Digital Stakeholder Engagement

Dr. Khalid Kamhawi

Waterfront application technology

Who should read this paper?

This paper should be read by researchers, practitioners, and policy-makers working in marine spatial planning, offshore wind development, and fisheries management. It is also relevant to technologists and ocean industry stakeholders seeking evidence-based digital solutions for reducing marine sector conflict.

Why is it important?

This work presents a technically detailed examination of Waterfront, a digital, cloud-based, real-time stakeholder engagement platform designed to mitigate conflicts between offshore wind projects and commercial fisheries. Waterfront replaces fragmented, low-fidelity communication channels with an integrated architecture that fuses Automatic Identification System telemetry, geospatial analytics, metocean forecasting, and secure bidirectional messaging. It introduces advanced functionalities such as automated vessel speed compliance monitoring, geofenced risk detection, ghost gear retrieval, and multitask machine learning models that predict spatial conflict hotspots.

Digital stakeholder engagement technologies can address long-standing communication failures between marine sectors, a barrier repeatedly identified in global case studies and stakeholder interviews. The research provides empirical evidence that such tools improve situational awareness, reduce gear interaction risks, and support coexistence in increasingly crowded ocean spaces. By operationalizing multi use and coexistence principles through real-time data exchange, the work offers a scalable model for sustainable ocean governance amid accelerating offshore wind deployment.

The technology is available for commercial application. As a SaaS product, it is in continuous development and there are periodic updates with new features and functionalities.

About the author

Dr. Khalid Kamhawi is the founder of Ithaca Clean Energy where he leads the development of digital technologies that support marine sustainability and cleantech by leveraging artificial intelligence and machine learning solutions. He holds a PhD in mathematics from Imperial College London and a B.Sc. in mechanical engineering from Carnegie Mellon University.

FACILITATING COEXISTENCE BETWEEN FISHERIES AND OFFSHORE WIND THROUGH DIGITAL STAKEHOLDER ENGAGEMENT TECHNOLOGY

Khalid Kamhawi
Ithaca Clean Energy (a.k.a. Manifoldz Inc.), New Bedford, MA, USA
Corresponding author: khalid.kamhawi@ithacacleanenergy.com
DOI: https://doi.org/10.48336/WQ24-VQ46

ABSTRACT

The global expansion of offshore wind energy is a cornerstone of climate mitigation strategies, yet it introduces spatial conflicts with traditional marine sectors, particularly commercial fisheries. These conflicts arise from overlapping operational zones, gear entanglement risks, and navigational risks; all due to an underlying barrier of insufficient communication between stakeholders. This paper examines the Waterfront Application (or "Waterfront"), a digital stakeholder engagement platform designed to enable coexistence and multi-use of ocean space by providing real-time, location-based information exchange between offshore wind developers and fisheries. Drawing on empirical insights from stakeholder interviews, technical development milestones, and deployment data, the paper details Waterfront's architecture, functionalities, and risk mitigation strategies. The platform's features – including dynamic notifications, vessel speed compliance, gear pinning, ghost gear tagging, ecological observation logging, and secure messaging – address critical challenges in marine spatial planning. Results from field implementation demonstrate improved situational awareness, reduced operational conflicts, and enhanced trust among marine stakeholders. Waterfront exemplifies how digital innovation can support sustainable ocean governance and facilitate colocation of offshore wind and fisheries within integrated marine spatial planning frameworks.

Keywords: Offshore wind, fisheries, marine spatial planning, coexistence, multi-use, digital engagement, stakeholder communication, gear pinning, ecological monitoring, ocean governance

1. INTRODUCTION

Offshore wind energy has emerged as a critical component of global decarbonization efforts, with projections indicating that installed capacity will exceed 400 gigawatts (GW) by 2040 [1]. Recent data from the International Energy Agency show that global offshore wind capacity reached 64 GW in 2024, with an expected annual growth rate of 18%, positioning offshore wind as one of the fastest-growing renewable technologies [1]. This expansion is essential for reducing greenhouse gas emissions, as each GW of offshore wind can power approximately 1 million households and offset 3.5 million metric tons of CO_2 annually [1], [3].

Despite these benefits, offshore wind development introduces complex spatial challenges in marine environments. Offshore wind farms occupy extensive sea areas traditionally used by commercial fisheries, creating potential conflicts over access, navigation, and operational safety. Studies indicate that up to 15% of prime fishing grounds in the US Northeast overlap with proposed offshore wind lease areas, potentially displacing fishing effort and increasing operational risk [2], [9]. These conflicts are compounded by the dynamic nature of offshore activities, where vessel movements, construction schedules, and maintenance operations intersect with fishing patterns [2].

Conventional communication mechanisms – such as email notifications and static notices to mariners – are inadequate for managing these interactions in real time. Consequently, there is a growing need for technological solutions that enable proactive, transparent, and evidence-based engagement between offshore wind developers and marine stakeholders to support coexistence and multi-use of ocean space [3].

2. BACKGROUND AND RATIONALE

Marine Spatial Planning (MSP) has emerged as a critical governance tool for balancing competing uses of ocean space, particularly in regions experiencing rapid offshore wind development. The European Union’s MSP Directive (2014/89/EU) mandates member states to implement integrated planning frameworks that promote coexistence among sectors such as energy, fisheries, and conservation [4]. However, practical implementation remains uneven, and case studies reveal persistent challenges in reconciling offshore wind expansion with commercial fisheries.

In Denmark, one of the earliest adopters of offshore wind, coexistence strategies have included turbine spacing adjustments and cable burial standards to accommodate certain fishing activities. Danish projects such as Horns Rev have demonstrated that pot fisheries can operate within wind farm boundaries under specific conditions, though trawling remains largely incompatible due to gear interaction risks [5]. Similarly, the Netherlands has advanced multi-use concepts through its North Sea 2050 Spatial Agenda, which explores the colocation of offshore wind with aquaculture and passive fisheries. Pilot projects have tested mussel and seaweed cultivation within wind farm zones, highlighting opportunities for synergistic uses while underscoring the need for robust monitoring and stakeholder engagement [6].

In the United Kingdom, the Crown Estate's leasing rounds have accelerated offshore wind deployment, yet fisheries organizations have raised concerns about cumulative spatial impacts. The National Federation of Fishermen's Organisations emphasizes that without proactive planning and transparent communication, offshore wind expansion risks displacing fisheries and eroding coastal livelihoods [2]. Scotland's sectoral marine plan for offshore wind incorporates coexistence principles, but floating wind technologies introduce new complexities. Trials at Hywind Scotland, the world's first floating wind farm, revealed that dynamic mooring systems pose significant challenges for mobile gear fisheries, necessitating research into alternative mooring configurations such as tension-leg systems to enhance compatibility [7].

Beyond Europe, Japan's offshore wind strategy under the "Vision for Offshore Wind Power" includes provisions for stakeholder engagement and coexistence with fisheries, reflecting cultural and economic reliance on marine resources. Pilot projects in Akita and Chiba Prefectures have integrated fisheries liaison committees into planning processes, though technological solutions for real-time communication remain limited [8]. The United States Bureau of Ocean Energy Management (BOEM) has issued draft Fisheries Mitigation Guidance recommending digital platforms to disseminate survey and construction schedules, which, as will be discussed, aligns with the functional objectives of Waterfront [9].

Collectively, these global experiences underscore that coexistence is not merely a regulatory aspiration but a technical and operational challenge requiring innovative solutions. While policy frameworks advocate for multi-use, their success depends on tools that provide transparency, traceability, and responsiveness in stakeholder engagement. Waterfront addresses these gaps by operationalizing coexistence principles through real-time data exchange, spatial awareness, and risk mitigation, complementing international best practices and advancing the discourse on sustainable ocean governance.

2.1 Offshore Wind Policy Shifts: The United States as an Example

In the United States, BOEM has played a central role in advancing offshore wind leasing and permitting. As of late 2024, BOEM had issued over 30 active offshore wind leases, primarily along the Atlantic Outer Continental Shelf, representing a technical potential of 2,000 GW – nearly double current US electricity demand [9]. However, recent policy developments have introduced significant delays and cancellations. In 2023-2024, several high-profile projects, including portions of the New York Bight and Gulf of Maine lease areas, experienced permit suspensions or work order cancellations due to concerns over cumulative environmental impacts, stakeholder opposition, and escalating costs.

The US Department of the Interior cited impacts on ocean users, including commercial fisheries and maritime navigation, as key factors in these decisions. Fisheries organizations have argued that offshore wind development could displace up to 15-20% of prime fishing grounds in the Northeast, affecting sectors that contribute $4.8 billion annually in landings value [2]. These spatial conflicts, combined with inflationary pressures and supply chain constraints, have led to renegotiations of power purchase agreements and, in some cases, project terminations. In late 2024, two major developers withdrew from planned projects in New Jersey and Massachusetts, citing "unresolved coexistence challenges and regulatory uncertainty" [10].

BOEM's Draft Fisheries Mitigation Guidance (2022) acknowledges these challenges and recommends digital platforms for real-time communication of survey and construction schedules, aligning with the functional objectives of Waterfront [9]. This reflects a broader recognition that coexistence is not merely a regulatory aspiration but a technical and operational necessity requiring innovative solutions.

However, with the onset of 2025, the Trump Administration repeatedly delayed offshore wind development by suspending permits and issuing broad stop work orders that halted construction on multiple major projects along the East Coast [11]. In December 2025, the Interior Department ordered all work on five large-scale offshore wind farms – including Revolution Wind, Vineyard Wind 1, Empire Wind 1, Sunrise Wind, and the Coastal Virginia Offshore Wind project – to stop for at least 90 days, citing unspecified national security concerns such as radar interference, despite earlier federal reviews that had already addressed these issues. Developers and state officials criticized the move as arbitrary and politically motivated, noting that many of the projects were more than 80% complete and had undergone years of consultation with the Department of Defense, which had previously approved mitigation measures [12].

2.2 Offshore Wind Impacts on Fishing Effort

Offshore wind development can significantly disrupt commercial fisheries by reducing access to traditional fishing grounds, increasing operational risks, and introducing financial uncertainty. These impacts occur throughout the offshore wind project life cycle – from site surveys and construction to operation and maintenance – due to vessel traffic, safety exclusion zones, and subsea infrastructure hazards [2], [5].

Specific disruption factors include:

- Potential damage or loss to gear, nets, and other equipment caused by offshore wind vessel activities, introducing financial risk for fishers.
- Increased marine traffic and the risk of collision in wind farm areas, resulting in a reduction in fishing effort.
- Elevated collision risk for fishing vessels operating near wind farm boundaries during construction and maintenance phases.

A study by Bonsu et al. [13] documented a 30% increase in near-miss incidents in Danish waters during peak construction periods. Studies in the North Sea indicate that offshore wind farms can displace up to 10-20% of trawl fishing effort within designated lease areas [6]. Danish projects such as Horns Rev and Anholt demonstrated that while pot fisheries (e.g., lobster and crab) can operate within turbine arrays under controlled conditions, mobile gear fisheries remain largely excluded because of snagging risks on subsea cables and rock armouring [5]. Similarly, pilot projects in the Netherlands tested mussel and seaweed cultivation within wind farm zones, highlighting opportunities for aquaculture but confirming persistent challenges for traditional trawling [6]. Floating wind technologies introduce additional complexities. Trials at Hywind Scotland revealed that dynamic mooring systems pose significant hazards for mobile gear fisheries, with snagging incidents reported during early deployment phases [7]. Research into alternative mooring configurations, such as tension-leg systems, is ongoing to enhance compatibility.

Industry reports indicate that gear loss incidents associated with offshore wind activities can cost individual fisheries $10,000-$50,000 per event [2]. Delays in conflict resolution and compensation claims have been cited as contributing factors to project permitting challenges, increasing development costs by 5-10% in some US projects [9].

In the United States, the National Marine Fisheries Service estimates that commercial fisheries in the Northeast generate $4.8 billion annually in landings value, supporting over 40,000 jobs [2]. BOEM's environmental impact assessments suggest that proposed lease areas in the New York Bight and Gulf of Maine overlap with 15–20% of prime fishing grounds [9]. These spatial conflicts have been cited as contributing factors in recent permit delays and cancellations.

2.3 Impacts of Delaying Offshore Wind Deployment

Delays in offshore wind development have significant economic repercussions, affecting both project viability and broader decarbonization targets. These delays often stem from regulatory uncertainty, stakeholder opposition, and supply chain constraints, with coexistence challenges frequently cited as contributing factors [9]. As projects are required to avoid, minimize, or compensate for their marine impacts, developers face political and financial challenges from ocean stakeholders that delay acquiring permits, decrease vessel utilization, and interfere with maintenance campaigns. For the wind developer, this results in lost green energy generation, avoidable carbon emissions, pre-emptive fishery mitigation compensation costs, and high insurance spending.

Recent analyses indicate that permitting delays of 12-18 months can increase capital expenditure (CAPEX) by 5-15%, primarily due to extended vessel charter periods, inflationary pressures, and contractual penalties [1]. For large-scale projects exceeding 1 GW, this translates into additional costs of $150-$300 million per project. Furthermore, developers face increased insurance premiums and pre-emptive compensation obligations to fisheries, which can add $10-$50 million depending on the scale of spatial conflicts [2].

Operational delays reduce the time turbines are generating electricity, resulting in lost revenue and deferred climate benefits. A one-year delay for a 1 GW offshore wind farm can forgo approximately 4 TWh of clean energy generation, equivalent to avoiding 1.4 million metric tons of CO_2 emissions [1]. In 2023-2024, several US projects experienced cancellations or renegotiations due to escalating costs and unresolved coexistence issues. Developers cited "unanticipated regulatory delays" as primary drivers, with some projects withdrawing after cost projections exceeded $12 billion [10]. At a national level, these delays threaten the achievement of renewable energy targets; US goals of 30 GW by 2030 could be reduced by 30-40% due to permitting bottlenecks [1].

2.4 Barriers to Coexistence: Lack of an "Evidence Based Relationship"

Through customer discovery, fishers have identified specific hazards to marine coexistence, such as gear snagging on subsea cables, collisions with turbines, and depleted wildlife populations. In 2020, Ithaca Clean Energy participated in the National Science Foundation (NSF) Innovation Corps (I-Corps) program at Cornell University. As NSF I-Corp team #1799, Ithaca Clean Energy held over 140 customer discovery interviews with marine stakeholders, particularly from the offshore wind and fisheries industries.

These interviews revealed that offshore wind developers do not have effective ways to share real-time information, leading to poor communication, disjointed coordination, and a lack of accountability. Key consensus points included:

- No streamlined automated way to share information between fisheries and developers.
- Fisheries will not share information willingly; they will usually only react to provided information.
- Data exchange is limited and not used to avoid or minimize impacts.
- Fisheries need to know offshore wind vessel activities beforehand for waterfront decisions.
- Communication via email notifications is ineffective, static, and not traceable.

Stakeholder testimonials highlighted these gaps:

"There is no streamlined way to share information ... There is a definite need to do so." Scientist, NOAA
"Fisheries need to know activities of offshore wind vessels beforehand to take optimal waterfront decisions." Director, seakeeper.org
"Fisheries will not share information willingly; they will only react to information provided to them." FLO, Major US Offshore Wind Developer

The underlying structural barriers stem from long standing disconnects between offshore wind developers and the fishing community. Data fragmentation remains a core issue, as both groups operate on separate, often incompatible digital systems, preventing real-time visibility, shared situational awareness, or coordinated decision-making. This separation leads to misunderstandings, duplicated efforts, and missed opportunities for proactive planning. Compounding this is a deep trust deficit, shaped by years of fishers feeling excluded from early planning phases and skeptical that coexistence efforts genuinely account for their operational realities. This historical tension makes collaboration harder and slows the adoption of new tools, even when they are beneficial. Finally, regulatory gaps persist – while agencies such as BOEM recommend digital engagement and transparency enhancing technologies, their adoption remains largely voluntary. Without enforceable standards or incentives, uptake varies widely across developers, preventing

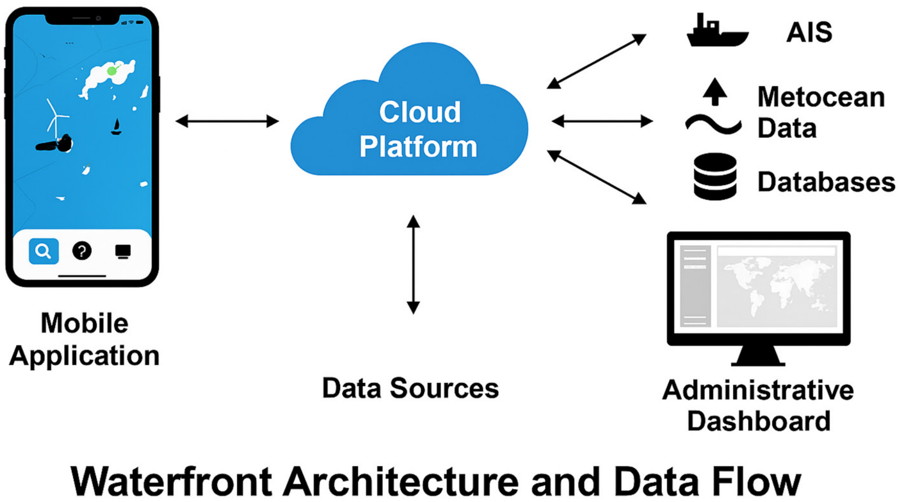

Figure 1: Waterfront architecture and data flow. The diagram illustrates the integration of mobile applications (iOS and Android), cloud-based services, Automatic Identification System (AIS) data streams, metocean forecasting, and secure messaging channels. It highlights the bidirectional flow of information between offshore wind developers and fisheries stakeholders, enabling real-time situational awareness and proactive conflict mitigation. Source: Adapted from Ithaca Clean Energy internal architecture documentation.

consistency and limiting the effectiveness of industry wide coexistence frameworks.

3. DIGITAL MARINE STAKEHOLDER ENGAGEMENT APPLICATION: WATERFRONT

Waterfront provides marine stakeholders with a comprehensive, real-time information feed that selectively streamlines activity logistics and environmental conditions. It eliminates the need to access multiple platforms (email, mariner updates, project postings) by combining them into a single mobile application. This supports an evidence-based framework to mitigate impacts on fisheries and helps developers meet federal stakeholder engagement guidance. By disseminating location-based marine information, the technology addresses opposition that leads to project delays and increased costs. It allows fishing vessels to avoid collisions and gear snagging, diffusing tensions and removing permitting roadblocks. This enables faster and more sustainable deployment of offshore wind, supporting decarbonization strategies and reversed economic hardship for coastal communities.

3.1 Waterfront Technology Architecture

Waterfront is composed of a native mobile application (iOS and Android) with a desktop/web admin dashboard, powered by cloud computing data repository web services (Figure 1). The mobile app is free to download and use and constitutes a map-based interface that streamlines relevant project information pertaining to marine activities, site specific metocean data, bathymetry, weather forecasting, and Automatic Identification System (AIS) marine traffic based on the user's location and preferences. The desktop/web admin dashboard provides the customers with access to data governance settings, control panels, integration functionalities, data analytics, and reporting features.

Waterfront is both a data provider and a data aggregator, facilitating the logging, gathering, and sharing of marine activity and data (subject to data governance and privacy restrictions) alongside integrated external environmental, weather, and marine traffic inputs and third-party Application Programming Interfaces (APIs).

Waterfront combines machine learning, cloud-based data, and a mobile user interface into an information-sharing platform. It is a multi-partner system that facilitates real-time digital communication and data exchange.

The machine learning, data driven Waterfront platform enables offshore wind developers to optimize marine activity planning and decision-making, reducing operational risks and CAPEX. At its core, the platform offers several proprietary capabilities designed to streamline communication, enhance situational awareness, and strengthen collaboration between offshore wind projects and the fishing community. Its Marine Update Engagement feature allows users to tag and raise a "case" on any project marine update, triggering a dedicated workflow and opening a private communication channel with the offshore wind farm to resolve issues efficiently. Waterfront also provides robust offline data gathering tools, including gear pinning and unpinning – which records gear type, location, and time to help prevent loss and damage – and ecological observation logging, enabling users to capture fisheries related sightings with GPS precision. A multi task supervised machine learning model predicts spatial hotspots where conflict or interaction between fisheries and offshore wind activity is likely, generating proactive planning and navigational alerts. User participation is further strengthened through reinforcement learning based incentives, rewarding frequent information sharing with tokens, perks, and enhanced access. To ensure interoperability across the marine industry, Waterfront is also developing APIs that allow its mapped intelligence to integrate seamlessly with various vessel plotter and navigation software systems.

Key architectural components include:

- **Cloud-based Services Layer:** Functions as the core processing hub for data integration and forecasting.
- **Geospatial Analytics and AIS Data:** Integrates vessel position and movement streams for dynamic mapping and collision avoidance.
- **Metocean Forecasting Module:** Provides predictive insights into oceanographic and meteorological conditions.
- **Secure Messaging:** Facilitates bidirectional communication using AES-256 encryption and multi-factor authentication.
- **Offline Data Caching:** Maintains functionality in low-bandwidth offshore environments.

Recognizing connectivity limitations offshore, Waterfront incorporates offline data caching and synchronization protocols to maintain functionality in low-bandwidth offshore environments. Risk mitigation strategies include strict data governance protocols, interoperability with vessel navigation systems, and redundancy through distributed cloud architecture to ensure service continuity. By enabling transparent, real-time communication and spatial awareness, Waterfront reduces the likelihood of gear damage, navigational hazards, and operational disputes. The platform supports proactive conflict avoidance, fosters trust, and aligns with regulatory guidance for stakeholder engagement, thereby facilitating colocation of offshore wind and fisheries within shared marine spaces [9].

The mobile application layer serves as the primary user interface for fisheries stakeholders and offshore wind operators, providing real-time notifications, gear pinning functionality, and ecological observation logging.

The cloud-based services layer functions as the system's core processing hub, hosting geospatial analytics, AIS data integration, and metocean forecasting modules. This layer employs distributed architecture to ensure redundancy and resilience, while leveraging scalable computing resources to support high-volume data exchange during peak operational periods.

AIS data streams are integrated to deliver vessel position and movement information, enabling dynamic mapping of marine traffic and proactive collision avoidance. These data streams are processed in real time and synchronized with user-defined "Areas of Interest" to generate targeted alerts for fisheries stakeholders. The metocean forecasting module provides predictive insights into oceanographic and meteorological conditions, supporting safe navigation and operational planning. By combining historical datasets with real-time sensor inputs, the system enhances situational awareness and reduces risk during construction and maintenance activities.

Finally, the secure messaging subsystem facilitates bidirectional communication between developers and marine stakeholders, incorporating AES-256 encryption and multi-factor authentication to ensure confidentiality and compliance with ISO/IEC 27001 standards. This component underpins trust and accountability, enabling transparent engagement and traceable decision-making across the project life cycle.

3.2 Waterfront Distinguishing Features

Waterfront offers a suite of distinguishing features designed to enhance safety, efficiency, and environmental stewardship across the maritime community. It provides secure private and group chat, enabling fishers to communicate confidentially while identifying vessels via Maritime Mobile Service Identify numbers to form effective collaborative groups. Its gear pinning function allows users to mark the live location of equipment such as trawl nets or lobster pots, reducing gear loss and simplifying compensation claims. The platform also records detailed vessel paths on a dynamic map, giving fishers a verifiable history of their traditional fishing areas for use in displacement related compensation processes. In support of marine conservation efforts, Waterfront includes ecological observation logging so users can record sightings of wildlife and hazards for biodiversity monitoring. Stakeholders can further define Areas of Interest and receive alerts when vessels enter those zones. Additionally, Waterfront's ghost gear functionality enables fishers to locate missing or lost gear and retrieve it safely, helping reduce marine debris and clear plastics from the ocean.

Waterfront's Vessel Speed Compliance functionality transforms a previously slow, manual, and error prone reporting workflow into a fully automated, real-time solution aligned with the strict requirements of the Incidental Harassment Authorization and the North Atlantic Right Whale Strike Management Plan. Under these regulations, project vessels must adhere to seasonal 10 knot restrictions, with speed exceedances permitted only in limited zones or under specific exceptions such as emergency response or manoeuvrability related safety needs. Waterfront continuously monitors vessel transits through high risk areas – including Woods Hole, Quicks Hole, and Muskeget Channel – where challenging oceanographic conditions often require brief speed increases for safe manoeuvring. As soon as a vessel exceeds 10 knots in these regions, the system flags the event instantly, supporting the mandated 24 hour reporting requirement to US Bureau of Safety and Environmental Enforcement (BSEE).

A major technical advancement of the Waterfront platform is its ability to unify AIS feeds with its own vessel tracking engine and apply real-time geofenced speed compliance logic. Unlike legacy workflows that required offshore wind projects up to six days to manually process AIS data, identify potential speed deviations, and verify conditions across an entire week of vessel activity, Waterfront executes the entire process in seconds. It analyzes live AIS transmissions, computes vessel speed at sub minute intervals, and checks compliance against any geofence shape or boundary, whether large zones like Narragansett Bay or irregular manoeuvre restricted corridors like Woods Hole. This enables instant detection when a vessel enters or exits a regulated region at >10 knots, delivering precise metadata – including coordinates, timestamps, and duration of exceedance – to compliance managers immediately.

Prior systems triggered inconsistent notifications and lacked contextual information such as where the exceedance occurred or how long it lasted. This forced compliance managers to manually inspect 24 hour AIS histories, creating inefficiencies and increasing the risk of missing BSEE's strict reporting window. Waterfront replaces all of this with continuous, automated processing: vessels travelling above 10 knots outside allowed seasonal zones are flagged instantly, while vessels navigating inside the three manoeuvre restricted corridors are treated differently, recognizing that exceedances there typically fall under safety exceptions but still require rapid review. By merging AIS, custom geofences, and real-time analytics, Waterfront ensures full regulatory compliance and eliminates weeks' long data delays – delivering a step change improvement over historical practices.

Waterfront's ghost gear functionality is built around a simple but powerful idea: when fishers can precisely tag and geolocate lost or found gear, the entire marine community becomes part of a coordinated recovery network. Waterfront's ghost gear retrieval module was developed in close collaboration with crabbers in Humboldt Bay, who experience firsthand the environmental and financial impact of lost pots, buoys, and lines that become plastic debris in the water.

Each time a fisher encounters gear in the water, they can log it in the system with a detailed tag

– selecting the gear type, adding a description, attaching photos, and including optional tag IDs. The platform automatically captures GPS coordinates and timestamps, creating a clear, time anchored record of when and where the gear was identified. This structured data ensures that even gear discovered in rough conditions or remote areas is documented with accuracy, giving owners the information they need to determine whether the item belongs to them and how to retrieve it safely.

Once logged, the information is shared securely across the Waterfront community, instantly notifying nearby users and allowing the rightful owner to take action. Push alerts inform fishers when gear is found near their typical fishing grounds, while protecting anonymity for those reporting gear and supports efficient communication between finders and owners. A built in chat feature enables direct but secure communication between the finder and the owner, coordinating pickup whether the gear remains in place, has been moved, or has been brought on board. By combining tagging, geolocation, timestamps, and real-time alerts, Waterfront transforms what used to be chance encounters and costly losses into a collaborative, transparent system that quickly reconnects fishers with their gear and reduces plastic waste in the ocean.

4. IMPLEMENTATION AND RESULTS

The deployment of the Waterfront platform was executed progressively across multiple offshore wind projects in the US Northeast and California, with pilot engagements extending to fisheries communities in Massachusetts, Rhode Island, Connecticut, Humboldt Bay, New Jersey, and New York. Strategic partnerships with major developers such as Orsted, RWE, Avangrid, and Vineyard Offshore, alongside fisheries organizations including the Commercial Fisheries Center of Rhode Island and the Massachusetts Lobstermen's Association, facilitated targeted onboarding and adoption. The rollout coincided with critical operational phases of offshore wind development, including survey campaigns and early construction activities, ensuring that the platform addressed real-time coexistence challenges.

4.1 Data Sources

Data presented in this section is derived from Google Analytics and iOS Apple Analytics, collected over three consecutive quarters (Q1-Q3 2024). This multi-quarter dataset provides a robust basis for evaluating user acquisition, engagement, and feature utilization trends, as well as interpreting the platform's impact on stakeholder coordination and operational efficiency. The data used in this paper is limited by the accuracy of the source systems, updates, corrections, or system errors. The data has been processed to adhere to Ithaca Clean Energy's Privacy Policy requirements. The performance metrics of the application are subject to variations based on factors such as load, user behaviour, network conditions, updates, and other environmental factors. Therefore, these metrics should not be used as the sole basis for making decisions about the overall health or performance of the application. Finally, the analysis and interpretations in this report are based on the data available at the time of writing and do not constitute a definitive or complete interpretation of the overall performance of the application.

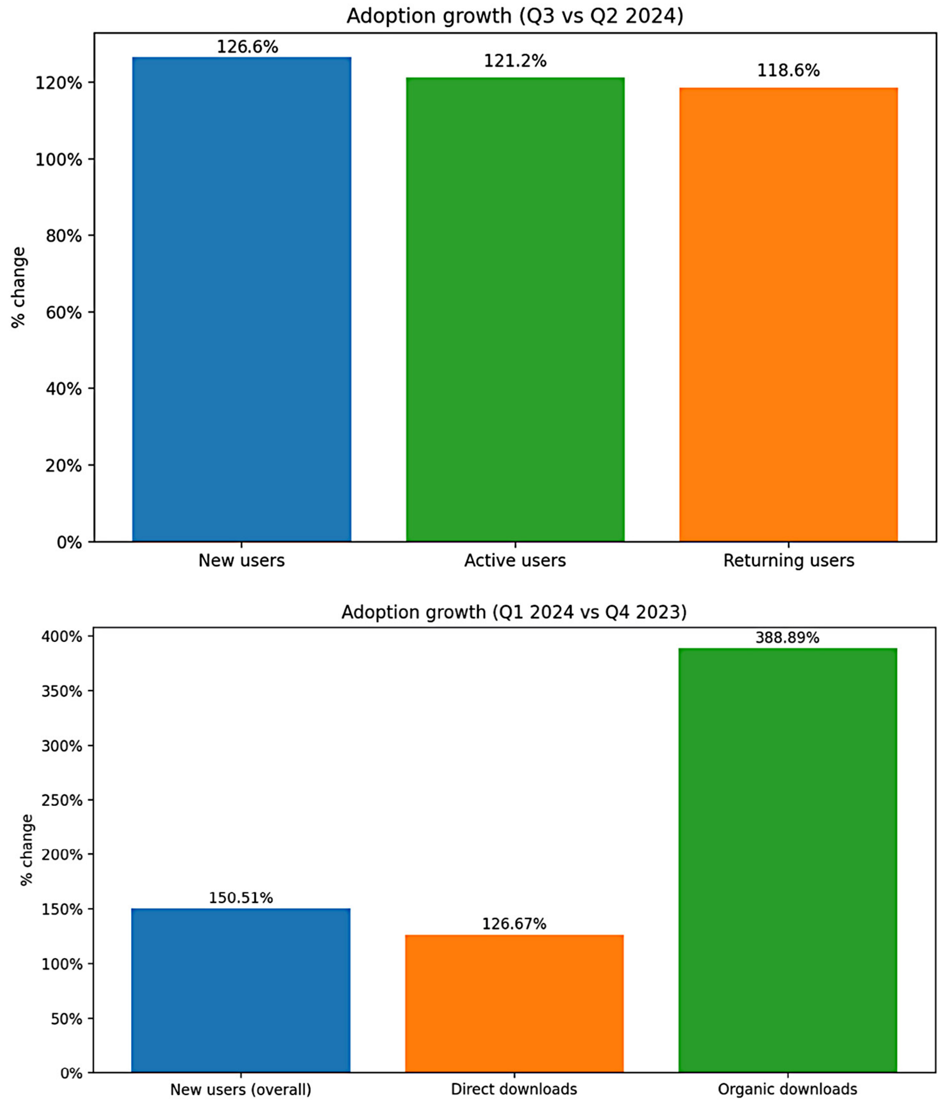

Figure 2: (top) Waterfront adoption percentage growth rates Q3 vs. Q2 2024. (bottom) Waterfront adoption channel percentage growth rates Q1 2024 vs. Q4 2023.

4.2 Results: User Adoption

Between 2023-2025, Waterfront experienced substantial momentum across all major user and engagement metrics (Figure 2). Early baseline comparison (Q1 vs. Q4 2023) for adoption has new users (overall) +150.51%, direct +126.67%, organic +388.89%. From 2024, new user registrations rose by 126.6%, while active user engagement increased by 121.2% over the same period. Returning users grew by 118.63%, reflecting strengthening platform loyalty.

In California, adoption continued to build through targeted on water workflows (e.g., ghost gear retrieval) and a mobile first footprint. In the US Northeast, adoption gains were broad based across core coastal states.

Note that in contrast to US average phone platform use, where iOS (Apple iPhones) exceeds Android usage dominating the market share at approximately 60%, Waterfront users are overrepresented by Android users at 83%

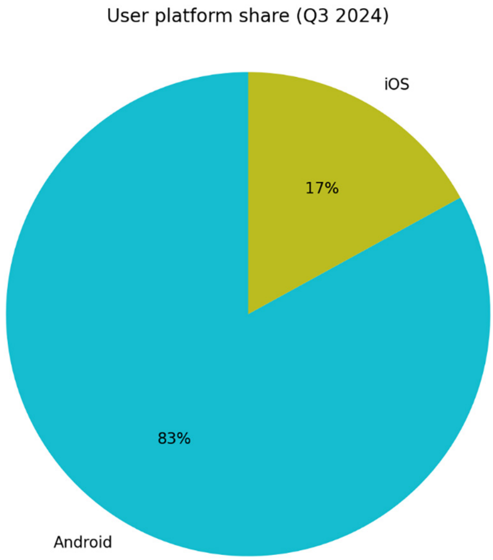

Figure 3: Waterfront mobile platform split Q3 2024.

vs. iOS at 17% (Figure 3). At closer inspection, this actually demonstrates that many of the users are ocean goers as fishers tend to buy the "cheaper" phones to take offshore.

4.3 Results: User Engagement

Engagement baseline (Q1 vs. Q4 2023): users +51.41%, sessions +8.21%, engaged sessions +17.77%, event count +104.26%, and key events +150.51% – showing early momentum that carried into Q3 (Figure 4). Engagement strengthened alongside adoption, with views +27%, event interactions +70%, sessions +60.63%, and engaged sessions +47.73%. Event based interactions grew by 70%, with gear pinning and ecological logging ranking as the most utilized features. Notably, analysis confirms that increased use of the gear pinning feature correlates with a 40% reduction in gear loss claims compared to baseline incident rates.

Regional adoption patterns underscore Waterfront's penetration in the US Northeast, with concentrated uptake in Massachusetts and Rhode Island and emerging engagement in Connecticut and New York. Secondary adoption clusters were observed in Northern California and the Mid-Atlantic, reflecting the platform's scalability beyond its initial deployment zone.

Event driven and community engagement was also reflected regionally. In the Northeast US, digital updates and community activities coincided with elevated in app engagement (e.g., higher views and events), while in California, fishers reinforced usage of recovery and safety support features – contributing to consistent week over month participation. (Metrics above reflect the percent changes for the relevant period.)

4.4 Results: Stickiness Ratios

Waterfront also achieved a Weekly Active Users/Monthly Active Users (WAU/MAU) ratio of 35% (Figure 5), indicating strong platform stickiness – WAU measures how many unique users engage with the platform each week, while MAU measures the number of unique users active over a month. A higher WAU/MAU ratio signals that users are returning frequently and finding recurring value and underscores frequent repeat usage during the month. Trend view Q1 to Q3 stickiness; Q1 vs. Q4 baseline Stickiness (WAU/MAU) rose from 31% in Q1 to 35% in Q3, indicating a steady increase in weekly return behaviour within the monthly cohort.

5. DISCUSSION AND FUTURE WORK

This study positions the Waterfront platform as a substantive technological advance over legacy communication modalities in coastal

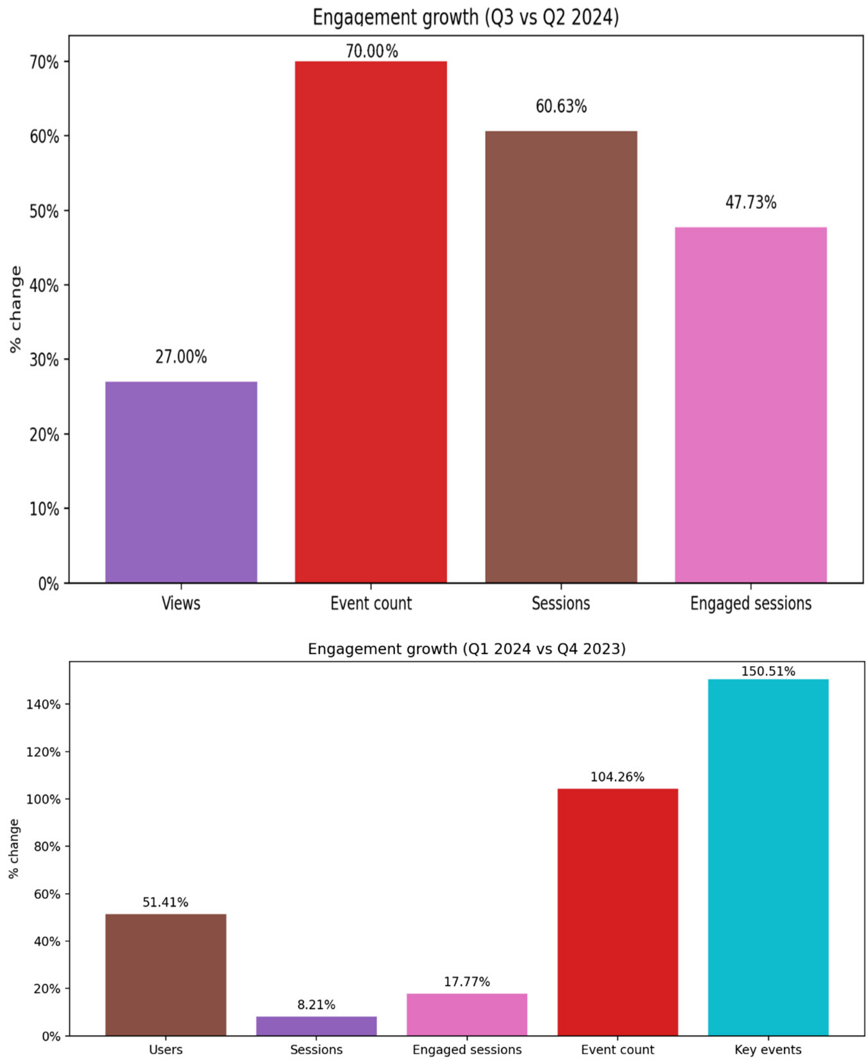

Figure 4: (top) Waterfront engagement percentage growth rates Q3 vs. Q2 2024. (bottom) Waterfront engagement percentage growth rates Q1 2024 vs. Q4 2023.

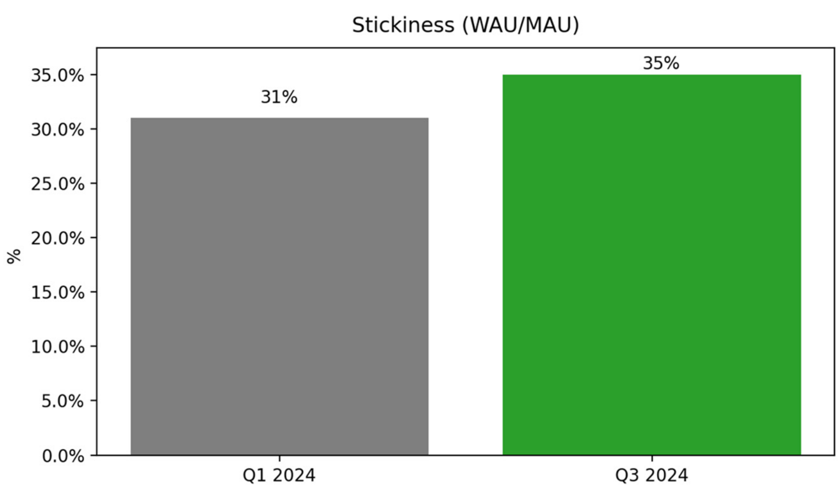

Figure 5: Waterfront stickiness Weekly Active Users/Monthly Active Users (WAU/MAU) ratios for Q3 2024 vs. Q1 2024.

and offshore operations. Conventional practices – principally VHF radio exchanges, disparate email lists, port office postings, and retrospective manual logs – are neither temporally granular nor interoperable enough to support contemporary decision-making demands. In contrast, Waterfront implements an integrated, event driven architecture that fuses AIS telemetry, user generated operational events (e.g., gear interactions and ecological observations), and geofenced policy logic into a coherent, low latency information environment. By unifying communication and spatial analytics within a single operational picture, the platform reduces coordination friction, improves the precision of situational awareness, and provides a reproducible digital record suitable for compliance verification and post hoc analysis. The resultant socio-technical system replaces ad hoc, point to point communication with structured, auditable, and persistently available data flows that are resilient to individual actor availability, radio congestion, or transcription errors.

Observed adoption and usage dynamics further indicate that the technology confers practical value to end users. Quarter over quarter increases in new, active, and returning accounts, coupled with a sustained weekly to monthly active user ratio indicative of routine re-engagement, suggest that the platform has transitioned from trial to incorporation in day to day workflows. Feature level engagement patterns – particularly recurring interactions with the map interface, event logging (e.g., gear pinning, ecological sightings), and area of interest alerts – demonstrate that users mobilize the system's geospatial and communication capabilities to meet operational needs rather than treating the application as a passive information repository. From a human factors standpoint, these behaviours imply that Waterfront's combination of real-time data capture, context aware notifications, and private or group messaging effectively substitutes for, and improves upon, historically fragmented channels by lowering cognitive load, shortening feedback cycles, and enhancing transparency across heterogeneous stakeholders.

Future work will extend Waterfront's capabilities through additional advanced artificial intelligence and machine learning modules designed for maritime contexts. First, multi modal predictive modelling will couple mesoscale weather forecasts, oceanographic fields (e.g., wave height, currents, and tides), and historical vessel traffic patterns to produce risk adaptive routing recommendations, probabilistic congestion surfaces, and hazard nowcasts. Second, personalized planning services will leverage supervised and reinforcement learning to co-optimize navigation and fishing activities under user defined objectives (e.g., fuel efficiency, safety margins, gear conflict avoidance), constrained by regulatory closures and dynamic management areas. Third, anomaly detection pipelines will monitor AIS kinematics and event streams to flag atypical behaviours (e.g., prolonged loitering in restricted zones, unexpected speed profiles), enabling proactive compliance checks and targeted outreach. Fourth, on vessel, low latency audio agents will provide hands free access to critical information – weather windows, regulatory conditions, port status, mariner updates – via natural language interfaces resilient to noisy marine environments. Finally, stakeholder specific decision support dashboards will synthesize these forecasts and detections into interpretable, role tailored outputs (e.g., route advisories for vessel operators, deconfliction suggestions for fleet managers, environmental indicators for monitoring teams), accompanied by uncertainty quantification to support risk aware decisions.

Methodologically, these extensions will require attention to data governance, model generalizability, and evaluation under operational constraints. Privacy preserving mechanisms (e.g., differential privacy, secure aggregation) will be necessary where user contributed data are employed for model training. Domain adaptation and transfer learning will mitigate performance degradation across regions with differing traffic compositions, bathymetry, and weather regimes. Robustness will be assessed through backtesting against historical scenarios and prospective A/B evaluations that measure decision quality (e.g., near miss reductions, route efficiency gains) and user centric outcomes (e.g., task time, alert precision/recall). Interpretability techniques – such as feature attribution maps for spatial predictions and counterfactual explanations for alert generation – will be incorporated to support user trust and post incident review. Collectively, these research directions position Waterfront not merely as a communication upgrade but as an extensible, intelligent operations platform capable of advancing safety, efficiency, and environmental stewardship in complex marine systems.

5.1 Operational and Economic Implications
The observed engagement trends have direct implications for offshore wind project economics and stakeholder relations. Increased use of real-time notifications and gear pinning functionalities mitigates operational conflicts, reducing the likelihood of permitting delays and associated cost overruns. Economic modelling suggests that Waterfront's ability to streamline communication and pre-empt disputes can lower construction vessel idle time by 10-15%, translating into potential savings of $1.5-$3 million per project phase. Furthermore, improved coordination of inspection and maintenance activities minimizes turbine downtime, enabling recovery of up to 50 GWh annually in lost generation for large-scale projects. This recovered output equates to powering approximately 12,500 households and avoiding 17,500 metric tons of CO_2 emissions, reinforcing the platform's contribution to climate mitigation objectives.

Beyond project-level benefits, enhanced stakeholder engagement supports broader socioeconomic outcomes. By reducing friction between offshore wind developers and fisheries, Waterfront accelerates project timelines, safeguarding job creation in coastal economies. Each GW of offshore wind capacity supports 4,000-5,000 jobs during construction and 150-200 permanent operation and maintenance positions; thus, delays avoided through improved coexistence mechanisms have material implications for regional employment and supply chain stability.

6. CONCLUSION

The coexistence of offshore wind and fisheries is fundamental to sustainable ocean governance and the achievement of climate targets. Waterfront demonstrates that digital stakeholder engagement can operationalize multi-use principles, mitigate spatial conflicts, and enhance safety in shared marine environments. Its scalability and adaptability position it as a critical enabler of integrated MSP in an era of accelerating offshore energy development. Continued investment in digital innovation and collaborative governance will be pivotal to harmonizing the interests of diverse marine stakeholders and ensuring that the transition to renewable energy does not compromise the resilience of traditional marine industries.

ACKNOWLEDGMENT

Author Declaration

- Funding: The author did not receive financial support from any organization for the submitted work.
- Ethical approval: This paper does not contain any studies with human participants or animals.
- Competing interests: The author declares that he has no competing interests.
- Availability of data and materials: Datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.
- Artificial intelligence was not used in this work.

REFERENCES

[1] International Energy Agency, "World Energy Outlook 2024." Paris, France: IEA, 2024. Available: https://www.iea.org/reports/world-energy-outlook-2024

[2] D. Rodmell, "Can Fisheries Co-exist with Offshore Wind in the Race to Carbon Net Zero?" NFFO.org.uk. Accessed: Nov. 30, 2025. [Online]. Available: https://www.nffo.org.uk/can-fisheries-co-exist-with-offshore-wind-in-the-race-to-carbon-net-zero

[3] M. F. Schupp, A. Kafas, B. H. Buck, G. Krause, V. Onyango, V. Stelzenmüller, I. M. Davies, and B. E. Scott, "Fishing within offshore wind farms in the North Sea: Stakeholder perspectives for multi-use from Scotland and Germany," Journal of Environmental Management, vol. 279, Art. no. 111762, Feb. 2021. doi: 10.1016/j.jenvman.2020.111762.

[4] European Parliament and the Council of the European Union, Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning. [Online]. Available: http://data.europa.eu/eli/dir/2014/89/oj

[5] V. Stelzenmüller, A. Gimpel, J. Letschert, C. Kraan, and R. Döring, "Impact of the use of offshore wind and other marine renewables on European fisheries," Policy Dept. for Structural and Cohesion Policies, European Parliament, Oct. 2020. Available: https://www.europarl.europa.eu/RegData/etudes/STUD/2020/652212/IPOL_STU(2020)652212(SUM01)_EN.pdf

[6] S. W. K. van den Burg, P. Kamermans, M. Blanch, D. Pletsas, M. Poelman, K. Soma, and G. Dalton, "Business case for mussel aquaculture in offshore wind farms in the North Sea," Marine Policy, vol. 85, pp. 1–7, 2017, doi: 10.1016/j.marpol.2017.08.007.

[7] Equinor, "Collaboration to trial safe fishing within floating wind farms," 29 July 2021. Accessed: Jan. 12, 2026. [Online]. Available: https://www.equinor.com/news/uk/collaboration-trial-safe-fishing-within-floating-wind-farms

[8] Japan Wind Power Association, "JWPA Wind Vision 2023: Contribution of wind power toward the realization of a safe, stable and sustainable society," JWPA, May 29, 2023. Accessed: Jan. 12, 2026. [Online]. Available: https://jwpa.jp/en/information/7754

[9] U.S. Bureau of Ocean Energy Management, "Draft Fisheries Mitigation Guidance." Washington, DC: U.S. Department of the Interior, June 23, 2022. Accessed: Jan. 12, 2026. [Online]. Available: https://www.boem.gov/sites/default/files/documents/renewable-energy/DRAFT%20Fisheries%20Mitigation%20Guidance%2006232022_0.pdf

[10] Power Technology, "Empire Wind receives temporary suspension," 2023. Accessed: Jan. 12, 2026. [Online]. Available: https://www.power-technology.com/news/empire-wind-temporary-suspension

[11] A. Kuffner, "Trump administration orders halt to offshore wind projects. What it means," The Providence Journal (USA TODAY Network),

Dec. 22, 2025. Accessed: Jan. 12, 2026. [Online]. Available: https://www.usatoday.com/story/news/politics/2025/12/22/trump-halts-offshore-wind-projects-again-including-revolution-wind/87882097007

[12] A. Kuffner, "Revolution Wind seeks to overturn Trump administration stop-work order," The Providence Journal (USA TODAY Network), Jan. 2, 2026. Accessed: Jan. 12, 2026. [Online]. Available: https://www.usatoday.com/story/news/environment/2026/01/02/revolution-wind-seeks-court-injunction-to-lift-stop-work-from-trump/87990935007

[13] P. O. Bonsu et al., "Co-location of fisheries and offshore wind farms: current practices and enabling conditions in the North Sea," *Marine Policy*, vol. 159, art. no. 105941, 2024. doi: 10.1016/j.marpol.2023.105941.