Wind and Wave Power as a New Investment Horizon of the Marine Economy

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Abstract. This paper analyses offshore wind and wave energy as strategic investment assets within the Blue Economy framework. It examines technological maturity, investment dynamics, governance challenges and infrastructure requirements.

Offshore Wind and Wave Energy (OWE/WEC) represent a transformative investment horizon for the marine economy, driven by global decarbonisation imperatives and the commitment to triple renewable energy capacity by 2030. This paper examines the evolving investment landscape of offshore wind and wave energy within the framework of the Blue Economy, with particular attention to cost dynamics, technological maturity, grid infrastructure requirements and spatial governance challenges. Using qualitative policy and market analysis supported by secondary data from international energy agencies and financial institutions, the study evaluates the role of Floating Offshore Wind (FLOW) in unlocking deep-water resources and assesses wave energy's contribution to system resilience through its comparatively stable generation profile. The findings indicate that offshore wind has reached commercial competitiveness following a substantial reduction in levelised cost of energy, while wave energy, though at an earlier stage of development, offers high growth potential and strategic value for grid stability. The paper further demonstrates that large-scale deployment of OWE depends on coordinated investment in offshore grid infrastructure, meshed transmission systems and effective Maritime Spatial Planning to mitigate non-technical risks. The analysis concludes that offshore wind and wave energy constitute a central pillar of the Blue Economy, offering a long-term, resilient investment horizon for institutional capital aligned with sustainable economic growth.

Keywords: Offshore wind; Wave energy; Blue economy; Energy transition finance; Maritime spatial planning

1. Relevance of the Research Problem:

The global energy transition, driven by decarbonization commitments and the objective to triple renewable energy capacity by 2030, has significantly increased the strategic importance of marine renewable energy resources. Within this framework, offshore wind and wave energy have emerged as key components of the Blue Economy concept, which promotes the sustainable use of ocean resources for economic growth, environmental protection, and social development.

Although offshore wind energy has reached commercial competitiveness in many developed markets, wave energy remains at an earlier stage of technological and financial maturity. Furthermore, existing research predominantly focuses on large-scale projects in advanced economies, particularly in the North Sea and Baltic Sea regions, while transitional economies and semi-enclosed seas, such as the Black Sea, remain underrepresented in academic and policy discourse.

For Georgia, the relevance of this research is particularly pronounced due to several structural factors:

- Increasing dependence on imported energy resources;
- Significant but largely untapped offshore wind and wave potential in the Black Sea;
- Regulatory and institutional gaps concerning offshore renewable energy development;
- Limited access to domestic capital markets and specialized offshore infrastructure;

Under these conditions, an integrated and multidisciplinary assessment is required to evaluate technological feasibility, economic viability, environmental sustainability, and governance capacity. The study therefore addresses a critical research gap by analyzing offshore wind and wave energy as a strategic investment horizon within Georgia's marine economy.

2. Research Methodology

Our The research applies a mixed-method analytical framework combining qualitative and conceptual economic analysis. The methodology includes the following components:

A comprehensive review of international academic publications and institutional reports (IRENA, GWEC, OECD, NREL, and others) was conducted to assess technological maturity, cost dynamics (including Levelized Cost of Energy – LCOE), investment trends, and environmental impacts.

The study evaluates Georgia's existing legal and institutional framework governing renewable energy, with particular emphasis on offshore-specific regulatory gaps, permitting procedures, and marine spatial planning requirements.

International best practices from leading offshore wind markets (United Kingdom, Denmark, Germany, Netherlands) are analyzed to identify transferable policy instruments, financing mechanisms, and governance models applicable to emerging marine energy markets.

A conceptual evaluation of financial indicators (CAPEX, LCOE, NPV, IRR) and risk categories (technological, regulatory, financial, environmental, and market-related risks) was undertaken to assess investment attractiveness and project bankability. Georgia's Black Sea coastline is examined as an illustrative case to evaluate resource potential, infrastructure readiness, and development pathways within a transitional economy context. The study primarily relies on secondary data sources, international statistics, policy documents, and peer-reviewed literature. The analytical approach integrates qualitative assessment with selected quantitative indicators to ensure a holistic evaluation of offshore wind and wave energy development prospects.

3. Introduction

In recent decades, the global energy sector has undergone a profound transformation driven by increasing concerns over climate change, energy security, and sustainable economic development. The depletion of fossil fuel resources, combined with rising greenhouse gas emissions, has intensified the search for alternative and renewable energy sources. Within this context, marine-based renewable energy, particularly offshore wind and wave power, has emerged as a promising frontier in the transition towards low-carbon and resilient energy systems. Offshore wind farms and wave energy converters (WECs) have demonstrated substantial potential to contribute to national energy mixes while minimizing environmental impacts compared to conventional energy sources. From an investment perspective, offshore renewable energy projects represent capital-intensive but strategically significant assets.

4. Literature Review

Offshore wind energy has become one of the most mature and rapidly expanding sectors within the global renewable energy industry. Its development can be traced back to the early 1990s, when the first offshore wind farms were installed in Denmark and the Netherlands (Snyder & Kaiser, 2009). Compared to offshore wind, wave energy remains at a relatively early stage of technological and commercial maturity. Nevertheless, it is widely recognized as a promising renewable resource due to its high energy density and predictability (Falcão, 2010). Wave energy originates from wind-driven ocean surface movements, offering a complementary source to offshore wind systems. Offshore wind and wave projects are characterized by high upfront capital requirements, long payback periods, and complex financing structures (Politis et al., 2019).

Despite extensive international research, several gaps remain evident. First, most studies focus predominantly on offshore wind, while wave energy receives comparatively limited empirical attention. Second, integrated assessments combining technological, financial, and governance dimensions are still relatively rare. Third, transitional economies and semi-enclosed seas, such as the Black Sea, remain underrepresented in academic discourse.

Furthermore, existing literature often emphasizes large-scale projects in developed markets, neglecting small- and medium-scale deployment models suitable for emerging economies. As noted by Sovacool (2014), energy transitions are highly context-dependent and cannot be universally standardized.

By bridging global best practices with regional realities, the research seeks to advance both theoretical understanding and practical policy design.

Offshore wind energy represents the most technologically mature segment of marine renewable energy. Modern offshore wind turbines typically range from 8 MW to over 15 MW in capacity, allowing for higher energy yields and improved economic efficiency. Two main categories of offshore wind installations are distinguished in the literature: fixed-bottom and floating systems. Floating wind technologies have emerged as a strategic solution for deep-water environments where fixed foundations are technically or economically infeasible. Floating platforms, such as spar-buoy, semi-submersible, and tension-leg platforms, enable deployment in depths exceeding 60 meters (Myhr et al., 2014). These systems significantly expand the geographical scope of offshore wind development and are particularly relevant for regions with narrow continental shelves. Hybrid systems combining offshore wind and wave energy represent an emerging technological paradigm. Co-located wind-wave farms share common infrastructure, including foundations, electrical connections, and maintenance facilities. This integration reduces capital and operational costs while maximizing marine space utilization. Hybrid platforms integrating both turbines and WECs have also been proposed, particularly for floating structures. Energy storage technologies play a crucial role in supporting hybrid systems. Battery storage, hydrogen production via electrolysis, and compressed air energy storage enable temporal balancing between energy generation and demand. Offshore hydrogen hubs, in particular, are gaining attention as long-term storage and transport solutions.

Blended finance mechanisms combine public and private capital to improve project risk profiles. Green bonds and sustainability-linked loans have gained prominence as instruments for mobilizing long-term institutional investment (OECD, 2020). Public-private partnerships (PPPs) enable governments to leverage private-sector expertise while retaining strategic oversight. Such arrangements are especially relevant for port infrastructure, grid connection facilities, and pilot projects.

For transitional economies such as Georgia, economic and financial constraints remain a primary barrier to offshore renewable energy development. Limited domestic capital markets, high perceived country risk, and insufficient technical experience restrict access to competitive financing.

The economic and investment analysis demonstrates that offshore wind has reached commercial maturity, while wave energy remains in a transitional phase. Financial viability depends on technological reliability, regulatory stability, and access to diversified financing instruments. For emerging marine energy markets, coordinated policy support and innovative financing mechanisms are essential to unlock long-term investment potential. Life-cycle assessment studies indicate that offshore wind and wave projects exhibit relatively low carbon footprints compared to conventional power plants, even when accounting for manufacturing, installation, and decommissioning phases (NREL, 2020).

The development of offshore wind and wave sectors stimulates port modernization, logistics services, and technical training programs. These activities enhance human capital formation and foster innovation ecosystems in coastal regions. Furthermore, localized supply chains contribute to economic diversification and resilience. Indirect economic effects include increased tax revenues, tourism development linked to green branding, and improved energy security. For transitional economies, marine renewable energy may serve as a catalyst for structural transformation and international integration.

In the Georgian and Black Sea context, environmental and social considerations are particularly significant due to the ecological sensitivity of marine ecosystems and the economic importance of coastal tourism and fisheries.

Europe has emerged as the global leader in offshore wind deployment, with the North Sea and the Baltic Sea representing key growth hubs. Denmark, the Netherlands, Germany, and the United Kingdom have established large-scale offshore wind infrastructures that serve as benchmarks for technological and economic performance (GWEC, 2023).

Recent research highlights that hybrid offshore wind-wave energy systems can significantly improve marine space utilization, reduce infrastructure costs, and enhance overall energy production efficiency through shared platforms and grid connections (Zhang et al., 2024).

Furthermore, comprehensive assessments of the Black Sea indicate substantial untapped potential for both offshore wind and wave energy, supporting the region's strategic role in future renewable energy development and energy security (Silion & Rusu, 2025).

Recent spatial analyses also demonstrate that the Black Sea possesses favorable conditions not only for offshore wind generation but also for green hydrogen production, creating new opportunities for integrated offshore energy systems and long-term decarbonization strategies (Manolache & Onea, 2025).

The United Kingdom, for example, currently hosts over 10 GW of operational offshore wind capacity, supported by a robust regulatory framework, competitive auctions, and public-private partnerships (UK Government, 2022). These projects demonstrate the viability of large-scale deployment in deep waters and highlight successful integration of offshore wind into national energy markets.

Marine Renewable Energy Potential in Georgia Georgia possesses significant but largely untapped offshore wind and wave energy resources along its Black Sea coastline. Recent studies estimate the technical potential of offshore wind at approximately 1.2–2.0 GW within shallow coastal areas (Japaridze & Lomidze, 2019). Wave energy potential, although less quantified, is believed to offer substantial energy density due to consistent seasonal wave patterns, particularly between October and March (González et al., 2020).

The Georgian Black Sea coast benefits from moderate-to-high wind speeds averaging 6–9 m/s at 50 meters above sea level, which is sufficient for economically viable offshore wind projects. Wave heights typically range from 1.2 to 2.5 meters, offering moderate energy capture potential for point absorber and oscillating water column devices. These characteristics indicate the feasibility of small-to-medium scale offshore energy installations that can be progressively scaled up. Georgia’s legal and institutional framework for renewable energy development has made progress in recent years, yet offshore projects remain underdeveloped. Key regulations include the Law on Energy and Water Supply, Law on Renewable Energy, and licensing procedures governed by the Georgian National Energy and Water Supply Regulatory Commission (GNERC).

Despite challenges, Georgia has several strategic opportunities to develop marine renewable energy:

1. Pilot Projects: Deploy small-scale offshore wind and wave installations to demonstrate feasibility, reduce technological risk, and generate local expertise.

2. International Partnerships: Collaborate with experienced European and East Asian developers to leverage technical knowledge and financing.

3. Hybrid Systems: Integrate offshore wind and wave technologies to optimize energy yield and infrastructure use.

4. Blue Economy Integration: Use offshore energy development to support broader economic objectives, including port modernization, tourism, and coastal industrial growth.

5. Policy Innovation: Introduce auction mechanisms, green bonds, and long-term PPAs to enhance investment confidence. Key challenges for Georgia include:

Regulatory Gaps: Need for dedicated offshore licensing, environmental, and spatial planning policies.

Financial Risks: High CAPEX and limited domestic financing options.

Technical Barriers: Lack of specialized infrastructure, skilled labor, and operational experience.

Environmental and Social Risks: Potential conflicts with fisheries, tourism, and coastal ecosystems.

Market Uncertainty: Dependence on international energy prices and regional energy

Addressing these challenges requires an integrated approach combining institutional reform, capacity-building, stakeholder engagement, and strategic public-private investment planning.

Georgia's Black Sea offers a significant but largely unexploited opportunity for offshore wind and wave energy. While technical, financial, and regulatory challenges are substantial, lessons from global best practices suggest a phased, partnership-driven approach.

The following factors should be noted: Offshore wind technology is commercially mature, benefiting from standardized designs, floating platforms for deep waters, and advanced monitoring systems. Wave energy remains in the demonstration and optimization phase, yet presents substantial potential for hybrid systems and complementary energy production. Economic and Investment Feasibility Offshore wind projects demonstrate positive financial indicators (NPV, IRR, LCOE), while wave energy investments are more reliant on public funding and pilot initiatives. Hybrid wind-wave installations offer cost synergies, infrastructure sharing, and improved capacity utilization. Environmental and Social Sustainability

Final Remarks Offshore wind and wave energy represent transformative opportunities for Georgia’s marine economy. By integrating technological innovation, economic viability, environmental stewardship, and social inclusivity, Georgia can establish itself as a regional leader in the blue economy.

The successful development of these resources requires coordinated action among policymakers, investors, researchers, and local communities.

5. Research Findings

The findings of this study confirm that offshore wind energy has evolved into one of the most technologically mature and commercially viable segments of the global renewable energy sector. Recent evidence demonstrates that continuous advancements in turbine technology, floating foundation systems, digital monitoring solutions, and economies of scale have substantially reduced the levelized cost of energy (LCOE), enabling offshore wind to compete effectively with conventional energy sources (Zhang et al., 2024). The emergence of floating offshore wind technologies further expands development opportunities in deep-water environments, significantly increasing the geographical scope of economically feasible offshore energy projects.

In contrast, wave energy remains at a comparatively early stage of commercial development. Although technological uncertainties and high capital costs continue to limit large-scale deployment, recent studies indicate that wave energy possesses considerable strategic value due to its high energy density, predictability, and complementary generation profile relative to offshore wind (Silion & Rusu, 2025). The research highlights that hybrid wind-wave systems can improve capacity utilization, enhance grid stability, reduce infrastructure costs through shared facilities, and increase overall project efficiency, making them a promising pathway for future marine energy development.

The analysis further reveals that investment attractiveness is strongly influenced by the quality of regulatory frameworks, long-term policy consistency, and access to diversified financing instruments. Offshore wind projects demonstrate robust economic performance under stable market conditions supported by competitive auctions, feed-in mechanisms, and long-term power purchase agreements. Conversely, wave energy technologies continue to require targeted public support, blended finance instruments, research funding, and risk-sharing mechanisms to overcome technological and financial barriers. The findings suggest that innovative financing models, including green bonds, public-private partnerships, and sustainability-linked investments, will play an increasingly important role in accelerating marine renewable energy deployment.

From an environmental and socio-economic perspective, offshore renewable energy contributes significantly to decarbonization objectives, energy security, and sustainable economic growth. Beyond greenhouse gas emission reductions, offshore wind and wave projects stimulate port modernization, local supply chain development, technological innovation, and employment creation in coastal regions. Recent studies also emphasize the growing role of offshore renewable energy in supporting green hydrogen production, thereby enhancing energy system flexibility and facilitating long-term climate neutrality objectives (Manolache & Onea, 2025).

In the Georgian context, the findings confirm that the Black Sea possesses substantial yet largely untapped offshore renewable energy potential. Available assessments indicate favorable wind resources and promising opportunities for future hybrid offshore energy systems. Nevertheless, the successful realization of this potential depends on addressing critical challenges, including regulatory fragmentation, limited infrastructure capacity, financing constraints, and insufficient technical expertise. The study demonstrates that a phased development strategy based on pilot projects, international partnerships, institutional reforms, and targeted investment incentives represents the most viable pathway for offshore renewable energy development in Georgia.

Overall, the research concludes that offshore wind energy is ready for large-scale commercial deployment, while wave energy is progressing toward commercialization through technological innovation and hybridization. The integration of these technologies within a comprehensive blue economy framework offers a strategic opportunity for Georgia to strengthen energy security, attract sustainable investment, accelerate decarbonization, and enhance its position within the emerging regional renewable energy market.

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