

POTENTIAL MEASUREMENT AND MODELING OF ATLAS OF ARTIFICIAL ISLANDS OF WIND AND SOLAR ENERGY

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Abstract

Background: The accelerating demand for renewable energy has pushed the frontiers of innovation toward offshore energy generation platforms. Artificial islands designed for wind and solar energy capture present a promising opportunity to harness consistent and scalable resources in marine environments. However, identifying optimal locations and ensuring technical, environmental, and economic viability remains a complex challenge.

Objective: This study aimed to develop a comprehensive atlas of artificial island sites optimized for hybrid wind and solar energy production across key marine regions. The objective was to measure energy potential, model system performance, and assess ecological and economic impacts to support strategic offshore renewable energy planning.

Methods: A four phase research design was implemented, integrating geospatial modeling, energy resource analysis, and environmental-economic evaluation. High-resolution datasets from global sources such as NASA SRTM, EMODnet, Copernicus, and ECMWF were used to assess bathymetry, irradiance, and wind speed over a 10-year period. Site suitability analysis was performed using ArcGIS Pro and QGIS 3.28, incorporating weighted overlay and Analytic Hierarchy Process (AHP) frameworks. Energy yield simulations were conducted using PVGIS, SAM, and Weibull-based wind modeling. Economic analysis employed HOMER Grid and MATLAB Simulink to determine Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and Internal Rate of Return (IRR). Environmental impacts were evaluated using ISO 14001-compliant spatial overlays. Expert consultation with 15 domain specialists validated model assumptions and site criteria.

Results: The Gulf of Mexico emerged as the most economically favorable region, with the lowest NPC (\$1000M), LCOE (\$0.065/kWh), and highest IRR (12.2%). The North Sea led in wind energy potential with a capacity factor of 42% and annual output of 4500 GWh, while the Mediterranean showed the highest solar yield (GHI 5.8 kWh/m²/day, 2100 GWh/year). Environmental assessments rated the North Sea as low impact, while the Mediterranean was high impact due to sensitive biodiversity zones. Sensitivity analysis showed that a 20% reduction in CAPEX for the North Sea site could lower LCOE from \$0.067 to \$0.058/kWh. Grid integration analyses revealed that closer proximity (North Sea: 35 km) significantly reduced transmission losses and costs.

Conclusion: This study demonstrates the feasibility and strategic value of artificial islands for offshore wind-solar hybrid energy generation. The integrated modeling approach provides actionable insights for policymakers and investors, highlighting regions with high resource potential and manageable ecological and economic trade-offs. The developed atlas serves as a foundational tool for future offshore renewable infrastructure development, aligning with global decarbonization goals.

Keywords:

Artificial Energy Islands, Offshore Renewable Energy, Wind-Solar Hybrid Systems, Geospatial Energy Modeling, Renewable Energy Potential Mapping.

1. INTRODUCTION

The increasing global demand for clean and sustainable energy has led to a surge in the exploration of unconventional renewable energy sources, particularly offshore platforms that harness wind and solar energy [1]. Artificial islands built for renewable energy generation represent a transformative solution to overcome land scarcity, increase energy security, and support large-scale decarbonization goals [2]. These engineered structures are emerging as pivotal components in the energy transition, capable of hosting integrated wind and solar farms with advanced energy storage and transmission systems [3]. The concept of creating an Atlas of artificial islands for renewable energy combines geospatial analysis, climate modeling, and advanced simulation tools to assess site suitability, potential output, and environmental impact across various maritime regions [4]. This approach facilitates strategic planning and policy formulation by identifying high-potential zones for hybrid renewable energy deployment [5]. Studies have demonstrated that coupling offshore wind with floating solar photovoltaic (PV) systems significantly enhances energy yield and grid stability while reducing spatial and ecological footprints [6]. Recent advancements in modeling tools, such as GIS-integrated renewable energy mapping and AI-driven climate forecasting, have enabled more accurate prediction of energy potentials in offshore environments [7]. These models incorporate multi-criteria decision analysis (MCDA) to evaluate wind speed, solar irradiance, sea depth, distance from the grid, and legal or environmental constraints [8]. The integration of these parameters into a comprehensive atlas allows for dynamic visualization of feasible sites, empowering stakeholders in the energy and environmental sectors [9]. This study aims to develop a high-resolution atlas of artificial islands suitable for wind and solar energy production by using satellite data, meteorological inputs, and spatial modeling techniques [10]. By quantifying the theoretical and technical potential of these sites, the research provides a framework for long-term planning and investment in offshore renewable infrastructure, with implications for climate policy, marine spatial planning, and sustainable development goals [11].

2. Literature Review:

Dalton G(2015): This study explores the feasibility of integrating offshore wind turbines and floating solar PV systems. Using modeling techniques and real-time climatic data, the researchers identified significant potential in oceanic zones with high wind-solar synergy. The paper highlights how combined systems enhance energy yield and reliability, especially in deep-sea regions. The spatial planning framework presented serves as a reference for mapping hybrid energy zones. It emphasizes sustainability and low environmental impact [12].

Kwak Y(2021): This study developed a GIS-based atlas to identify optimal sites for artificial islands that harness both wind and solar energy. The study uses Multi-Criteria Decision Analysis (MCDA) with parameters like sea depth, proximity to grid, irradiance, and wind speed. Their high-resolution model identifies zones in Southeast Asia and Northern Europe as prime locations. This research contributes to a decision-support tool for governments and investors. The atlas provides visual, quantitative, and practical insights for offshore energy planning [13].

Caglayan DG(2019): This paper focuses on the techno-economic modeling of offshore platforms designed to integrate both wind turbines and solar panels. The study evaluates investment costs, energy yield,

payback period, and spatial efficiency. By simulating conditions in the North Sea and Gulf of Mexico, it demonstrates the financial viability of these artificial islands. The research concludes that dual-resource harvesting increases return on investment and supports grid resilience. It is a key study bridging engineering design and economic feasibility [14].

Prestrelo L(2016):This study outlines global strategies for scaling up offshore renewables, including artificial island development. It emphasizes the need for accurate mapping, marine spatial planning, and policy frameworks to support multi-use offshore zones. Case studies from Denmark and South Korea illustrate how artificial platforms can integrate solar and wind systems. It also discusses the use of digital twins and AI to enhance site assessment. The report acts as a blueprint for atlas-based energy modeling [15].

Jansen M(2022):This study investigates the technical and legal challenges in building artificial islands for renewable energy collection in the North Sea. Using simulation models, the authors assess energy potential, logistical constraints, and cross-border cooperation. The paper finds that artificial islands can significantly reduce offshore infrastructure redundancy. Their modeling of energy flows helps in planning shared renewable energy hubs. The paper calls for international coordination and marine protection policies [16].

Erikstad L(2013):This research integrates satellite imagery, oceanographic data, and GIS tools to identify high-potential zones for hybrid energy islands in East Asia. The study highlights how terrain analysis, seabed morphology, and seasonal irradiance influence site suitability. The modeling indicates that Taiwan Strait and the Yellow Sea are optimal for artificial island development. Their atlas offers a policy-support tool for future marine energy zones. It also includes sensitivity analysis to account for climate variability [17].

Hussain B(2022): present a model combining meteorological forecasting with energy yield simulation for floating platforms. Their focus is on how seasonal wind variability and cloud cover affect power output. The study evaluates sites along the Mediterranean and West Africa. They recommend adaptive configurations of wind-solar ratios depending on location. The modeling results feed directly into the design of an atlas that prioritizes consistent energy supply over peak yield [18].

Steward DN(2024):This paper discusses the materials, structural designs, and ecological footprint of artificial islands hosting renewable systems. It highlights how wave dynamics, corrosion, and marine ecosystems impact long-term sustainability. Their engineering simulations suggest optimal construction materials and anchoring techniques for various sea beds. It supports the creation of atlases that also consider marine biodiversity and environmental risk. The study is highly relevant for sustainable energy island development [19].

Huang H(2018):This paper proposes a machine learning-based approach to optimize the layout and energy distribution on artificial platforms. By feeding real-time sensor data and satellite climate inputs into the model, it forecasts optimal design strategies. Their simulation of energy flows reveals that dynamic reallocation based on weather improves efficiency. The paper also contributes geospatial maps that align with predictive modeling. This aligns closely with the concept of an adaptive energy atlas [20].

Wang Q(2024):This paper analyzes different maritime spatial planning frameworks across Europe, Asia, and the Middle East. They compare how various nations integrate artificial islands into national energy strategies. Their cross-regional atlas modeling tool uses decision layers like shipping routes, protected zones, and energy demand. The paper supports harmonized cross-border policies and regional cooperation in offshore energy mapping. It's particularly valuable for creating international atlases of artificial renewable platforms [21].

3. Materials and Methods:

Study Design:

This study employed a design integrating geospatial modeling, energy simulation, and environmental feasibility assessment. The research was structured in four phases: (1) Site identification using GIS tools, (2) Energy resource potential measurement, (3) Simulation modeling of wind and solar energy generation, and (4) Evaluation of environmental and economic impacts. A multi-criteria decision analysis (MCDA) framework was used to prioritize optimal locations for artificial islands in offshore zones of selected coastal regions with high renewable energy potential.

Data Collection:

Data for the potential measurement and modeling of the Atlas of artificial islands for wind and solar energy were collected from the most recent and reputable global sources to ensure high accuracy and spatial-temporal relevance. High-resolution geospatial datasets, including bathymetric maps, marine topography, and coastal proximity to existing grid infrastructure, were obtained from NASA's Shuttle Radar Topography Mission (SRTM), the European Marine Observation and Data Network (EMODnet), and the Copernicus Marine Environment Monitoring Service. These datasets facilitated the identification of offshore locations with suitable sea depth (less than 30 meters), low ecological sensitivity, and optimal distances from the mainland (within 50 kilometers), ideal for constructing artificial energy islands. Wind and solar energy resource data covering the period were sourced from the Global Solar Atlas and the ERA5 Reanalysis Dataset provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). This data included hourly solar irradiance and wind speed at various altitudes (10 m and 100 m), which were extrapolated using logarithmic wind profile models to reflect turbine hub heights between 80 and 120 meters. Additionally, environmental and regulatory constraints, such as marine protected zones, shipping corridors, migratory wildlife routes, and sediment transport dynamics, were mapped using data from the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), the International Maritime Organization's GISIS portal, and regional oceanographic institutes to ensure compliance with ecological and navigational standards. Technical and economic specifications, including turbine types like the Vestas V150-4.2 MW and high-efficiency monocrystalline photovoltaic panels, as well as detailed cost estimates for installation, operation, and maintenance, were collected from the latest reports by the International Renewable Energy Agency (IRENA) and BloombergNEF, providing a robust foundation for energy and economic modeling.

Participants:

In this study on the potential measurement and modeling of an atlas of artificial islands for wind and solar energy, participants did not include human subjects in the traditional sense but rather involved structured consultations with a panel of fifteen multidisciplinary experts. These participants were selected based on their extensive experience and technical knowledge in key domains relevant to the study. Experts in marine engineering provided insights on the structural feasibility and technical challenges associated with constructing artificial islands in offshore environments. Renewable energy specialists contributed to defining accurate system performance parameters for wind turbines and photovoltaic arrays under varying marine climatic conditions. Environmental scientists were engaged to assess the potential ecological impacts, such as disruption to marine ecosystems, bird migration patterns, and sediment transport. Additionally, professionals in policy and energy economics offered critical perspectives on regulatory frameworks, permitting procedures, and economic viability. The structured interviews conducted with these stakeholders were instrumental in validating the modeling assumptions, site selection criteria, and the integration of environmental and economic variables, thereby enhancing the study's overall credibility and relevance to real-world applications.

Data Analysis:

The data analysis for evaluating the potential measurement and modeling of an Atlas of artificial islands for wind and solar energy involved a comprehensive multi-dimensional approach combining spatial, technical, environmental, and economic assessments. Site suitability was determined using a weighted overlay model executed in ArcGIS Pro and QGIS 3.28, where criteria such as sea depth, average wave height, wind and solar resource availability, proximity to grid infrastructure, and environmental restrictions were integrated. To prioritize site selection, the Analytic Hierarchy Process (AHP) was used to assign relative weights to these criteria based on expert input and literature benchmarks. For energy yield estimation, wind power output was modeled using the Weibull distribution and turbine-specific power curve integration, accounting for hourly wind speeds at multiple hub heights. Solar energy modeling was conducted using PVGIS and the System Advisor Model (SAM), incorporating hourly solar radiation data and accounting for system losses such as shading, inverter inefficiency, and transmission losses, cumulatively assumed at 15%. Environmental impact assessment followed ISO 14001 protocols, involving spatial overlay of risk zones—such as marine protected areas and migratory routes—with high-potential sites to avoid ecological conflicts. Finally, economic viability was assessed through simulations in HOMER Grid and MATLAB Simulink to calculate the Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and Internal Rate of Return (IRR), while also conducting sensitivity analyses for variations in capital costs, discount rates ranging from 4% to 10%, and fluctuating electricity prices, ensuring robustness in investment decision-making.

4. Results and Discussion:

Table 1: Site Suitability Scores by Region

Region	Depth (Score)	Wind Resource	Solar Resource	Grid Proximity	Environmental Constraints	Final Suitability Index
North Sea	0.80	0.90	0.70	0.85	0.90	0.83
Baltic Sea	0.90	0.85	0.65	0.80	0.88	0.82
Mediterranean	0.70	0.60	0.90	0.75	0.85	0.76
Gulf of Mexico	0.85	0.88	0.85	0.90	0.80	0.86
South China Sea	0.75	0.92	0.80	0.70	0.75	0.78

This table highlights the solar resource potential across three marine regions by using Global Horizontal Irradiance (GHI), capacity factor, and annual output. The Mediterranean region shows the highest GHI (5.8 kWh/m²/day), correlating with the highest capacity factor (21%) and annual output (2100 GWh). The Gulf of Mexico and South China Sea follow in descending order. This suggests that the Mediterranean has slightly superior solar energy conditions, though all regions are viable for solar projects.

Table 2: Wind Energy Output Estimates

Region	Avg Wind Speed (m/s)	Capacity Factor (%)	Annual Output (GWh)
North Sea	9.2	42	4500
Baltic Sea	8.5	38	3800
Gulf of Mexico	8.8	40	4100

Wind conditions are favorable in all three listed regions. The North Sea stands out with the highest average wind speed (9.2 m/s), resulting in the highest capacity factor (42%) and annual energy output (4500 GWh). The Baltic Sea and Gulf of Mexico have slightly lower outputs but still demonstrate strong wind energy potential. This table underlines the superior wind conditions in Northern Europe.

Table 3: Solar Energy Output Estimates

Region	GHI (kWh/m²/day)	Capacity Factor (%)	Annual Output (GWh)
Mediterranean	5.8	21	2100
Gulf of Mexico	5.6	20	2000
South China Sea	5.4	19	1900

This table reiterates the solar metrics from Table 1. The Mediterranean region again ranks highest for solar energy potential, followed by the Gulf of Mexico and South China Sea. The differences in GHI and capacity factor are small but meaningful when considering large-scale solar developments.

Table 4: Environmental Impact Matrix

Region		Marine Biodiversity	Bird Migration	Sediment Risk	Overall EIA Rating
North Sea		Low	Low	Medium	Low Impact
Baltic Sea		Medium	Low	Low	Medium Impact
Mediterranean		High	Medium	High	High Impact
South China Sea		Medium	High	Medium	Medium Impact

The environmental impacts vary notably across regions. The Mediterranean scores the highest in terms of negative environmental impact (high marine biodiversity and sediment risk), resulting in a "High Impact" rating. In contrast, the North Sea shows minimal environmental impact, making it more favorable for renewable energy deployment. The South China Sea poses challenges due to high bird migration and medium sediment risk.

Table 5: Economic Indicators

Region	NPC (M USD)	LCOE (USD/kWh)	IRR (%)
North Sea	1200	0.067	11.5
Baltic Sea	1100	0.072	10.8
Gulf of Mexico	1000	0.065	12.2

From an economic perspective, the Gulf of Mexico offers the most favorable conditions, with the lowest Net Present Cost (NPC) of \$1000 million, the lowest Levelized Cost of Electricity (LCOE) at \$0.065/kWh, and the highest Internal Rate of Return (IRR) at 12.2%. The North Sea and Baltic Sea follow closely but with slightly higher costs and lower returns, indicating viable but less economical options compared to the Gulf.

Table 6: Sensitivity Analysis – CAPEX Variation (North Sea Example)

CAPEX Variation	NPC (M USD)	LCOE (USD/kWh)
-20%	960	0.058
Base	1200	0.067
+20%	1440	0.076

This sensitivity analysis evaluates how changes in capital expenditure (CAPEX) affect the North Sea project's NPC and LCOE. A 20% reduction in CAPEX significantly lowers the NPC to \$960 million and

the LCOE to \$0.058/kWh. Conversely, a 20% increase raises the LCOE to \$0.076/kWh. This highlights the importance of cost control and its influence on project feasibility.

Table 7: Grid Integration Distance Analysis

Region	Distance to Grid (km)	Transmission Loss (%)	Additional Cost (M USD)
North Sea	35	4	50
Baltic Sea	40	5	55
South China Sea	50	6	65

Grid integration costs increase with distance from the grid. The North Sea, with the shortest distance (35 km), has the lowest transmission losses (4%) and additional cost (\$50 million). The South China Sea, at 50 km, shows the highest losses and cost. This indicates that proximity to the grid is a key factor in reducing transmission inefficiencies and expenses.

Table 8: Combined Potential Index

Region	Energy Index	Economic Index	EIA Index	Final Ranking Score
North Sea	0.88	0.87	0.91	0.89
Gulf of Mexico	0.84	0.89	0.82	0.85
Baltic Sea	0.81	0.80	0.85	0.82
Mediterranean	0.76	0.78	0.68	0.74

This table integrates energy potential, economic feasibility, and environmental impact into a final ranking score. The North Sea leads with the highest overall score (0.89), driven by strong wind resources, favorable environmental conditions, and manageable economic indicators. The Gulf of Mexico ranks second (0.85), offering strong economic and solar conditions. The Mediterranean, despite high solar potential, ranks lowest due to its high environmental impact.

Discussion:

The results indicate that offshore artificial islands hold strong potential for integrated wind and solar energy development [2]. The Gulf of Mexico scored highest in combined solar and wind energy generation (Table 2 & 3) and economic returns (Table 5), thanks to balanced irradiance, wind speeds, and grid proximity. However, the North Sea emerged as the most feasible overall site (Table 8), combining high wind resource availability, relatively low environmental impact (Table 4), and strong economic feasibility (IRR = 11.5%) [22]. The region also demonstrated manageable integration costs and low transmission losses due to its proximity to European grid infrastructure (Table 7).The Baltic Sea, although economically viable and environmentally moderate, had slightly lower energy potential, especially for solar (Table 3). The Mediterranean, while excellent for solar energy, presented high environmental risks (Table 4), significantly reducing its final ranking (Table 8) [23].Sensitivity analysis (Table 6) confirmed the financial viability of artificial islands is highly dependent on CAPEX control, with LCOE ranging from 0.058 to

0.076 USD/kWh depending on capital variation. These values are competitive with global renewable benchmarks (IRENA, .Grid distance emerged as another key cost driver [24]. Every additional 10 km offshore added approximately 15% to transmission cost (Table 7), highlighting the importance of grid mapping during site planning. Overall, this multi-criteria analysis validates the viability of a renewable energy atlas for artificial islands, particularly in regions like the North Sea and Gulf of Mexico, which balance energy potential, ecological impact, and economic feasibility [25].

5. Conclusion:

The comprehensive assessment and modeling of the Atlas of artificial islands for wind and solar energy reveal that integrated offshore renewable energy platforms hold significant promise for meeting future sustainable energy demands. Based on site suitability, energy output estimates, environmental impact analysis, and economic indicators, regions such as the North Sea and Gulf of Mexico emerge as top candidates due to their high wind capacity factors, favorable solar irradiance, low environmental risks, and competitive economic performance. The final suitability index underscores the strategic advantage of these regions in developing hybrid energy islands. Moreover, sensitivity analyses emphasize the importance of optimized CAPEX and grid integration planning to ensure economic viability. Overall, the research validates that multi-criteria decision frameworks and geospatial modeling provide accurate, scalable tools for guiding policy and investment in offshore renewable infrastructure, enabling a balanced approach to energy security, environmental preservation, and economic growth.

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