ACCELERATING OFFSHORE WIND

The role of innovative technology in decision-making and faster consenting

REPORT

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EXECUTIVE SUMMARY

One of the major challenges facing the offshore renewable energy sector is the speed and extent of deployment needed to meet Net Zero targets, which include deploying 50 GW of installed offshore wind capacity by 2030. Projects need to undergo pre-development planning, consenting applications and construction which takes several years. The deployment of offshore wind at very high levels could potentially result in a change to the ecosystem and therefore consideration of the environmental impacts is essential. Using autonomous technologies for environmental monitoring could help address the knowledge gaps associated with these impacts.

Despite over two decades of experience in constructing offshore wind farms in the UK there is still a scarcity of robust data upon which to predict the effects on certain receptors, such as marine mammals, fish and birds. Uncertainties regarding the prediction of ecological effects mean that UK regulators often take a precautionary approach to consenting new developments.

This report provides an overview of the current consenting process for offshore wind in the UK and explores if and where the potential exists for smart technology to streamline the data gathering, analysis and decision-making process to accelerate consenting.

The report concludes that innovative technologies have the potential to reduce overall consenting timelines from an average of five years to three years, resulting in potential time and cost reductions whilst dramatically increasing data confidence. We propose a number of recommendations that will support the aims of the UK Government's Offshore Wind Environmental Improvement Package to reduce the time to get planning consent from four years to one year while continuing to protect the marine environment:

1) There is a need to showcase the capabilities, speed, and accuracy of innovative technologies and their potential to create a step change in the way we gather and process marine ecological data.

2) ORE Catapult, technology and service providers work with statutory bodies, policy-makers, and environmental stakeholders to ensure new technologies can be confidently incorporated into environmental impact assessments and future monitoring plans.

3) Explore the potential for a large-scale data acquisition trial involving a) the review of existing data in new ways and b) the use of new, high-autonomy technologies to help proactively develop this important area for floating wind.

4) Explore the potential for industry to work collaboratively on joint data acquisition projects in key future development areas.

CONTENTS

NOMENCLATURE

AAM	Active Acoustic Monitoring
AI	Artificial Intelligence
AMP	Adaptable Monitoring Package
AUV	Autonomous Underwater Vehicle
BEIS	Department for Business, Energy and Industrial Strategy
BESS	British Energy Security Strategy
BVLOS	Beyond Visual Line of Sight
CAA	Civil Aviation Authority
COLREGS	Convention on the International Regulations for Preventing Collisions at Sea
DCO	Development Consent Order
DESNZ	Department for Energy Security and Net Zero
EIA	Environmental Impact Assessment
ES	Environmental Statement
ESO	Electricity System Operator
FOW	Floating Offshore Wind
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile communications
GW	Gigawatt
HRA	Habitats Regulations Assessment
IMO	International Maritime Organisation
IROPI	Imperative Reasons of Overriding Public Interest
LCOE	Levelised Cost of Energy
LiDAR	Light Detection and Ranging
LoRaWAN	Long Range Wide Area Network
LSE	Likely Significant Effect
MASS	Maritime Autonomous Surface Ships
MCA	Maritime and Coastguard Agency
MCZ	Marine Conservation Zone
ML	Machine Learning
MMO	Marine Maritime Organisation
MSC	Maritime Safety Committee
MW	Megawatt

MWh	Megawatt Hour
NSIP	Nationally Significant Infrastructure Project
OWAT	Offshore Wind Acceleration Taskforce
OWEIP	Offshore Wind Environmental Improvement Package
OWEKH	Offshore Wind Evidence and Knowledge Hub
PAM	Passive Acoustic Monitoring
RAI	Robotics and Artificial Intelligence
ROV	Remotely Operated Vehicle
RPA	Remotely Piloted Aircraft
SAC	Special Area of Conservation
SEA	Strategic Environmental Assessment
SEIA	Socio-Economic Impact Assessment
TCE	The Crown Estate
UAV	Unmanned Aerial Vehicle
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
VHR	Very High-Resolution
VLOS	Visual Line of Sight
WAMP	Wave-Powered Adaptable Monitoring Package

1 INTRODUCTION

1.1 Ambition for offshore wind

The UK Government has set ambitious targets associated with climate change and decarbonisation, including achieving Net Zero by 2050. One fundamental activity underpinning this target is the decarbonisation of UK's energy system through the transition from conventional fossil fuel generation to investment in the growth of low carbon, renewable technologies. As of December 2022, the targets set out that offshore wind will provide up to 50 GW of generation capacity by 2030 (including 5 GW of floating offshore wind (FOW)) and 100 GW by 2050 (BEIS, 2022).

The UK now has around 13.7 GW of connected offshore wind energy across 43 wind farms totalling over 2,652 turbines (Renewable UK, 2022a). The total installed offshore wind capacity for Europe is around 255 GW (WindEurope, 2023). The UK also boasts Ørsted's Hornsea 2, which with a capacity of 1.3 GW, is currently the world's largest offshore wind farm (DNV, 2022) and SSE Renewables is currently building Dogger Bank Wind Farm, which will have a capacity of 3.6 GW (SSE Renewables, 2023). It's been suggested that the UK will have to build approximately 2,600 more wind turbines costing £48bn by 2030 in order to meet the 50 GW target, which translates to 260 new wind turbines each year in the run up to 2030 (DNV, 2022).

There has been a significant decline in the levelised cost of energy (LCOE) generation, with the cost of offshore wind falling from £150/MWh to £40/MWh over the last decade (Renewable UK, 2022b). Fixed bottom mega projects achieved a new UK record low of £37.35 per MWh during the fourth Contracts for Difference (CfD) auction round. While it's possible that there will be further price reductions in the next CfD auction rounds, supply chain challenges and inflation concerns may cause temporary increases in the LCOE. However, the long-term trend for the LCOE for floating wind is expected to reduce by 80% in the next 30 years – with 74% of the cost reduction occurring before 2030 (DNV, 2022), reaching price parity with fixed bottom wind in 2040.

The UK is working to make the technology more productive and cost-competitive, but how realistic is it that the industry can achieve its ambitious 50 GW target within the next seven years? Development timescales have historically been long, taking at least a decade to get an offshore wind farm to commercial operation. The pace of change over the next decade will have to accelerate dramatically. Acceleration depends on near-term actions to unlock investment, as well as longer-term strategic reforms that will maximise economic opportunity (Renewable UK, 2022b). Plans to reduce approval times for consent of new offshore wind farms from four years to one year will radically reduce the time it takes for new projects to reach construction stages, whilst ensuring minimal impact to the environment.

1.2 Pressures on the seabed real estate and the need for responsible siting

The expansion of offshore wind farms to meet energy production objectives, including floating devices in deeper areas and farther offshore, has resulted in technical, economic, social, and ecological concerns worldwide. Additionally, it will add to and be affected by the increasing demand for ocean space. Interactions with other traditional and strategic human uses of the ocean need to be considered to avoid, or at least minimise, spatial conflicts (Galparsoro et al., 2022). There may be constraints imposed on the siting or design of offshore wind farms because of the presence of other activities or offshore infrastructure.

The UK's continental shelf is becoming an increasingly crowded marine space, encompassing busy shipping lanes, existing wind farms, the oil and gas and aggregates sectors, the telecoms cables sector, and other emerging sectors such as mariculture and potentially other types of marine energy. This unprecedented expansion in the blue economy is taking place within the context of the network of Marine Protected Areas (MPA) that now cover 38% of UK seas (JNCC, 2022).

There are, for example, many competing spatial pressures on fishing activity, of which offshore wind and MPAs top the list. The displacement of existing maritime activities, such as fishing can be avoided, minimised and mitigated through technology choice, design and siting, innovation and management of offshore wind farms. Integral to offshore wind farm development is the installation, operation and maintenance of the supporting electrical infrastructure of inter-array and export cables. There is potential for some fishing activity to continue within the arrays, as shown by a recent study carried out on the Block Island wind farm off the east coast of the US. The study by Wilber et al., (2022) found that during Block Island's construction and operation, there were no significant negative impacts on demersal fish or invertebrate populations. In fact, the opposite occurred for black sea bass and Atlantic cod populations, which increased within the wind farms. However, the anchoring and mooring systems of FOW turbines mean that fishing within floating arrays could be extremely hazardous, depending on the type of tethering system used, and may be excluded completely. Equinor and Marine Scotland recently collaborated to conduct trials using static fishing gear at the Hywind Scotland FOW to better understand how fishers can safely operate around such arrays. The trials showed that with the right conditions and the right information, it is possible to fish safely in and around FOW turbines, however further studies are planned in the near future to trial other fishing methods.

The identification of areas that are potentially suitable for offshore wind farm development can present many challenges. When determining the suitability of a site for the development of a wind farm, a number of parameters need to be considered, including; wind strength, seabed geology, environmental impact, distance from grid, and shipping lanes. Responsible siting and project permitting can enable the steady growth of a thriving industry, while maximising opportunities for ocean co-use and ensuring there is minimal impact to the environment. The industry needs predictable and efficient regulatory reviews that are advanced by clear and efficient permitting processes to better understand and mitigate offshore wind's potential impacts on the marine environment, ocean co-users, and communities.

1.3 Concerns around the impacts of offshore wind

There are still considerable gaps in scientific knowledge about the ecological impacts of wind turbines potentially leading to a gap between perceived and actual risk. Consequently, the uncertainties around the assessment of impacts resulting from cumulative pressures caused by offshore wind development can also lead to substantial delays during the consenting process.

There are major environmental concerns related to offshore wind developments, such as increased noise levels, collisions with bird and marine mammals, changes to benthic and pelagic habitats, alterations to food webs, and pollution from increased vessel traffic or release of contaminants from seabed sediments. Maxwell et al., 2022 documented the environmental impacts of FOW which are shown in Figure 1.

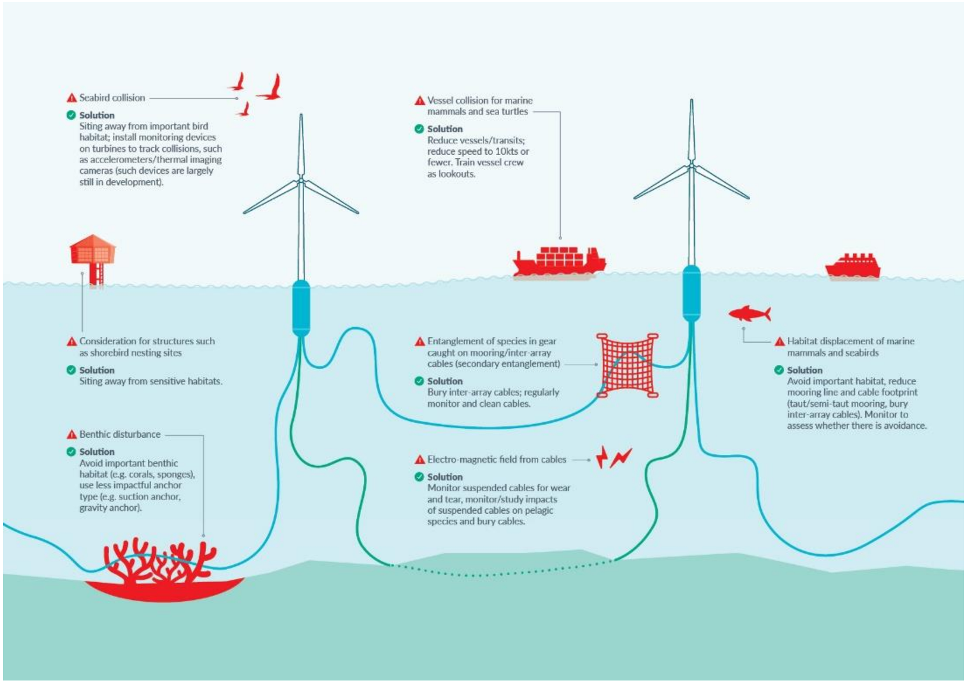

Figure 1. Potential impacts of floating offshore wind and associated potential solutions (adapted from Maxwell et al., 2022)

Offshore energy production can have both negative and positive impacts on marine ecosystems. Negative impacts are reported more frequently for birds, marine mammals, and ecosystem structure. Positive effects are less reported, relating mostly to fish and macroinvertebrates. For example, wind turbine foundations may act as artificial reefs, providing a surface to which animals attach. There can be increased numbers of shellfish, and those animals that feed on them, including fish and marine mammals. The study by Wilber et al., (2022) on Block Island wind farm revealed that a total of nearly 664,000 individual fish representing 61 species were collected in the seven years of the demersal trawl survey. Block Island's wind turbines are each half a nautical mile apart and there has been no significant negative impact on fish populations. A second possible benefit is the sheltering effect. A safety buffer zone surrounding the wind turbines may become a de-facto marine reserve, as the exclusion of boats within this zone would reduce disturbance from shipping. Exclusion of some or all types of fishing could also result in local increases in prey abundance for top predators, whilst reducing the risk of bycatch in fishing gear. There may be opportunities in the future to combine offshore wind farms with open-ocean aquaculture (Bailey et al., 2014). A recent study by Heinatz and Scheffold (2023) showed that in addition to their proven mitigation potential as renewable energy, offshore wind farms can also promote carbon storage and increase carbon stocks in the surrounding sediments.

There is often little information publicly available about the potential environmental effects at a site projected for an offshore wind development; regulators expect developers to undertake comprehensive baseline and post-installation monitoring surveys to fill in these information gaps (Copping et al., 2020). The assessment of the cumulative effects of offshore wind with other anthropogenic activities is also a concern for regulators and other stakeholders.

2 REGULATORY PROCESS

2.1 Consenting process and timelines today

2.1.1 Process overview

Figure 2 shows the different phases and current indicative timeframe for developing an offshore wind farm, the largest component of which is consenting. The process starts with leasing the seabed which will determine the location of the wind farm, and this is managed by The Crown Estate and Crown Estate Scotland. After obtaining a seabed lease, the developer applies for a grid connection from the National Grid Electricity System Operator (ESO). Once this has been granted, the developer will start to plan cable corridors, undertake surveys, and prepare for the planning and consenting process.

The consenting part of the process for offshore wind farm developments in the UK consists of the pre-application and post-application phases. Pre-application requires the developer to prepare the application for examination or determination (depending on jurisdiction) and can typically take between 2 and 4 years, depending on the complexity of the application and the scope of data collection required, giving rise to a great deal of uncertainty. Once the application is submitted, the post-application phase involves the review and eventual determination of the application. Timelines for this phase are guided by legislative requirements and can vary significantly depending on the complexity and completeness of an application, with one prior wind farm application taking up to 48 months to complete and the average timeframe for the windfarms built between 2013 and 2021, taking 19 months. Throughout this stage, developers undertake stakeholder engagement, to ensure that their views are sufficiently represented in the application.

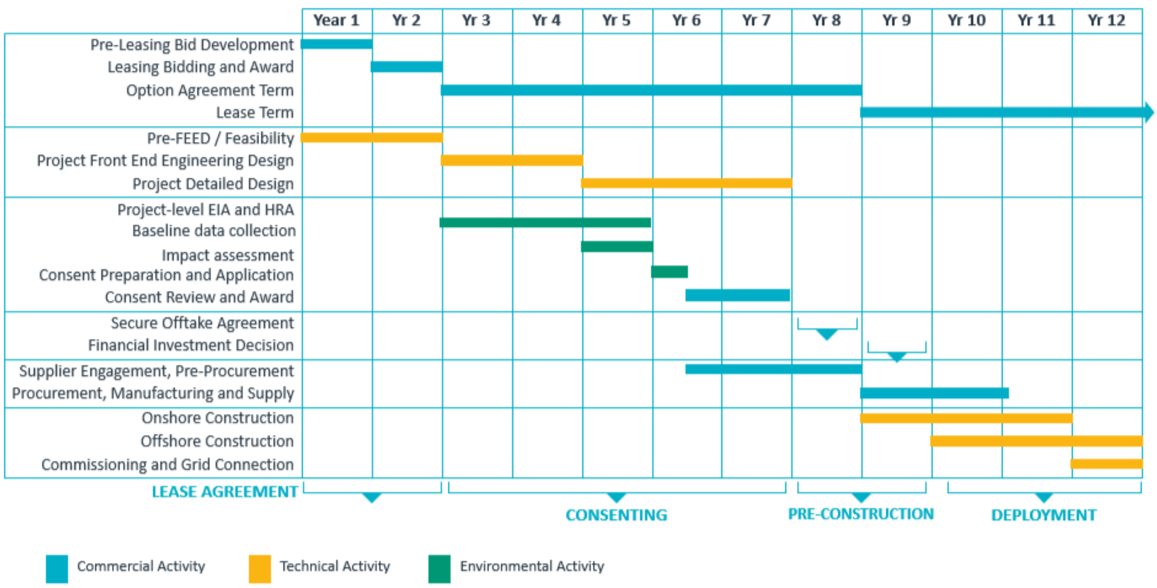

Figure 2. Indicative offshore wind development timeline

The pre-application stage includes the Environmental Impact Assessment (EIA) and Habitats Regulations Assessment (HRA), the process for which is shown in Figure 3. Both an EIA and HRA are required as part of the application for an offshore wind farm. The purpose of the EIA is to describe and assess both direct and indirect impacts of the proposed development on the environment, as required by EIA Regulations. The EIA is then taken into consideration by the competent authority[1] which determines whether to grant consent for the development. A HRA assesses the impact of the development on European sites that have been designated under the Habitats Directive to protect important habitats and species. The competent authority can only grant a consent for a project if it will not affect the integrity of a European site.

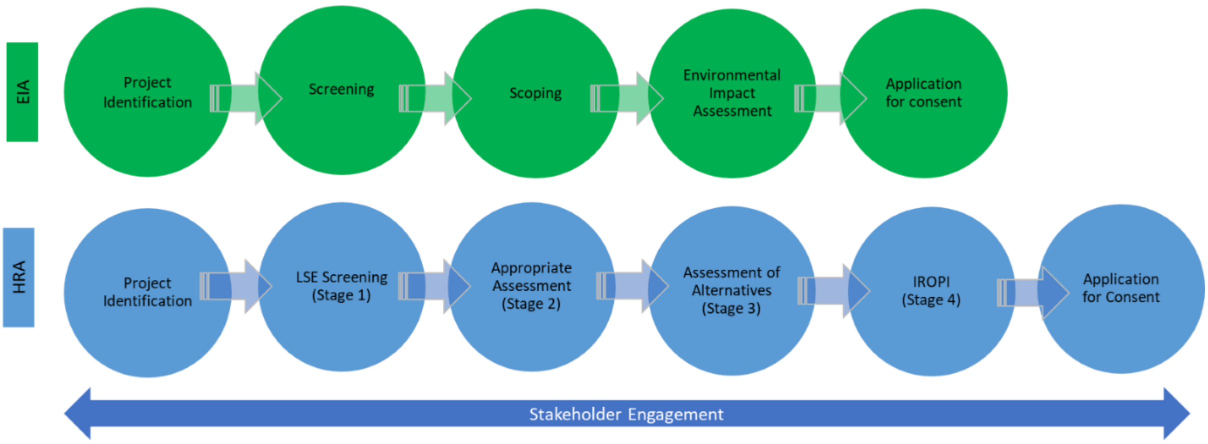

Figure 3. The EIA and HRA process (adapted from Pathways to Growth, OWIC)

2.1.2 Environmental Impact Assessment and Habitats Regulations Assessment

The EIA process involves four key stages: screening, scoping, undertaking the EIA, and the final application for consent. The construction of an offshore wind farm will require an EIA to be undertaken and therefore the EIA process usually jumps straight from the screening stage to scoping the project. EIA scoping is a key stage within the EIA process, and although not mandatory, it is advisable to undertake as the developer can ask the regulator for their opinion on the requirements for the EIA, providing an opportunity to present the project to regulators and stakeholders to receive initial feedback on the key environmental issues that must be addressed. For each of the topics/receptors identified in the scoping process, an EIA is undertaken. The baseline surveys required as part of the EIA include marine mammal, fish, ornithology, benthic, underwater noise, geophysical and geotechnical, metocean and onshore surveys. The developer then documents the

[1] In England, the competent authority for offshore wind consent applications is the Secretary of State for Department for Energy Security and Net Zero (DESNZ), formerly Business Energy and Industrial Strategy (BEIS). In Scotland, the competent authority is the Scottish Ministers, in Wales with Welsh Ministers and in Northern Ireland the Department of Agriculture, Environment and Rural Affairs (DAERA).

results of the EIA in the form of an Environmental Statement (ES) which is then submitted with the application for consent.

There are four key stages to the HRA process as shown in Figure 3. The purpose of Stage 1 is to determine the Likely Significant Effect (LSE) on a species or habitat of a European site. If there is no potential impact for LSE on any European site, then authorisation will be granted. However, if there is any doubt, a Stage 2 Appropriate Assessment will be carried out. This is similar to the EIA process, except that the assessment focuses on the conservation features of the relevant site and considers the implications of the proposed activities on the conservation objectives. It provides a better understanding of the potential effects and identifies measures which can be put in place to cancel, avoid or reduce those effects. The competent authority will conclude whether the proposed work will represent an ‘Adverse Effect on Integrity’ using the ‘Integrity Test’. If no deemed effect, then the project can be granted, however, if an Adverse Effect on Integrity cannot be ruled out, then the project will be refused unless it is carried forward to the next two stages, known as the HRA Derogations; Stage 3 Assessment of Alternative Solutions and Stage 4 Imperative Reasons of Overriding Public Interest (IROPI). If there are no feasible alternative solutions and it is shown that there are imperative reasons of overriding public interest, then compensatory measures need to be taken. These measures will need to fully offset the damage that will or could occur at the site. For more information on each of these stages, refer to the Offshore Wind Industry Council’s (OWIC) Pathways to Growth programme, which provides free online modules covering the offshore wind consenting process[2].

2.1.3 Marine Conservation Zones and Marine Protected Areas

Other designations are also in place across the UK including Marine Conservation Zones (MCZs) in English, and Welsh waters, and MPAs in Scotland. Specific consideration of MCZs and MPAs is required under the Marine and Coastal Access Act 2009, for any marine licence or Development Consent Order (DCO) applications in UK waters. Whilst an EIA and HRA will always be required for an offshore wind farm project, the requirement for MCZ/MPA assessments will depend upon the proximity of the project to one of these sites.

For MCZs, the regulator considers how significant the risk of the activity is to the conservation goals of the conservation site. If deemed to, then the developer must consider other means of proceeding, like alternative methods or location. If there are no other means of moving forward, then there is a Stage 2 assessment, where the developer must demonstrate that the benefit to the public outweighs the potential damage to the environment. The regulator may also request that the developer makes proportionate environmental enhancement (that does not involve disproportionate cost), such as nature inclusive designs.

A network of Nature Conservation MPAs have been designated in Scottish waters, protecting habitats and species such as maerl beds and common skate. Public Authorities (including the Scottish

[2] https://www.owic.org.uk/p2g-learn-osw-consenting

Ministers) are required to consider whether a project can significantly affect a protected feature in an MPA (Marine Scotland, 2018). The Public Authority must not grant consent to the activity unless satisfied that there is no significant risk of the activity impeding the achievement of the objectives of the site.

2.1.4 Risk management and data collection

Throughout the consenting stage, developers need to consider relevant policy documents and marine plans as well as develop mitigation and monitoring plans. In order to determine the potential significance of impacts, developers will use a combination of primary and secondary data collection, project-specific modelling studies, and impact assessment processes to ensure impacts are minimised and / or mitigated as far as possible. Engagement with the regulators and nature conservation groups is also required to inform the application for consent.

Following successful completion of required environmental assessments, surveys, studies and policy considerations, a developer then needs to obtain required planning permissions and consents for their development. For applications in English waters above 100 MW or in Welsh waters above 350 MW, before submitting a formal application for consent, a developer will have to complete a ‘design envelope’ for their project, which includes the technical specifications of the project (BEIS, 2021). A developer will also have to carry out consultation with statutory consultees and interested parties on their proposals. Once these are complete, they can submit their DCO application (and deemed Marine Licence) to the Planning Inspectorate, called the ‘DCO process’. The Planning Inspectorate submits recommendations to the Secretary of State for the Department of Energy Security and Net Zero (DESNZ), (formally BEIS) who makes the final decision to grant or refuse the DCO. The formal DCO process usually takes about 18 months. The DCO process does not apply for all projects in Scottish waters where instead developers apply for Section 36 of the Electricity Act 1989 and for a separate Marine Licence. Once the consent is granted, a developer can enter their lease and commence the post-consent discharge of licence conditions which include provision of relevant documents, environmental monitoring and surveying (BEIS, 2021).

2.1.5 Risk and uncertainty in the process

In addition to being a complex process, achieving project consent is often a key milestone in a development schedule and can quickly become critical path. As the industry matures, developers are looking for greater certainty in the timelines required to achieve consent. Clearly, there is a need and a valuable opportunity across the industry to optimise the consenting process, primarily to remove or reduce potential delays but also to drive consistency in approach and robustness of assessment outcomes (Xodus, 2021).

ORE Catapult (2021) commissioned a study into the development and consenting processes around the UK for the commercial development of FOWs. The following provides a summary of the key risks and opportunities to commercial projects relevant to the consenting process.

1. *Duration of decision-making process* - the lack of alignment between the timings of CfD rounds and The Crown Estate leasing processes, combined with a consent decision process

for offshore wind taking several years, may affect ability for offshore wind proposals to be constructed in time to meet policy deadlines for achieving UK's Net Zero and decarbonisation ambitions.

2. *Insufficient resources to process applications* - this can increase timescales for consent decision, particularly with more complex applications.
3. *Lack of strategic and spatial planning in all geographic areas* – varied marine planning processes across the UK. However, Defra is leading a cross-government programme of work to consider marine spatial prioritisation that will help to support co-existence between all sea users.
4. *Lack of suitable grid infrastructure in coastal areas close to potential sites* – leading to additional costs and environmental impacts arising from increased cabling to grid connection points.
5. *Uncertainty around environmental impacts* – which may result in increased costs and longer consenting times.
6. *Timing of the HRA/environmental assessment process differs between Scotland and the rest of UK*. Scotland applies constraints assessments and opportunities analysis, public consultation and stakeholder engagement, plan-level HRA, strategic environmental assessment and socio-economic impact assessment in advance of sites being made available for leasing bids. Sites are where wind farms should be feasible rather than just possible. In England and Wales these matters have, up to now, not been considered in a similar level of detail, placing greater risk on the developers. In December 2022, The Crown Estate announced it was investing in a multi-million pound programme of marine surveys to speed up plans for FOW in the Celtic Sea. The Crown Estate stated that 'by investing in these surveys at an early stage and making the data freely available to successful bidders, they aimed to accelerate the delivery of projects, making it easier for developers to take early decisions and manage risk, while supporting future project-level EIAs as part of the planning process.
7. *An accurate assessment of the cumulative and in-combination impacts that will affect each development* - a combination of time pressures on the industry from the renewable energy targets, combined with the fact that developers have traditionally been responsible for these assessments, has meant public organisations like The Crown Estate and the Marine Management Organisation have not taken full responsibility for assessing cumulative and in-combination impacts.

2.1.6 Opportunities from UK Government's proposed changes to infrastructure planning

The planning process for major infrastructure projects, such as offshore wind, can be a significant barrier to deployment which can lead to both substantial delays, as well as driving up the cost of development.

In September 2022, the UK government declared that new legislation to address the UK's "slow" and "fragmented" planning system would be introduced in the months ahead to support the accelerated delivery of "priority major infrastructure projects". According to the Treasury, delays to the delivery of major infrastructure projects "undermine investor confidence and restrict the growth potential of the government's landmark public investment in high quality infrastructure". It has attributed the delays, in part, to "a complex patchwork of environmental and regulatory rules", which it said it wants to "reform and streamline". The Treasury said the new legislation will reduce "the burden of environmental assessments" and "bureaucracy in the consultation process" and reform "habitats and species regulations". Legislation will also provide greater flexibility to make changes to a DCO once it has been submitted. The DCO planning regime applies to nationally significant infrastructure projects (NSIPs). The Treasury confirmed plans for a new cross-government action plan for reform of the planning system that applies to NSIPs and said that new national policy statements for energy, water resources and national networks would be prioritised.

In the case of development offshore, the measures announced in the British Energy Security Strategy are aimed at accelerating the current consenting process and industry is working with Government through the Offshore Wind Acceleration Taskforce to progress these changes.

The government is seeking legislation to deliver an Offshore Wind Environmental Improvement Package to support the accelerated deployment. Environmental impacts identified within HRAs can often cause significant delays to the consent. This is primarily caused by the complexity of those impacts and the requirement for novel compensatory measures to be developed. In January 2022, BEIS (now DESNZ) published the measures as part of its British Energy Security Strategy and include:

- Delivery of Offshore Wind Environmental Standards (previously called nature-based design standards in the British Energy Security Strategy);
- Development of regulations and guidance to streamline the HRA and MCZ assessment process for offshore wind projects;
- Delivery of environmental compensatory measures across one or more offshore wind projects to compensate for adverse environmental effects on protected sites that cannot be otherwise avoided, reduced or mitigated;
- Implementation of a Marine Recovery Fund; and
- The introduction of strategic monitoring to improve understanding of the marine environment and the measures needed to further protect it.

Compensatory measures are relatively new in the marine environment and designing packages of such measures has proved to be challenging, leading to significant delays while measures are developed and agreed. New legislation will enable the delivery of strategic compensatory measures, facilitating collaborative work between developers and government to work collectively across offshore wind projects to compensate for negative environmental effects. The Government states that by considering compensatory measures upfront and strategically through new HRA legislation, it will reduce the time spent resolving issues for each project.

There can be confusion as to the difference between environmental enhancement measures and mitigation or compensation measures. Enhancement measures are actions that are specifically designed to achieve net environmental gain[3] i.e., to move the environment from its baseline state to an improved state as a result of implementing the development. To achieve positive impacts, either passive or active nature enhancement measures can be taken. Active measures change the marine environment by increasing the effects an offshore wind farm has on nature, while the passive approach limits those effects. Passive measures include eliminating and mitigating some of the risks such as collision and underwater noise, and an active approach involves measures such as building artificial reefs. Mitigation or compensation measures are actions that aim to reduce, remedy or compensate for the negative environmental consequences of a development.

In December 2020, a requirement of the DCO for Hornsea 3 offshore wind farm, was the inclusion of ecological compensation measures for the vulnerable species, Black-legged kittiwake. The Danish developer, Ørsted's compensation plan focused on providing artificial nesting structures for kittiwake along the east coast of England. Each structure will be purpose-built, bespoke and specific to the landscape characteristics of each location, having approximately 500 nesting spaces to introduce enough new chicks into the population. In response to government approval of the 'giant' wind farm, RSPB stated that "It may be a decade or more by the time we know if the compensation measures have been successful, by which time Hornsea 3 and many more projects may have been constructed and the damage to (Yorkshire kittiwake colonies) could be irreversible."

In order to gain a better understanding of, and greater certainty around each compensatory, mitigation or enhancement measure, it is important to maintain and advance the current evidence base, including a strategic review of post-consent monitoring data and through shared learning. Natural England recently reported that wind farm developers have expressed support in principle for increasing environmental monitoring if this was linked to a clear process in which the consultation and consenting phase could be accelerated. "Additionally, as more data is collected at wind farms, it would be beneficial if there was an opportunity for the growing collection of environmental datasets to be used to support the consenting of future wind farms (for example, if this could be used to increase the shared understanding of recoverability of certain habitats such as areas investigated in the HRA)" (Natural England, 2022).

Where the evidence base is insufficient to support the EIA, the responsibility of providing supporting evidence to justify the impact assessment outcomes falls on the developer. The absence of a strong evidence base can extend consenting timelines, as:

- Gathering of supporting evidence often includes project specific data collection and modelling, which can take long periods of time to complete.

[3] 'Marine net gain', which is not yet noted in legislation or policy, specifically aims to improve the marine environment by protecting, restoring or creating environmental features of greater ecological value than any losses associated with marine infrastructure projects. The principle of Marine Net Gain is currently being considered by government and builds on commitments in the Environment Act which aims to drive forward action to protect nature and improve biodiversity, with a target to halt species decline by 2030.

- Supporting evidence specific to a project is unpublished, and therefore the submitted EIA must present enough information and data for the regulator and stakeholders to understand the scope, methodology and results. This results in large EIA submission, which take longer to prepare and longer to review during the determination process. Developers cannot be confident in the timelines due to the uncertainty surrounding data collection and review, and therefore need to build contingency into their consenting approach (Xodus, 2021).

With a growing need to better understand the functioning of the UK marine ecosystems within which large-scale offshore wind deployment is situated, it is critical to take advantage of innovative technologies, such as the use of robotics and artificial intelligence (RAI) that will support the need for highly efficient survey and environmental monitoring procedures that limits potential costs and that fit with the regulators' needs.

3 TECHNOLOGY INNOVATION

3.1 The role of innovation and smart technology

One of the potential options to shorten the time of consenting is improving data collection and marine monitoring for environmental activities as shown in Figure 4.

Marine monitoring can be both a time and resource-intensive process that often covers a network of sampling stations where data is collected manually by divers or using in situ water samples at different depths at fixed positions followed by laboratory analysis. As such, there is often a time-lag in reporting the environmental status of a monitored site. However, recent advances in technologies, such as remote sensing, machine learning (ML) techniques, acoustic monitoring, and intelligent integration of modelling and sensor measurements is revolutionising the future of marine environmental monitoring and monitoring systems.

Scientists and conservationists use a combination of unmanned aerial vehicles (UAVs) and remotely operated vehicles (ROVs) with artificial intelligence (AI) and cloud technologies to systematically find, track and follow marine mammals. The traditional methods of marine monitoring are now being supplemented by new, often automated monitoring techniques. For example, Seiche Ltd (UK) and Deep Vision Inc. (Canada) are collaborating to develop a real-time camera system for automated detection, geo-location and quantification of marine mammals. The system will be resilient under all weather conditions and operable at both surface level and above, e.g., mast mounted for ships. By leveraging unsupervised ML techniques, the system will be truly autonomous. Deep Vision's software capabilities can rapidly assess changes in the environment and automatically tune detection algorithms to optimise performance. Saildrone, based in the US, will utilise advanced uncrewed observing, AI, and ML technologies to create a line-of-sight monitoring network to detect, classify, and localise marine mammals in areas with offshore wind developments. Microsoft AI for Earth's partner, Conservation Metrics, combines ML, remote sensing and scientific expertise to increase the scale and effectiveness of wildlife surveys. NatureServe, another partner organisation, leverages Esri ArcGIS tools and Microsoft cloud computing to generate high-resolution habitat maps for imperilled species.

The two basic categories of technology used to monitor seas are: (1) the platform from which a measurement is taken, such as a research vessel, a static observatory, or an unmanned automated vehicle; and (2) the actual sensor or methodology used to take the measurement, such as a multibeam sonar array, a seabed camera or a chemical analysis of a physical sample. Both categories have seen rapid advancement into more technology-based solutions. The next section discusses the more recent developments and novel approaches to monitoring the marine environment.

3.2 Monitoring platforms

There exists a diverse collection of robotic vehicles for use in the marine environment, including autonomous underwater vehicles (AUVs), deep-sea landing vehicles, unmanned surface vehicles

(USVs), remotely operated vehicles (ROVs), and gliders/drifters which can be untethered, self-propelled and self-navigating and operate freely from a shore or vessel carrying scientific payloads and performing various sampling and monitoring tasks (Figure 4).

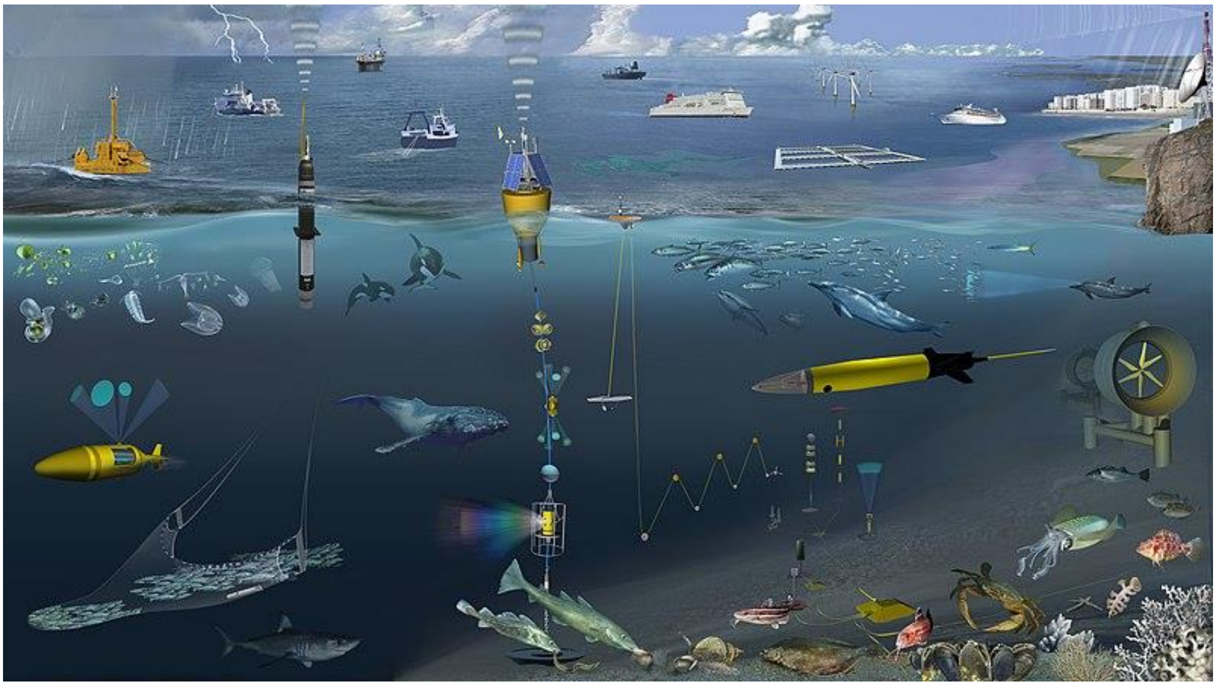

Figure 4. A depiction of the many autonomous and remote sensing platforms that comprise an ocean observation system (source: Glynn Gorick and the NeXOS project).

AUVs operate under their own propulsion, extending the range and area covered relative to a control base, and are revolutionising the capability to survey the marine world. When a mission is complete, the AUV will return to a pre-programmed location where the data can be downloaded and processed. Mission lengths generally vary from hours to days, however advances in size and power of AUVs are enabling missions lasting weeks or months with ranges of more than 1000 km that can reach depths in excess of 1000 metres (Bean et al., 2017). ROVs are generally tethered to a ship and are used as a platform from which to make measurements and observations under the control of an active operator. The cabling supplies power and transfers data making intensive and detailed operations possible. An ROV may include a video camera, lights, sonar systems and an articulating arm. The Kincardine Floating Offshore Wind Farm in Scotland has integrated load cells with the mooring lines to periodically monitor line performance and potentially detect the entanglement of floating marine debris, including derelict fishing gear. The farm uses ROVs and vessel-mounted sensors (such as multibeam sonar) to periodically survey floating cable systems.

Submarine or buoyancy gliders are a relatively recently developed instrument platform for measuring the internal ocean and navigate rather than simply drifting with the current. They operate independently of ships but communicate via satellite enabling data upload, mission planning and updating. The design of gliders facilitates very low power consumption allowing them to be deployed for months at a time (Bean et al., 2017).

A new group of autonomous vehicles are the USVs that include Liquid Robotics Wave Glider, AutoNaut and ASV's C-Enduro. The former two primarily use wave power for propulsion, leaving the internal batteries for navigation, communications and sensor payload. They are faster than buoyancy gliders but do not have the speed of survey/research vessels. However, their lower operating costs (compared to manned vessels), robustness and long-term endurance make them an ideal platform to take measurements in surface waters under conditions where operating a manned vessel would not be deemed safe. USVs can be fitted with a range of sensors including water quality, passive and active acoustics, current profiling (Bean et al., 2017).

Unmanned aerial vehicles (UAVs), remotely piloted aircraft or more commonly drones, are small flying vehicles capable of carrying various sensors, typically some form of camera system. They are equipped with hardware and software for navigation, control and data acquisition. UAVs typically acquire aerial imagery and digital terrain models can also be produced by post-flight image processing using the correct image geographical referencing and appropriate software (Westoby et al., 2012). UAVs offer potential advantages over traditional human-based survey techniques: greater speed and coverage of data acquisition and the ability to produce data with smaller teams more quickly. These advantages can offer better data collection at reduced cost, provided an appropriate platform and sensor combination is available and the required survey location is logistically suitable (Bean et al., 2017).

Integrated instrumentation packages are an attractive option for environmental and ecological monitoring as they can support a range of sensors and provide a more efficient and cost-effective solution. The Adaptable Monitoring Package which integrates active acoustic, passive acoustic and optical sensors into a single instrumentation package that can be cabled or operated autonomously has been developed by researchers in the US (Polagye et al., 2020). The Wave-Powered Adaptable Monitoring Package was a first-of-a-kind integration of a sensor package with a wave energy converter that was tested for a duration of 3.5 months. Ongoing developments are in the pipeline for WAMP2 with a target test duration of 12 months[4]. Overall, researchers have found that integrated instrumentation can provide powerful capabilities for observing rare events, managing the volume of data collected, and mitigating potential bias to marine animal behaviour, with capabilities as relevant to the broader oceanographic community as they are to the offshore marine renewables sector.

3.3 Monitoring sensors

A suite of environmental monitoring instruments are used to monitor the potential environmental effects of offshore wind developments. The most common instrumentation used to document interactions of marine animals and habitats include both passive and active acoustic instruments, and optical cameras, while other instrumentation is used to help define the physical environment in which these interactions may occur.

[4] https://tethys.pnnl.gov/sites/default/files/events/ADAPTA~1.PDF

3.3.1 Acoustics

Some marine mammals use sound for various life functions, including communication, locating prey, avoiding predators and navigation. Such sounds can be used to detect, classify and track these marine mammals by using passive acoustic monitoring (PAM). PAM encompasses a suite of technologies that can inform management and/or mitigation decisions over long temporal and large spatial scales (Gibb et al., 2019). The tools that are available to acquire and analyse passive acoustic data have undergone a revolutionary change over the last couple of decades and have substantially increased the ability to collect extensive time series and apply PAM as a functional management tool (Desjonquères et al., 2020). PAM instruments have primarily been used to characterise the soundscape of marine environments (e.g., ambient sound and offshore wind-associated noise) and monitor for echolocating marine mammals. These technologies include conventional cabled or autonomous hydrophone and analogue-to-digital instrument packages, internally recording hydrophones with digital interfaces, cabled and autonomous hydrophones or vector instrument arrays, and integrated hydrophone and data processing systems for marine mammal detection. PAM platforms include moored recording buoys, autonomous underwater or surface vehicles, profile drifters, and towed hydrophone arrays, which can be strategically located to provide real-time information for immediate mitigative decision-making, monitor or assess the effects from specific activities, and gather continuous archival recordings for long-term monitoring, periodic evaluation, and adaptive management (Van Parijs et al., 2021). PAM technologies are a rapidly developing area, and new technologies and applications are likely to be available in the near future.

Active acoustic monitoring (AAM) systems, also known as sonar, is one of the key tools to monitor the subsea environment. Sonar is an echo-ranging technology that use acoustic energy to locate and survey objects on or under the surface of the water. Pulses of sound (‘pings’) are produced electronically underwater using a sonar projector and the system then monitors for echoes of these pulses as they reflect off objects using a series of hydrophones (Hastie et al., 2019). Active sonar has been used extensively in studies of marine mammal behaviour but to be efficient as a long-term behavioural monitoring tool, there is a need for an effective means of automatically identifying marine mammals and to reduce large data volumes to a manageable size.

3.3.2 Cameras

Digital image capture and analysis are now incorporated into marine mammal and seabird monitoring, using autonomous vehicles. High-definition cameras can be mounted in combination with sensor arrays that record changes in various environmental parameters, whilst infrared imagery is able to detect and, with image processing, identify marine mammals. Detailed processing can be carried out following acquisition using both manual and automated image analysis methods to understand communities associated with certain habitat types or to build a more comprehensive inventory of species that are present in an area. Seabed imagery typically produces 10's of gigabytes of data per survey including video and digital still images and species abundance and habitat information. There is currently a requirement for a bespoke data archive centre that can store seabed imagery data and facilitate the analysis of multiple datasets (Bean et al., 2017).

Researchers at Massachusetts Institute of Technology (MIT) have developed a battery-free, wireless underwater camera that is about 100,000 times more energy efficient than other undersea cameras. The device takes colour photos, even in the dark, and transmits image data wirelessly through the water. The autonomous camera is powered by sound and converts mechanical energy from sound waves travelling through water into electrical energy that powers its imaging and communications equipment. After capturing and encoding image data, the camera also uses sound waves to transmit data to a receiver that reconstructs the image. As there is no need for a power source, the camera could run for weeks before retrieval.

3.3.3 Electronic tags and tracking tools

Monitoring animals with electronic tags is an important tool for fundamental and applied ecological research. Tags may either log data in memory (biologging), transmit it to a receiver or satellite (biotelemetry), or have a hybrid design. The tag used will generally depend on the size of the system under study, the ability to recapture the animal, and the research medium (e.g., aerial, freshwater, saltwater, terrestrial) (Cooke et al., 2021). Biologging refers to the use of miniaturised animal-attached tags for logging and/or relaying of data at constant or frequent time intervals about an animal's movements, behaviour, physiology and/or environment (Rutz and Hayes, 2009). Biologging technology allows for the opportunity to observe, and take measurements from free-ranging, undisturbed subjects, but requires physical recovery by researchers to access the data onboard. Biotelemetry uses transmitters that overcome the limitation of having to recover the tags by communicating data remotely to receivers. The data transmitted by these devices are often at a lower temporal and spatial resolution and only collected when the tagged animals are within range of receivers (Cooke et al., 2004) or greatly compressed to enable the transmission of data (Cooke et al., 2021).

Acoustic, radio and satellite telemetry have been used in hundreds of studies to monitor and track wildlife. Acoustic transmitters, for example, are attached to or implanted within an individual and emit coded ultrasonic signals which are logged by receivers (Hardin and Fuentes, 2021). Individuals can be actively followed and tracked with a single receiver or tracked passively via an array of receivers moored throughout the study site. Because individuals must pass within the detection range of a receiver to be detected, acoustic telemetry provides presence-only data and studies are spatially constrained by the receiver array, limiting their applicability for highly migratory species (Hardin and Fuentes, 2021).

The Motus Wildlife Tracking System (Motus) is an international collaborative research network that uses coordinated automated radio telemetry to facilitate research and education on the ecology and conservation of migratory animals. The system uses nano-tags that can be detected at a distance of about 10 miles by a small antenna system.

Geolocators, at less than a third of a gram, are among the smallest and lightest tracking devices available, comprising of a battery, light sensor, clock and memory chip. Geolocators record light levels every few minutes and by plotting these against time, the times of local dawn and dusk can be estimated. The British Trust for Ornithology website provides an overview of the technology.[5]

The ability to use the positions of animals derived from satellite data has evolved significantly over the last decade. With satellite telemetry, an animal carries a tracking device, and its location is calculated via satellites. For bird surveys, two types of satellite tags commonly used are GPS and Argos tags. GPS tags receive and collect information about the time and position from a satellite and use this information to calculate an exact location, whereas Argos tags send information to a system of satellites which then transmit the location of the tag back to receivers on the Earth's surface. The advantages of this method are the low transmitter power consumption and instant location opportunities during satellite passes.

Gauld et al., (2023) describe a new type of GNSS (Global Navigation Satellite System) tracking device, which transmits data via LoRaWAN (long range wide area network) gateways which in turn forwards the data to a server via a GSM, WiFi or Ethernet internet connection. These tags have the potential to be a low-weight and power-consumption solution for tracking the movement of animals at high resolution (Gauld et al., 2023).

The idea of equipping unmanned underwater vehicles (UUVs) and USVs with fish telemetry receivers represents an emerging approach with the potential to advance the current operational limits of fish movement studies. Dallolio et al. (2022) merged the integration of a real-time acoustic receiver into an ocean-going wave and solar-powered USV (AutoNaut) to monitor the seaward migration of Atlantic salmon post-smolts. The vehicle was able to detect an acoustically tagged post-smolt into the open ocean beyond the reach of the study's stationary receiver grid. The ability to observe individual fish in the ocean environment using an energy-autonomous robotic vehicle creates novel and unprecedented opportunities for scientific inquiry in fish behaviour and movement ecology studies at sea (Dallolio et al., 2022).

3.3.4 Biomonitoring tools

In addition to platforms and sensors, the use of environmental DNA (eDNA) is another novel approach to monitoring marine biodiversity. In recent years, eDNA has emerged as a revolutionary tool for cost-effective, sensitive, non-invasive species monitoring and a growing number of studies have successfully implemented this approach for the detection and identification of marine mammals (Suarez-Bregua), 2022). The term eDNA refers to intracellular and extracellular DNA that can be extracted from environmental samples (e.g., water, soil or air). All multicellular organisms naturally shed cellular material from skin, faeces, urine and/or gametes into their surroundings, thereby leaving a molecular signature in the environment they inhabit (Barnes et al., 2014). For example, the blow exhaled by cetaceans when they surface to breathe is composed of a mixture of cells, mucus and fluids from the respiratory tract that are deposited on the water surface. The "footprint" that cetaceans leave behind in surface waters when breathing and diving includes genetic

[5] https://www.bto.org/understanding-birds/articles/bird-tracking-%E2%80%94-masterclass

material from skin and potentially also mucus and/or faeces (Suarez-Bregua), 2022). Figure 5 shows the process for the collection and analysis of eDNA.

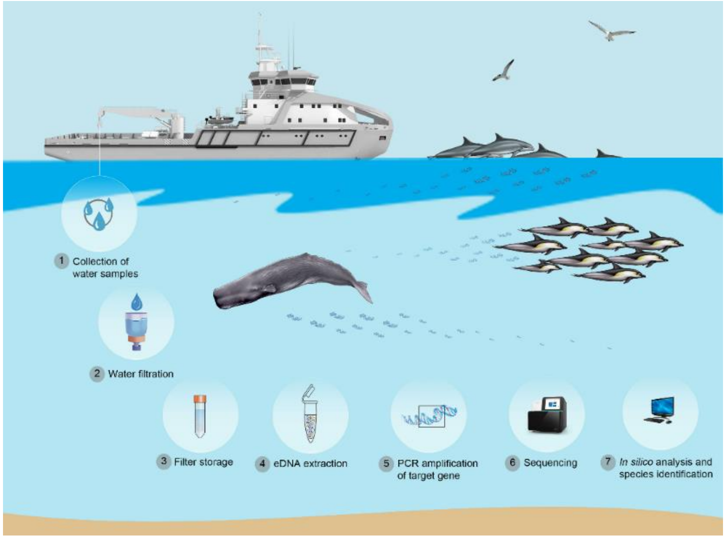

Figure 5. Application of eDNA methodology for marine mammals monitoring (source: Suarez-Bregua et al., 2022).

A pilot study by Equinor and the Norwegian Research Centre used eDNA to monitor the biodiversity and abundance of marine life in waters around the Hywind Scotland floating wind farm in August 2021. The pilot study was conducted to learn more about the potential effects that floating offshore wind farms may have on marine habitats. The study identified a total of twenty-six fish species in the area. There was no significant difference in biodiversity observed between the wind farm area and the reference zone, however, at the time of sampling, the relative abundance of sprat and herring were higher around the wind farm. In addition, a faint eDNA signal was detected from harbour porpoise in the waters surrounding the wind farm.

In March 2022, renewable energy consultancy and service provider, Natural Power, along with project partners, EDF Renewables and environmental DNA and nature specialist, NatureMetrics, kicked off a research project aimed at validating offshore fish environmental DNA (eDNA) survey methods using the Blyth Offshore Demonstrator site. Comparison of the eDNA results with concurrent trawl data and historical fish community data will be undertaken to provide a robust assessment and validation of the technique. EDF Renewables stated that:

> *"We believe eDNA techniques have the potential to reduce barriers in consenting for offshore wind farm projects in the future through more targeted baseline data collection, mitigation, and monitoring measures. If such techniques can be validated within the offshore environment as a viable alternative to traditional fish survey techniques, it may have significant benefits to both the developer and stakeholder communities".*

Collecting data on fish biodiversity with traditional trawling campaigns has typically been time-consuming and costly, while also having the potential to negatively impact the environment. There is a need to employ non-destructive sampling methodologies for better assessing and monitoring fish assemblages. The use of eDNA as a complimentary monitoring tool can reduce the disturbance to the marine environment, and lower $C0_2$ emissions. eDNA shows great promise in contributing to achieving improved monitoring programs for marine mammal and fish assessments and for baseline descriptions of the presence of species surrounding offshore wind farm projects, aiding in the identification of potential receptors for EIA monitoring.

3.4 Data and digital solutions

Marine environmental monitoring can be performed either on-site using sensors that are able to collect data or remotely through satellite observation. In most cases, a huge amount of data is gathered, and advanced intelligent methodologies such as AI and ML algorithms must then be created in order to handle it. The growing trend towards using AUVs for marine-based studies has only escalated the challenge. Computer vision algorithms for underwater robotic systems are attracting attention due to significant advances in vision capacities. Vision and image processing applications can benefit from cloud computing, as many are data- and compute-intensive and, by remotely locating storage and processing capabilities in the cloud, image processing applications can be deployed remotely (Salhaoui et al., 2020).

Bringing massive connectivity to low-cost, low-power ocean sensors is important for numerous oceanographic applications across climate/weather modelling, marine biology, aquaculture, and defence. However, standard Internet of Things technologies (e.g., Bluetooth, Wi-Fi, GPS) cannot operate underwater, which is of particular importance for the offshore wind industry. There is ongoing research to redesign those technologies for ocean use (e.g., MIT). Seamless underwater operation would support the development of underwater sensing, networking, localisation and imaging.

Remote sensing data can be used as an effective tool in EIA studies “to assist the understanding of complex interactive effects within the physical and biological environment, to support the understanding of cumulative effects and minimise uncertainty with future climate change to aid the evidence-based decision-making process” (Patil et al., 2002). However, it presents some limitations relating to image resolution and targets.

LiDAR (Light detection and ranging) is an example of a remote sensing method that can be used for offshore wind site characterisation. LiDAR has been used to map and measure terrestrial vegetation for some time. A series of pulses are fired from the LiDAR system in an aircraft, which then travel down to the earth and reflect back up to a sensor on the LiDAR system. Once the pulse hits an object and reflects back to the sensor, the difference in return timings allows an accurate picture to be created. Applying the technology to measure the flight height of birds above the sea surface is both novel and pioneering for pre-construction surveys.

In terms of environmental monitoring, satellite data can be used in the measurement of ocean physical processes, as well as fisheries, mammals and birds, and habitat change. “Due to the expense and impracticality of in situ measurements, the spatial coverage and resolution offered by satellite data has large potential benefits, particularly for long–term monitoring to characterise site conditions and continuous real–time observation for operations and short-term forecasting" (Medina-Lopez et al., 2021).

There is growing interest in using very high-resolution (VHR) satellite imagery (i.e. less than 1 metre resolution) as a new platform to study marine mammals. VHR satellite imagery can either be accessed through "satellite tasking (i.e., image capture is requested at a specific time and place), or archives of previously captured images" (Höschle et al., 2021), as shown in Figure 6.

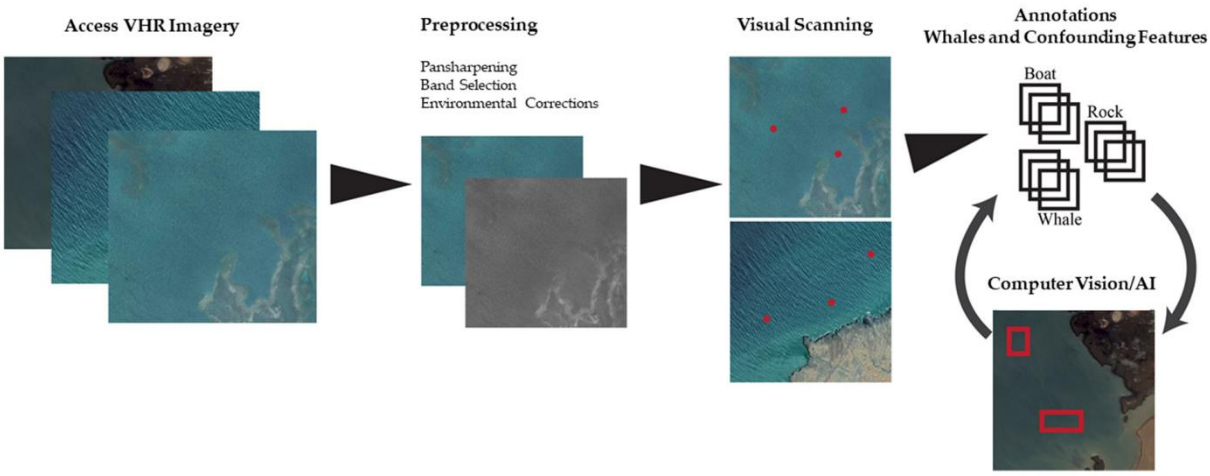

Figure 6. Processing method to detect whales using very high-resolution satellite imagery (source: Höschle et al., 2021).

Satellite surveys need relatively cloud free and calm survey conditions. However, traditional monitoring methods are equally limited as well as being constrained by location. The use of satellites presents an opportunity for data collection in remote and inaccessible regions and are able to capture relatively large areas in a short space of time (Höschle et al., 2022). SPACEWHALE technology[6], originating in Germany, uses a novel method for detecting whales in VHR satellite imagery which can monitor areas where traditional boat or aerial-based surveys are difficult to perform and combine this with deep learning algorithms.

In Höschle et al., (2021), it was reported that all VHR satellites are commercially owned (e.g., Airbus, Maxar Technologies and Earth-i) with the exception of one that is a government-owned satellite (Cartosat-3 for India), therefore obtaining VHR satellite imagery is expensive. The cost may be competitive when compared with that of an aerial or ship-based survey in a remote region, but when surveying large areas, the costs involved would certainly be considerable.

There is a growing number of 30 cm resolution satellites in the planning and some are already on offer, which represent even greater image clarity and detail. In order to overcome some of the challenges associated with satellite imagery, such as the cost of access, bandwidth and transmission, and data storage, providers must invest heavily in advanced technology and infrastructure which

[6] https://www.spacewhales.de/

then gets passed on to the end user (GeoAwesome, 2023). Space-based methods might then prove to be faster, safer, environmentally friendly *and* more cost-effective than traditional techniques.

Recent developments within the area of EIAs aim to make advanced marine modelling, which is usually only accessible to experts, now easily accessible for non-experts. Digital EIA is seen as the next natural step in EIA progression and can offer optimisation in the timeline for consenting. Approaches combining advanced modelling and technologies validated against traditional, thoroughly tested techniques, will guide sustainable marine management in the future by improving the knowledge base and predictability of management scenarios. Recommendations suggest the use of models and observations in combination; to increase the understanding of marine ecosystems.

Similarly, the data collection, analysis, and archiving are ever-evolving as the needs and applications grow. There is a need to develop, launch, operate and maintain a flexible online central repository for data, evidence, guidance and good practice on impact assessments for offshore wind. This will support offshore wind developers and other stakeholders in using the significant wealth of data and knowledge that has accumulated within the industry and its key stakeholders to undertake proportionate EIA of offshore wind farm developments.

3.5 Regulatory barriers

The use of innovative technology for marine monitoring has many benefits and the potential applications are significant, but there are several limitations, such as regulatory barriers, to the use of automated and unmanned air and sea vehicles offshore. A brief overview of the current regulatory issues is documented in the following section.

3.5.1 Autonomous surface vehicles

Autonomous, driverless vehicles hold enormous promise at “the intersection of the Maritime Transportation System and Industry 4.0” according to Kessler and Shepard (2022). However, autonomous vehicles (or ships) are *not* all created equal. The International Maritime Organisation (IMO) has devised a classification system for maritime autonomous surface ships (MASS) which is summarised by Fenton and Chapsos (2023);

- Degree 1: Encompasses ships with human crews aboard, but with some automated systems
- Degree 2: Remotely controlled ships with human crew aboard
- Degree 3: Remotely controlled ships with no human crew aboard
- Degree 4: Ships that are able to operate autonomously with no human controller, either on board or at a remote location. The operating system of the ship is able to make decisions and determine actions by itself.

Fenton and Chapsos (2023) also note that “autonomous” and “uncrewed” are not equivalent terms. “A vehicle may be uncrewed but not autonomous if it is remotely controlled by a human operator

(Degree 3). A vehicle may also be autonomous but able to carry crew—the crew may be aboard to supervise or maintain the ship only".

While there is great potential, the use of this technology is proceeding with regulatory caution, given the removal of human oversight. Naturally, "this raises [regulatory] questions about how the technology can be accommodated under a complex web of international laws and conventions that have developed over hundreds of years on a universal assumption that ships have crews onboard" (Fenton and Chapsos, 2023).

Regulation must ensure that such technological advancement places public safety as a priority. Verfuss et al., (2016) describe the regulatory framework for marine autonomous vehicles as being in a 'state of flux'. Today, there is still a need for greater clarity around legal issues and unmanned and autonomous vessels must earn the confidence of the wider maritime community to be accepted as safe marine users. IMO and the UK-based Maritime and Coastguard Agency (MCA) are engaging in the huge task of regulating this new development in shipping and ensuring best practice.

Autonomous and remotely controlled vehicles are being trialled in some areas and in 2019, the Maritime Safety Committee (MSC) which sits under the IMO, issued interim guidelines for trials of autonomous surface ships.

In the UK, MCA has issued guidance to developers of autonomous ships in the form of Marine Guidance Note (MGN) 664, and has released a draft revision to the Workboat Code Edition 3, and after recent public consultation, is due to come into force in Summer 2023 (MCA, 2022). " The revised code will comprehensively embrace the use of uncrewed workboats and implement a system for regulating and certifying their operation" (Jenson and Chapsos, 2023).

IMO recently completed a regulatory scoping exercise on (MASS) designed to assess how existing IMO instruments might apply to ships with different levels of automation (IMO, 2023). In November 2022, further progress was made on the development of a goal-based instrument regulating the operation of MASS. "The aim is to adopt a non-mandatory goal-based MASS Code to take effect in 2025, which will form the basis for a mandatory goal-based MASS Code, expected to enter into force on 1 January 2028" (IMO, 2023).

It is recognised that some of the developing legislative instruments may be regarded as arduous by manufacturers and developers. However, as the technology becomes more established, recognised and trusted, these processes will become more streamlined (Fenton and Chapsos, 2023).

3.5.2 Autonomous underwater vehicles

Unlike surface vehicles, AUVs are unlikely to be considered a "ship" under English law or for most of the international conventions and as such the maritime standards set out in the Convention on the International Regulations for Preventing Collisions at Sea 1972 (COLREGs) are unlikely to apply to many types of AUV. These vehicles require sophisticated obstacle avoidance and the ability to self-diagnose faults and if necessary surface or return to base if a fault or low-power state is detected.

3.5.3 Collision avoidance

Every vessel at sea, including unmanned vehicles, must obey the IMO rules approved by the COLREGS. Collision avoidance for an unmanned vehicle is significant for the fulfilment of autonomous navigation and manufacturers have been developing more reliable collision-avoidance algorithms compatible with COLREGS (Naval Technology, 2021).

3.5.4 Unmanned aerial vehicles

It is essential for UAV (drone) pilots to obtain the necessary certifications to ensure they can operate their vehicles safely and legally. In the UK, drone laws require them to be operated within Visual Line of Sight (VLOS), unless additional permissions are in place. Beyond Visual Line of Sight (BVLOS) refers to drone operations where the drone flies beyond the range where the pilot can visually observe it. BVLOS operations enable drones to cover larger distances and perform tasks that would be challenging or impossible within the restrictions of VLOS operations, such as offshore wind farm monitoring and inspection. BVLOS operations require a higher level of safety and risk mitigation measures to ensure the protection of other airspace users, as well as people and property on the ground.

Trials have enabled the demonstration of uncrewed flights BVLOS of the pilot which have led to substantial innovations. The downside to the rapid pace of innovation is that standards and regulations lag behind industry. The growing commercial demand for routine BVLOS services cannot be met within the current regulatory environment. Drone laws on BVLOS operations are being developed by the Civil Aviation Authority (CAA) to enable authorised operators to fly BVLOS in a scalable and sustainable manner while ensuring safety for other airspace users and minimising risk to people and property.

In March 2023, the BVLOS Operations Forum developed a series of recommendations for the UK Government and regulator to help drive the safe integration of new types of aircraft without causing undue disruption to existing airspace users; and to create a sustainable, modernised, and integrated future for UK airspace[7]. With reduced emissions, reduced cost, and improved safety, uncrewed aircraft offer great potential and benefits, including enhanced environmental monitoring, but clear regulations are needed to achieve this.

3.6 Breakdown of each stage and how it can be impacted by new approaches, and what would need to happen to ensure adoption

Figure 7 shows the stages of the pre-application phase of the consenting process. During this period, multiple baseline characterisation surveys are conducted to evaluate the impact of proposed activities on physical, biological, and socio-economic resources. These characterisations employ vessel, aerial, and acoustic survey methods to develop datasets that are relevant to the specific area of planned operation and can individually take up to three years to complete. Ornithology and

[7] https://www.nats.aero/wp-content/uploads/2023/03/WhitePaper_South_of_the_clouds_March23.pdf

marine mammal surveys can take between 24 to 36 months to gather the required amount of evidence. Metocean, geophysical and benthic surveys generally require less time (2-24 months). Onshore environmental surveys which consider the potential ecological impact that cable-laying and onshore substations may have on the onshore environment typically takes 6-12 months.

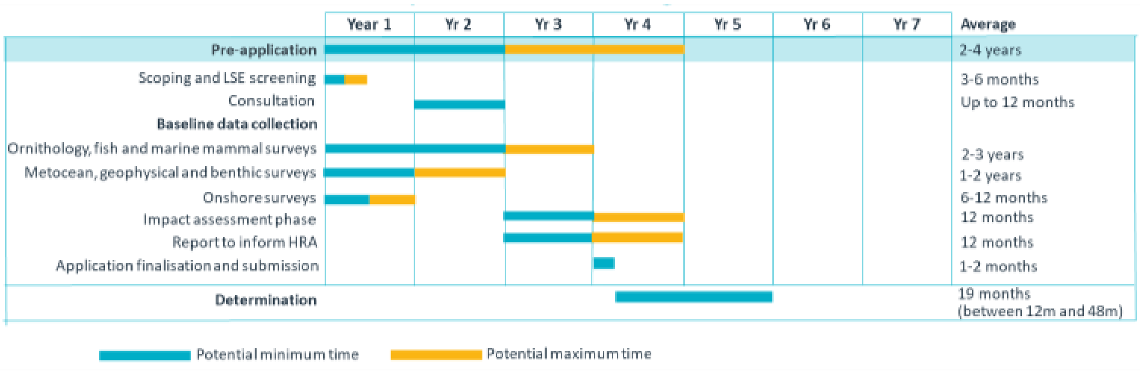

Figure 7. The pre-application stages of the consenting process

Figure 8 gives examples of emerging innovative technology and digital solutions that could be used during the pre-application stage and for post-consent monitoring. Combining the integrated platform and sensor with digitalisation can provide a fully autonomous monitoring system. Figure 8 also includes examples of how novel technology can be used in compensation, mitigation and enhancement measures. For example, offshore wind stakeholders have identified the need for routine monitoring and mitigation measures to both understand and reduce the risk of entanglement with floating offshore wind mooring lines and cables. Recommended entanglement monitoring and mitigation techniques include the use of underwater cameras, monitoring mooring and line loads or motion, and the use of underwater vehicles to detect and remove marine debris.

There is great potential for the use of digitalisation when it comes to optimising the timeline of environmental activities for offshore wind development. For example, the use of ML algorithms to support ornithological and marine mammal imagery data from UAVs. Technological advances in detecting, monitoring and assessing wildlife has been limited by the extensive time and expertise required to process and extract the relevant information. The advancement in automating data processing would aid the delivery of tangible improvements to the body of evidence needed to support the rapid decision-making that is essential to achieving timely delivery of new offshore wind projects.

Making use of innovative monitoring technology could reduce the time required to conduct the baseline surveys. For example, concerns regarding seabirds can be one of the biggest risks to offshore wind farm project development. There is uncertainty around bird behaviour – a factor that makes EIAs more difficult and creates a challenge for offshore wind consenting and in turn creates a potential barrier to offshore wind sector growth. Currently, bird surveys are collected for a minimum of 24 consecutive months but often longer to allow for the most reliable, accurate and precise estimates of the distribution, density and abundance of focal species and allow for any uncertainty in the estimates from sampling or measurement errors.

In 2020, Vattenfall commissioned a study using state of the art radar-camera based digital technology to monitor the flight patterns and responses of gannets, kittiwakes and large gulls flying through and close to one of their wind farms off the Aberdeenshire coast. The camera collects three-dimensional radar tracks as well as video footage of birds moving through the wind farm. This cutting-edge technology ensures that specific species, flight height as well as individual and group behaviour can be identified. In February 2023, Vattenfall reported the findings from the two-year study, revealing that from more than 10,000 videos of birds at the 11-turbine offshore wind farm, no collisions or near-misses with the wind turbines were recorded. Nearly all species of tracked seabirds avoided the zone of the wind turbine blades by adjusting their flight paths to fly in between the turbines. This pattern was similar for all three species of large gulls, Vattenfall says. The research revealed kittiwakes displayed avoidance behaviour from around 150 metres from the rotors, commuting herring gulls from around 100 metres, and feeding herring gulls from 70 metres. In general, gannets and small and large gulls showed a strong tendency to avoid flying into the area swept by the turbine blades, the study found. Of the birds that came within 10 metres of the zone swept by the blades, more than 96 per cent adjusted their flight paths to avoid a collision, often by flying parallel to the plane of the rotor. Vattenfall says the findings could help speed up the consenting process for wind farms by providing more accurate information about the risk of bird collisions using realistic values for flight speed, orientation and altitude.

In April 2022, a two-year operational study began at Neart na Gaoithe Offshore Wind Farm in Scotland using STRIX technology consisting of cameras and radars installed on nine of the 54 wind turbines. The study will monitor the flight activity of gannets and kittiwakes and provide further insight into how these seabirds behave around offshore wind turbines. It could also improve understanding of the behaviours of other species such as lesser black-backed gulls and great black-backed gulls.

Ørsted have partnered up with Norway-based Spoor to help test and commercialise new technology to collect more and better bird data at its offshore wind farms. Spoor's system, compared to alternatives such as the combination of high-specification cameras, radars, and human observers, uses computer vision and AI technology to accurately identify and track birds with no blind spots and is more cost-effective. It is possible to collect more complete and accurate data that accurately represents bird activity in a shorter timeframe, whilst reducing project uncertainties.

APEM has developed a novel system of using LiDAR with high-resolution digital aerial surveys, to calculate a bird's flight height above the sea with a high degree of confidence. LiDAR can identify the height of birds in flight to an estimated accuracy of within one metre over the sea surface, and can rapidly cover large areas of open habitat. This combined LiDAR and digital photography method enables the recording and analysis of flight heights and direction, age classes, distribution and bird numbers, thereby providing valuable information to inform the EIA, as well as the broader offshore wind sector.

During the consenting process, collision risk modelling is carried out to estimate the probability of a bird colliding with a wind turbine. Being able to more accurately determine the flight height which is a key parameter in collision risk modelling, by using technology such as LiDAR, there is the potential to reduce uncertainty and address a key consenting concern for all new UK offshore wind farms.

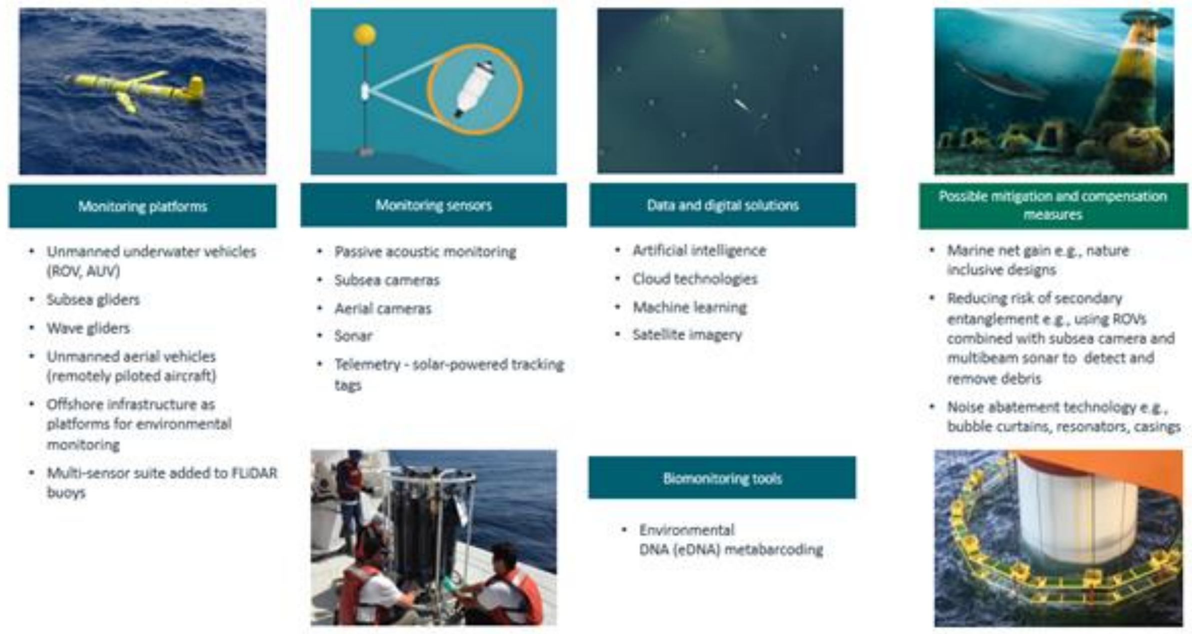

Figure 8. Types of innovative technology and digital solutions for use during the pre-application process and for post-consent monitoring

Each of these technologies has the capacity to resolve uncertainties, decrease the possibility of overestimating ecological effects in the EIA stage, reduce risk in the consenting process and improve the consentability of potential development sites.

The use of smart technologies has the potential to accelerate the consenting timeline, but only in combination with the development of a central platform that hosts a comprehensive evidence base of environmental impacts associated with offshore wind development, with emphasis on the species and habitats of greatest sensitivity and consenting risk. At the end of 2022, The Crown Estate announced they were funding an initiative to design and build a sector-wide open portal to help streamline the consenting process and support wider efforts to develop digital strategy within the offshore wind industry, termed the Offshore Wind Evidence and Knowledge Hub (OWEKH). There are numerous ongoing research programmes relating to the environmental impacts of offshore wind and the research outputs should be directly applicable for use in marine policy, management and consenting, which would then allow policy makers and advisors to provide more informed advice and make timely consent application decisions and the OWEKH hopes to achieve this.

All parties need to understand the likely ecosystem responses to the cumulative pressures of large-scale deployment of offshore wind, in combination with other stressors and importantly, give reassurance to the regulator around the effects associated with rapid build-out. There is a need for consistent guidance on the evidence and methodologies required to inform cumulative impact assessment within the EIA, that consider target deployment of offshore wind.

The use of ecological risk assessment in offshore wind projects would complement the existing EIA process and help inform decision-making. The ecological risk assessment has been used extensively as a process for estimating the probabilities of undesired ecological effects resulting from physical, chemical, and biological stressors present in the environment. For example, Whale Safe is an innovative integration of near real-time data streams from PAM, habitat suitability modelling, and visual observation to create a tool to help prevent ship strikes within the Santa Barbara Channel[8]. The risk-based tool integrates data from near real-time acoustics detections with visual observations generated by trusted observers and recorded within the Whale Alert (National Marine Fisheries Service, 2020) and Spotter Pro (Conserve IO, 2020), and habitat model-based estimates of probability to generate ratings of likelihood of whale presence and maps of known and likely occurrence. In addition to generating ratings and maps of whale presence, Whale Safe also monitors vessel traffic within the Santa Barbara Channel and rates vessel operators based on compliance with NOAA-identified voluntary vessel speed reduction zones. By integrating data on the presence and intensity of threat of vessel strike with data on probability of species' occurrence, the Whale Safe model represents a multispecies tool for assessing and managing risk in near real time over large areas of habitat and development (Macrander et al., 2022).

There is the opportunity to model ecological risk associated with offshore wind development if a rich data trove on marine mammal and bird presence, movement and biology exists. Clearly, there needs to be a strong foundation of data, tools and models upon which to build, but the advancement of emerging technologies to monitor the marine environment, will see the rapidly expanding body of relevant datasets that would enable risk-based monitoring approaches.

Monitoring offshore, energy-related activities has long been spatially and temporally limited, and the range of mitigation options is narrow, most commonly consisting of pausing or delaying activities when marine mammals are detected close to operations. The incorporation of risk assessment and risk management in the procedures is extremely limited to non-existent, resulting in an approach that is highly precautionary (Macrander et al., 2022). By contrast, risk-based monitoring and mitigation approaches for marine mammals is growing, for example, Whale Safe, which manages the risk of vessel strikes. Risk is estimated through the collection of data and modelling to allow decision-makers to establish and address mitigation priorities. The risk profile of an area containing multiple species and subject to constantly changing ecological profiles and industrial development is extremely dynamic, requiring near real-time data and projection capacities (Macrander et al., 2022). Given the potential large-scale movements of marine mammals, together with the high spatial coverage of future offshore wind activities, a regional approach is needed. However, for the regional approach to be successful and to benefit all stakeholders, there needs to be an emphasis on coordination, data sharing, standardisation and transparency.

The adoption of innovative technology to better monitor how ecosystems respond to pressures from offshore wind development would help to address risks and reduce uncertainty in planning and consenting regimes, as well as the ability to develop a consenting process that can be applied

[8] https://whalesafe.com/

without being constrained by location or specific criteria. It is imperative to build a collaborative, solution-focused relationship between developers, statutory authorities and environmental stakeholders, with the objective of obtaining consensus to deliver sustainable offshore wind growth. In order to effect change in the consenting process, there needs to be stronger collaboration between the academic community, government and industry to support wider research and evidence gathering for offshore wind and ensure that research projects are not being duplicated.

3.7 Risk and uncertainty vs. speed trade-off?

One of the most relevant non-technical barriers affecting the expansion of the offshore renewable energy sector is the potential environmental risk (and related uncertainties). There are substantial gaps in the knowledge of environmental impacts relating to offshore wind, which entails significant repercussions in the promptness of the consent process and associated economic costs. The EIA process is used to manage the environmental impacts of human activities and identify projects risks avoiding adverse effects and adopt mitigation and compensation measures. Developing standardised EIA practices would allow for potential impact concerns to the marine environment to be identified and mitigated early during project development. A strong evidence base is required to support informed and effective policy and management solutions, including delivery of marine environmental net gain and restoration. In October 2022, Natural England published several research reports to inform and support the sustainable development of offshore wind farms, contributing to economic growth and energy security. The research provides evidence to support the government's vision for 50 GW of offshore wind by 2030 and highlights how sound evidence applied early is key to enabling timely decision-making throughout the consenting process.

The rapid increase in the number and size of offshore wind farms means that the cumulative contribution from the many turbines may be considerable. Offshore renewable energy industries should not be considered in isolation because the significance of environmental impacts depends on the full spectra of human activities in each area. Possibly through the development of an adaptive regional risk assessment and risk management program, practitioners and stakeholders can move beyond the limitations of current standards. It is argued that through the integration of data in a real-time, risk-based paradigm, the dual goals of protecting marine mammal resources and achieving timely development of wind energy would most successfully be achieved (Macrander et al., 2022).

Ultimately, while legislation to reduce the local impacts of offshore wind energy is necessary, it must be proportionate and weighed against the global environmental, social, and economic benefits that come from reducing fossil-fuel emissions.

4 RECOMMENDATIONS AND NEXT STEPS

Offshore wind is and will continue to play a very important role in the UK's energy mix, but will the UK government meet the 50 GW target by 2030? It appears to be challenging and streamlining the consenting process will be essential to achieve this goal. Uncertainty during the consenting process is a major issue for developers. It is therefore crucial to manage the risks and reduce that uncertainty. Table 1 provides a summary of current approaches to different activities within the consenting process, alternative solutions and follow-up recommendations.

There is a need for research that takes advantage of innovative technologies to better understand the functioning of the UK marine ecosystems within which large-scale offshore wind deployment is situated. A sound evidence base is essential to inform policy and marine management responses and provide confidence to regulators on guidance and data requirements for project-level EIA and HRA. By applying and evolving expertise within ORE Catapult, it can support streamlining sustainable offshore renewable energy project consenting. There needs to be a collaborative effort in enabling a transformation in data gathering driven by trialling and testing new technologies that can be confidently incorporated into impact assessments and future monitoring plans and ORE Catapult is well-placed to lead this. ORE Catapult will build and support a collaborative and effective network of innovative companies involved in marine environmental monitoring to enable rapid improvement and cost reduction in monitoring the marine environment and facilitate their collaboration with industry.

The use of innovative technologies has the potential to reduce overall consenting timelines from an average of five years to three years[9], resulting in a potential time saving of 40%. This will support the aims of the UK Government's Offshore Wind Environmental Improvement Package to reduce the time it takes for approval to one year while continuing to protect the environment. Understanding the implications of implementing Marine Net Gain and how developers can meaningfully address this is also highly important, to ensure new projects are not delayed because of policy ambiguity or unrealistic measures; piloting nature-inclusive designs that we are confident will benefit the marine environment is one of those measures.

The key challenge and what is essential to achieve real progress is to develop the governance and co-operative mechanisms to harness emerging information technology to deliver on the goal of generating the information and knowledge required to sustain oceans into the future and ensure the sustainable deployment of offshore wind farms.

[9] Three years includes two years for the pre-application stage and one year for the determination stage.

Table 1. Summary of current approaches to different activities within the consenting process, alternative solutions and follow-up recommendations

Current approach	Alternative solutions	Recommendations
Developers utilise the Crown Estate's Marine Data Exchange to submit their offshore renewables survey data. Only when the data is no longer commercially valuable does the data become accessible.	• Development of a central data repository.	• Aggregation of disparate data streams into one interactive central repository - the platform will aid more informed decision-making to drive faster consenting. • Collaborate with The Crown Estate on the OWEKH initiative.
Marine monitoring is often a costly and resource-intensive process with manually collected data.	• **Monitoring platforms** (e.g. ROV, AUV, UAV, subsea gliders) • **Monitoring sensors** (e.g. subsea or aerial cameras, passive acoustic monitoring, telemetry)	• Establish a network of innovators building marine monitoring equipment, linking those manufacturing platforms with those developing the sensors. • Use ORE Catapult's facilities / UoP's COAST Lab to test and trial the monitoring equipment.
Large amounts of marine environmental data is often collected during surveys. The follow-up data processing and analysis can then be a time-consuming and manual process.	• **Data and digital solutions** (e.g. cloud technologies, satellite imagery, machine learning)	• Algorithm development and data processing • Combine advanced modelling techniques with observations to improve the knowledge base and predictability.
Cumulative impact assessment is an area of increasing concern for offshore wind developers and contributes to substantial delays in planning consents. Highly variable approach and difficulties in quantifying the impact.	• Assess cumulative and in-combination effects at a strategic and project level. • Clear guidance on methodology for cumulative impact assessments to assist developers when making applications. A well-documented baseline is critical for all proposed development areas.	• Improvement needed in the coverage and quality of spatial data. • Research the impact of potential interactions of multiple stressors on vulnerable habitats and receptors. Establish the magnitude and extent of these impacts.
Stakeholder engagement practices generally involve holding workshops, meetings, drop-ins, surveys.	• **Utilise innovative stakeholder engagement tools** e.g. Built-ID's digital stakeholder tool for renewable energy consultation.	• Help to transform community consultation into a source of positive stakeholder engagement and support for renewable energy projects. Early and ongoing consultation is essential.
The Offshore Wind Environmental Improvement Package plans to enable measures to compensate for impacts on the marine environment.	• **Possible enhancement, mitigation and compensation measures** (e.g. nature inclusive designs, noise abatement technologies)	• Work with the supply chain involved in enhancement, mitigation and compensation measures for offshore wind development.

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