

HUMAN MADE OCEAN

HUMAN-MADE OCEAN

Exploring the possibility of offshore oil and gas platforms

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ABSTRACT

This paper explores the future of offshore oil and gas infrastructure and examines its legacy and future in the context of a global shift toward renewable energy. It highlights that human-made structures, often considered harmful to marine ecosystems, can also promote ecological sustainability and biodiversity.

It investigates the impact of industrial infrastructure on cities and economies during the period of industrialization and economic revival. It also considers the preparation for the decline of the oil industry and the transition to renewable energy. The study questions the impact of offshore platforms on marine ecosystems and examines their role in the context of sustainable offshore development. The text highlights the varied impacts of human-made structures on different geographic and cultural landscapes. It demonstrates that these structures have not only modified but also generated new marine ecosystems.

The research argues for an approach to the management and reuse of offshore platforms, moving beyond the dichotomy between natural and human-made. The study proposes flexible, site-specific strategies for managing and repurposing offshore platforms that consider environmental, economic, social, and cultural factors. The thesis examines the integration of offshore structures within the narrative of urban and coastal development, highlighting the symbiotic relationship between the offshore industry and coastal communities. It provides an architectural perspective on sustainable development and explores the trade-offs between human and machine intrusion and nature preservation for future sustainable architecture.

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INTRODUCTION

The sea is often viewed as a symbol of untouched wilderness due to its vast expanse and sprawling horizons. However, this view sharply contrasts with the reality of the artificial influence that humans have had on the seas. Over centuries, maritime activities, resource exploitation, and industrialization have indelibly altered the ocean's ecological and physical landscapes. The 20th century saw the emergence of offshore oil and gas exploration, which introduced ubiquitous structures across the global marine landscape. This thesis aims to explore in-depth the ecological repercussions and structural possibilities for sustainable development arising from these marine installations.

MARIN INFRASTRUCTURE

Current estimates suggest that over 70% of the world's oil and gas production is derived from aging infrastructure located over mature fields, many of which are rapidly approaching their economic and functional limits. This extensive network of marine facilities is a significant source of greenhouse gas emissions, contributing to global warming and associated climate changes. As these structures age, the need for decommissioning becomes increasingly urgent. A study conducted by the Commonwealth Secretariat in early 2023 highlights the scale of the task at hand. According to the study, there are intentions to decommission over 50,000 offshore wells and 10,000 offshore structures worldwide, in addition to numerous onshore wells and facilities.

TRANSITION TO RENEWABLE ENERGY

As the world moves towards a future dominated by renewable energy sources, the significance of marine oil and gas infrastructure, both past and future, becomes increasingly important. The decommissioning of marine facilities and the expansion of renewable energy infrastructures, such as offshore wind farms, offer a unique opportunity to reconsider our relationship with the marine environment. This research explores the ecological, structural, and socio-economic dimensions of marine structures in the context of a changing global energy landscape.

RESEARCH QUESTION

This research aims to answer two primary questions: What are the impacts of offshore oil and gas platforms on marine ecosystems? And, in light of the ongoing energy transition, what are the existing components and potential elements for sustainable development in the ocean? Despite the substantial coastal presence of the global population, the ocean remains a relatively unexplored and misunderstood domain. The relationship between marine ecosystems and industries, such as oil exploration and telecommunications, is complex and poorly understood due to the vastness and intricacy of the ocean. This lack of understanding presents significant challenges in conducting research and developing informed policies for oceanic management.

EFFECTS ON MARINE ECOSYSTEMS

The effects of offshore oil and gas operations on marine ecosystems are not uniform, but vary widely across different geographic, cultural, and policy contexts. Therefore, a comparative approach is adopted, scrutinising country-specific cases to gain broader insights into the future trajectory of offshore activities. Upon examining these diverse cases, it is evident that anthropogenic structures have not only altered existing ecosystems but have also fostered the formation of new ones, which may be rich in ecological value. This realization highlights the significance of comprehending and utilizing the transformative potential of these structures in marine ecosystems.

POTENTIAL OF HUMAN-MADE STRUCTURES

While exploring offshore oil and gas platforms, this research highlights the importance of moving beyond the conventional distinction between artificial structures and ‘natural’ ecosystems. This paper argues for acknowledging the functional and ecological benefits of these human-made interventions. By acknowledging the complex role and potential benefits of artificial marine structures, we can pave the way for ecological enhancements and sustainable coexistence models between human enterprise and the marine world. This shift in perspective is vital as it can offer profound insights into the future of sustainable architecture, teaching us how to create structures that harmonise with the environment rather than dominate it.

The study explores the history, typology, and productivity of offshore structures, with a focus on their architectural scale and impact on the marine environment. It also examines the ecological effects of these platforms, both

positive and negative, and proposes architectural approaches for their de-commissioning, repurposing, or removal. The concept of an offshore energy hub is explored as a potential sustainable future, integrating renewable energy sources and innovative architectural designs to create a harmonious coexistence with the marine environment.

In conclusion, this research proposes an architectural reimagining of the human-made ocean. It advocates for a nuanced understanding of these structures, recognizing their potential to contribute to sustainable development and ecological enhancement. The future of our man-made oceans depends on our ability to comprehend, appreciate, and transform the vast structures that we have imposed upon the marine environment. This thesis is a call to action for a new architectural approach that embraces the complexities of the marine world and seeks harmony between human endeavours and the natural ecosystem, offering a blueprint for future sustainable architecture.

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URBANISATION OF THE OCEAN

OFFSHORE OIL AND GAS INDUSTRY

OFFSHORE OIL AND GAS PLATFORMS TYPOLOGY

JACKET STRUCTURE

INFRASTRUCTURE TO SUPPORT

OFFSHORE WIND FARM

MARITIME ZONES

MAP OF OIL & GAS RIGS PLATFORMS

URBANISATION OF THE OCEAN

Following the critical perspective presented in the introduction, which discusses the impact of offshore oil and gas platforms on marine ecosystems and the need for their decommissioning, the focus shifts to the broader concept of oceanic urbanisation. This phenomenon includes not only the physical expansion of infrastructure into the marine environment but also the integration of the ocean into our collective urban consciousness.

Throughout history, human development has mainly focused on continents and terrestrial infrastructure. However, as resources and space on land became increasingly scarce, the vast ocean is emerging as the frontiers for exploration and the arena for urban development. The concept of urbanising the ocean represents a paradigm shift, reimagining our relationship with the sea from one of mere exploitation to strategic cohabitation.

CONVENTIONAL PERCEPTION AND MODERN IMPACT

Traditionally, the sea has been considered as a ‘natural’ space without boundaries, serving as a backdrop for human civilization rather than an integral part of it. This perception, combined with the technical and logistical challenges of the marine environment, has obscured the significant impacts of urbanisation processes on marine spaces. Industries such as oil drilling, shipping, and aquaculture have traditionally been viewed as separate from urban life. However, as these industries grow and expand, the ocean is becoming more urbanised, with the development of infrastructure, specialised economic zones, and emerging communities.

PERCEPTION AND INTEGRATION CHALLENGES

The urbanisation of the ocean is often overlooked, both physically and perceptually. Despite being navigated by sailors, exploited by industries, and studied by scientists, the sea is still considered a realm of specialists. For many, it remains an abstract space, a place of myth and mystery rather than a site of critical infrastructure and urban functions. This concept hinders the integration of marine areas into the broader urban consciousness, despite its contribution to the cultural allure of the sea.

However, the relationship between land and sea is changing as coastal cities expand and marine industries grow. Coastal zones, ports, and beaches are now sites of intense economic, social, and ecological interaction. The impacts of marine activities on terrestrial life are increasingly apparent, from the seafood we consume to the global shipping networks that supply

our cities. Climate change and rising sea levels have made the ocean an undeniable presence in urban life. This has forced us to recognize our cities’ marine extensions and vulnerabilities.

POTENTIAL OF OCEANIC URBANISATION

The description of urbanisation here does not immediately present itself in the form of dense cityscapes. Instead, it takes the form of dispersed and networked urbanism defined by shipping routes, cables, pipelines, and energy grids. The materiality of ocean urbanisation is submerged and spread out, characterised by the vastness and fluidity of the marine environment. This makes it less perceptible but no less impactful.¹ Marine structures, such as oil platforms and wind farms, are industrial facilities that also serve as artificial ecosystems. They have significant impacts on both human economies and natural habitats.

The urbanisation of the ocean is not merely an extension of cities into the sea. It involves reimagining the concept of urbanisation to include the marine environment and recognising the ocean as a space of both natural and cultural production. This requires new ways of thinking and new forms of architecture, planning, and governance. It means viewing the sea not as a surface to be crossed or a volume to be filled, but as a complex and dynamic environment that is an integral part of our urban world.

The transformation of marine areas into urban spaces is already in progress, with shipping lanes, oil platforms, and wind farms representing the initial stages of this transition. However, the real potential of oceanic urbanisation lies in its capacity to promote sustainable coexistence between human and marine life. This means looking beyond the traditional land-centric view of urban development and embracing the ocean’s potential as a space for sustainable and innovative growth.²

In conclusion, as we strive for a more sustainable future, the urbanisation of the ocean presents a unique opportunity to reconsider our relationship with the marine environment. This requires a new architectural and urban planning paradigm that balances human needs with the health of the marine ecosystem.

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OFFSHORE OIL AND GAS INDUSTRY

The offshore oil and gas industry includes activities related to exploring, mining, transporting, and processing offshore oil and natural gas. The exploration and development of offshore oil and gas have become a crucial strategy for various countries and regions due to the importance of these resources.

Offshore platforms are large structures made of steel or concrete that are used to explore and extract oil and gas from the earth’s crust. Oil and gas are transported from the platform and transported to shore via pipelines or tankers. These structures may be made of steel, reinforced concrete, or a combination of the two.

In 2019, there were 6,500 offshore oil and gas production facilities world-wide, located on the continental shelves of around 53 countries. The Gulf of Mexico has over 4,000 offshore platforms, while Asia has approximately 950, the Middle East has around 700, and Europe, the North Sea, and the North-East Atlantic have 600. The Mediterranean basin holds only 0.4% of the world’s oil and gas reserves, with 127 offshore platforms producing oil and gas.³

In 2015, over 27 million barrels of oil were produced offshore across more than 50 countries, according to the U.S. Energy Information Administration (EIA). However, a few countries, namely Saudi Arabia, Brazil, Mexico, Norway, and the United States, accounted for 43% of total offshore oil production.

Offshore production mostly occurs in shallow waters, which are less expensive and technically challenging. However, technological advancements and the depletion of shallower prospects have prompted companies to explore deeper waters, especially in Brazil and the Gulf of Mexico.⁴

Fig. 1
Offshore oil and gas
platform and offshore wind
turbines



WOODEN PIERS (Late 19th Century)

The first offshore drilling for oil began in 1896 off the coast of Summerfield, California, just south of Santa Barbara [Fig.2]. The earliest offshore structures were simple wooden structures built on piles or stilts in shallow water, resembling boardwalks, with rows of narrow wooden piles extending to the shoreline. These were mainly used for drilling and extracting oil and gas in relatively calm and shallow coastal areas.⁵

The impact of the oil industry on Summerland was immediate and significant; they transformed the quiet coastal community into an industrial hub, leading to an influx of workers and the establishment of supporting industries. Summerland’s transformation set a precedent for future coastal towns, reshaping their economic and social landscapes around the burgeoning oil industry.

FIXED PLATFORMS (Mid 20th Century)

Fixed platforms are constructed on either concrete or steel legs that are anchored directly onto the seabed. These platforms support a deck that provides space for drilling rigs, production facilities, and crew quarters. Due to their immobility, they are designed for long-term use. Fixed platforms are economically feasible for installation in water depths of up to 150m.⁶

The use of fixed platforms has led to significant urban and economic transformation in cities such as Galveston, Texas, and Aberdeen, Scotland. The oil industry requires various services, including construction, maintenance, logistics, and administration, resulting in job creation and urban expansion. Aberdeen, also known as the ‘Oil Capital of Europe,’ had experienced exponential growth in population and economy.⁷ The city has expanded its port facilities, developed new residential and commercial areas, and invested in education and training institutions to supply the oil industry with a skilled workforce. They have not only transformed the physical landscape but also the social fabric, bringing wealth, diversity, and international influence.

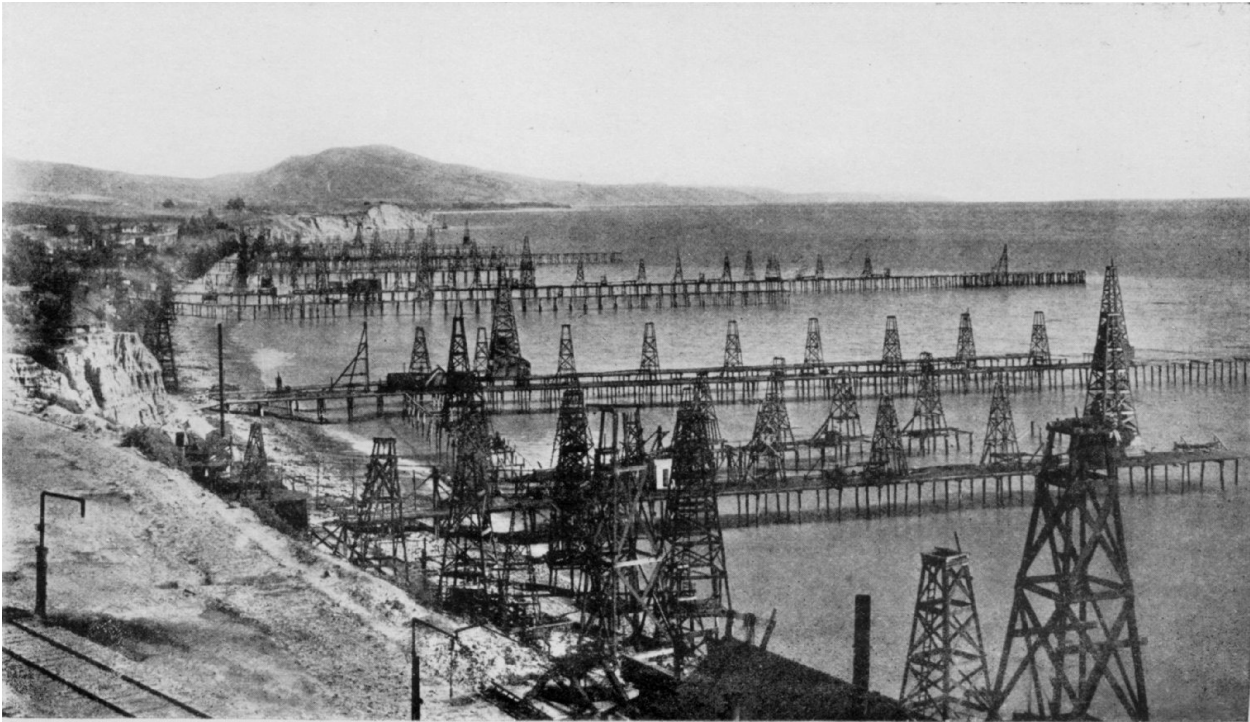


Fig. 2
Many of the earliest offshore oil wells were drilled from piers at Summerland in Santa Barbara County, California. Circa 1901 photo by G.H. Eldridge courtesy National Oceanic & Atmospheric Administration.

COMPLIANT TOWER (Late 20th Century)

Compliant towers are structures similar to fixed platforms but they are supported by a narrow tower made of steel or concrete structure at the top, anchored to the seabed, and designed to withstand forces associated with sea and climate conditions. The tower’s lateral flexibility enables it to withstand extreme sea conditions and strong wind forces, including those experienced during hurricanes. Compliant tower can operate at depths ranging from 450 to just over 900 meters.⁸

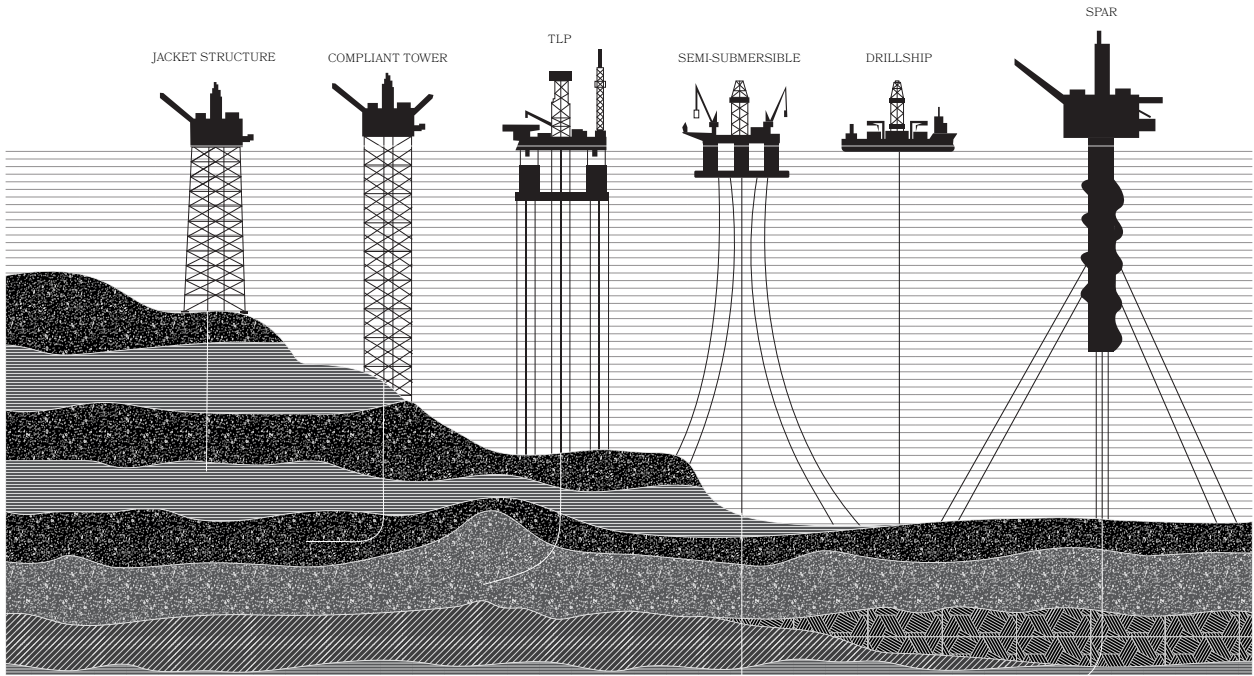
The compliant towers required advances in engineering and technology, which in turn required specialized workforce training and infrastructure development. Cities that support these structures, such as those in the Gulf of Mexico, have expanded their educational institutions to create a skilled workforce capable of handling the complexities of deep-water drilling. The local economies diversified and urban areas expanded to accommodate population growth, increased demand for housing, services, and recreational facilities.⁹ The presence of these towers contributed to continued economic growth and a more diverse and sophisticated urban environment.

TENSION-LEG PLATFORMS(TLP) (Late 20th Century)

Tension-leg platforms(TLP) are anchored permanently using tendons (ropes) grouped at each corner of the structure. TLP has high axial stiffness (low elasticity), which eliminates almost all vertical movement of the platform. This allows for production wells to be located on the deck, providing easier access to downhole intervention operations. This method reduces production costs in water depths of up to 1500 meters while maintaining many of the operational benefits of a fixed platform.¹⁰

The development and operation of TLP, such as the Snorre in the North Sea, have had a significant impact on neighbouring cities, particularly in Norway. The growth of specialized engineering and maritime institutions has been driven by the need for a highly skilled workforce.¹¹ The urban communities has been contributed to by the influx of skilled workers and their families, resulting in more vibrant and diverse communities.

Fig. 3
Different types of offshore
fixed and floating platforms
(redrawn from Deep Trek-
ker)



SEMI0SUBMERSIBLE PLATFORM (Late 20th Century - 21st Century)

Floating structures are preferred over fixed structures as water depth increases. Semi-submersible platforms are used for offshore drilling operations in water depths up to 3000 metres.¹² The main advantage of semis is their ability to withstand waves due to their structure being mostly below the sea surface.¹³

With exploration and drilling operations in deeper waters via semi-submersibles, many cities have become essential bases for offshore operations. Rio de Janeiro, located adjacent to Brazil's pre-salt deposits, is an example of a city whose urban and economic development has been significantly influenced by this structure.¹⁴ The impact of oil industry on the city extends beyond the economy, affecting local culture, social structure, and even politics.

SPAR PLATFORM (Late 20th Century - 21st Century)

SPAR is a type of floating structure that was developed as an extreme deep-water alternative to conventional platforms. The deep draft design of spars makes them less affected by wind, waves, and currents, allowing for both dry tree and sub-sea production.¹⁵

The introduction of the SPAR platform required significant investment and innovation, which had an impact on cities such as Houston, Texas, known for their high concentration of energy companies.¹⁶ The growth of various support services boosted the city's economy and transformed its landscape with new business districts, research parks, and residential neighbourhoods. Economic prosperity also led to cultural and social investment, making cities more vibrant, diverse, and dynamic places.

The development of offshore oil and gas structures has had a significant impact on neighbouring cities and societies. The impact of the offshore site extends beyond its immediate location, affecting economic growth, urban development, social and cultural change, and contributing to the global discourse on energy, economics, and the environment. The decline or end of the oil industry can trigger a crisis in once-thriving cities, leading to economic downturns, job losses, and infrastructure devaluation can become widespread as the industry declines. Cities that heavily rely on oil for economic prosperity may struggle to diversify their economy. The challenge faced by for these cities is to adapt and change, finding new industries and opportunities to ensure sustainable growth and stability beyond the oil life-cycle.

Fixed jacket structures are the most common and long-standing jacket structures in the offshore oil and gas industry. They are typically found in relatively shallow water and are optimally placed for access and connectivity from land. These structures can be considered for sustainable development after the decline of the oil industry, in conjunction with land as well as offshore. Therefore, this book focuses on the jacket structures of offshore oil and gas platforms and analyses their possibilities.

TOPSIDE

Above the jacket structure, there is a deck known as the topside. This deck serves as the operational and residential centre of the platform, where a balance is maintained with human-made structures. The offshore structure is designed to accommodate processing equipment necessary that is essential for the extraction and preliminary treatment of oil and gas. It demonstrates the interplay of engineering and architecture in challenging environments.¹⁷ The topside of the offshore structure provides living and working quarters for the crew, ensuring a safe and functional environment for personnel to sustain the rigours of their work.

VERTICAL PIPES

Integral to the functioning of these platforms are vertical pipes, known as conductors, which firmly anchor to the seabed and rise through the water to the platform.¹⁸ These conduits are crucial for transporting the extracted oil and gas from the well-head to the processing facilities on the topside, epitomizing the vital connectivity between the sub-sea resources and surface operations.

JACKET STRUCTURE

The stability of the monumental structures in the dynamic marine environment is ensured by their large pile foundations. These deep-rooted elements provide critical support for the substantial decks, enabling a diverse range of activities and operations. The initial construction and installation of jacket structures are significant undertakings, typically executed at specialized on-

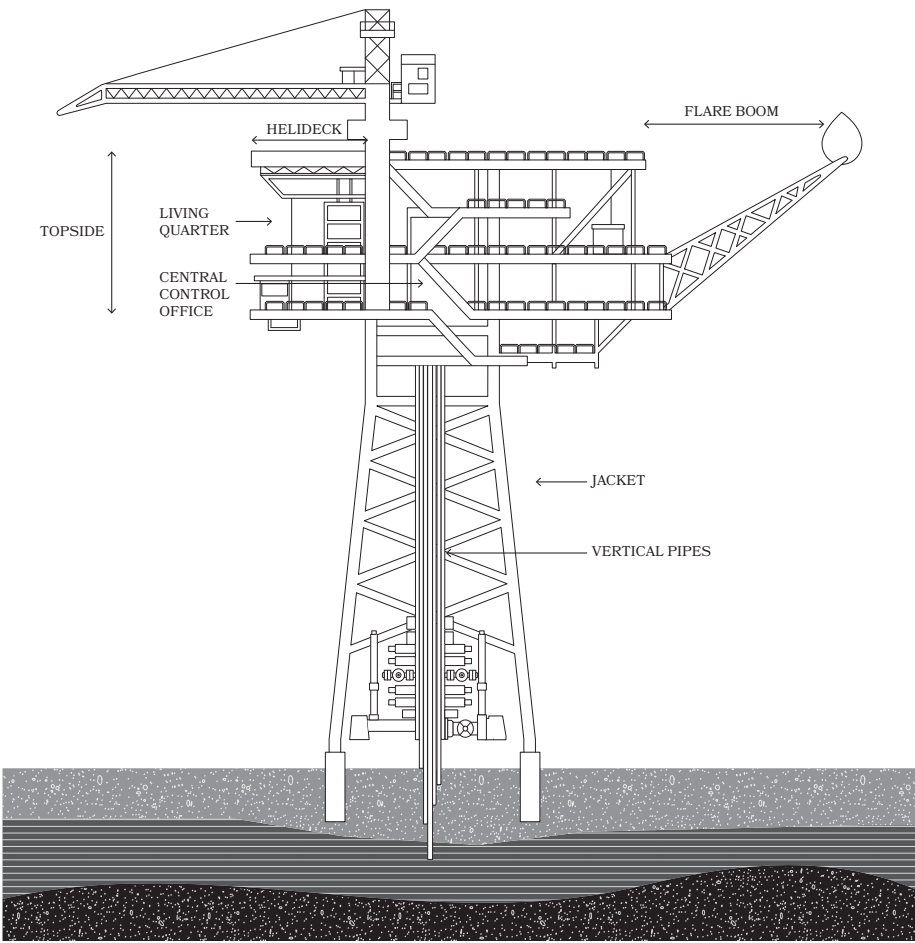


Fig. 4
Example jacket structure
section (redrawn from
BSOL)

shore fabrication yards. The components are assembled at this location and then transported to their final offshore destination via cargo barges. This ensures controlled movement and positioning during the installation process.¹⁹

WEAKNESS

However, the architectural and structural integrity of jacket platforms must withstand the relentless forces of nature. These steel structures in marine environments are susceptible to corrosion, which is exacerbated by factors such as high humidity and the presence of sea salt, increasing the electrical conductivity of seawater. Therefore, corrosion resistance methods are essential. Cathodic protection involves covering the steel surface with sacrificial anodic metals such as magnesium, aluminium, or zinc.²⁰ These metals preferentially corrode, protecting the structural integrity of the steel. However, regular inspection and maintenance are necessary to ensure continued protection of the platform.

The offshore oil and gas industry involves a complex and systematic process of extracting, transporting, and refining hydrocarbons from offshore platforms to onshore refineries. The offshore oil and gas industry involves a complex and systematic process of extracting, transporting, and refining hydrocarbons from offshore platforms to onshore refineries. This process requires the use of platforms, pipelines, onshore processing facilities, and distribution networks, which are determined by the production process.

SEISMIC SURVEY

The first step in oil and gas extraction is conducting seismic surveys to reveal underground geology and identify potential reservoirs. Seismic surveys and the subsequent exploitation of the world’s offshore oil and gas reserves focus on the continental shelf, which is located closest to the coast. Seismic waves are used to map the subsurface geology beneath the ocean floor. Once a promising location is identified, an exploration well is drilled to assess the presence of oil and gas. Seismic surveys enhance the efficiency of the offshore oil and gas extraction by providing critical geological information for informed decision-making during resource extraction.²¹

OIL AND GAS EXTRACTION

Crude oil and natural gas are extracted from offshore platforms, which often contain impurities such as water, sand, and gas. Therefore, offshore processing facilities are necessary to prepare crude oil for transport and refining. The process of separation, which utilise the use of separators and heaters, eliminates impurities from the crude oil, resulting in a cleaner product for subsequent processing.²²

TRANSPORTATION VIA SUBSEA PIPELINES

Crude oil is processed and transported to an onshore facilities via sub-sea pipelines installed on the ocean floor. These pipelines are a crucial component of the infrastructure for transporting hydrocarbons from offshore to onshore, ensuring a continuous and reliable flow of crude oil. It is important to main-

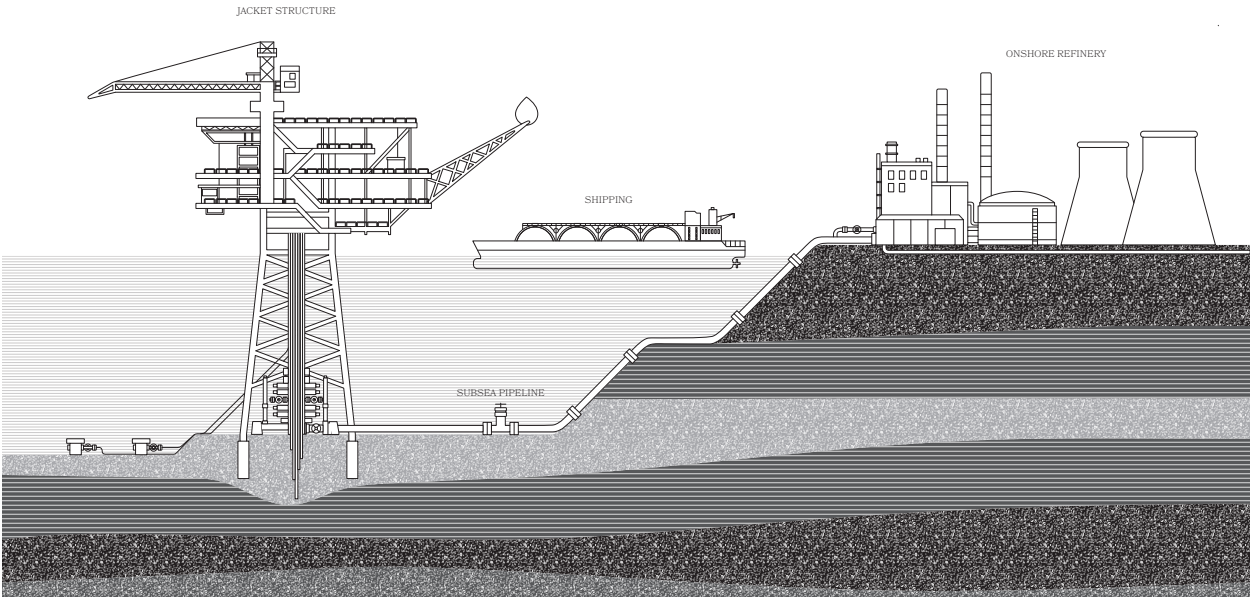


Fig. 5
Offshore production process
diagram (redrawn from
BSOL)

tain the integrity and durability of sub-sea pipelines is crucial due to their exposure to the harsh marine environment and interactions with marine life.²³

RECEPTION AT ONSHORE FACILITIES

Upon arrival at an onshore facility, crude oil undergoes initial inspections and measurements. It may be temporarily stored in storage facilities before continuing through the refining process. The crude oil is then transported to refineries where it undergoes a series of complex processes to be transformed into valuable refined products.²⁴

REFINERY PROCESSING

Refineries may also engage in petrochemical production, using by-products to create chemicals for various industrial applications.²⁵ The last stage involves distributing refined products, such as gasoline, diesel, jet fuel, and petrochemicals, to end-users and distribution points via an extensive network of pipelines, ships, trucks, or railways.

Offshore oil and gas production on offshore platforms is not a standalone activity but part of a larger, interconnected system that spans from the depths of the ocean to the far reaches of the consumer market. Offshore platforms require a comprehensive and interconnected infrastructure that extends from the marine environment to terrestrial facilities.

OFFSHORE WIND FARM

The energy sector is currently facing two significant challenges: sustainable economic development and global climate change. Addressing these challenges is often linked to the decarbonisation of today's energy system, achieved through the transition from fossil fuels to renewable energy. Fundamental structural changes are taking place worldwide in the energy sector, involving energy sources, structure, scale, economics, and energy policy.²⁶

Green energy is essential in the fight against climate change as it reduces greenhouse gas emissions. Offshore wind turbines have been implemented globally and offer a significant alternative to fossil fuels or other energy sources. Offshore wind power especially has several advantages over onshore wind power. By placing wind turbines far enough offshore, visual and noise issues can be virtually eliminated.²⁷

WIND TURBINE TYPOLOGY

Offshore wind farms are a crucial component in the transition to renewable energy, utilizing wind power over the oceans to generate electricity. The anchoring or floating of turbines is a critical aspect within this field, resulting in various structural typologies. These structures must endure marine conditions, support the weight of the turbines, and maintain efficiency throughout their lifespan. The two main categories of offshore wind structures are fixed and floating Structures.

Fixed structures, such as monopiles and jacket structures, are commonly used in offshore wind farm construction. However, they are only suitable for shallower waters and smaller turbines. Monopiles, which are large steel tubes driven into the seabed, are favoured for their simplicity and cost-effectiveness. Therefore, It is important to consider the water depth and turbine size when selecting the appropriate structure. Jacket structures provide increased stability and strength, particularly in difficult seabed conditions. They are used to allow wind turbines to efficiently capture wind energy in deeper waters, despite their higher complexity and cost.

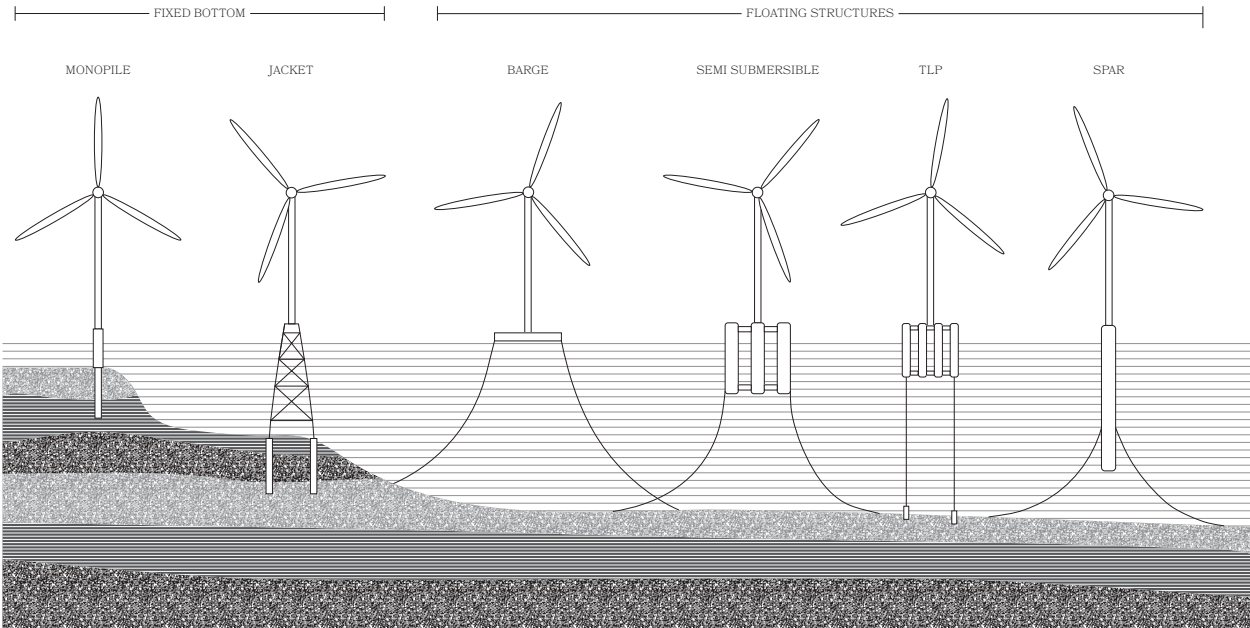
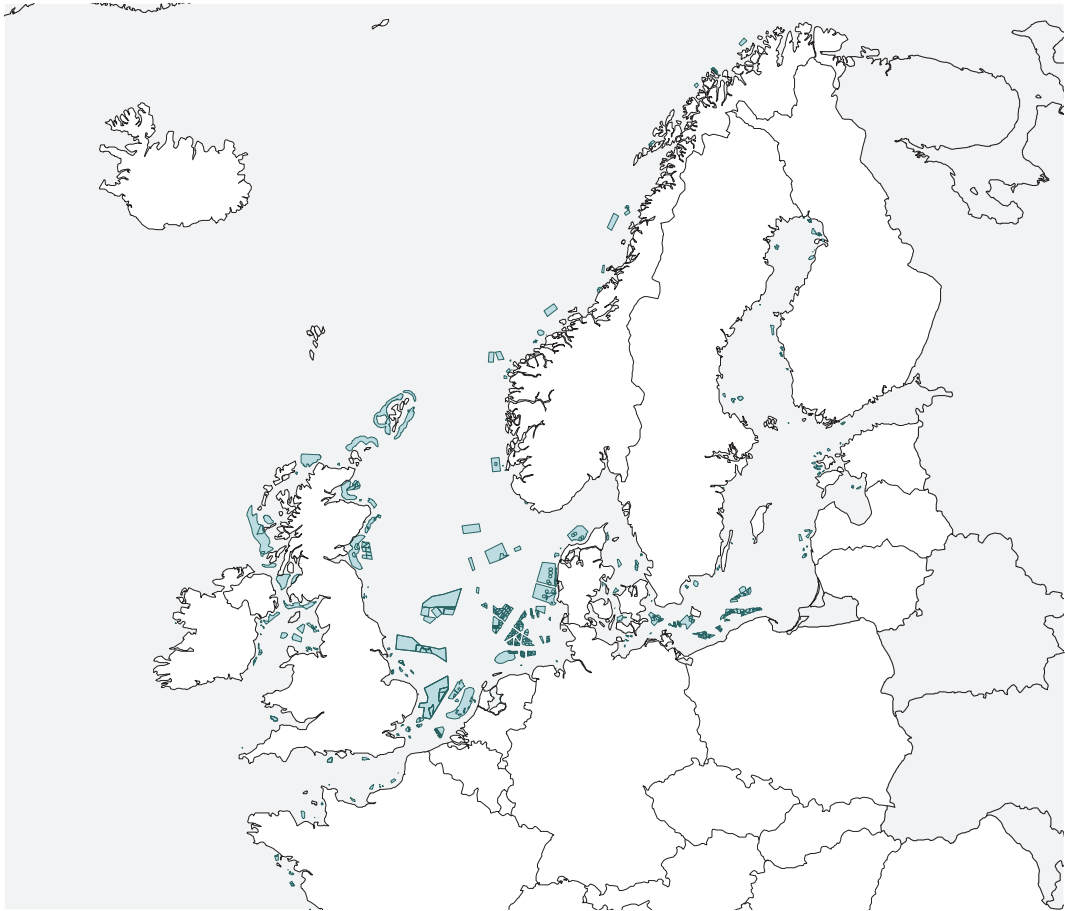


Fig. 6
Types of wind turbines support. Offshore wind energy projects utilise technology that was originally developed for the offshore oil and gas industry. In the offshore wind turbine market, various support structures are available for wind turbines, depending on the water depth.(redrawn from Dornhelm 2019)

As the offshore industry expands, floating structures have become essential for placing turbines in deep waters that were previously inaccessible to fixed structures. This category includes barges, semi-submersibles, tension leg platforms (TLP), and spars, each designed to float while maintaining stability and support for the turbines. Barges, with their simple flat platform design, are cost-effective but best suited for calmer marine environments. Semi-submersibles, TLP, and spar foundations are all types of offshore wind turbine foundations. Semi-submersibles offer flexibility and adaptability to various conditions. TLP are anchored to the seabed with tensioned mooring lines, providing a stable base for turbines in varying water depths. Spar foundations have a deep-reaching cylindrical structure, providing stability in very deep waters, but with more complex installation requirements.²⁸



WIND ENERGY GROWTH

Since the installation of the first wind farm in Denmark, the European wind energy market has continued to grow. According to the *WindEurope* database, there are currently 120 wind farms in Europe, with 5,566 turbines installed and a capacity of 26,351MW. The North Sea is a crucial area for Europe, with abundant resources and important sea lanes, as well as major ports for maritime transport. The North Sea is home to over 41 wind farms, with a combined capacity of approximately 100,133 MW and around 2,630 turbines, according to 4C Offshore’s Global Offshore Wind Farm Map and

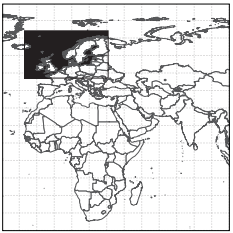


Fig. 7
Development of wind farm
areas in North Sea, Europe
(redrawn from European
Environment Agency)

Database. The potential wind energy in the North Sea could make a significant contribution to increasing renewable energy sources and combating global warming. By 2050, most of the infrastructure related to oil and gas production will have been reused or moved onshore. Between 10,000 and 25,000 new wind turbines are expected to be constructed in the North Sea, covering almost 10% of the total area.²⁹

While the European offshore wind industry has experienced significant growth, the United States currently only has two small offshore wind facilities. European countries have been early adopters of renewable energy policies and have set ambitious targets to reduce carbon emissions and increase the share of renewable energy in their energy mix. Specifically the European Union has implemented supportive policies and regulations to encourage the development of offshore wind projects. Offshore wind installations are often more challenging and expensive than onshore ones. They can be up to twice as costly as onshore installations, making them unaffordable for companies without state support.³⁰

Furthermore, the establishment of wind farms requires extensive ocean areas, which emphasizes the need for improved planning and cooperation between the state and industry. Large-scale offshore wind farms can frequently conflict with other concerns, such as shipping, fishing, sediment extraction, cable and pipeline laying, and military activities. These activities may have a negative impact on seascapes, which can harm tourism and recreation, and must be taken into account.

Fig. 8
Sea zones defined by the 1982 United Nations Convention on the Law of the Sea, progressing across a jurisdictional continuum from the coastal boundaries of nation States into the international spaces of the high seas and deep sea. UNCLOS promotes 'the peaceful uses of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment (redrawn from Sundaramurthy, 2018)

The development of the offshore oil and gas industry has had a significant impact on the evolution of ocean zoning, the legal frameworks, and regulatory structures for managing resource extraction in the marine environment. As countries seek to benefit from the economic potential of seabed resources, debates over ownership and the need for a comprehensive management system have arisen. The maritime zoning framework, as defined by the United Nations Convention on the Law of the Sea (UNCLOS), categorises maritime areas into five zones: Internal water, territorial Sea, Contiguous Zones, Exclusive Economic Zone (EEZ), and High Seas [Fig.8].³¹ Oil and gas activities are mainly carried out within the EEZ and the continental shelf.

The concept of the Exclusive Economic Zone (EEZ) originated from the post-1945 trend of coastal states asserting rights and jurisdiction over an expanding area of seabed due to the abundant natural resources beneath it. EEZ is an area where sovereign states have jurisdiction over resources and extends 200 nautical miles from the baselines. It grants coastal states

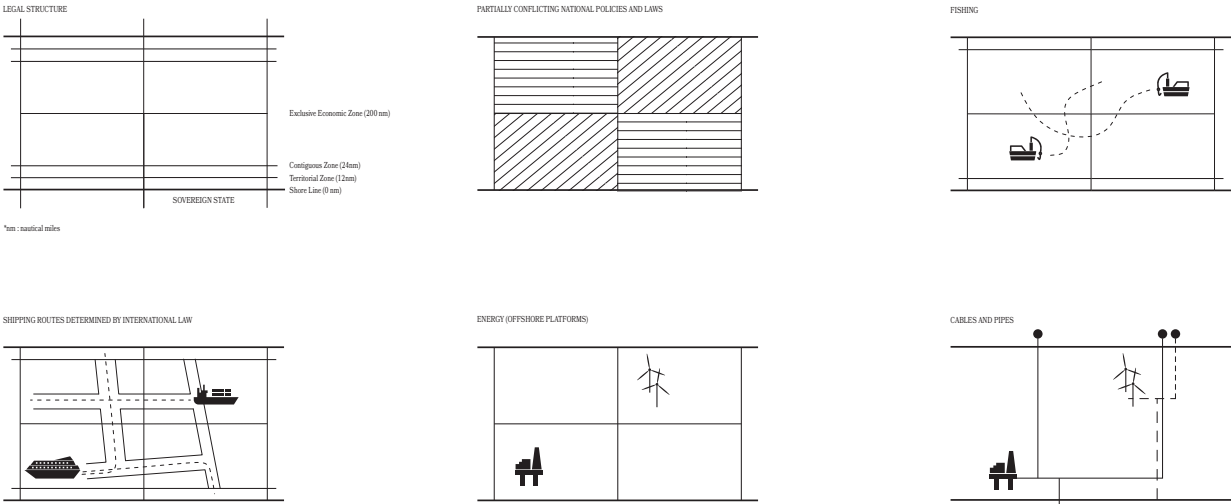
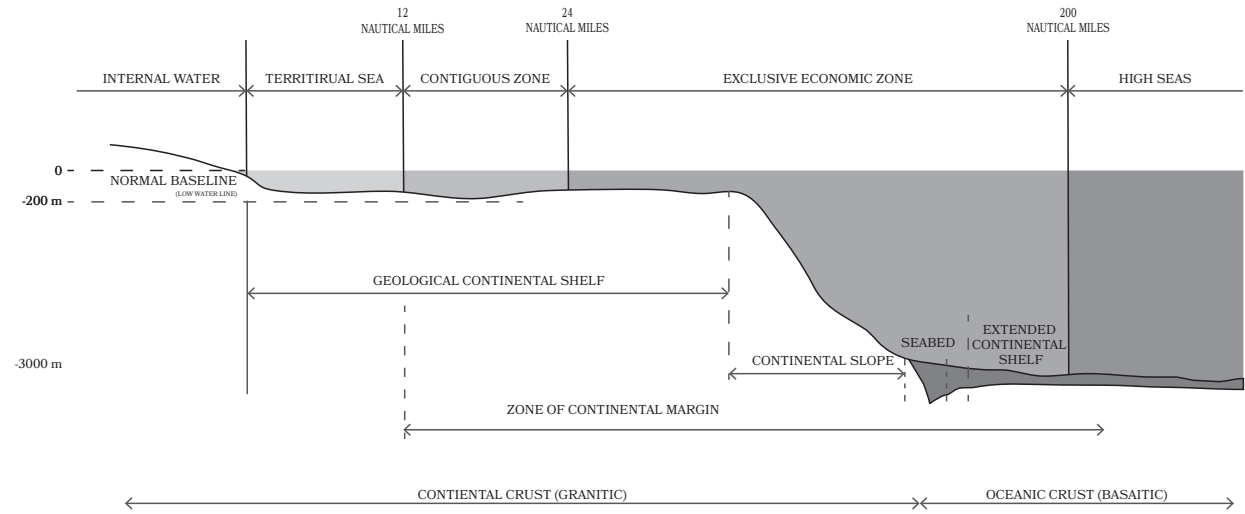


Fig. 9
Diagrams for understanding exclusive economic zones (EEZ) covering a variety of topics. (redrawn from Jan 2018)

sovereignty over the natural resources in the area. This serves as a delicate compromise that recognises both the interests of coastal states and the rights of the international community to navigation and overflight.³² Within the EEZ coastal states have exclusive rights to explore and develop marine resources including oil and gas.

Maritime zoning primarily regulates the continental shelf, which is closely tied to offshore oil and gas activities. According to UNCLOS, coastal states have the sovereign right to explore and exploit the natural resources of their continental shelves, including oil and gas reserves.³³ Therefore, the delineation of the continental shelf and the management of its resources are crucial aspects of maritime zoning. Coastal states must maintain control over resource extraction while respecting the rights of their neighbours.

However, this can practically lead to conflict, particularly in areas rich in oil and gas resources. The strategic value of these resources increases competition, and disagreements over the interpretation of UNCLOS provisions can escalate into protracted geopolitical conflicts. State conflicts related to offshore oil and gas activities often involve legal disputes over maritime boundaries, territorial delimitation, and resource-sharing agreements. Although UNCLOS provides a mechanism for peacefully resolving disputes, it does not eliminate the geopolitical complexities that give rise to them. This limitation is not due to the treaty itself, but rather to the physical limitations of the ocean as a vast, dynamic, and limited visible land mass.³⁴

MAP OF OIL & GAS RIGS PLATFORMS

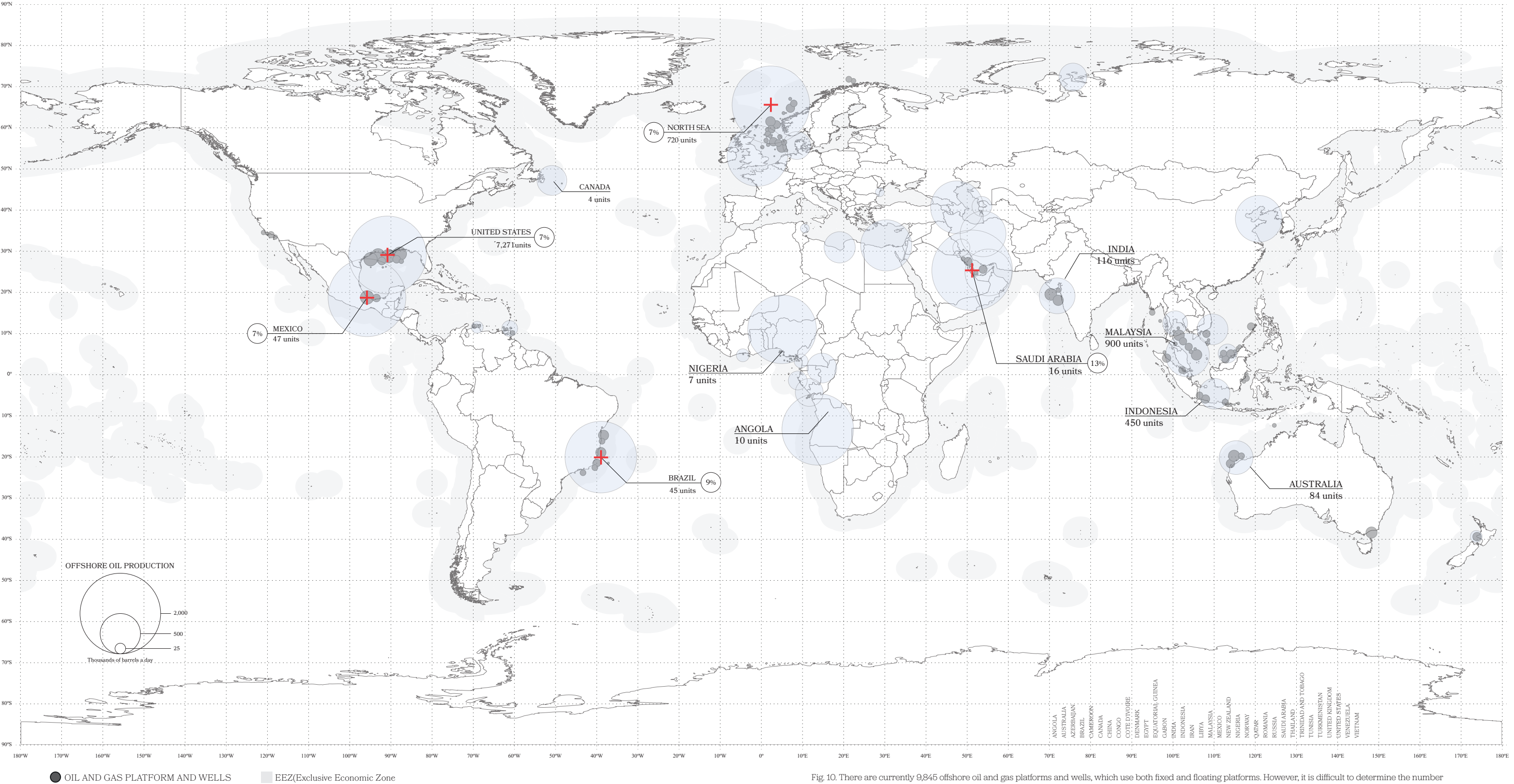


Fig. 10. There are currently 9,845 offshore oil and gas platforms and wells, which use both fixed and floating platforms. However, it is difficult to determine the number of units that are no longer in operation. (redrawn from qgis data)

ECOLOGICAL IMPACTS

ENVIRONMENTAL IMPACT BY PHASE

DECOMMISSIONING

OFFSHORE PLATFORMS AS ARTIFICIAL REEFS

OFFSHORE WITH BIODIVERSITY

NOVEL ECOSYSTEM

Oil and gas extraction is a complex industrial process that involves multiple phases, each with its unique environmental impact. This industry plays a significant role in meeting global energy demands, from the initial stages of seismic surveys to the eventual extraction and transportation of hydrocarbons. However, it also poses various environmental challenges and concerns that arise from activities carried out at different phases of the extraction process.

SEISMIC SURVEYS

The impact of seismic surveys on fish is still uncertain. However, there is growing evidence that human activities have negative effects on marine wild-life, including underwater noise and light emissions, as well as increased vessel traffic. While most assessments of acoustic disturbance have focused on marine mammals, it has been found to cause behavioural disruptions, including disturbances in feeding, breeding, resting, migrating, communication, and navigation, as well as local displacement. Physiological stress and physical injury, such as temporary or permanent hearing damage, can occur within a range of a few metres to kilometres from the source. It should be noted that avoidance behaviour can also be detected at greater distances, although its variability should be taken into account.³⁵

During a seismic survey of the North Carolina Outer Continental Shelf in the USA, there was a 78% decrease in the abundance of reef fish during evening hours, which is when fish habitat usage peaked, compared to the previous three days without seismic noise.³⁶ The decrease in fish occupancy indicates that seismic surveys may disrupt daily patterns and affect the use of coastal habitats by fish.

OFFSHORE INSTALLATION

Offshore installations can have direct impacts on habitats and associated fauna. There are two main concerns regarding alterations to the seabed environment caused by installations. The first concern is the impact of physical disturbance on animal habitats. Infrastructure installations, such as

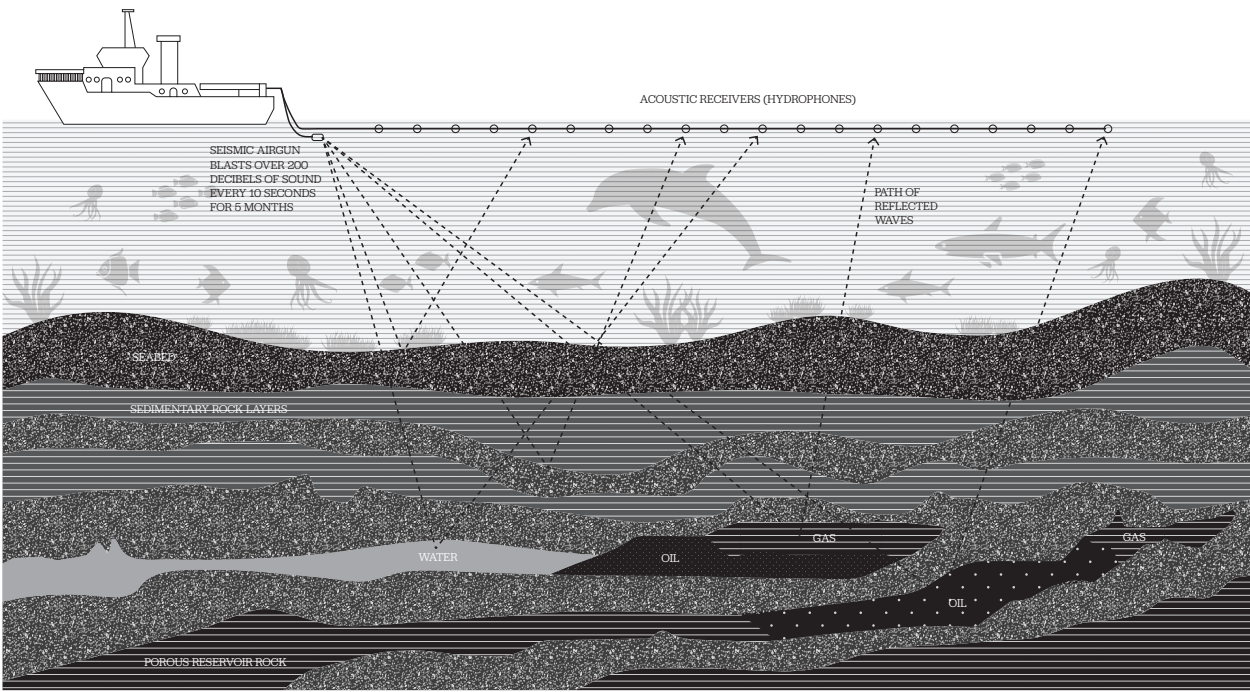


Fig. 11
Environmentalists warn that the high-noise blasting of sonar cannons underwater for seismic testing is a threat to whales, dolphins, fish and other marine life. (Redrawn from Sgqolana)

anchors and pipelines, disturb the seabed and directly affect coral clusters by increasing localized sedimentation. When anchored, they are dragged along the seabed and can cause harm to benthos. Pipeline installation can affect local seabed conditions by adding substrate, potentially creating new habitats for indicator species, or attracting motile organisms.³⁷

The second type of impact is chemical, through corrosion and leakage. Pipeline installations pose a risk of corrosion and leakage, which can expose deep-sea fauna to harmful chemicals and cause significant damage to the marine ecosystem. It is important to note that the impact of these risks is not limited to the immediate area of the installation, but can have far-reaching consequences. The occurrence of such leaks can have a devastating impact on the environment.³⁸

DRILLING PROCESS

During the drilling process, various wastes are generated, such as drill cuttings, excess cement, drilling mud, produced water, and other chemicals. Therefore, it is important to handle them properly. Drill cuttings are pieces of rock that can have ecological impacts if introduced into the seabed, disrupting local ecosystems and habitats. The composition of drill cuttings can vary depending on the geological formations being drilled.³⁹

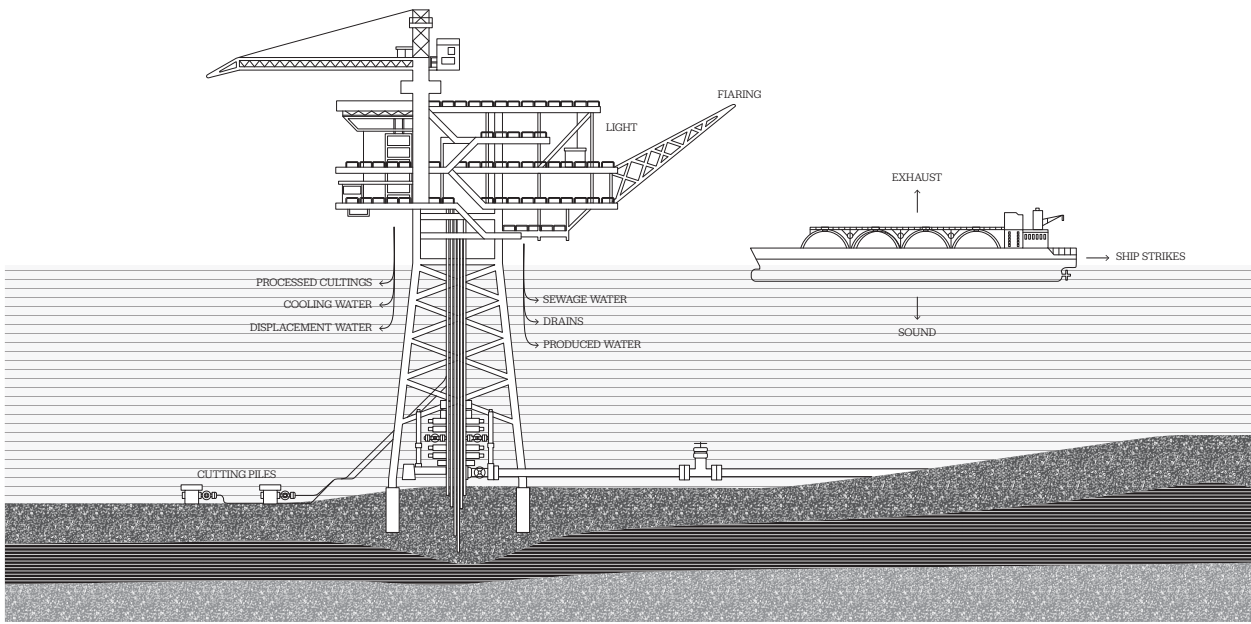


Fig. 12.
Diagram of impacts from
typical deep-sea drilling
(Redrawn from Jocelyn Erik
E. Cordes et al.,)

Drilling fluids, also known as drilling muds, are used to lubricate the drill bit, cool the drilling equipment, and carry drill cuttings to the surface. The chemical composition of drilling muds has evolved over time, with modern formulations being less toxic than older oil-based muds. However, even modern drilling muds can have biological effects. The discharge of chemicals and additives into the marine environment can introduce chemicals and additives that may be harmful to marine life.⁴⁰

Oil and gas extraction activities produce significant pollution through the discharge of produced water. This water is primarily formation water extracted during oil and gas recovery but it also contains various contaminants, including dissolved inorganic salts, hydrocarbons, minerals, trace metals, naturally occurring radioactive materials, production chemicals, and dissolved gases. Proper treatment and disposal of produced water is essential to prevent environmental harm.⁴¹

Operations on offshore platforms can impact the behaviour of marine organisms, including plankton, due to artificial lighting. Plankton often migrate in response to light, and artificial lighting can alter their natural migration patterns. This redistribution of plankton can have cascading effects on the marine ecosystem, potentially altering its structure and diversity.⁴²

DECOMMISSIONING PROCESS

The decommissioning process, like the installation process, can have a negative impact on the surrounding marine ecosystem due to the noise and vibration generated during the operation. These impacts are particularly sensitive to marine life and can result in alternations to the marine environment. Platforms typically remain in place for decades, providing new habitats for marine life. However, if the habitat is destroyed further and lost due to the decommissioning of the structure, the various species will face significant challenges in migrating and adapting to the new environment.⁴³

These environmental changes can disrupt the ecological balance and affect the daily behaviour and reproduction of marine organisms, leading to a decline in ecological function. In addition, after decommissioning, it takes long time and effort for new marine ecosystems to form. Decommissioning can cause habitat loss, which may temporarily reduce the diversity and stability of marine ecosystems. Although ecosystem recovery will occur through natural processes, it is important to take action to accelerate and support it.

Furthermore, proper wasted management is necessary after decommissioning. Operators face technical challenges when safely removing large structures weighing anywhere between 10,000 and over 150,000 tonnes from deep water and transporting them to shore for reuse and recycling. Although the industry has gained significant technical expertise in commissioning large structures, even in hostile deep water environments such as the North Sea, decommissioning these structures remains a relatively unexplored area.⁴⁴

DECOMMISSIONING ISSUE

Offshore oil and gas infrastructure is facing an existential threat due to the urgent need to address the climate emergency. According to the International Panel on Climate Change (IPCC), GHG emissions from existing and planned fossil fuel infrastructure will cause global warming to exceed the Paris Agreement's 1.5°C threshold. The IPCC also suggests that to stay within a 1.5°C carbon budget, nearly 60% of oil and fossil methane gas must remain unextracted.⁴⁵ There is a rising public concern regarding the reduction of greenhouse gas emissions, which is accompanied by a global drive for electrification and decreasing renewable energy costs. This may result in a substantial decrease in oil and gas demand, leading to the closure of offshore facilities on a large scale.

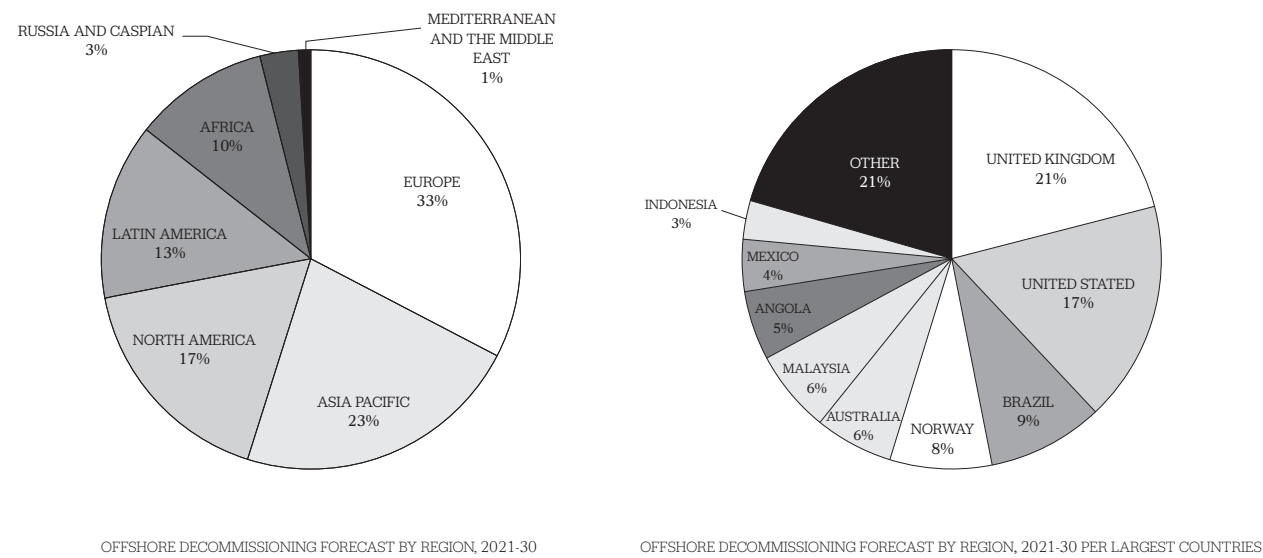


Fig. 13
IHS Markit forecasts global offshore decommissioning spending to reach almost USD100 billion for the 2021-30 period, up by over 200% compared to the previous ten-year period.

Fig. 14
IHS Markit's proprietary database Petrodata™ Fields-Base, nearly 2,800 fixed platforms and 160 floating platforms could be decommissioned during the 2021-30 period. That represents 33% of fixed platforms and 43% of floating platforms currently in operation.

Worldwide, many offshore Oil & Gas structures are scheduled for decommissioning in the coming years as fossil fuel exploration and production comes to an end. Over 600 platforms require decommissioning, with many structures reaching the end of their productive life or doing so within the next decade. Additionally, numerous oil and gas fields are nearing the end of production due to age and resource depletion. The global economy is transitioning towards a low-carbon economy and energy, further contributing to this trend. Over the next decade, numerous oil and gas platforms and their associated infrastructure will become obsolete and remain inactive. According to IHS Markit, global offshore decommissioning spending is expected to reach almost \$100bn between 2021 and 2030, which is more than a 200% increase from the previous decade.⁴⁶

The removal of depleted offshore rigs is highly regulated by international, regional, and national laws. These include the UN Convention on the Law of the Sea, guidelines from international maritime organisations, and the Oslo and Paris Conventions for the Protection of the North East Atlantic. International law permits the complete or partial removal of structures built

before 1998. For structures installed after 1998, complete removal must be possible due to design requirements. Therefore, when governments enter into offshore oil leases with rig operators, they must ensure that the infrastructure is safely removed from the sea when the oil is depleted. Depending on the country and type of installation, this may involve partial or complete removal. In California, operators are legally obligated to restore the seabed to its original state by removing the entire structure.⁴⁷

However, decommissioning an oil or gas facility is a complex and costly process. The average cost of removing an entire platform in shallow waters like the Gulf of Mexico is estimated to be between \$15 million and \$20 million. In deeper waters, such as the North Sea, the cost can range from £30 million for a small platform to £200 million for a large structure, according to the UK Oil and Gas Trade Association. According to a 2008 economic report by Oil and Gas UK, the cost of decommissioning oil rigs currently offshore the UK North Sea could reach £16bn by 2030 and £19bn by 2040. Decommissioning represents a significant financial burden for the UK government, as operators of fields leased before 1993 can claim a rebate of up to 75% of decommissioning costs from past oil revenue tax payments.⁴⁸

As the world transitions towards green energy, debates continue over the future of offshore drilling and the fate of unused offshore rigs. Some argue for the complete removal of these structures due to environmental concerns and visual pollution, while others highlight their ecological potential. Environmental groups are advocating for the removal of rigs to restore a cleaner ocean environment. The responsibility of managing the end of their product's life cycle is emphasized for fossil fuel companies.

HISTORICAL PROTESTS AND INTERNATIONAL RESPONSE

On 30th April 1995, Greenpeace activists boarded the *Brent Spar* to protest against Shell's plan to dispose of it in deep-sea trenches, which had been approved by the UK government. This resulted in a confrontation in the North Sea between Shell, who advocated for cost-effective undersea disposal, and *Greenpeace*, who were driven by concerns about environmental pollution. In the end, Shell abandoned the plan due to the protest.⁴⁹

The protests resulted in international efforts to prohibit the disposal of offshore installations in the North Sea. Consequently, an international conference issued the Esbjerg Declaration on June 7, 1995, calling for a global ban on offshore platform disposal. In response, the Oslo and Paris Conventions for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) suspended all platform disposal and prohibited it at sea until formal disposal rules were established. However, Norway and the UK were granted exceptions, allowing steel bases weighing more than 10,000 tonnes to be dumped under certain conditions.⁵⁰

In July 1998, OSPAR members debated the conditions for deep-sea disposal and enacted legislation banning the dumping and demolition of all steel platforms. The *Brent Spar* incident significantly influenced OSPAR's policy development, even though it did not pertain to reef creation. Shell and the UK government argued that the disposal of Brent Spar was a deep-water disposal with no environmental benefits. However, Greenpeace's protest and the international response influenced OSPAR's evolving policies.⁵¹



Fig. 15
Greenpeace activists from the Netherlands, Germany and Denmark boarded two oil platforms in Shell's Brent field in a peaceful protest against plans by the company to leave parts of old oil structures with 11,000 tons of oil in the North Sea. Climbers, supported by the Greenpeace ship Rainbow Warrior, scaled Brent Alpha and Bravo and hung banners saying, 'Shell, clean up your mess!' and 'Stop Ocean Pollution'. (credit by © Marten van Dijk / Greenpeace)

DECOMMISSIONING CHALLENGES AND OPPORTUNITIES

In 2009, there were 1,212 offshore installations in the North Sea area. By 2012, 129 facilities had been decommissioned, with *Norwegian and UK waters* hosting 354 and 612 operational structures, respectively. It is estimated that over 220 production sites and associated structures will be decommissioned in *UK waters* by 2025. This makes the next decade crucial for offshore structure removal.⁵²

Research suggests that the *RIGS TO REEFS* concept could provide advantages for fish conservation in the North Sea. A recent comprehensive review of scientific literature on rigs and reefs concluded that these structures can have a positive impact on deep-sea benthic communities. The surge in decommissioning presents an opportunity to create large-scale deep-sea artificial reef complexes that can benefit marine life.⁵³

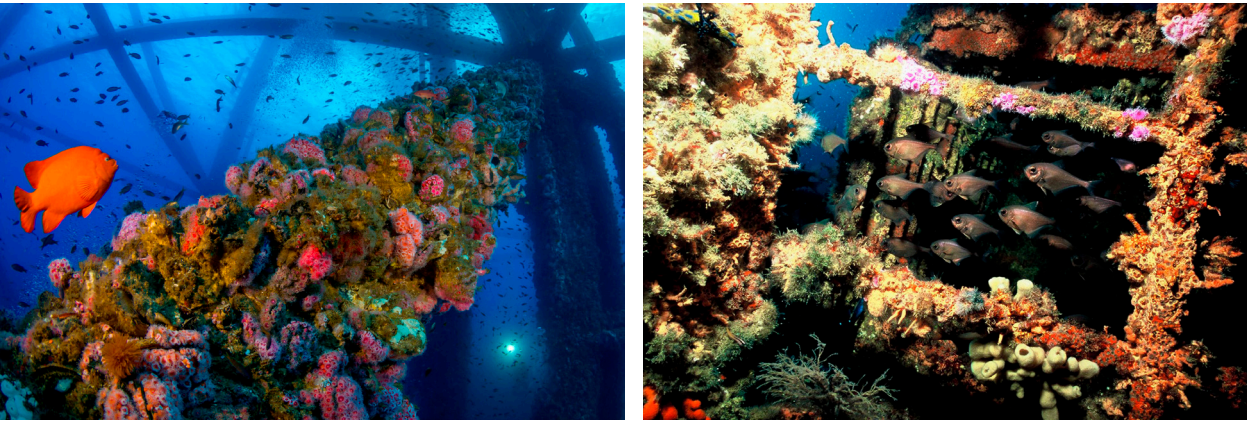
Studies conducted in the North Sea have shown that artificial reef complexes on offshore structures can serve as safe havens for fish. Certain species, like cod, exhibit fidelity to offshore platforms, offering protection to fish populations. Additionally, offshore platforms provide important nocturnal dolphin feeding sites that safeguard fish populations, and some even host threatened cold-water coral communities.⁵⁴

The decommissioning of offshore oil and gas platforms is a complex challenge that involves significant costs, technical difficulties, and environmental impacts. Conventional approaches to deconstruction of these platforms often involve restoring ecosystems to a state that existed before human intervention, which removes the unique artificial ecosystems that have developed over decades of coexistence with the marine environment. To address this issue, scientists and environmental advocates have proposed a sustainable solution: reusing aging offshore platforms as artificial reefs.

The main aim of constructing artificial reefs is to improve the environment and increase the biological productivity and diversity of marine ecosystems. This practice has been implemented globally to strengthen biological communities and increase fish abundance, diversity, and community composition among adjacent habitats. These materials create a suitable foundation for marine organisms, such as corals, algae, and invertebrates, to attach and grow on the rough surface of the structure. Artificial reefs are designed with a variety of shapes, crevices, and holes that mimic natural reef formations, providing complex structures that offer refuge and hiding places for marine life. This contributes to increased biodiversity.⁵⁵

Fig. 16, 17

California has a law that allows rigs to be converted into reefs, but it faced resistance and few companies have taken advantage of it



REUSING OFFSHORE PLATFORMS AS ARTIFICIAL REEFS

Offshore platforms, which are primarily constructed from steel, possess unique qualities that make them ideal candidates for repurposing into artificial reefs. The structural intricacies of these platforms, particularly the jacketed structures, offer a framework for the formation of thriving artificial reefs. Scientists and environmentalists have developed a strategy to harness the ecological potential of these structures while preserving the unique artificial ecosystems they host.⁵⁶ The strategy involves strategic analysis of the potential for ecosystem development on the structures.

ECOSYSTEM DEVELOPMENT ON ARTIFICIAL REEFS

These platforms offer a stable base for stationary organisms such as sponges and corals to settle on. Algae and coral larvae can easily find appropriate sites to attach to the platforms, eventually becoming primary producers within the ecosystem. As these organisms develop and thrive, they attract a diverse range of marine life and establish the basis for intricate marine food webs. In addition, offshore platforms have an intricate structural design that attracts various marine plants, serving as both shelter and food sources for a wide range of species, including seals, whales, and numerous fish species.⁵⁷

One of the most noteworthy aspects of artificial reefs is their rapid transformation into complex habitats that resemble natural reefs, typically occurring within five to six years after installation. The expedited development significantly contributes to increased biodiversity by providing shelter and resources for a variety of species that may otherwise lack suitable habitats.⁵⁸ This, in turn, provides valuable insights into ecological processes and species interactions, thereby deepening our understanding of marine ecosystems.

ENHANCED PRODUCTIVITY AS ARTIFICIAL REEFS

Research findings indicate that repurposed offshore platforms as artificial reefs are highly productive. Biomass, which measures the number of fish and other organisms per unit of space and their spatial distribution, provides strong evidence of their ecological significance. Studies have shown that these repurposed platforms are about 27 times more productive than natural rocky reefs found off the coast of California.⁵⁹ The preservation of aging offshore platforms as artificial reefs has significant environmental benefits. It contributes to enhanced marine biodiversity and the resilience of marine ecosystems.

RIGS TO REEFS

The Rigs to Reefs project was launched in response to these findings. Its objective is to convert aging offshore platforms into artificial reefs instead of disposing of them entirely. This process may involve demolishing or partially removing existing structures or relocating them to designated reef planning areas to provide habitat for marine life. Typically, only the support structure, known as a jacket, is retained and used in reef construction. When assessing the suitability of a platform as a reef, important factors to consider include its size, complexity, structural integrity, and location. A platform that is complex, stable, durable, and clean is typically crucial. Platforms that have collapsed due to structural failure are not suitable candidates for reef conversion.⁶⁰

The Rigs to Reefs project has been successful, particularly in areas such as the Gulf of Mexico. In the 1980s, platforms that were no longer in production in Louisiana were transported to Florida to be repurposed as artificial reefs. As of December 2012, around 573 offshore platforms had been transformed into artificial reefs in the Gulf of Mexico, with Louisiana and Texas accounting for most of these conversions.⁶¹

ECOLOGICAL BENEFITS AND ENHANCED FISHING ZONES

The repurposing of offshore platforms into artificial reefs offers a range of ecological advantages. For example, a standard eight-legged structure can provide habitat for 12,000 to 14,000 fish, while a typical four-legged structure offers habitable space of between two and three acres for hundreds of marine species. This transformation creates an ‘enhanced fishing zone’ extending from 200 to 300 meters for pelagic species and from 1 to 100 meters for benthic species. In areas where fishing and diving around offshore rigs are permitted, these structures have become a significant attraction for local tourism. In Louisiana, recreational fishing mainly revolves around offshore platforms, which account for over 70% of trips to the Exclusive Economic Zone for this purpose.⁶²

CHALLENGES AND CONSIDERATIONS

The conversion of both active and decommissioned offshore platforms into artificial reefs brings ecological benefits, but it also presents challenges. One of common criticism is the impact on commercial trawling, and the issue of allowing fishing around these platforms remains uncertain and requires careful management. It is important to note that any exclusion of

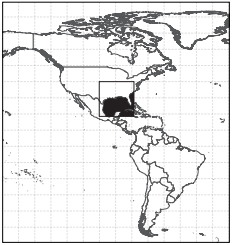
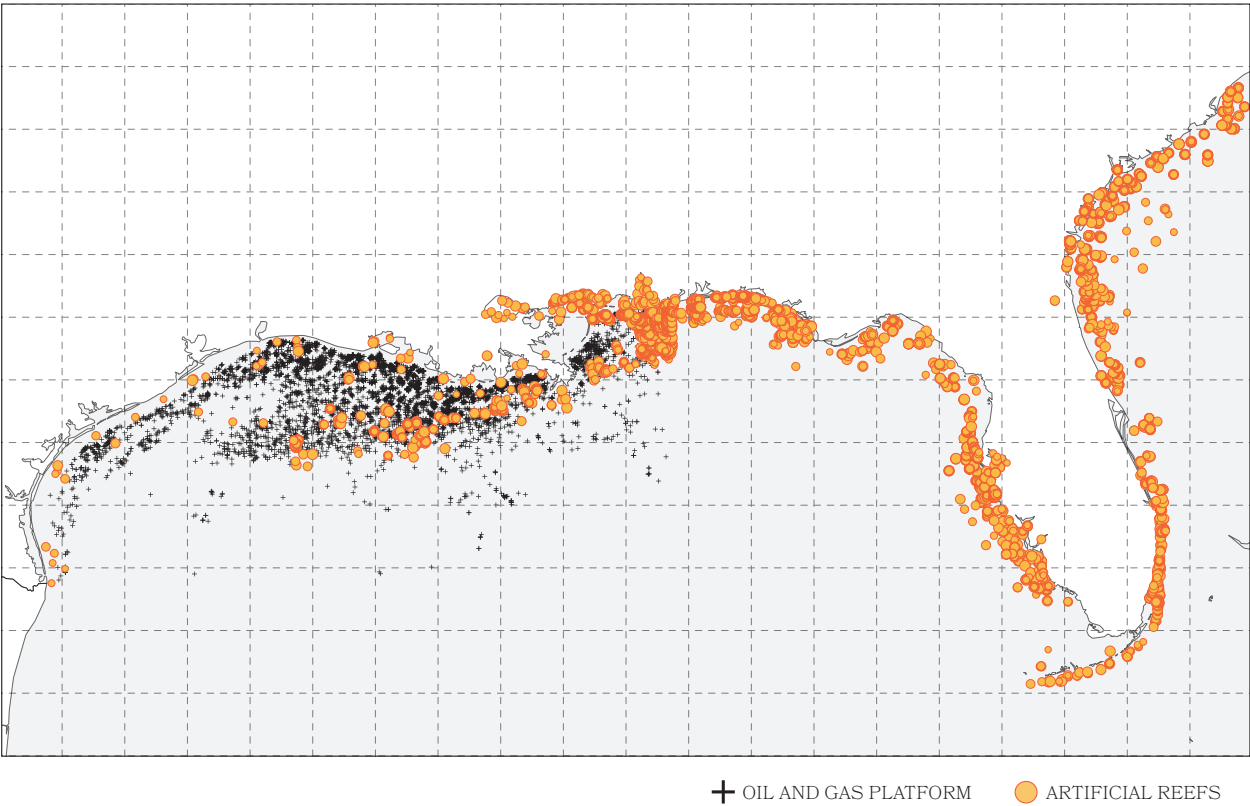


Fig. 18
Gulf of Mexico offshore plat-
forms and artificial maps
(redrawn from qgis data)

fishing should be implemented only after careful consideration of the ecological and economic impacts. In certain instances, platforms have become vital breeding grounds for endangered or economically significant species, which justifies the prohibition of all fishing activities in the area. Although this exclusion may have negative impacts on commercial fishing, it is ecologically beneficial as it preserves the habitat.⁶³

There are debates as to whether the fish produced around offshore platforms are attracted from surrounding natural reefs or directly generated by these structures. In certain areas, fishing is not allowed around platforms due to safety concerns, which can work effectively as marine protected areas. These platforms offer shelter for fish, especially those with limited habitat options, resulting in an increased in population abundance. Artificial reefs can be used as a tool for ecological compensation to counteract biodiversity loss or habitat degradation caused by human activities.

Offshore oil and gas structures are intricate parts of a larger ecological system in the marine environment. It is crucial to comprehend their role in this system and their potential biological impacts for sustainable environmental management. Although there are many hypotheses about the ecological impacts of these structures, scientific knowledge remains limited, with only a few field studies conducted on a small number of platforms. Considering the global distribution of such infrastructure and its overlap with marine biodiversity, it is crucial to not underestimate its long-term impacts.

LARVAL DISPERSAL AND CONNECTIVITY

Most marine species undergo a dispersing larval stage. Offshore infrastructure can have a multifaceted impact on larval dispersal, affecting the spatial scale and intensity of dispersal and connectivity. The impact of these structures may vary among species due to biological characteristics, metamorphosis periods, settlement behaviours, and interactions with physical dispersal processes. Offshore infrastructure has the potential to emit reef-like sounds and anthropogenic stimuli, such as light, sound, and vibrations, if colonized and occupied by various marine organisms. These stimuli can attract larvae, influencing their settlement patterns. The impact on larval dispersal and settlement can differ based on the location of the platforms. In offshore waters lacking natural reef features, oil and gas platforms can significantly impact larval dispersal and settlement compared to those in naturally connected environments. This suggests that platforms can affect larval recruitment and settlement in various ways, ultimately impacting geographic and population connectivity. If larvae settle on the platform, they can become source populations, further impacting local biodiversity.⁶⁴

EXAMPLES OF SPECIES RANGE EXPANSION

The ecological impact of offshore oil and gas infrastructure extends to the expansion of species ranges, including the spread of non-native species. For example, in the North Sea, the larvae of *Lophelia pertusa*, a species of cold-water coral species protected by the inter-annual North Atlantic Oscillation, disperse up to approximately 300 kilometres from these structures.⁶⁵

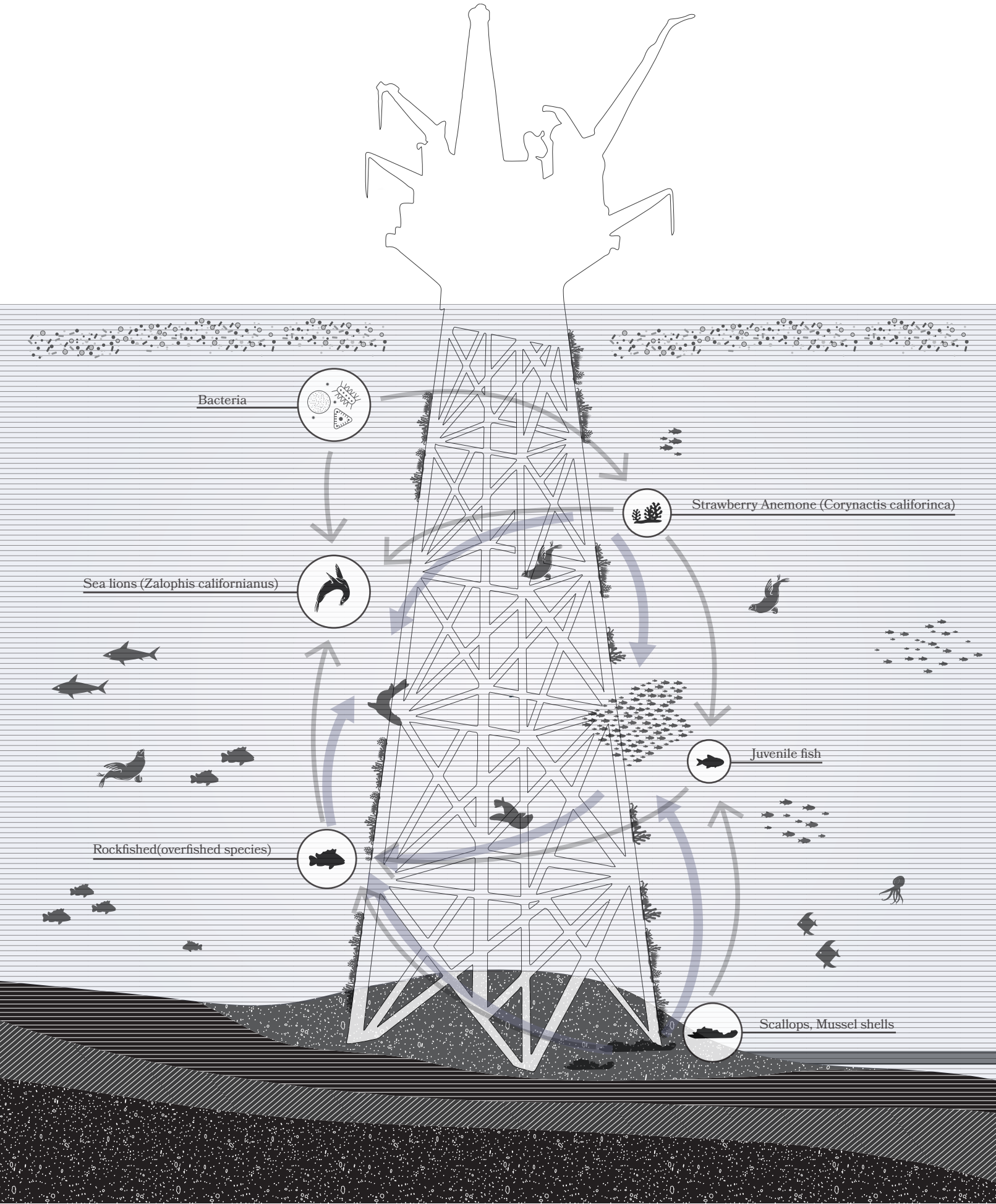


Fig. 19
The Blue Latitudes Foundation, using data from NOAA and Global Fishing Watch, is analyzing how commercial and recreational fishermen in California use the fisheries near the state's 27 offshore oil and gas platforms, to understand the potential impact of platform decommissioning (redrawn from National Geographic)

Similarly, in the Adriatic Sea, offshore platforms can also improve the connectivity of moon jellyfish (*Aurelia* spp.) populations, supporting sustaining sub-populations on land. However, they can also lead to jellyfish proliferation in certain areas. Thus, offshore oil and gas infrastructure has the potential to reshape the distribution and abundance of marine species.⁶⁶

CURRENTS AND HABITAT CONNECTIVITY

Currents are crucial in facilitating the movement of marine organisms over long distances and connecting subsea infrastructure downstream. For instance, circulation patterns in the Gulf of Mexico suggest that larval dispersal can occur throughout the basin over varying time scales. However, it is important to note that genetic affinities may affect larval dispersal, creating geographical barriers between different platforms, affecting larval dispersal.⁶⁷

Connectivity in the ocean is determined by the density of linkages, the influence of nodes on linkages, and the directionality of linkages. Offshore oil and gas structures are man-made nodes in the ocean that are connected by pipelines, umbilical cables, currents, and mobile marine organisms that inhabit, invade, or visit these structures. The design and placement of offshore infrastructure can also facilitate the vertical and horizontal movement of migratory species. Platforms often create clusters of ‘hard habitat’ patches within seascapes dominated by soft sediments. These structures can alter currents, influencing the directional movement of organisms. Fur-

Fig. 20
How oil and gas offshore structures could provide connections (weight of line indicative of strength of connection) between natural environments or between other structures and the natural environment, potentially enhancing the connectivity (or connectedness) of a system by adding nodes (redrawn from Mclean, 2022)

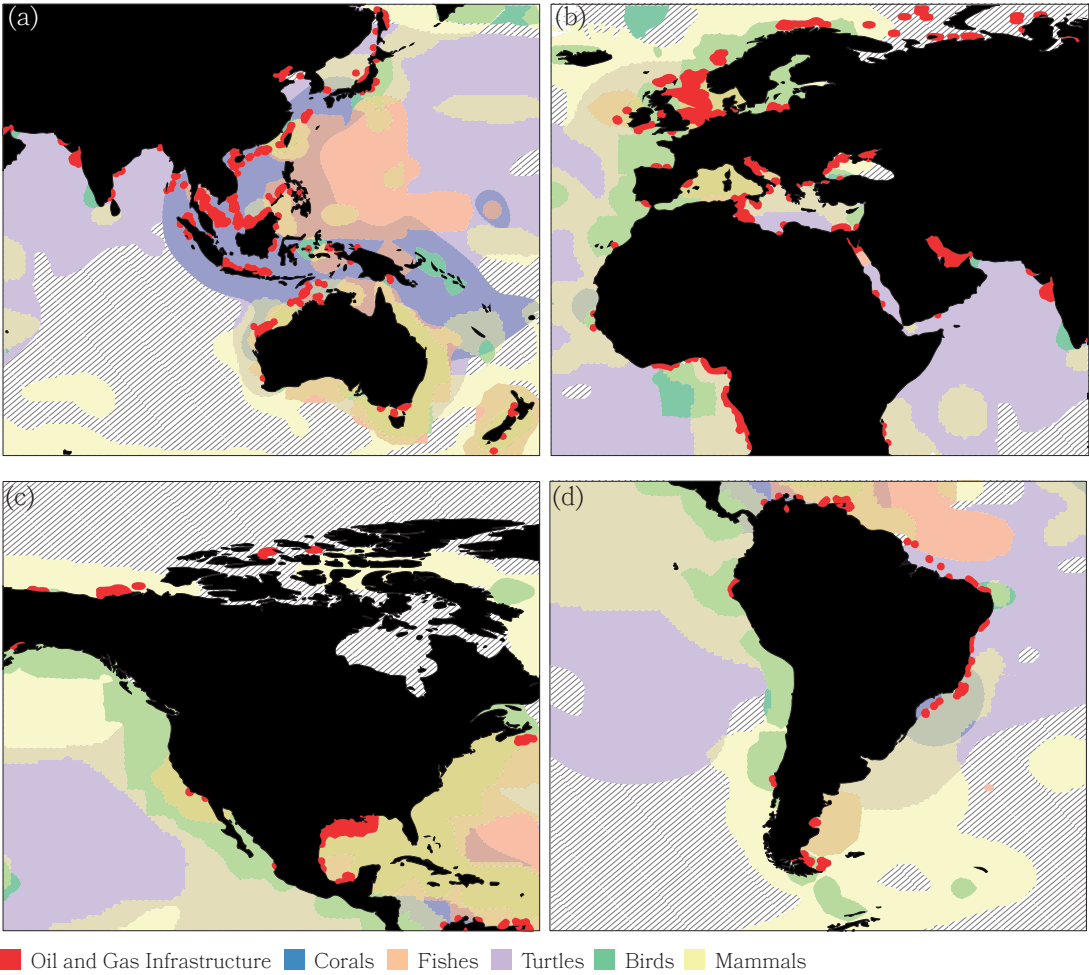
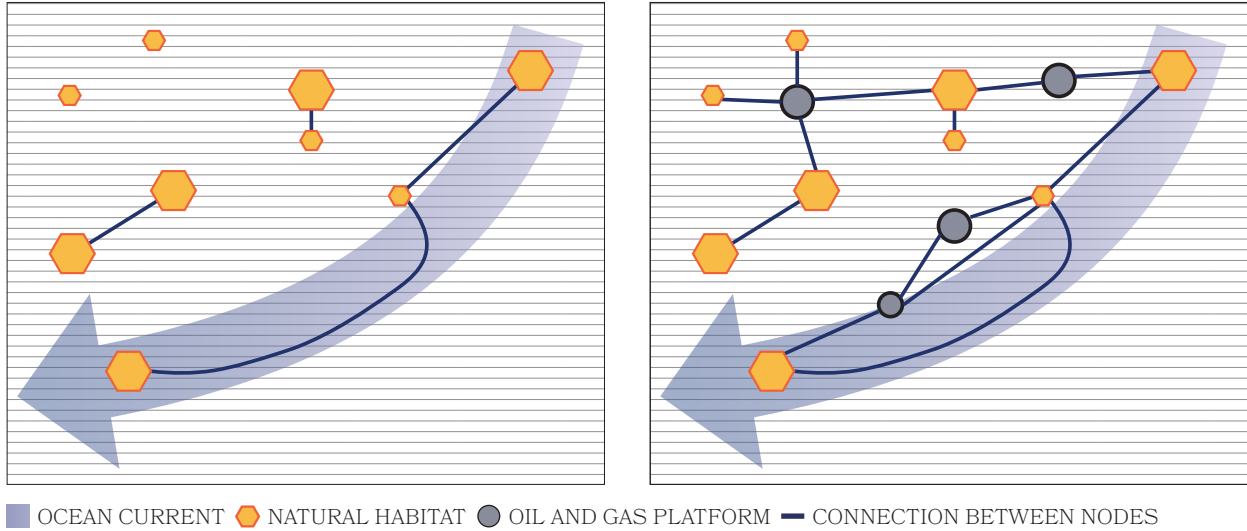


Fig. 21
Extent of offshore O&G infrastructure and hotspots of marine biodiversity. (a) Indo-Pacific region, (b) Europe/Mediterranean, eastern Atlantic Ocean and northern Indian Ocean, (c) Northern America and Gulf of Mexico, (d) South America, (redrawn from Mclean, 2022)

thermore, pipelines at different depths can provide continuous habitat over extended distances, promoting habitat connectivity and facilitating the expansion of species across various geographic and depth ranges.⁶⁸

Human-made structures have become integral components of ecological systems within the marine environment. It is important to understand their potential ecological impacts for sustainable environmental management.

NOVEL ECOSYSTEM

The conventional perspective suggests that nature and human-made structures in nature are incompatible entities. However, the relentless transformation of ecosystems by human activities worldwide challenges this notion. Although extensive research and conservation efforts aim to restore ecosystems altered by historical practices, post-industrial development has created environments so profoundly impacted by human activity that the conventional concept of a ‘natural ecosystem’ loses its meaning. The concept of Novel Ecosystems provides management alternatives for environments where ecological restoration is impractical or could reduce ecosystem value. In some cases, these novel ecosystems may even provide more advantageous ecosystem services than their historical counterparts. This change in perspective is essential for making informed decisions, aligning social, ecological, and economic goals, and recognising the potential opportunities at the intersection of human activities and the marine environment.⁶⁹

The Divide Between Human-Made and Natural

Many people experience the sea mainly from coastal areas, where they enjoy in leisure activities such as swimming, surfing, and sunbathing, while appreciating the nature beauty of the ocean. However, this perception of the sea as an undisturbed wilderness is often interrupted by the sight of offshore installations or other industrial reminders. Regulatory and maritime spatial-planning frameworks often separate nature, leisure, and industrial activities, reinforcing the idea of untouched nature versus human-made. It is important to acknowledge that human activities have a significant impact on the marine environment.

ANTROPOGENIC IMPACT ON MARINE ECOSYSTEMS

However, this perspective overlooks a critical reality: today’s marine ecosystems are largely anthropogenic. Areas that are referred to as ‘sandy habitats’ were previously covered with ‘hard substrates’ such as oyster and sabellaria reefs, cold-water coral reefs, and moorlog [Fig.22]. These ecosystems have been significantly drastically altered by human activities, including intensive oyster fishing and bottom trawling. Oyster reefs, which once covered 32 %

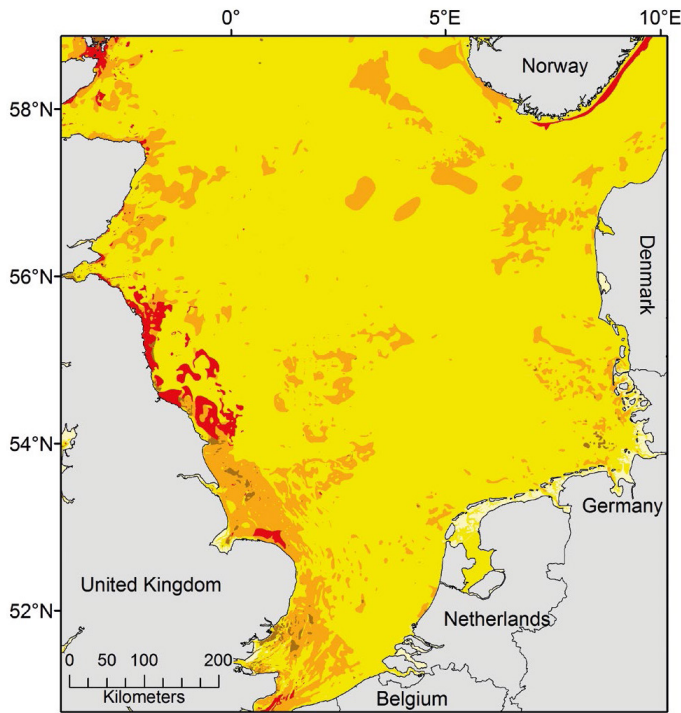


Fig. 22
Benthic habitats are sand and mud (yellow), mixed (brown), coarse sediment including gravel (orange), and rocky reef (red).

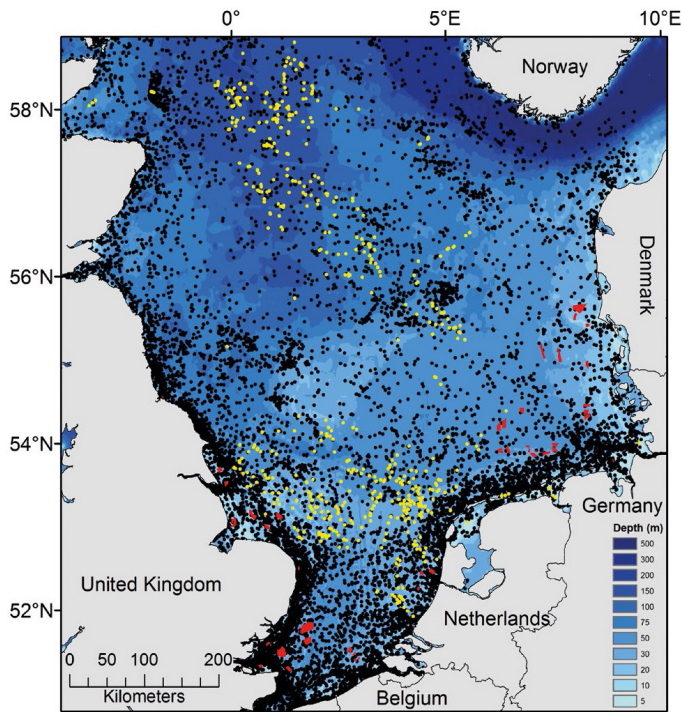


Fig. 23
Locations of O&G platforms (yellow dots), wind turbines (red areas), and shipwrecks (black dots) in the North Sea in 2015.

of the Dutch North Sea bottom in 1883, have been reduced to just 1.%, replaced by vast expanses of sand, gravel, or mud.⁷⁰ In addition, the seabed is now dominated by human-made structures such as oil and gas installations, wind turbines, pipelines, cables, and shipwrecks, which are now referred to as ‘reefs’. These structures have altered the seabed and provided alternative habitats for marine life. However, current conservation frameworks often perceive them as disturbing elements. The focus is solely on preserving the ‘original nature’.

Novel ecosystems

Human activities have significantly transformed ecosystems on a globally, challenging the notion that nature is separate from artificial or mechanical entities. While extensive research and conservation efforts focus on restoring ‘natural ecosystems’ to their historical states, a new perspective has emerged with the concept of Novel Ecosystems. Altered ecosystems, resulting from human activity, may not be able to return to their original state. However, they do offer ecosystem new diversity, which is a benefit of altered ecosystems. Novel Ecosystems offer an alternative management approach that acknowledges the potential advantages of altered ecosystems over their historical counterparts. This perspective is useful for decision-making, as it aligns social, ecological, and economic objectives and explores opportunities at the intersection of human activities and the marine environment.⁷¹

Offshore platforms, these structures transform the marine environment, and create unique ecosystems. Although they were initially considered disturbances, offshore platforms have evolved into habitats for diverse marine life, forming ecosystems with distinct characteristics.

Novel ecosystems should be evaluated for their ecological value should be evaluated on a case-by-case basis, especially during the decommissioning process. This approach does not replace conservation efforts but provides a practical framework for ecosystems where traditional restoration is not feasible or less advantageous. Recognising the ecological role of offshore platforms in this way opens up possibilities for rethinking conservation strategies and acknowledging the ecological value created through human activities. The concept of Novel Ecosystems facilitates a more nuanced understanding of the interplay between human-made structures and nature. It emphasises the need to appreciate and manage these ecosystems in their altered state for their unique contributions to biodiversity and ecological services.

In conclusion, it is important to acknowledge the significant changes that have occurred in nature over time before attempting to restore it to a pristine and wild state. Human activities, along with environmental factors such as climate change and changes in food availability, have left lasting impacts on the natural world. The desire for an untouched wilderness may be a longing for a reality that no longer exists. Therefore, it is essential to use clear and objective language when discussing complex issues.

Natural ecosystems have demonstrated remarkable adaptability to changing conditions, often creating new habitats in response. This adaptability emphasises the significance of recognising the environmental damage and habitat destruction caused by human activities and finding ways to coexist more harmoniously with nature.

It is important to reconsider the idea of dismantling artificial ecosystems simply because it does not align with our preconceived ideas of what is 'natural'. We may have been limited by a binary view of nature versus human-made or artificial entities. Recognising the ecological value of human-made structures and the emergence of novel ecosystems presents an opportunity to reassess our approach to the marine environment.

By embracing the potential benefits and ecological opportunities that arise at the intersection of human actions and the preservation of marine biodiversity, we can strive for a more informed and balanced coexistence. This shift in perspective holds the promise of fostering ecosystems and safeguarding endangered species while minimizing negative impacts. Ultimately, this change in perspective presents new opportunities for our developing relationship with the ocean and the preservation of its valuable biodiversity.

OFFSHORE CLUSTERS

SUSTAINABLE DEVELOPMENT

ENERGY CLUSTER

ECOSYSTEM CLUSTER

ENVIRONMENTAL RESEARCH CLUSTER

OFFSHORE CLUSTERS

The concept of *Novel Ecosystem* provides insight into the relationship between human-made structures and natural ecosystems. The maritime industry is increasingly focused on sustainable development through the reuse of existing production facilities. The reuse of industrial structures is a significant contribution to environmental conservation, as it preserves their historical and cultural value while maintaining social connectedness. This practice demonstrates how sustainable development and environmental conservation can coexist harmoniously.

The pursuit of sustainable development has led to new perspectives on resource efficiency and minimal environmental impact. One of the strategies is to reuse existing production facilities instead of demolishing them. This reflects the broader social changes towards environmental conservation and cost-effectiveness. Recycling structures that symbolise industrialisation era and economic revival is an important step towards integrating environmental conservation and sustainability into maritime activities.

The transformation of production organisations can facilitate sustainable development on several fronts. By reusing existing structures, costs can be reduced by decreasing raw material consumption and increasing efficiency. Recycling structures can alleviate waste disposal burdens and minimise environmental pollution, resulting in a positive impact on both the environment and the economy. This approach described here aligns with the values of sustainable development, echoing the principles of *Novel Ecosystems*, which recognise the potential ecological impact of modified environments.

However, it is important to note that not all infrastructure is suitable for recycling. The decision to partially use, or demolish and restore offshore platforms should be made judiciously, considering a multitude of factors specific to the regional, and environmental context. This approach aims to explore the various possibilities that offshore platforms offer, rather than advocating for a unique solution. It acknowledges the distinctive conditions and limitations of each structure and aims to identify the most sustainable and advantageous outcome for both the environment and society.

Fig. 24
The Port of Los Angeles from a satellite. Container ships waiting to be unloaded.



OFFSHORE HUB

Reusing offshore infrastructure into energy hubs is a forward-thinking approach to renewable energy production. It addresses the critical need for sustainable development and climate change mitigation. These hubs serve as physical nodes, incorporating three distinct yet interconnected clusters: Energy, Ecosystem, and Environment. Each cluster plays a vital role in harnessing and managing renewable energy sources. The use of renewable sources and advanced technologies can improve the sustainability and resilience of our energy future. This multifaceted approach to energy production, ecological conservation, and technological innovation can contribute significantly to a more sustainable and resilient energy future.

ENERGY CLUSTER: SUSTAINABLE ENERGY INFRASTRUCTURE

Energy cluster focuses on the direct production and management of renewable energy. It includes repurposing offshore oil and gas platforms in strategic locations to use the natural energy of the ocean, such as wind, solar, and wave energy. The Energy Cluster facilitates the integration of renewable energy sources, such as offshore wind farms, solar parks, and wave turbines, into a cohesive system that feeds the larger energy grid. This maximises the use of renewable energy sources and plays a critical role in reducing reliance on fossil fuels, decreasing greenhouse gas emissions, and ensuring a stable supply of clean energy.

RENEWABLE ENERGY FROM THE OCEAN

Offshore wind farms are clusters of wind turbines placed in the ocean to take advantage of stronger, and more consistent winds available at sea. Floating solar panels are mounted on buoyant structures in bodies of water and can generate electricity more efficiently than onshore turbines, making a significant contribution to the renewable energy mix. The untapped water surface is used for energy generation, and the cooling effect of the water improves efficiency.⁷²

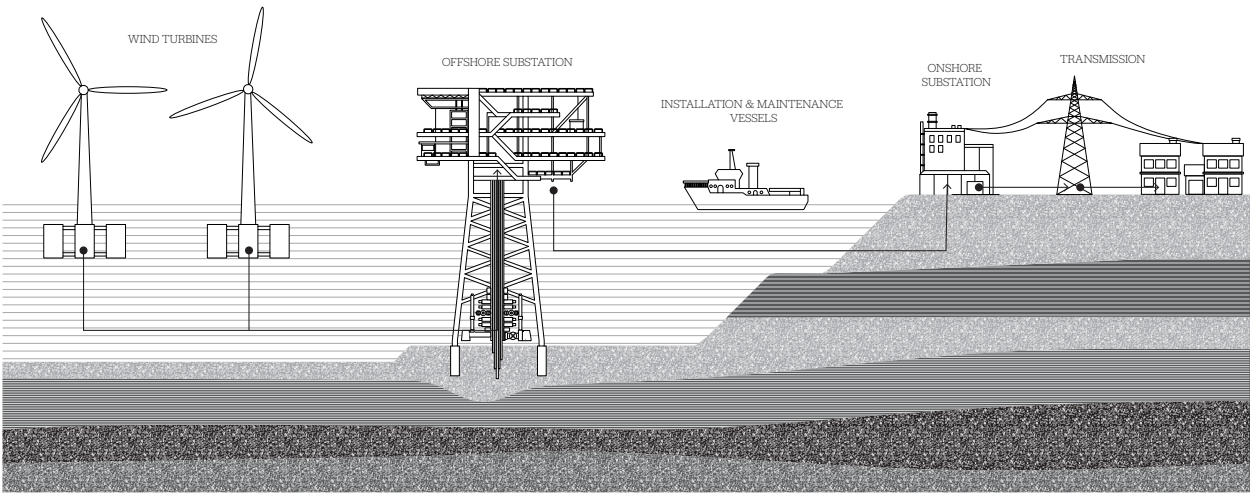


Fig. 25
Environmentalists warn that the high-noise blasting of sonar cannons underwater for seismic testing is a threat to whales, dolphins, fish and other marine life.

Efforts are being made to use the ocean’s renewable resources for sustainable energy production. These resources include wave power generation, floating solar panels, and geothermal energy production. Although offshore wind power is currently the most developed and has high production and large scale, other renewable energy sources can be considered depending on geographical and environmental characteristics. For instance, in the Adriatic Sea, where wind energy availability is limited, offshore solar water parks are the most suitable. Conversely, in the North Sea, where solar irradiation is low, wind-generated energy scenarios are the most economically feasible.⁷³

GREEN HYDROGEN(RELife Project)

The RELife project is an innovative approach to sustainable energy solutions that repurposes offshore oil and gas platforms for green hydrogen production. This project utilises existing structures and the process of electrolysis to harness the vast potential of sea-based renewable energy sources. This method utilizes electricity generated from renewable sources such as wind, solar, or tidal energy to split water into hydrogen and oxygen, producing hydrogen as a clean fuel.

This project aims to create a sustainable future by reducing dependence on fossil fuels and minimizing environmental impact. The production and supply of green hydrogen through this method can be used in various energy sectors, such as powering vehicles and medical fields.⁷⁴ The project aims to foster a more environmentally friendly and efficient energy landscape by focusing on sustainable production and supply of green hydrogen.

SUBSTATION

Moreover, offshore platforms can function as power substations to collect and distribute electricity from renewable sources onshore or to maintain other energy production on the platform. Utilising its proximity to existing power grids and transmission lines can significantly reduce the environmental and financial costs associated with bringing renewable energy onshore.⁷⁵

These applications are all energy-related and can contribute to better coupling and energy system integration offshore, as envisioned in a series of projects. To address their energy-intensive nature, it is recommended to use local offshore renewable energy resources, such as solar, wave, and wind energy. The proposed hybrid system aims to provide a reliable and sustainable energy supply. The scenario recognises the importance of using marine renewable energy to power maritime activities and establish a sustainable system. Delaying the decommissioning of oil and gas infrastructure, such as platforms and pipelines, is expected to bring significant financial benefits from an economic perspective.

ECOSYSTEM CLUSTER: FOR FISHING INDUSTRY AND BIODIVERSITY

ECOSYSTEM CLUSTER:

Recognising the integral relationship between energy infrastructure and the marine environment, the Ecosystem Cluster aims to harmonise offshore activities with ecological sustainability. The cluster as energy hubs improves local biodiversity, support sustainable aquaculture, and provide infrastructure for fishing communities. Furthermore, the underwater data centre addresses latency and service delivery issues associated with centralised urban data centres. Underwater data centres can efficiently and sustainably meet decentralisation. Additionally, artificial reefs provide ecological benefits by enhancing marine biodiversity.

DATA CENTRE: SUPPORTING THE LOCAL COMMUNITY

The Infrastructure for data, often referred to as the new oil of the digital age, is becoming increasingly important. Researchers are actively working to locate data centres that process this data in the ocean. Over the past decade, the power consumption of existing land-based data centres has doubled every four years due to increasing demand. According to data, U.S. data centres spend \$13 billion on electricity and emit nearly 150 million tonnes of greenhouse gases. A Efforts are being made to find solutions to reduce energy consumption as the demand for energy increases worldwide.⁷⁶

Microsoft’s Project Natick has been tried to decentralised, and efficient data and energy infrastructure, specifically targeting the significant proportion of the world’s population residing in coastal regions. This initiative is a response to the predominantly urbanised location of current data centres and aims to bring data storage and processing closer to coastal users, thereby enhancing service delivery and reducing latency.⁷⁷

The deployment of underwater data centres is a central component of Project Natick. It provides a sustainable and operationally efficient alternative to traditional, land-based facilities. These underwater servers are reported to be eight times more reliable than their terrestrial counterparts, significantly increasing operational reliability and reducing data flow interrup-

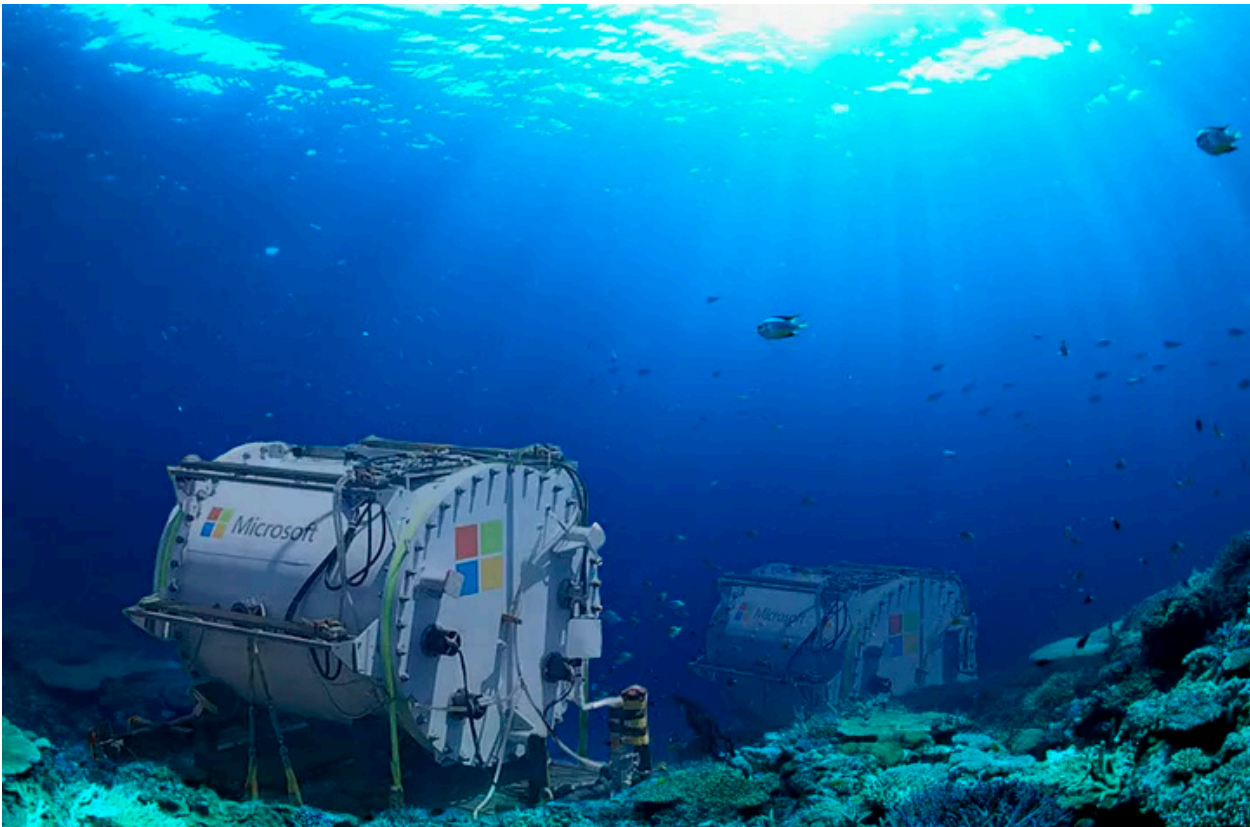


Fig. 26
According to Sean James’ research paper, the future of cloud computing is the underwater data center.

tions. Furthermore these submerged data centre utilise the natural cooling properties of seawater, which significantly reduce their ecological footprints and eliminates the need for energy-intensive artificial cooling systems.⁷⁸

Project Natick, located in the Orkney Islands, is powered entirely by renewable energy sources, including wind and solar power.⁷⁹ These connections to renewable energy sources demonstrate the potential for linking to various forms of renewable energy clusters, such as wind, solar, and tidal.

DATA CENTRE AS ARTIFICIAL REEFS

Moreover, Project Natick’s contribution to marine biodiversity by creating an artificial reef ecosystem around the submerged servers, aligns with the broader goals of ecological integration inherent in the concept of energy hubs. The bio-attachment process used by the servers enhances local biodiversity and provides habitat for marine life. Additionally, the energy hubs contribute to a sustainable and resilient energy future by using advanced technologies and renewable energy sources.⁸⁰

The integration of underwater data centres with offshore energy hubs is a comprehensive approach to addressing the challenges of sustainable energy and data management. This strategy promises to enhance service delivery, decentralise data centres, and contribute significantly to global efforts to combat climate change while also leaving a smaller environmental footprint.

Supporting Fishing Activities through Aquaculture

Offshore infrastructure, such as oil platforms and wind turbines, can be converted into sustainable marine aquaculture facilities to support fishing activities. The offshore location of these structures creates ideal conditions for cultivating marine life due to their high durability. They can be converted into multi-level fish or shellfish farms to support the growing demand for seafood while reducing the pressure on natural fish stocks.⁸¹

Convenient maintenance can help create a controlled environment that minimises the effects of disease and predation, resulting in healthier and more productive fish population. Furthermore, it reduces environmental damage caused by traditional fishing methods and minimises carbon emissions associated with long-distance seafood transport. Multi-level fish or shellfish farms can significantly increase seafood production, reduce reliance on wild fisheries, and create more controlled environments that mitigate disease and predation. Programmes like *RIG TO REEFS* in the US Gulf of Mexico have illustrated improvements in fish habitat, increased marine biodiversity, and provided economic benefits through enhanced recreational and commercial fishing opportunities.⁸²

Advancements in Offshore Aquaculture

The North Sea in the Netherlands, which historically had oyster reefs covering 20% of its area, has experienced a significant decline in these natural beds over the past two centuries. To address this issue, initiatives such as the *Rich North Sea programme* have been established to investigate and implement restoration and conservation strategies, recognising the crucial role that these reefs play in marine ecosystems. This programme focuses on integrating oyster farming within offshore wind turbines. The structures are utilized to create artificial reefs that aim to replicate the ecological functions of their natural.⁸³

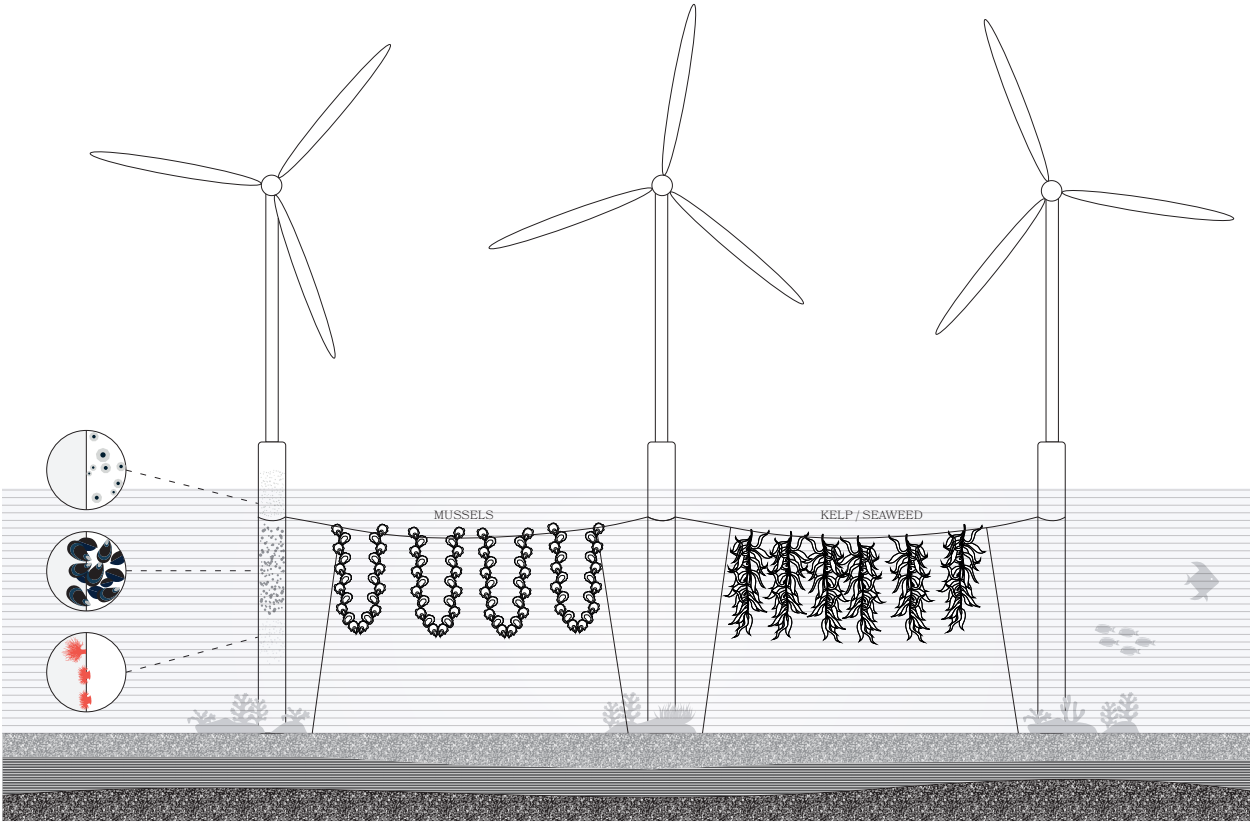


Fig. 27

The process of acting as an artificial reef is consistent with the jacket structure. Algae capture carbon dioxide through photosynthesis, and oysters and algae provide ecological, economic, and recreational benefits to marine ecosystem.

The introduction of oyster reefs under the offshore wind turbines has shown promising results for biodiversity enhancement. These artificial reefs provide a structured habitat for various marine species including crabs, mussels, anemones, starfish, hake, and squid, effectively creating a thriving ecosystem around the otherwise barren sea floor. In addition to promoting biodiversity, these oyster reefs contribute to shoreline protection by reducing erosion and improving water quality through their natural filtration capabilities.⁸⁴

The Ecosystem Cluster presents a strategy for offshore infrastructure with marine environmental conservation. It focuses on enhancing biodiversity through artificial reefs, supporting sustainable aquaculture, integrating innovative data centre solutions, and advancing marine research. This multi-faceted approach aims to ensure that offshore energy development aligns with ecological sustainability and community support, promoting economic development.

ENVIRONMENTAL RESEARCH CLUSTER

This cluster converts energy hubs into centres of innovation and research centres, with a focus on environmental monitoring, climate change research, and the development of green technologies. The facilities include carbon capture and storage, underwater data centres, and ocean science stations, which transform the hubs into living laboratories for studying and mitigating environmental impacts. The integration of research and conservation efforts within the energy production infrastructure exemplifies a holistic approach to sustainable development. This ensures that advancements in energy technology are aligned with ecological preservation and scientific discovery.

MARINE SCIENCE STATION

Marine science stations are a sustainable approach to reusing offshore platforms, particularly those previously used for oil and gas extraction. These transformed structures serve as dedicated bases for marine research. They contribute significantly to the overall study and conservation of ocean observations, fisheries resources, and marine ecosystems.

The station has been designed with care to ensure a pollution-free environment, with efforts made to minimise noise and other disturbances. This enables accurate scientific research while significantly reducing the human ecological footprint in sensitive areas. The platforms are located in economically important fishing grounds and provide critical data essential to understanding tidal patterns, weather conditions, and environmental changes. These stations are important for enhancing the safety and sustainability of the neighbouring fishing grounds and promoting wider conservation efforts in the marine environment. These stations are essential for further scientific knowledge of ocean dynamics, marine biology, and ecosystem changes.

The structure of the jacket can be reused as a marine science base. The superstructure can be redesigned and equipped with laboratories, accommodation, research equipment, and other facilities necessary for marine re-

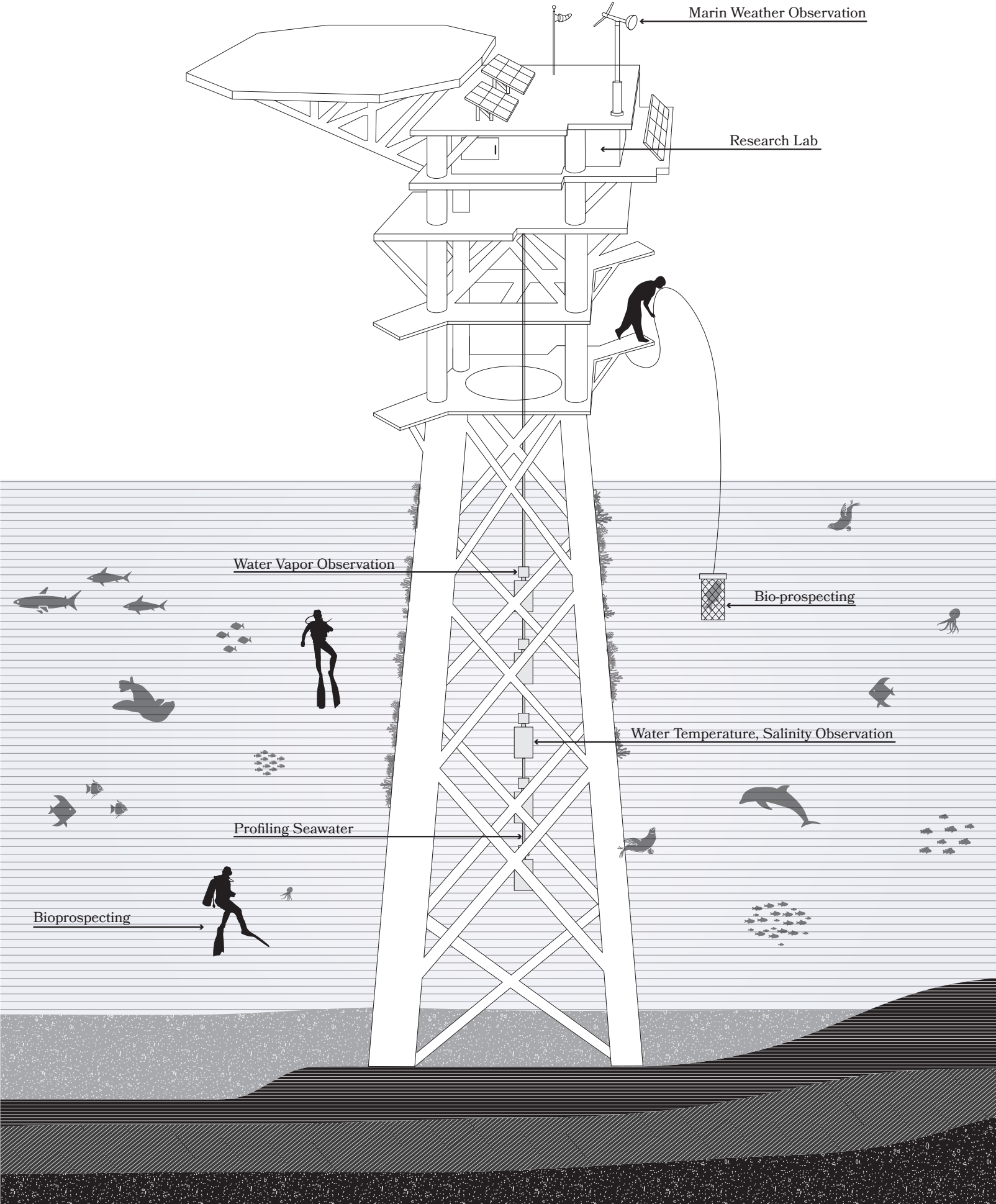


Fig. 28
Plans for a marine science
base in Korea (redrawn
from 국립해양조사원)

search and monitoring activities. This may include installations for oceanographic data collection, weather stations, and research facilities for marine biology and ecology.

The shallow water location facilitates maintenance, modification, and accessibility for researchers and educators. Furthermore, it can be connected to land, enabling educational purposes. This is crucial for continuous monitoring and study of the marine environment.

CO₂ CAPTURE AND STORE(CCS)

In response to the pressing need to address global warming and achieve carbon neutrality, the Research Cluster has incorporated Carbon Capture and Storage (CCS) technologies. This approach utilises the ocean’s natural capacity to sequester carbon by using sub-sea formations as storage sites for captured CO₂. By repurposing existing infrastructure, such as decommissioned oil wells, for CO₂ injection, this method offers a promising avenue for significantly reducing greenhouse gas emissions. The transportation of carbon dioxide (CO₂) through pipelines and its injection into existing wells can be facilitated by utilizing the current infrastructure.⁸⁵ The Carbon capture and storage (CCS) technology in the marine environment not only aids in achieving carbon peak goals but also contributes to the long-term stability of carbon storage, thereby playing a crucial role in global climate change mitigation strategies.

The Research Cluster represents a vision of offshore platforms as living laboratories for developing and testing innovative solutions for environmental protection and sustainable energy production. It integrates marine science stations with CCS technology, harnessing scientific knowledge and technological innovation for the betterment of the environment and society. It emphasizes the importance of advanced research in comprehending and mitigating the effects of climate change, promoting sustainable practices, and contributing to the broader objectives of ecological preservation and sustainable development.

OFFSHORE CLUSTERS

The repurposing of offshore platforms for sustainable development and environmental conservation is a narrative of change. These offshore oil and gas platforms, once symbols of hydrocarbon exploitation, now have the potential to contribute to a sustainable future. They demonstrate that even the most industrial infrastructure has the potential to protect and enhance marine ecosystems.

ADAPTABILITY OF CLUSTERS

The main advantage of a cluster is its ability to adapt and respond to the unique characteristics of its surroundings. Whether the focus is on renewable energy, biodiversity conservation, or scientific research, each cluster must be tailored to the specific ecological, cultural, and social nuances of its location. This customisation is essential for several reasons. Firstly, it ensures that the solutions implemented are effective in addressing local environmental challenges and opportunities. For instance, an energy cluster located in a region with ample solar radiation will give priority to the use of solar energy, while a region with abundant wind will prioritise wind energy.

LOCAL INTEGRATION AND COMMUNITY ENGAEMENT

Secondly, adapting these clusters to local conditions can foster strengthened connections with the surrounding communities. This can be further improved by considering linkages to the land, such as promoting fisheries, tourism, or research clusters that are tailored to the local characteristics. This approach not only enhances social acceptance of the project but also encourages community participation and ownership, leading to more sustainable outcomes.

They should not operate in isolation but rather as integrated components of a larger environmental and economic system. To effectively contribute to sustainable development goals, such as reducing carbon emissions, preserving biodiversity, and promoting inclusive and environmentally responsible economic growth, it is crucial to integrate these clusters into the wider urban and industrial ecosystem.

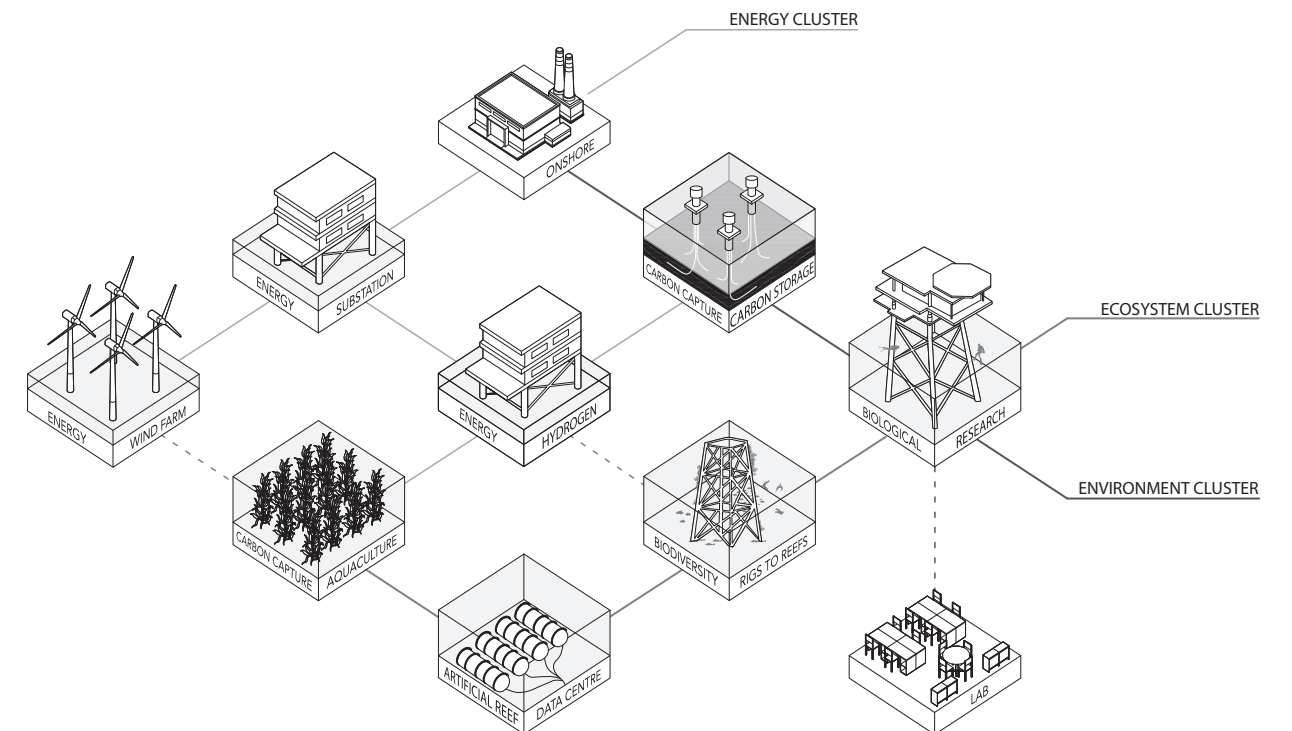


Fig. 29

Repurposing offshore oil and gas platforms into sustainable clusters, tailored to local ecological, cultural, and social contexts, can transform them from symbols of hydrocarbon exploitation into integrated components of environmental conservation and sustainable development, fostering community engagement and addressing local challenges.

VISION FOR FUTURE SUSTAINABLE DEVELOPMENT

Developing a sustainable cluster in the maritime industry is an ongoing process of learning, adaptation, and evolution. It requires a thorough understanding of the local context, a commitment to community engagement, and a willingness to embrace change and innovation. By adopting this adaptive approach, sustainable clusters can become catalysts for a more resilient, ecologically balanced, and prosperous future.

A vision of sustainable development based on flexibility, respect for local conditions, and continuous improvement can facilitate future initiatives that aim to integrate industrial development with environmental and social considerations.

CONCLUSION

CONCLUSION

The global shift towards low-carbon and renewable energy policies is an important step in combating climate change and moving towards a post-oil era. The offshore oil and gas industry is undergoing a transformation as the world acknowledges the pressing need to reduce greenhouse gas emissions and shift towards cleaner energy sources. The impact of this transition on the industry has been significant. The offshore industry has left thousands of platforms and infrastructure in the world's oceans.

CHALLENGES OF DECOMMISSIONING

At the end of their operational life, offshore structures need to be completely removed. This process involves physically decommissioning the platform and removing its solid bottom, as well as the rich marine ecosystem that has flourished around it for 30 to 40 years. Offshore drilling and human-made structures are often perceived negatively, which can overshadow their potential environmental benefits. Despite this, decommissioning these structures over the next 20 to 30 years will come at a significant financial and environmental cost, running into tens of billions of dollars. The upcoming economic burden is accompanied by the environmental impact of dismantling thousands of structures, each of which serves as a hub for marine life and biodiversity.

The marine ecosystem surrounding decommissioned structures holds significant value and contributes to fisheries, tourism, and conservation efforts. Therefore, it is necessary to re-evaluate the conventional approach to decommissioning, which often results in the destruction of established ecosystems. It is important to reconsider the consequences of decommissioning in terms of ecosystem destruction, rather than assuming it is the only option.

NOVEL ECOSYSTEMS

This research found and recognises the inherent value of marine life that thrives around man-made structures. These ecosystems can significantly contribute to fisheries, tourism, and conservation efforts. The conventional approach to disposal, which often results in the destruction of these developed ecosystems, needs to be re-evaluated. It is time to move beyond the simplistic view of human-made structures as strictly artificial and harmful and recon-

sider the implications of disposal. The term ‘novel ecosystems’ is significant in this context as it helps us understand the potential value of a modified environment and promotes the repurposing of offshore infrastructure. This perspective urges us to reconsider our approach to the ecological value of the marine environment and human-made structures. By recognising the intersection of human behaviour and marine biodiversity conservation, it is recognised that human intervention can result in the emergence of ecosystems that differ from their original state, but may hold significant ecological value.

OFFSHORE CLUSTERS

However, it is also crucial to acknowledge that not all infrastructure is appropriate for recycling or repurposing. The decision to reuse, partially use, demolish, or restore an offshore platform should be based on a comprehensive evaluation of factors such as environmental impact, technical feasibility, economic viability, and social impact. It is essential to adopt a flexible, site-specific approach to determine the most sustainable and beneficial outcome for each offshore structure.

The proposed energy, ecosystems, and research clusters offer a framework for considering disposal options that are tailored to the local, environmental, and cultural characteristics of each site. Each cluster provides opportunities to customize strategies to the specific conditions of the site, contributing to a comprehensive and sustainable approach to decommissioning. By implementing intelligent, context-specific strategies, we can ensure that the transition to renewable energy and pursuit of sustainable development are both environmentally sound and socially and economically beneficial.

INTEGRATION WITH URBAN DEVELOPMENT

An exploration of ocean development offers insights into the impact of humans on natural ecosystems, transcending the conventional land-centred perspective. It is important to understand the relationship between offshore development and cities, especially considering the development of the oil industry and its effects on coastal cities. The symbiotic relationship between offshore development and cities must be recognised. Exploring offshore development involves more than just installing structures in the marine space. It requires an understanding of how these interventions affect and are affected by the surrounding environment and the city.

This emphasises the need to consider the wider ecological context, highlighting the complex symbiosis between the utilisation of marine space and the resulting evolution of urban. When considering ecosystems in architecture, it is crucial to acknowledge their complexity and diversity instead of categorising them as either man-made or natural. This approach creates opportunities for sustainable development and environmental management, ensuring that human interventions are responsive to and respectful of the diverse ecological contexts in which they exist.

In conclusion, this paper explains for a balanced approach to marine development that explores the delicate balance between human and machine encroachment into marine space and the preservation of natural life. Additionally, for sustainable development, structures in marine areas should be recognized as a multidimensional issue, including environmental, economic, social, and cultural aspects. It is important to consider the relationship between surrounding communities.

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