainly due to limited applications in maritime infrastructure like ports, navigation buoys, or floating structures.

Maritime Applications: Solar panels are installed at ports or on vessels to power lighting, navigation equipment, and port operations. For example, some central Vietnam ports are testing solar panels for signal lights.

Trend: The 20% share reflects solar energy's economic potential, but limitations in marine installation space and maintenance costs in marine environments make it less competitive than wind.

Wave Energy (10%): A smaller share, reflecting the early development stage of this technology in Vietnam. Studies from Florida Atlantic University (2025) highlight wave energy potential in countries with long coastlines like Vietnam, but it remains underutilized.

Maritime Applications: Wave energy can power navigation buoys, marine research stations, or offshore aquaculture farms.

Trend: The 10% share indicates long-term potential, but current technological limitations and high costs make it less implemented than wind and solar.

Tidal Energy (5%): The smallest share, due to nascent technology and dependence on areas with significant tidal ranges, which are not widespread in Vietnam.

Maritime Applications: Can power small maritime devices or monitoring stations, but applications are very limited.

Trend: The 5% share reflects low potential and slow development of this technology in Vietnam, primarily due to high investment costs and lack of infrastructure.

Comparison and Implications:

Dominance of Offshore Wind: With 65%, offshore wind is the most promising marine renewable energy source, aligning with Vietnam's green energy strategy (Decision 500/QĐ-TTg, 2023). This suggests the maritime sector can rely heavily on wind energy to reduce emissions and operational costs.

Limitations of Other Sources: Solar energy (20%) has some potential but is limited by space and marine environmental conditions. Wave (10%) and tidal (5%) energy are still in research phases, requiring more time and investment for development.

Impact on the Maritime Sector: The chart shows offshore wind as the primary driver for transforming ports into green ports, supporting clean-energy vessels, and reducing fossil fuel dependence, aligning with IMO's goal of reducing maritime emissions by 50% by 2050.

Solutions to Promote Adoption:

Investment and International Collaboration: Continue partnerships with companies like Ørsted to transfer technology and attract investment.

Policy Improvement: The government should address legal bottlenecks, as urged by Deputy Prime Minister Nguyễn Hòa Bình to resolve pending renewable energy projects by May 2025.

Raising Awareness: Enhance training for seafarers and maritime stakeholders on the benefits of renewable energy.

3. CONCLUSION

The ocean has nurtured life for millions of years—now, humanity must act to nurture it back through sustainable awareness and actions. Renewable energy is not just a technology but an ethical choice for a green future. The topic "Renewable Energy in the Marine Environment: An Environmental Imperative, Awareness, and Action Towards a Greener Maritime Sector" underscores the importance of harnessing renewable energy (e.g., offshore wind, wave, tidal, and solar energy) in the marine environment to address environmental challenges while promoting individual and collective awareness and actions toward a sustainable lifestyle. It also highlights the critical role of renewable energy in the development of the maritime sector.

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