WHITE PAPER ON OTEC 2.0

ADVANCING DEPLOYMENT AND INNOVATION

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PLOTEC

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CONTENT

PLOTEC, funded by the European Union, aims to enhance efficiency and reduce costs by developing optimized system designs, lower-cost materials, and improved installation techniques. These innovations are expected to reduce overall infrastructure costs making OTEC a viable option, particularly for Small Island Developing States (SIDS) and tropical coastal regions.

1 INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) provides a continuous and stable baseload power supply, as the temperature gradient between warm surface water and cold deep-sea water remains relatively constant year-round in tropical regions.

Fossil fuel-based energy production is subject to price volatility influenced by global market fluctuations, geopolitical tensions and supply chain disruptions. This price instability affects electricity costs, particularly in island nations and remote coastal regions that rely heavily on imported fuels like diesel and natural gas. For island nations and remote coastal regions, the reliance on imported fuel means high logistical costs and risks of supply delays. OTEC, by contrast, operates independently of global energy markets. This makes it an ideal solution for energy security and resilience**,** particularly in regions where fuel imports are costly and unreliable.

However, the widespread adoption of OTEC has been hindered by high capital costs associated mainly with plant construction and deep-sea pipeline installations. Technological advancements in offshore engineering, materials, and manufacturing processes are opening new opportunities for cost reductions. Looking ahead, OTEC's cost trajectory is expected to follow the same economic scaling patterns observed in other renewable energy technologies, where increased deployment, technological advancements, and economies of scale drive cost reductions over time. As research and development progress, improvements in materials, system efficiency, and offshore infrastructure will enhance OTEC's competitiveness. The adaptability of OTEC to existing industrial supply chains - including shipbuilding facilities, turbine manufacturing, pump and heat exchangers fabrication - further strengthens its potential for cost-effective mass production.

These challenges have been addressed under PLOTEC project[1] by introducing novel designs and advanced materials for OTEC systems. PLOTEC, funded by the European Union, aims to enhance efficiency and reduce costs by developing optimized system designs, lower-cost materials, and improved installation techniques. These innovations are expected to reduce overall infrastructure costs making OTEC a viable option, particularly for Small Island Developing States (SIDS) and tropical coastal regions.

One of the key barriers to the widespread deployment of OTEC lies in a fundamental economic paradox. The countries best suited for OTEC - those located in tropical regions with significant temperature differentials between deep and surface waters - are often developing economies with limited financial resources.

1 https://plotec.eu/

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These countries face significant challenges in funding high-capital-cost projects and de-risking new technology deployment. Conversely, developed countries that could finance such projects have little domestic potential for OTEC, as their geographical locations lack the necessary thermal gradients to make the technology viable. This mismatch between resource availability and financial capacity creates a structural challenge: OTEC development has stagnated due to a lack of investment from financially capable entities and the inability of high-potential regions to shoulder the costs alone. Overcoming this challenge demands innovative financing models and policy-driven incentives to close the economic gap.

This white paper aims to provide a strategic and technical overview of OTEC, highlighting its potential, challenges, and pathways for large-scale deployment.

This white paper aims to provide a strategic and technical overview of OTEC, highlighting its potential, challenges, and pathways for large-scale deployment. Building on the **2024 White Paper on OTEC**[2], which provided a broad analysis of economic considerations, scalability challenges, key components, and mitigation strategies, this document goes deeper into the specific requirements for commercial implementation. Given the unique energy needs of Small Island Developing States (SIDS) and tropical coastal regions, it serves as a practical guide for decision-makers looking to integrate OTEC into national and regional energy strategies.

The document outlines the role of OTEC as a stable, baseload renewable energy source, highlighting its multi-functional applications. It evaluates environmental and social considerations, addressing marine ecosystem impacts and community engagement strategies to ensure responsible deployment. Additionally, it identifies key economic, policy, and regulatory barriers, emphasizing the need for financial mechanisms, workforce development, and supportive policy frameworks. It also explores technological advancements and deployment strategies, leveraging lessons from offshore wind, and assessing scalability through existing industrial supply chains. Finally, it provides strategic recommendations for OTEC's global expansion.

2 https://plotec.eu/white-papers

2

HARNESSING THE POTENTIAL OF OTEC: OPPORTUNITIES AND CHALLENGES

2.1 OTEC AND THE ENERGY TRANSITION IN SIDS

The best resources for Ocean Thermal Energy Conversion (OTEC) are found in tropical regions where the temperature difference between warm surface waters (≥ 25°C) and cold deep-sea waters (≈ 5°C at 800–1000 m depth) remains consistently high throughout the year. This ideal thermal gradient is strongest in equatorial waters, particularly in parts of the Pacific, Indian, and Atlantic Oceans. Interestingly, many Small Island Developing States (SIDS) are located within or near these optimal OTEC zones, making them prime candidates for OTEC adoption.

The alignment between high OTEC potential and the geographic location of SIDS presents a unique opportunity to address energy security, freshwater scarcity, and economic resilience in some of the world's most vulnerable island communities.

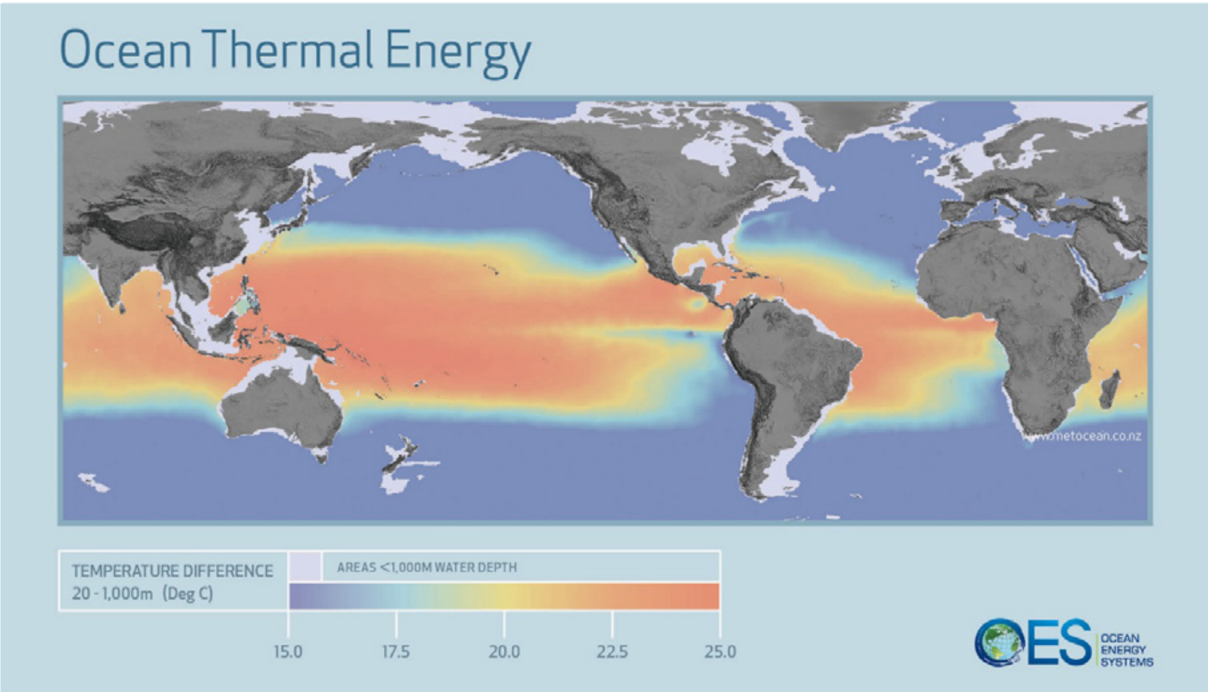

Figure 1: World Distribution Map of OTEC (Source: IEA-OES)

Small Island Developing States (SIDS) face unique energy challenges due to their geographical isolation, dependence on imported fossil fuels, and vulnerability to climate change. As a result, they urgently require sustainable and reliable energy solutions to enhance energy security and resilience.

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Many SIDS have set ambitious renewable energy targets in their Nationally Determined Contributions (NDCs) under the Paris Agreement. For example, Tonga aims for 70% renewable energy by 2030; Barbados has set a target of 100% renewable energy by the same year. By shifting away from fossil fuels, these nations can stabilize energy costs, reduce economic exposure to external fuel markets, and strengthen their resilience against global supply disruptions.

A diverse renewable energy mix is essential for SIDS to achieve energy security. OTEC presents a unique advantage by providing continuous baseload power. When integrated with other renewable sources such as solar, wind, and hydropower, OTEC helps create a balanced and resilient energy portfolio, ensuring reliable electricity generation and reducing dependence on fossil fuels.

To ensure successful deployment of OTEC it is essential to engage with communities in SIDS. Early and inclusive stakeholder engagement allows local communities, fishermen, and tourism operators to express concerns about environmental impacts, economic benefits, and social implications. Transparent communication using local languages, visual tools, and culturally relevant materials helps build trust and understanding.

To address social and economic concerns, community-led impact assessments should be conducted, ensuring that OTEC projects align with local priorities. Strategies such as vocational training, local hiring, and business development opportunities can ensure direct benefits for residents. Environmental considerations must also be prioritized, incorporating marine conservation measures and traditional ecological knowledge to minimize disruptions to fisheries and coastal ecosystems.

Long-term involvement can be ensured through community advisory committees and feedback mechanisms. Continuous dialogue is important for OTEC to become a socially accepted and sustainable energy solution that strengthens energy security while benefiting island communities.

2.2 OTEC AS A MULTI-RESOURCE SOLUTION

OTEC is primarily known for renewable electricity generation, however its potential extends far beyond power production, opening the door for diverse business models that maximize economic and environmental benefits. With the integration of additional revenue streams, OTEC can enhance its viability and attract investment. Key opportunities include:

Desalination for Freshwater Supply

Water scarcity is a global issue as it can be seen from the figure below. A good correlation between OTEC resources and water scarcity are evident in locations such as India, Southeast Asia, Central America and Central Africa. However, it is most severe in areas where water shortage is compounded by poor water infrastructure and a lack of available funding to invest in infrastructure. Energy is the main cost driver in desalination technology and if produced from fossil fuels results in large GHG emissions.

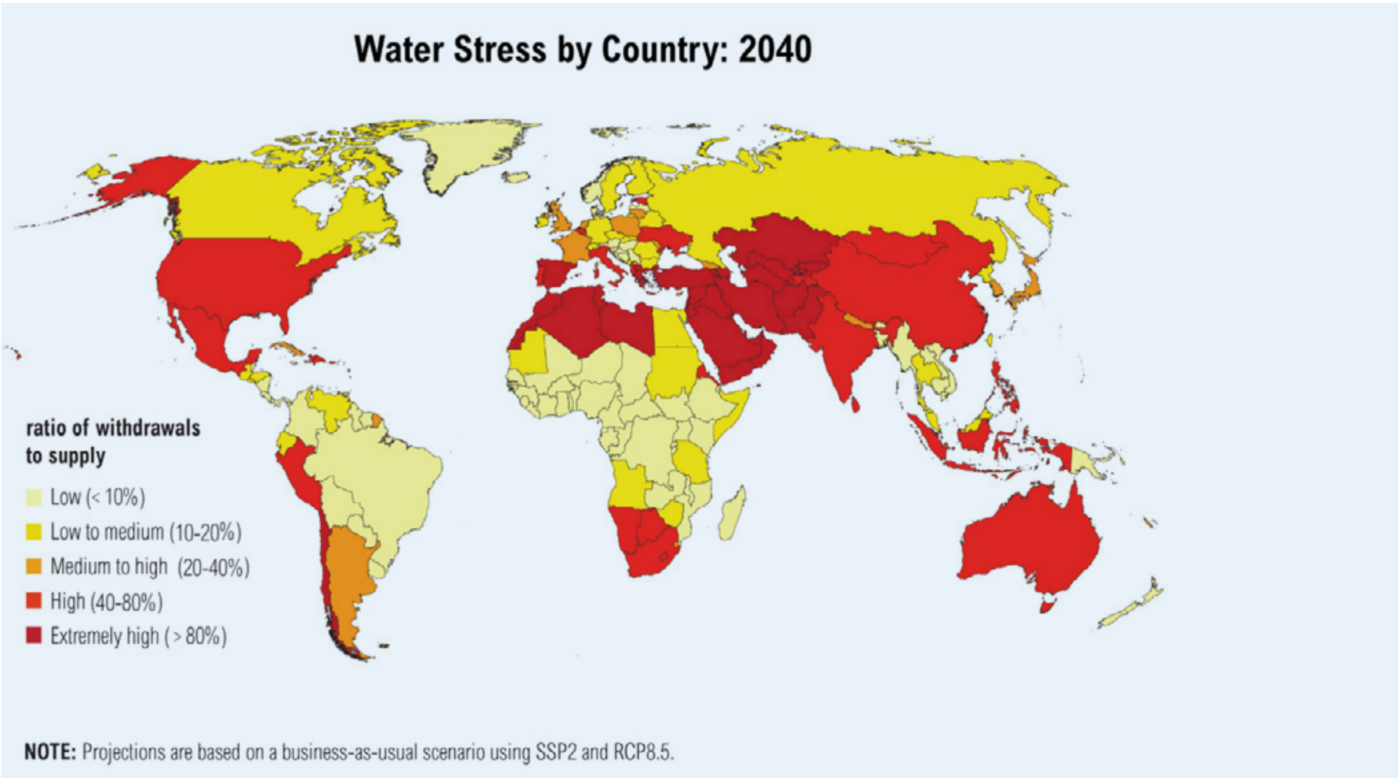

Figure 2: Water Stress by Country 2040 *(Source: World Ocean Forum)*

Combining Ocean Thermal Energy Conversion (OTEC) with a **thermal desalination plant** offers a synergistic approach to improving both cost-effectiveness and resource utilization. Since both systems rely on ocean temperature differences, their co-location and integration can enhance efficiency, reduce capital costs, and optimize energy use [1]. A thermal desalination plant removes salt and impurities from seawater using heat-based processes rather than membranes (as in reverse osmosis). These systems rely on phase change, where seawater is evaporated and then condensed to produce freshwater. In this setup: OTEC uses the temperature gradient between warm surface seawater and cold deep seawater to generate electricity; the thermal desalination plant uses the waste heat or the cold deep seawater from the OTEC process to enhance its freshwater production efficiency.

Supporting aquaculture

Aquaculture is one of the fastest-growing food industries, and OTEC creates a unique opportunity for aquaculture [2], as the cold, nutrient-rich water can be repurposed to enhance marine farming operations in multiple ways:

- **Temperature-Controlled Aquaculture:** many cold-water fish species (e.g., salmon, trout) cannot survive in warm tropical waters. OTEC's deep-sea water, typically around 4-5°C, can be used to create a temperature-controlled aquaculture system in warmer climates, allowing cold-water species to thrive in regions where they would not naturally survive.
- **Seaweed & Algae Farming:** Deep-ocean water is rich in nutrients essential for marine plant growth.
- **Improved Disease Resistance in Aquaculture:** Warm waters in tropical regions increase disease outbreaks in fish farms due to higher bacterial growth rates. OTEC's deep-sea water, when introduced into aquaculture systems, helps regulate water temperature, making conditions less favorable for harmful pathogens.

The co-location of aquaculture with OTEC, sharing resources, can improve efficiency and economic viability thus maximizing the value of OTEC systems.

Seawater Air Conditioning (SWAC): a complementary product of OTEC

Traditional air conditioning systems rely on electrically powered compressors and refrigerants, consuming significant amounts of energy and contributing to high electricity demand, especially in warm climates. This dependence on fossil fuel-based electricity intensifies carbon emissions and environmental impact, making energy-efficient alternatives like Sea Water Air Conditioning (SWAC) increasingly important for sustainable development.

SWAC is a highly energy-efficient cooling technology that originates from research and development in OTEC. Like OTEC, SWAC uses the naturally cold deep ocean water, but instead of using it for electricity generation, SWAC uses this resource to replace conventional air conditioning systems, significantly reducing energy consumption and environmental impact [3]. When developed alongside OTEC plants, SWAC operates entirely without fossil fuels, making it a fully sustainable cooling solution.

The Natural Energy Laboratory of Hawaii Authority (NELHA) was pioneer in SWAC technology in the 1980s as part of its broader OTEC research initiatives. While working on deep ocean water intake systems for OTEC, researchers realized that the same infrastructure could be repurposed to provide chemical-free, energy-efficient air conditioning. This insight led to the first SWAC demonstration projects and laid the foundation for commercial implementations worldwide.

Today, SWAC has been deployed in several locations, including Hawaii, and the Caribbean, with growing interest from tropical nations and coastal cities. As energy efficiency and climate goals become more urgent, SWAC's potential to replace conventional cooling systems continues to gain traction.

2.3 ENVIRONMENTAL CONSIDERATIONS

The successful commercialization of OTEC hinges on a comprehensive understanding of its environmental impacts. Initial studies suggest that OTEC's risks are manageable, however most assessments have been based on theoretical experiments rather than real-world, full-scale deployments. Consequently, to overcome uncertainties about OTEC's large-scale environmental viability, long-term monitoring is needed.

With the growing interest in OTEC energy production, research efforts have expanded to evaluate potential environmental disruptions and establish sustainable deployment strategies. Among the primary concerns is the interaction between OTEC's cold-water discharge and marine ecosystems, the entrapment of marine life in cold-water pipes, and chemical discharges. Other potential effects, such as the habitat modification, and potential displacement or entanglement of marine organisms, must also be addressed. While many of these effects can likely be avoided or mitigated, three major environmental aspects require scrutiny:

Thermal and Nutrient Discharge and Interaction with Ecosystems

The discharge of very large volumes of deep, cold ocean water, can alter marine ecosystems through thermal and nutrient changes [4]. The cold deep water will be brought to the surface at a temperature of about 4°C, while surface and subsurface waters will be about 24-28°C. After the heat exchange process, the cold water to be returned to the ocean is likely to be about 12-16°C [5], still significantly colder than the ambient surface seawater (Figure 3).

To mitigate impacts, standard OTEC designs discharge return water at intermediate depths, typically below the thermocline, ensuring it sinks to a depth where its density matches the surrounding seawater. The optimal discharge depth is determined using numerical modeling, validated by temperature, salinity, and depth measurements [6]. However, the discharge plume, which can reach a flow rate of hundreds of cubic meters per second, can modify nutrient availability and can contribute to eutrophication [7]. If released at inappropriate depths, the upwelling of nutrient-rich water may increase primary production but also trigger harmful algal blooms (HABs) [8].

Giraud et al. (2015) analyzed OTEC discharge impacts in Martinique and found a 0.3°C temperature variation at 150m depth, which altered phytoplankton assemblages within the deep chlorophyll maximum. Auvray et al. (2015) modeled the dispersion of discharged deep water at the Martinique OTEC project, concluding that while localized impacts may occur, long-term biogeochemical shifts remain a concern. More research is needed to assess whether nutrient upwelling could be beneficial or disruptive, particularly regarding carbon dioxide removal (CDR) and marine food web changes [7].

Impingement and Entrainment

Marine organisms may be affected by OTEC's intake and discharge systems, particularly through impingement (where organisms are trapped against intake screens) and entrainment (where smaller organisms pass through and enter the facility). Cold and warm water intake pipes could affect plankton, larval fish, and other marine species. Additionally, pumping systems pose risks to low-mobility species that can be trapped and dragged [9]. To mitigate these impacts, OTEC facilities require advanced screening technologies at both warm and cold-water intakes, reducing organism mortality and minimizing biodiversity disruptions.

The presence of marine life in the deep sea is sparse, as there is little food at these depths to sustain a complex food web. However, special consideration should be given to threatened and endangered species that might encounter an OTEC platform or pipes. Research on the interactions between OTEC infrastructure and marine ecosystems should focus on species vulnerable to entrainment and impingement [10].

Chemical Discharges

To prevent biofouling in heat exchangers, OTEC plants may require biocide treatments (e.g., chlorine), anti-corrosion coatings, or chemical dispersants. While these discharges are expected to remain within regulatory limits, their long-term impact on marine organisms is poorly understood [10]. Alternative antifouling methods, including environmentally safe coatings and non-chemical antifouling solutions, are recommended for minimizing chemical discharges [11]. Biofouling is considered a maintenance challenge, requiring periodic cleaning to prevent performance degradation.

Closed-cycle OTEC systems use ammonia-based working fluids due to their high thermal conductivity [12]. Leakage of these chemicals in gaseous form could be harmful to human and marine life. Ensuring robust containment, regular inspections, and leak detection systems is essential. Studies suggest that ammonia leakage risks remain low and manageable, given existing expertise in handling ammonia-based systems [13]. As part of any permitting process, a hazards analysis and a hazardous waste mitigation plan will be required.

Additional Environmental Considerations

Early studies suggest that OTEC risks are acceptable, but further assessments are needed to address:

1. **Underwater Noise:** Noise generated by pumping systems and turbo-alternators may interfere with species that rely on acoustic signals for communication, navigation, and foraging. Marine mammals, such as dolphins and whales, are particularly vulnerable to increased noise which can interfere with their ability to communicate and navigate, leading to potential disruptions in foraging behaviour. This disruption in communication can also affect their social structures and breeding patterns. The noise produced by the OTEC plant can also impact fish populations and other marine organisms breeding behaviors, impacting recruitment and survival rates among juvenile fish. Such a shift can disrupt the entire food web and ecosystem balance, with cascading effects on biodiversity. Noise modelling using Sound Pressure Level (SPL) and Sound Exposure Level (SEL) assessments can help identify high-risk areas [14].
2. **Displacement of organisms:** Interference with migratory routes of marine mammals, sea turtles, and large fish may occur if many large floating OTEC plants are deployed in a key migratory pathway for marine organisms; some displacement could occur. Careful siting and spacing between the floating structures could assure sufficient room for the organisms to reach their intended habitats.
3. **Other Ecological Considerations:** Potential impacts on habitats, including sensitive areas such as coral reefs; the formation of artificial reef-like structures that may attract marine life; the entanglement of large marine animals in mooring lines; and pathways for introducing invasive species [10].

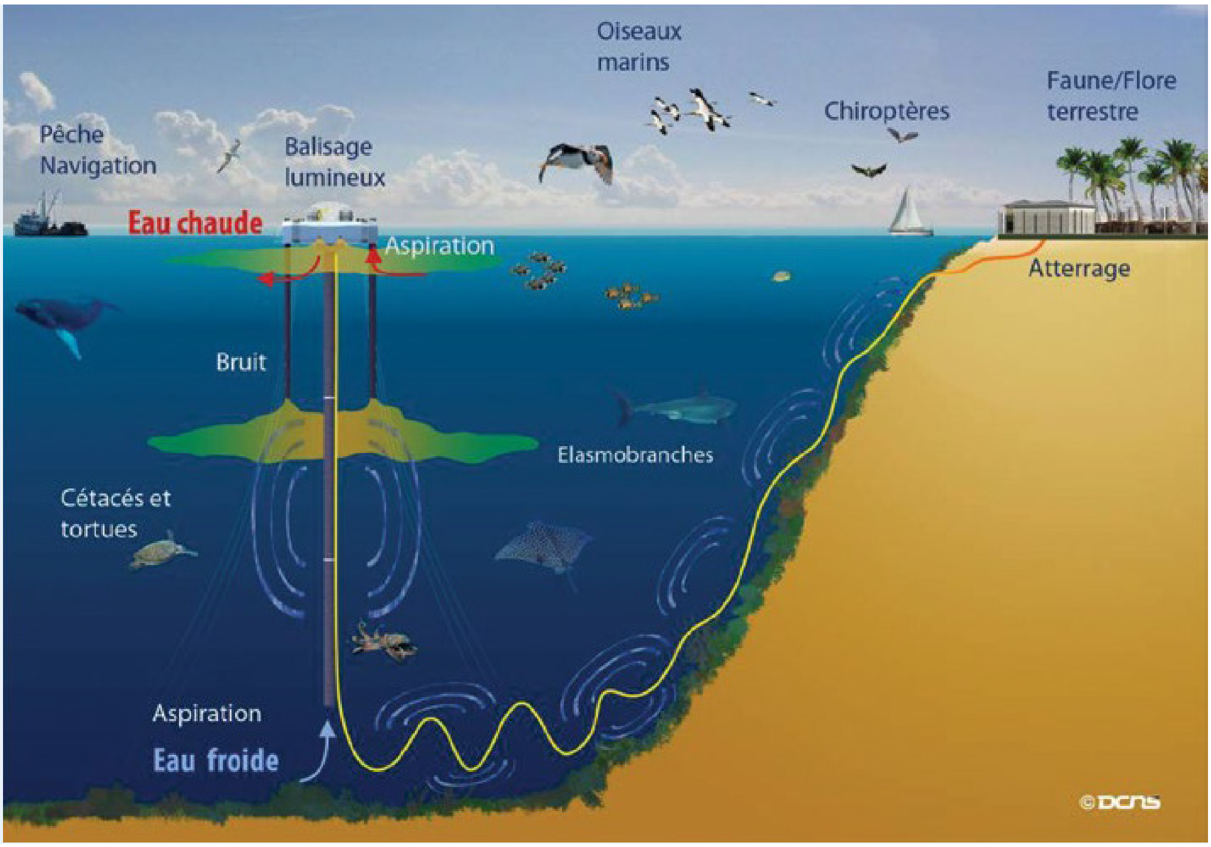

Figure 3: Simplified diagram of potential impact sources and environmental issues. Source:[14].

Potential Mitigation Measures

Mitigation strategies should focus on minimizing ecological disruptions and ensuring that OTEC operations align with best environmental practices. Potential measures include:

- **Optimized discharge depth selection** to prevent nutrient enrichment at inappropriate depths and mitigate ecosystem disruptions. If the cold water is returned at the correct depth to enable rapid sinking to the appropriate depths, there are likely to be no changes in the regional oceanography around OTEC plants, as they develop in the future.
- **Advanced intake screening technologies** to reduce impingement and entrainment impacts on marine life.
- **Environmentally safe biocide alternatives** or non-chemical antifouling methods to minimize harmful discharges.
- **Comprehensive environmental monitoring programs** to track long-term changes in marine ecosystems associated with OTEC operations (e.g. underwater noise, etc.).

Social Concerns

Public perception and social acceptance of OTEC projects are crucial for their long-term viability. The need for secure locally sourced renewable energy is likely to meet favorable community support. Even though OTEC offers a reliable, locally sourced renewable energy solution, community concerns must be addressed proactively:

- **Community Engagement:** Active participation of local stakeholders, particularly indigenous and coastal communities, is essential to ensuring alignment with sustainability goals and minimizing potential conflicts.
- **Economic Benefits:** OTEC can generate employment opportunities in construction, operation, and maintenance, fostering local economic development, particularly in island and coastal regions heavily dependent on imported fossil fuels.
- **Education and Outreach:** Implementing structured education programs will enhance public awareness and acceptance of OTEC projects. This includes highlighting environmental benefits, addressing misconceptions, and ensuring transparency regarding project risks and mitigation strategies.
- **Cultural and Traditional Considerations:** Many communities in tropical regions have deep cultural ties to the ocean. Integrating local knowledge and respecting traditional marine resource management practices can improve community acceptance and cooperation.
- **Energy Independence and Sustainability:** OTEC can contribute to energy independence by providing a renewable source of energy, reducing reliance on imported fossil fuels. This shift can enhance energy security for local communities and promote sustainable development by aligning with environmental goals (Auvray, 2015).
- **Policy and Regulatory Frameworks:** Governments should establish clear, transparent policies that provide financial incentives for OTEC development while ensuring environmental safeguards and equitable resource allocation. Well-defined regulatory pathways can facilitate smoother permitting processes and build investor confidence.

CONCLUSION

The study by [4] highlights the importance of continued research and comprehensive environmental and social assessments to ensure the successful and responsible commercialization of OTEC.

While previous studies have suggested that the risks of OTEC are manageable, long-term field studies are required to validate these assumptions [10]. As OTEC projects move toward commercialization, a robust environmental monitoring framework will be essential to ensure that potential ecological disruptions are mitigated. Similarly to other renewable energy technologies under development, adaptive management strategies will be critical for the sustainable deployment of OTEC as a viable marine renewable energy source.

2.4 ECONOMIC INSIGHTS

Economic Viability of OTEC

The economic feasibility of OTEC technology depends largely on plant size and the ability to secure initial investment. Various studies have evaluated the impact of scaling up OTEC plants, showing that smaller-scale systems struggle to compete with business-as-usual (BAU) electricity prices and more mature renewables such as wind and solar PV. The primary challenge stands on the high capital expenditure (CAPEX) required for offshore structure, mooring systems, equipment, and deep-water intake pipes. However, larger OTEC plants, particularly from 50 MW of capacity present more competitive levelized costs of electricity (LCOE), underscoring the importance of economies of scale.

On the other hand, OTEC benefits from low operating costs compared to fossil fuel-based power generation. While there is limited real-world data for such commercial-scales, O&M costs can be estimated at 3 - 5% of CAPEX based on conservative offshore energy industry practices. However, the high upfront investment remains a market challenge. Unlike conventional power generation, where fuel costs are spread over time, OTEC requires substantial initial capital, which can be difficult to finance under existing financial structures.

Findings from [15] estimate the LCOE for a 10 MW OTEC plant ranging from 0.19 to 0.62 €/kWh, while for a 100 MW plant, it is projected between 0.04 and 0.29 €/kWh, both assuming a 12% interest rate. Additional calculations by [16] suggest an LCOE between 0.34 and 0.42 €/kWh for a 10 MW OTEC plant, whereas a 50 MW first-generation plant could achieve 0.24 €/kWh. These variations likely stem from differences in cost assumptions, design and configuration, plant location, scaling methodologies, and financial mechanisms.

In comparison, for instance in the Barbadian context, solar PV benefits from a feed-in tariff (FiT), allowing utilities to purchase electricity at 0.10 €/kWh for systems ranging from 5 MW to 10 MW. Similarly, land-based wind projects of similar capacity achieve an LCOE of 0.09 €/kWh [17]. While Barbados' electricity prices are volatile due to reliance on oil imports, the BAU electricity price currently stands at approximately 0.26 €/kWh [18]. Such comparisons highlight the lack of competitiveness, especially for smaller OTEC plants and reinforcing the needs for financial incentives and policy support.

Pre-commercial OTEC plants are not yet financially viable, but their development is essential to overcome the 'Innovation Valley of Death', demonstrate risk mitigation and attract investment, given the potential market size. Cost reduction will be driven by technological advancements and industrial learning, particularly in the first decade of pilot projects. This includes design optimization, supply chain strengthening through project replication, and knowledge transfer from ongoing OTEC initiatives and related industries. Additionally, pre-commercial demonstrations, real-world data collection, and iterative improvements will enhance investor confidence by minimizing financial risks. This could enable similar interest rates to those in the wind and solar PV industries, making OTEC more competitive.

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Competitiveness of larger-scale OTEC plants and implications for SIDS

Larger-scale OTEC plants have the potential to enhance competitiveness by exploiting economies of scale, reducing the LCOE, and improving efficiency through advanced heat exchangers and optimized thermodynamic cycles. OTEC has potential for market expansion, particularly in the Pacific, Caribbean, Central America, and Africa. While larger OTEC plants (≥50 MW) are showed more economically viable, they are better suited for large tropical maritime countries due to their higher energy demand and infrastructure capacity [15].

Scaling OTEC from prototype to commercial levels can significantly increase the share of renewables in national electricity grids. The analysis conducted within PLOTEC project indicated that a 10 MW OTEC plant would raise the renewable energy share by 3%, but a 50 MW and 100 MW system could increase it by 16% and 33%, respectively. However, Small Island Developing States (SIDS) are generally better suited for small-scale plants (1–10 MW) [15]. Smaller OTEC systems align more closely with the energy demands of SIDS, providing a stable and manageable output without straining grid infrastructure. Additionally, many SIDS face infrastructure constraints, making large-scale OTEC deployment logistically challenging. Beyond electricity generation, small-scale OTEC plants provide valuable co-benefits such as desalination, aquaculture, and cooling applications. They also require lower upfront investment, which improves access to funding mechanisms and increases feasibility for SIDS with constrained financial resources. This affordability could make OTEC a more viable alternative to fossil fuel imports, strengthening energy security and stabilizing electricity prices.

In general, SIDS are heavily dependent on oil imports for power generation, making them vulnerable to price volatility, supply chain disruptions, and geopolitical risks, which in turn threaten energy security and drive high and unpredictable electricity costs. For example, as of 2020, over 90% of Barbados' electricity was generated from fossil fuels with fuel costs representing about 66% of total electricity expenses [19 - 21]. The fuel imports account for approximately 8% of GDP [22].

OTEC offers a strategic opportunity to enhance energy security by reducing reliance on imported fuels, stabilizing electricity prices, and mitigating exposure to global oil market fluctuations. Lower energy costs could also improve affordability for households and businesses, freeing up resources for essential needs and sustainable development investments. For businesses, volatile energy costs create financial uncertainty, limiting investment in expansion and innovation. Small and medium enterprises (SMEs), the backbone of many island economies, are especially vulnerable to electricity price spikes due to their tight profit margins. High and fluctuating energy costs also deter foreign direct investment, as multinational corporations prefer stable and predictable energy markets. Key economic sectors, such as tourism and manufacturing, face operational challenges when energy prices rise unexpectedly, reducing their global competitiveness.

Integrating OTEC into the energy mix could help SIDS mitigate these pressures and enhance economic resilience. Barbados has committed to significantly increasing the share of renewable energy in its energy mix, aiming for 100% renewable energy generation by 2030 as part of The Barbados National Energy Policy (BNEP) [23]. OTEC presents a potential complementary solution to support this transition by providing continuous baseload power that ensures grid stability. When integrated with solar PV and wind energy, OTEC can help SIDS establish a diversified and resilient energy system, reducing fossil fuel dependence while maintaining a stable and reliable power supply.

The integration of OTEC into SIDS' long-term energy strategy would also contribute to economic sustainability by reducing fuel expenditures, freeing financial resources for investment in social aspects, and unlocking local technological expertise in renewable energy solutions.

While SIDS contribute minimally to global CO_2 emissions their per capita emissions are relatively high due to heavy reliance on fossil fuels. For instance, in 2023, Barbados contributed to 0.003% [24] of global emissions, yet its per capita CO_2 emissions reached 4.2 metric tons, close to the global average of 4.7 metric tons [25]. Implementing OTEC can help reduce these emissions, aligning with global climate change mitigation efforts and protecting vital sectors like tourism, which are vulnerable to climate-related disruptions.

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Financing Mechanisms

Given the high initial costs associated with OTEC, financial mechanisms will be critical in bridging the investment gap and accelerating deployment. One of the most common approaches within the renewable energy sector is the implementation of Feed-in Tariffs (FiTs). Under a FiT scheme, the government establishes a fixed-term purchase price that is sufficiently attractive to encourage private sector investment. This mechanism helps mitigate project risks and supports the financial viability of renewable energy projects, similar to incentives used in offshore wind and solar PV. This approach aims to encourage renewable energy production by providing predictable returns, which can be especially helpful for technologies like OTEC that face high upfront costs and technological maturity challenges.

A Power Purchase Agreement (PPA) offers a viable alternative to support OTEC projects by establishing a long-term contract between the developer and an energy buyer, typically a utility company, wherein electricity is sold at a fixed, pre-negotiated rate. This arrangement provides financial certainty, offsets risk from high initial expenditures and creates a predictable revenue stream that attracts necessary investment. While PPAs guarantee repayment of capital, they are generally fixed for only 15 to 20 years, despite OTEC facilities having operational lives of up to 40 years. However, as pointed out by the IEA-OES Report [16], small-scale OTEC projects may struggle to achieve profitability with traditional PPAs, although a longer-term approach could lead to success in regions with high power generation expenses.

Public-Private Partnerships (PPPs) integrating seawater intake system within the OTEC project represent also an alternative for supporting OTEC initiatives and address resource management, particularly for islands and regions facing water resource challenges. Revenue generated from selling water to industries or residents would help cover operational costs, reducing pressures on public funds. The initial phase could be financed through a dedicated support project aimed at kickstarting new ventures or incorporated within the original OTEC's development plan [7].

International financial institutions and development agencies also play a crucial role in reducing the economic barriers to OTEC adoption. Tax incentives, including exemptions on equipment imports, reduced corporate taxes for renewable energy developers, and investment tax credits, could further encourage private sector participation in OTEC projects. According to the IEA-OES Report [16], an increase of the direct subsidy to capital expenditure from 30% to 67% would result in a decrease of LCOE to around 45%, enabling a competitive cost of electricity even over shorter terms, despite higher initial charges for the public. The trade-off is the effect on the cost of energy production and the subsequent price paid by consumers, while replacing fossil fuel production and reducing dependence on imported oil for countries where energy security is a concern. Indirectly, this unlocks capacity for investment in other critical sectors and generates socio-economic benefits, such as job creation and infrastructure development, as well as reducing greenhouse gas emissions, contributing to sustainability goals and global climate commitments.

Securing funding to transition from small demonstration plants to pre-commercial prototypes remains a significant hurdle in advancing OTEC technology. These prototypes are essential for collecting operational performance data and strengthening investor confidence, establishing groundwork for larger commercial-scale projects while reducing technological and financial risks. To overcome this challenge, beyond implementing tariff subsidies, providing financial incentives and grants for R&D is crucial to attracting private sector investment. Additionally, fostering international collaboration among national governments can facilitate knowledge sharing, joint project planning, coordinating joint projects, and pooled funding. At the same time, engaging private sector expertise, including project developers, venture capitalists, utility providers, and classification companies can further accelerate progress [7].

3

KEY TECHNICAL CONSIDERATIONS FOR OTEC DEPLOYMENT

3.1 SITE SELECTION FOR OTEC DEPLOYMENT

As it is typically the case for offshore renewable energies, selecting suitable sites for Ocean Thermal Energy Conversion (OTEC) deployment is a complex process that must balance technical, environmental, and socio-economic factors. The fundamental requirement for OTEC is a minimum thermal gradient of 20°C between warm surface waters and cold deep waters, typically found at depths of around 1000 m. However, additional criteria—including bathymetry, distance to infrastructure, environmental impact, and economic viability—are essential for determining the feasibility of a site.

The selection of the most suitable site(s) for the development of an offshore renewable energy project is a fundamental aspect of its planning. Traditional site selection processes used in the early stages of the sector tended to be predominantly based on a single parameter, namely the energy resource. While this provides a rough estimate of the economic viability of the project, first prototype developments and, more importantly, the arrival of the first commercial farms have raised awareness that several other factors determine the feasibility of offshore renewable projects. In order to anticipate potential legislation and regulatory barriers, as well as to properly plan logistics-related issues, it is essential to account for factors such as space usage restrictions, potential conflicting activities, and proximity to infrastructures when selecting the most suitable location. On the technical side, feasibility is greatly conditioned by factors such as water depth, seabed geology, and extreme metocean conditions. Failing to account for these constraints early in the planning process can lead to project delays, cost overruns, or even site inoperability, as seen in cases where offshore installations faced unforeseen permitting challenges or underestimated installation complexities. The recent need to integrate socio-economic and environmental aspects in the planning of energy generation projects has further complicated site selection, leading to the adoption of multi-criteria decision analysis (MCDA) as a valuable tool to structure and prioritize site selection based on multiple factors [26].

One of the primary challenges in OTEC site selection is the need for bathymetric suitability, as sites must have access to deep waters close to shore to minimize pipeline costs and efficiency losses. A steep continental slope with minimal distance between the shoreline and deep water is preferred to reduce the costs associated with cold-water intake systems. As noted in [27], the selection process must prioritize locations where the bathymetry allows for efficient pipeline installation while minimizing ecological disturbances. Floating OTEC plants, which

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avoid seafloor pipeline constraints, require stable mooring conditions and protection from strong deep-sea currents to prevent excessive structural loads. According to [28], steep seafloor slopes are necessary to ensure effective cold-water intake, and sites with excessive seabed irregularities may increase structural stress and maintenance requirements.

OTEC needs to collect deep, cold water, which is generally found below the thermocline. In most areas of interest, this water is typically at depths of at least 500–600 m, but for optimal thermal gradients, intakes are often placed at depths of 800–1000 m. This sets the typical range of depth requirements at a minimum of 600 m, with deeper intakes required in some locations. In regions with steep bottom slopes, such as near volcanic islands or continental shelf drop-offs, depths of 800–900 m can be reached within just 2–3 km from the coast. However, for more gradually sloping sites, intake pipelines must extend much further, sometimes tens of kilometers offshore. While no absolute maximum limit exists for platform-based applications, where OTEC-generated energy can be used directly for producing commodities such as desalinated water or hydrogen, an arbitrary working range of up to 200 km has been proposed. In cases where the energy is to be fed into an electrical grid, transmission efficiency becomes a limiting factor, similar to wave and tidal energy, making 10–20 km from shore a practical maximum to minimize transmission losses.

State-of-the-art Geographic Information System (GIS) software includes several advanced methods for space-use planning, providing decision-makers with powerful tools for spatial analysis. Originally developed for geographic data coordination, GIS has evolved to integrate analytical capabilities that incorporate logical and mathematical relationships between map layers to generate site suitability outputs. More recently, GIS has been enhanced with decision support capabilities, integrating MCDA approaches to handle complex, multi-criteria spatial planning problems [29]. The integration of GIS-MCDA has proven particularly effective for offshore renewable energy applications, as it allows for the visualization and weighting of multiple competing constraints. The first reported studies on GIS-MCDA integration date back to the late 1980s [30], with early applications focusing on land-use planning, including agricultural zoning [31], infrastructure development (such as power transmission lines [32] and pipeline routes [33], and environmental risk assessment, such as earthquake hazard vulnerability [34]. Over time, GIS-MCDA has gained traction in transportation, urban planning, hydrology, water resources, and forestry [35]. However, only more recently has attention shifted toward offshore renewable energy applications, including maritime spatial planning [36] [37]. The ability of GIS-MCDA to handle spatial conflicts, environmental restrictions, and economic feasibility assessments makes it an ideal tool for refining OTEC site selection.

Extreme weather events pose another significant challenge. Since OTEC is most viable in tropical regions, deployment sites are often located in hurricane-prone areas. Strong storms can cause severe damage to surface and floating structures, necessitating resilient designs and careful siting to minimize exposure. Structural reinforcements for offshore platforms and the consideration of seasonal weather patterns are crucial for ensuring system longevity. Additionally, the authors pointed out that land-based OTEC systems could be more suitable in certain regions where hurricanes present a recurring risk. Survivability considerations for OTEC installations align with the structural limits of the platform they are mounted on. While OTEC has relatively few moving parts—limited to the turbine, generator, and pumps—it remains sensitive to extreme platform movement. Although the system can tolerate significant oscillations, an upper limit exists beyond which operation would be compromised.

The selection of optimal locations for OTEC deployment requires balancing multiple technical and environmental considerations while ensuring economic feasibility. Although many coastal and island regions have sufficient thermal gradients to support OTEC, site-specific factors such as seafloor characteristics, exposure to extreme weather, proximity to infrastructure, and ecological constraints play a crucial role in determining viable locations. As OTEC technology advances, refining site selection methodologies with improved GIS-MCDA frameworks and oceanographic modelling will be essential for accelerating the deployment of commercially viable projects.

3.2 ASSEMBLY IN SHIPYARDS AND DEPLOYMENT

The deployment of Ocean Thermal Energy Conversion (OTEC) systems requires efficient assembly, logistics, and offshore installation strategies. Given that no large-scale offshore OTEC project has yet been implemented, parallels can be drawn from the offshore wind, oil and gas, and floating platform industries. In these sectors, shipyards and staging ports play a critical role in modularized fabrication and installation.

Floating Platform

The floating platform is the primary structural component of an OTEC system, housing key equipment such as turbines, generators, transformers, heat exchangers, water pumps, and seawater intake systems. It also integrates the top-joint connection system for the cold-water pipe (CWP), essentially a flexible joint or gimbal system that mitigate stresses from ocean movement. Given the substantial size and complexity of a large-scale OTEC platform—potentially comparable to floating offshore oil and gas structures—its design must prioritize structural stability, seaworthiness, and ease of deployment.

Various floating platform configurations can be considered for OTEC, ranging from semi-submersible platforms, where submerged pontoons provide buoyancy while the platform deck remains above water, to ship-shaped platforms, which resemble FPSO units and are well-suited for large-scale deployment. Other configurations, such as spar platforms, which feature a deep-draft cylindrical hull for enhanced stability, and tension-leg platforms (TLPs), which use vertical tendons to minimize movement, may also be viable depending on site-specific conditions.

To optimize construction efficiency, OTEC floating platforms should be built using a modular assembly approach in shipyards. The hull, power generation module, and seawater intake systems can be fabricated separately and integrated before deployment. Logistical requirements will largely depend on the platform's overall size and type, but assembly may take place in a specialized drydock, a large fabrication yard with a skidway, or a covered warehouse with load-out capabilities.

After assembly, the floating platform is transported to the installation site via heavy-lift vessels, semi-submersible transport ships, or tow-assisted operations using ocean-going tugs, depending on platform size and distance to the deployment site. Offshore operation planning must account for available weather windows to minimize risks from metocean conditions. Upon arrival, the platform is positioned using dynamic positioning (DP) systems before being secured to pre-installed mooring systems. Hook-up operations typically involve remotely operated vehicles (ROVs), winch-controlled connection systems, and automated subsea latching mechanisms for mooring and subsea connections.

Submarine Power Cables

Recent advancements in dynamic cables, driven by the floating wind sector, have led to the development of robust, high-voltage cables potentially capable of meeting OTEC requirements. Similar to floating wind applications, these cables must accommodate platform motions within the permissible excursion range dictated by the mooring system, typically employing a lazy wave configuration to mitigate stress and fatigue [38]. Currently, commercially available dynamic cables are limited to 66kV, though higher voltage variants are under development. At this voltage level, dynamic cables can support power capacities close to 100MW, being suitable for transmission over several dozen kilometers [39][40].

The choice of cable assembly and loading strategy depends on cable length and diameter. For shorter cable sections (typically <10 km), cables can be delivered on reels to the installation port, where a general-purpose vessel equipped with cable rollers, a chute, tensioners, and winches can be used for deployment. For longer cables (typically >10 km), a dedicated cable-laying vessel (CLV) with large turntables, dynamic tensioners, and advanced positioning systems is required.

The installation of dynamic power cables at depths exceeding 1000m presents significant challenges. At depths greater than 500m, seabed cable routing becomes less economical, making suspended configurations a potentially more viable solution [41]. Installation strategies involve either pre-laying the cable before platform deployment or pulling it in post-installation, both requiring specialized vessels equipped with dynamic positioning (DP) and tension control systems. To ensure the lazy-wave configuration, buoyancy elements must be strategically installed along the cable to control free span and mitigate fatigue loads. Additionally, ancillary components such as touchdown protection structures and bend restrictors may be required to minimize stress concentration at critical points, particularly at the seabed touchdown point and platform interface.

The termination interface at the platform must be designed for high mechanical resilience and electrical reliability, as it will be subject to cyclic loading, hydrodynamic forces, and potential platform movements. This typically involves the integration of a bend stiffener, which ensures gradual load transfer and prevents excessive curvature at the connection point.

Cold Water Pipe (CWP)

The CWP is one of the most critical and challenging components of OTEC projects, extending up to 1000 m in length with diameters potentially exceeding 10 m. The choice of material—steel, aluminum, HDPE, or FRP—directly affects logistics, transportation and installation methodology. The study [42] compared CWP designs across different materials, and showed that for a 12 m inner diameter CWP, material selection has a significant influence on total system weight, with steel reaching 17 tons/m, aluminum 10 tons/m, and FRP at 7 tons/m. These weight differences translate into substantial variations in fabrication, handling, and deployment requirements.

Steel and aluminum CWPs provide high structural strength, however, their heavy weight presents significant logistical and installation challenges. Due to their size and weight, steel and aluminum CWPs cannot be fabricated or installed as single units and must be produced in modular segments, to facilitate handling and transportation. Fabrication takes place in shipyard facilities, where pipe sections are precision-welded and coated with protective layers to prevent marine corrosion. Once fabricated, sections are transported to the deployment site on specialized heavy-lift vessels. At the installation site, they are gradually lowered using high-capacity cranes and tensioning systems. The modular segments are joined onboard the installation vessel, either through welding or mechanical couplings, the latter helping to reduce offshore welding time. Once connected, the CWP is progressively lowered using controlled flooding or tensioned deployment techniques. Given their immense weight, these components require ultra-stable deployment platforms, large lifting vessels, and long weather windows to ensure safe and precise offshore installation.

On the other hand, compared to metallic CWPs, HDPE and FRP offer significant reductions in weight, simplifying transportation, handling, and installation. HDPE is highly flexible, allowing for continuous pipe lengths fabrications of up to 600m, but structural limitations restrict its diameter to 4m or less, making it impractical for large-scale (100MW) OTEC applications unless deployed in bundled configurations. FRP, on the other hand, is the preferred choice for large-diameter CWPs due to its high strength-to-weight ratio, corrosion resistance, and deep-sea adaptability [5]. Typically fabricated in 10–20m modular sections, FRP requires precise mechanical or adhesive bonding to ensure seamless integration. Its established use in deep-sea risers and subsea pipelines demonstrates its potential for large-scale OTEC deployment. HDPE and FRP CWPs, being significantly lighter, allow for alternative installation techniques, such as float-and-sink deployment, where pipes are towed to the site, flooded, and gradually lowered.

Selecting the optimal CWP material and installation strategy is essential for ensuring the reliability and cost-effectiveness of OTEC systems.

3.3 MOORING AND ANCHORING SYSTEMS FOR OTEC

Mooring Systems

A mooring system is an essential infrastructure that ensures the station-keeping and stability of floating offshore structures, such as Ocean Thermal Energy Conversion (OTEC) plants. Figure 4 illustrates the three main types of mooring systems: catenary, taut, and semi-taut.

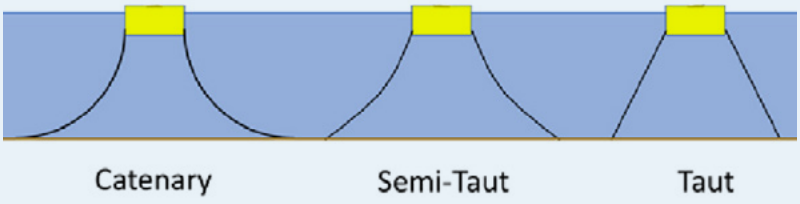

Figure 4: Mooring systems.

A catenary mooring system is a type of slack mooring that uses steel chains, wires, or synthetic ropes to form a catenary curve between the floating structure and the anchor. The slack allows movement both vertically and horizontally with the lower part of the mooring line lying on the seabed, thus increasing the footprint and acting as a counterweight near the anchor. This system is easier to install than taut mooring system and is most suitable for shallower waters. However, in deeper waters, maintaining the necessary slack requires longer mooring lines, increasing material costs and making the system less economical. The catenary mooring system is the most conventional and widely applied mooring configuration.

A taut-leg mooring system consists of pre-tensioned mooring lines which maintain a fixed distance between the anchor point and the floating foundation. This configuration provides stability to floating platforms that are not inherently stable in their design. The system has a small seabed footprint and offers high stability, but it is costly and challenging to install. In contrast to catenary moorings, taut moorings prevent vertical movement of the structure. However, they are more susceptible to fatigue loading, and failure of any single line could lead to catastrophic instability.

A semi-taut mooring system combines features of both taut and catenary mooring systems, allowing for some vertical and horizontal movement while reducing fatigue loading and requiring shorter mooring lengths than a catenary system. However, the increased movement reduces overall stability, which must be compensated for in the design of the structure. Semi-taut and taut mooring systems are both less costly in deep-water applications than catenary systems, as they require shorter mooring lines and occupy less seafloor space, which leads to material savings, reduced weight, and lower costs at greater depths.

Components and Ancillaries

A mooring system consists of several components, each serving a specific function in maintaining the position of the platform, while resisting environmental forces such as waves, wind, and currents. The primary components of a mooring system include mooring lines, anchors, connectors, and fairleads. A brief description is provided below:

Chains: chains are widely used in offshore mooring systems due to their durability, simplicity in inspection, and cost-effectiveness. Available in diameters ranging approximately from 25 to 180 mm, chains come in various grades (R3, K3, R3S, R4, R5), each offering different strength levels based on steel quality. Chains are used in catenary mooring systems due to their weight and abrasion resistance. There are two main types of chains: studlink (heavier, higher drag, better fatigue resistance) and studless. While chains are cost-effective and durable, they are depth-limited due to reduced working strength at greater depths and can be very complex and difficult to be safely deployed. Additionally, corrosion management is essential to maintain long-term performance.

Wire ropes: steel wire ropes are widely used in offshore mooring applications due to their strength, flexibility, and durability. Compared to chains with equivalent breaking load, wire ropes are lighter and exhibit higher elasticity. However, they are more susceptible to damage and corrosion. Wire ropes are primarily identified by their construction, which includes the number of strands in the rope and the number of wires within each strand.

Synthetic fiber ropes: synthetic fiber ropes have become increasingly popular in mooring applications due to their lightweight and high elasticity. However, their use adds complexity and increases installation costs. Various synthetic materials are available, with polyester being the most widely used due to its proven performance in offshore oil and gas applications. Polyester ropes are typically constructed from multiple smaller sub-ropes in a parallel configuration, offering strength and durability. However, an important disadvantage is their non-linear axial load elongation, meaning their stretching behaviour varies depending on the type of loading. Other synthetic alternatives include nylon and high-modulus polyethylene.

Although the different types of mooring lines can be described in isolation, mooring systems may use a hybrid configuration. An idealised deep-water catenary mooring line typically consists of three sections:

- Seabed chain section: provides dead-weight, friction, and high abrasion resistance.
- Synthetic fiber section: located just above the seabed to reduce weight and add elasticity.
- Steel wire rope section: located near the sea surface for increased abrasion resistance.

Connectors: connectors are used to join different chain sections, or to connect chains to ropes, to connect padeyes on anchors or vessels, etc. Typical connection elements include kenter shackles, D-shackles, C-links and swivels. The D-shackle is very common in the offshore industry. It has a D shape and consists of a bow, which is closed by a pin. Mooring connectors are designed to take the full breaking strength of the chain and rope, but their fatigue properties require special attention for long-term use in mooring systems.

Clump weights: clump weights are typically made from steel or concrete. Clump weights are added to the mooring line to increase the restoring force, limiting excursions and improving station-keeping. Furthermore, clump weights optimise mooring line geometry. Their installation along the mooring lines maintains a favourable catenary shape, which ensures flexibility under normal conditions, and provides the necessary stiffness during extreme weather events. Other advantages include: the ability to reduce peak tensions and fatigue loads by distributing these forces across the mooring system; contribution to the anchor holding capacity.

Buoyancy modules: subsurface buoys can be attached to the mooring line to provide compliance in the system and to reduce the vertical load component. This layout is ideal for deep-water applications, since it minimises the mooring line dynamics and reduces the weight of the mooring line supported by the platform. The buoyancy modules can also be used to create hybrid or semi-taut configurations.

Fairlead/chain stoppers: the connection between the mooring line and the floating platform is ensured by a fairlead or chain stopper. The fairlead is a device that guides the chain, wire or rope near the point where the mooring line is connected to the floating platform, preventing excessive wear by reducing the friction during the operational phase of the mooring lines. Fairleads should be designed against fatigue and extreme loadings. The chain stopper is a device used to secure and manage the chain of an anchor or mooring system. It is designed to stop the movement of the chain and to hold it in place when necessary.

Anchor Types

Anchors are used to secure the mooring lines to the seabed and are selected based on the seabed conditions and load requirements. As depth and environmental conditions increase, the factors of practicality, transportation, and installation costs become key considerations. In extreme cases requiring high loading capacity, rigidity, or uplift resistance, especially with size or space constraints, innovative and costly solutions may be required. The main anchor types are illustrated in Figure 5.

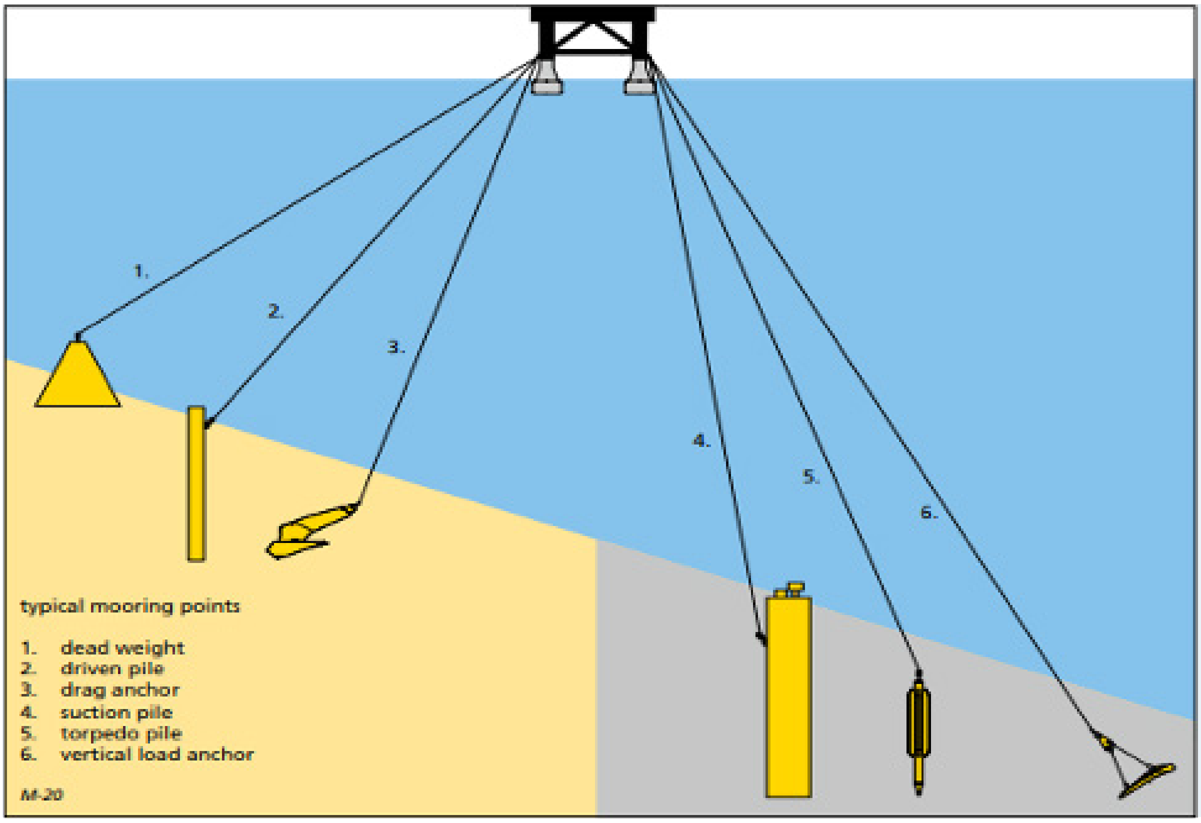

Figure 5: Different anchor types for various water depths. Source: [43].

A brief description of the main anchor types is presented below:

Dead weight/gravity anchor: a dead weight anchor is a heavy object placed on the seabed to resist vertical and/or lateral loads. The holding capacity is generated by the weight of the material used and partly by the friction between the dead weight and the seabed. Made of concrete or steel, it is cost-effective and adaptable to various conditions, but less efficient (ratio of holding capacity to weight) than other anchor types. Heavy lift capabilities are required for installation and are unsuitable for steep seabeds. However, it may be the only reasonable anchoring option on very hard bottoms.

Driven pile: driven piles are used when cheaper options like gravity or drag anchors are unsuitable. Typically made of rolled steel, they are long, slender tubular piles (L/D >~ 10) with diameters of 0.6 to 2.5 m for large mooring systems. The holding capacity is generated by a combination of friction of the soil along the pile and the lateral soil resistance. Installed by crane and driven with a piling hammer, they can be costly, especially underwater. On rocky seafloors or thin sediment over rock, pre-drilled sockets and grouting are required. Their main disadvantages are the high costs and the need for specialised installation equipment.

Drag embedment anchor: drag embedment anchors are common in industry, have broad use experience and are relatively easy to install and proof. They are designed to penetrate the seabed either partially or fully. Its holding capacity depends from the soil resistance in front of the anchor. They are well-suited for large horizontal loads, but generally not for vertical loads.

Suction pile: it is a relatively recent type of anchor, and is widely used in offshore oil and gas mooring. Unlike most driven piles, suction piles are shorter and wider, often called suction caissons. During installation, the suction caisson acts like an inverted bucket. Initial penetration occurs under its own weight, followed by further embedding through suction, created by pumping water out from inside. This pressure differential forces the caisson deeper into the seabed. After installation, the valves are sealed. The holding capacity of the suction anchor is generated by a combination of friction of soil along the suction anchor and lateral soil resistance, being capable of withstanding both horizontal and vertical loads.

Torpedo pile: torpedo piles are free-fall anchoring systems designed for deep-water mooring applications. They are long, slender, high-density steel piles that are dropped from a height of 100-150 metres above the seabed, allowing them to accelerate, fall freely, and penetrate the soil after impact. Their embedment depth depends on soil conditions, making them particularly suited for soft clayed soils, but not capable in stiff to hard clays. Torpedo piles can resist both horizontal and vertical loads, providing a secure anchoring point. The installation is low-cost and efficient, as it requires minimal equipment. These characteristics make torpedo piles an effective solution for deep water anchoring, where conventional piling methods are impractical.

Vertical load anchor: vertical load anchors are a type of drag embedment anchor designed to withstand both horizontal and vertical loads. They are installed similarly to conventional drag anchors, but penetrate much deeper into the seabed. Vertical load anchors are particularly suited for deep-water mooring applications, such as taut mooring systems that require vertical load resistance. They offer high efficiency, easy installation, and strong holding capacity for soft to medium-strength soils, where they can achieve the necessary depth and resistance for secure mooring.

Considerations for OTEC

OTEC plants must be placed in locations with sufficient thermal gradients between warm surfaces waters and cold deep waters for efficient operation. These locations are typically found near tropical islands or volcanic atolls, where the seabed features steep slopes, irregular bathymetry, and variable sediment thicknesses. Such conditions pose significant challenges for mooring and anchoring, requiring solutions capable of withstanding wind, waves, strong currents, and extreme events. The diversity of seabed conditions at potential anchor sites often necessitates the use of different anchoring solutions adapted to each specific location. In particular, volcanic rock formations, common in these regions, present unique challenges due to their hardness, heterogeneity, and potential for fractures. Optimised anchoring systems, such as specialised drilling techniques, grouted anchors, or dynamically installed solutions, are required to ensure secure and reliable mooring in these complex seabed conditions.

These challenges have been discussed in several studies. McHale et al. [44] described the deployment of a mini-OTEC plant in a seabed characterised by steep rocky slopes, where the cold water pipe made of polypropylene is also the mooring line. The Coastal Response Research Center discussed the technical readiness of OTEC systems, including the need for effective mooring systems on high slope bottoms [45]. It highlighted the importance of adapting codes and standards for OTEC platforms and pipes. Taylor et al. [46] conducted detailed site-specific assessments for selecting appropriate anchoring systems. Several anchor designs, including drag embedment anchors, suction piles, and vertical load anchors, have been investigated for different soil conditions.

These challenges are also critical to other offshore technologies. Somoano et al. [47] performed an experimental study on the effect of bathymetry irregularities on mooring dynamics considering a concrete-based semi-submersible platform. They concluded that the bathymetry has a strong influence on the energy dissipation of the mooring lines, becoming even more important under snap loading.

3.4 MITIGATING VORTEX-INDUCED VIBRATIONS IN OTEC INFRASTRUCTURE

Vortex-Induced Vibrations

Vortex-Induced Vibrations (VIV) occur when a bluff body, such as a pipeline, riser, or cold-water intake pipe, is exposed to a fluid flow. As the fluid moves past the structure, vortices are generated alternately on either side of the structure. The asymmetric nature of vortex shedding causes an irregular pressure distribution across the body, which generates a periodic lift force perpendicular to the flow direction, and thereby inducing oscillatory motion known as VIV. When not controlled, the low- to moderate-frequency oscillations can lead to fatigue damage or even structural failure.

The Reynolds number (Re) is a critical dimensionless quantity that predicts the transition from laminar to turbulent flow and determines whether vortex shedding occurs. It is defined as $Re = UD/v$, where U is the fluid velocity, D is the cylinder diameter, and v is the kinematic viscosity of the fluid. In the case of an OTEC cold water intake pipe, with a typical diameter of 2.5–4 metres and a flow velocity of approximately 0.1 m/s, the Reynolds number falls within the range of 2×10^5 to 4×10^5. This range suggests that VIV is a realistic concern for such structures.

Another key parameter in VIV analysis is the Strouhal number (St), which relates the vortex shedding frequency (f_s), the flow velocity, and the body diameter, given by $f_s = St\,(U/D)$. Empirical investigations have shown that for a wide range of Reynolds numbers ($300 \leq Re \leq 2 \times 10^5$), the Strouhal number remains relatively constant at approximately $St \approx 0.2$ [48]. This assumption is frequently used in VIV studies for predicting vortex shedding behaviour.

As a cylindrical structure begins to oscillate due to vortex shedding, the interaction between the vortices and the structure alters the wake dynamics, potentially increasing vortex strength and modifying the flow behaviour. The most critical consequence of this interaction is the phenomenon known as "lock-in," which occurs when the vortex shedding frequency synchronises with the natural frequency of the structure. The natural frequency (f_n) is the frequency at which the structure naturally vibrates when disturbed, and it depends on the mass and stiffness of the system. When lock-in occurs, there would be a sudden increase in the amplitude of the oscillations, resulting in more substantial vibrational effects. Even at low current velocities, the lock-in can create very large oscillation effects, which can sometimes be destructive, making it a major concern in VIV analysis.

A useful tool for describing lock-in behaviour is the reduced velocity (U_r), which is defined as $U_r = U/(f_n D)$ and approximated by $U_r \approx 1/St$. Empirical evidence suggests that lock-in normally occurs for values of U_r between 4 and 10, meaning vortex shedding frequencies could lie between 0.5 f_n up to 1.25 f_n [49]. Therefore, it becomes imperative to understand and design against VIV when considering OTEC cold-water intake pipes to prevent excessive vibrations and structural fatigue.

Vortex-Induced Vibrations Modelling

VIV can be modelled in many different ways, and over the years, different models have been developed and studied. A comprehensive overview of these models is provided by Gabbai and Benaroya [50]. Semi-empirical models, which are commonly used in engineering, can be classified into three broad categories: the first is single degree-of-freedom models, which use a single dynamic equation to describe the motion; the second is force-decomposition models, which are based on experimental measurements of specific force components acting on the structure; and the third is wake-body coupled models, where the motion of the body is connected with the wake oscillation through a common term in the governing equations.

An alternative approach to VIV modelling is the use of numerical methods, which includes techniques such as the vortex-in-cell method, where the flow field is represented by a collection of moving vortex elements. Other numerical approaches include Reynolds-Averaged Navier-Stokes (RANS) methods and the Finite Element Method (FEM). When coupled with Fluid-Structure Interaction (FSI) solvers, RANS-based simulations provide a reasonable balance between accuracy and efficiency in VIV modelling, when compared to Large Eddy Simulation (LES). However, due to the complexity and high computational requirements, numerical methods are often impractical for engineering applications. For this reason, semi-empirical models tend to be the preferred approach to most engineering applications, since they offer a computationally efficient and sufficiently accurate way for simulating VIV.

Suppression Measures

VIV poses a significant challenge for OTEC cold water intake pipes due to their large diameter, unsupported over long spans, and exposed to ocean currents. These pipes often extending up to 1000 metres in length and subjected to relatively low but steady ocean currents, are prone to fatigue damage and excessive vibrations if VIV is not effectively mitigated. Due to the long-recognised problem of VIV, various suppression methods have been extensively researched and developed. These suppression techniques can be classified as surface protrusions, shrouds, near-wake stabilisers, fairings, and hybrid strategies.

1. **Surface Protrusions:** Helical strakes are among the most widely used VIV suppression devices in offshore structures. They consist of spiral-shaped fins wrapped around the surface of a pipeline to disrupt vortex formation. By altering the flow separation points along the pipe surface, strakes prevent coherent vortex shedding, which in turn diminishes oscillatory forces. Advantages include: ease of installation on large-diameter OTEC pipes; they provide a passive suppression mechanism, requiring no external power. The disadvantages comprise the increase in drag forces, which can pose a major issue in deep-water applications where mooring loads must be minimised; may require additional structural reinforcement as a result of higher hydrodynamic forces. Figures 6 and 7 shows various examples of omnidirectional surface protrusions.

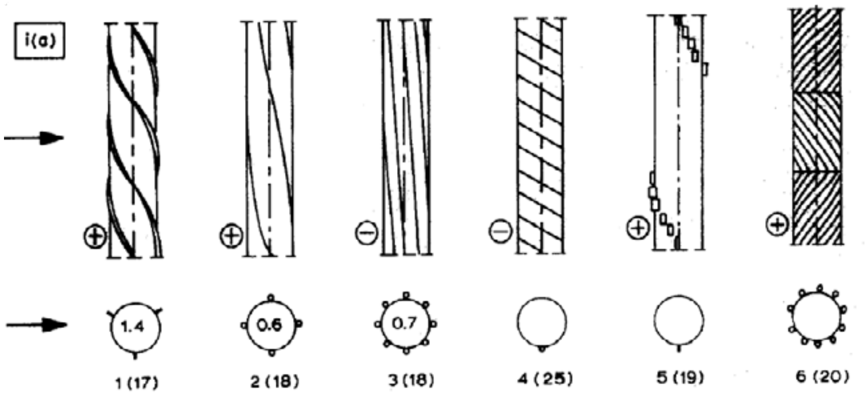

Figure 6: Omnidirectional surface protrusions. Source: [51].

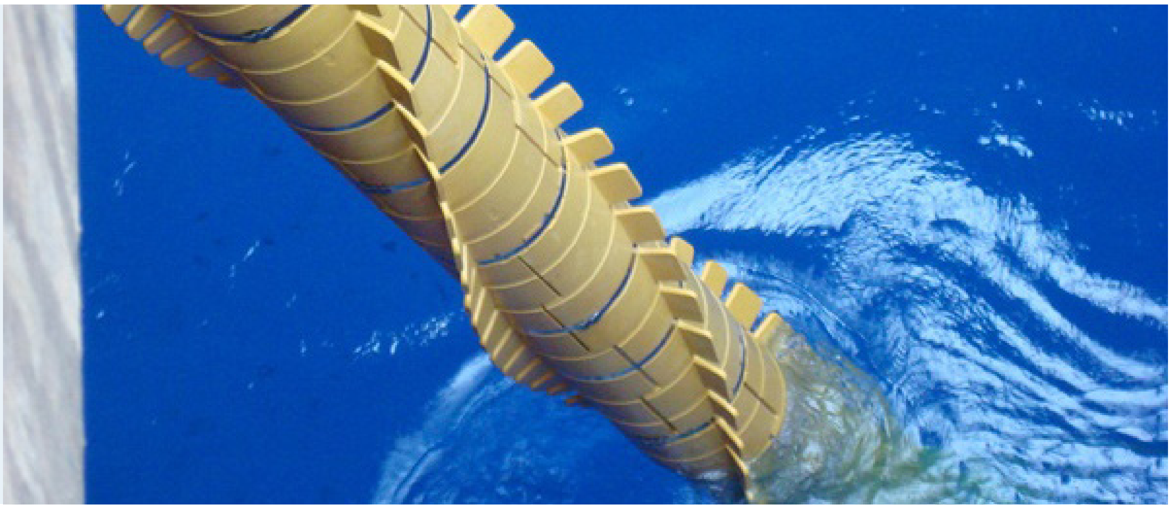

Figure 7: Lankhorst strakes for VIV suppression. Source: [52].

2. **Shrouds:** Shrouds, including perforated covers, gauze, axial rods and slats, act as a barrier to disrupt vortex shedding around the pipe. The main advantages are: reduce vortex shedding and VIV amplitude by modifying the wake structure; can be designed with minimal added weight, making it practical for ultra-deep installations. Main disadvantages include: difficulty to implement on very long OTEC pipes due to material and deployment constraints; high maintenance requirements due to potential marine bio-fouling and degradation over time. Figure 8 shows various examples of shrouds.

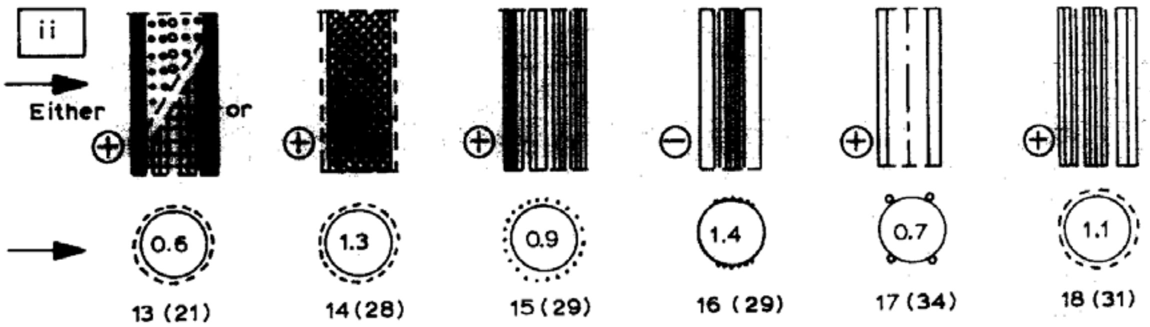

Figure 8: Shroud solutions for VIV suppression. Source: [51].

3. **Near-Wake Stabilisers:** The basic function of near-wake stabilisers, such as splitter plates, saw-tooth plates, guiding plates, or guiding vanes is to reduce VIV by modifying how the entrainment layers interact at the confluence point, preventing the formation of vortices. Its main advantages are the higher effectiveness of this method over surface protrusions for reducing both VIV and drag, and that it helps stabilise the wake and prevent alternating vortex shedding. The main disadvantages are the difficulty in scaling for large, flexible OTEC intake pipes that undergo VIV and bending deformations, and the costs and complexity of installation on submerged pipes of several hundred metres in length. Figure 9 shows various examples of near-wake stabilisers.

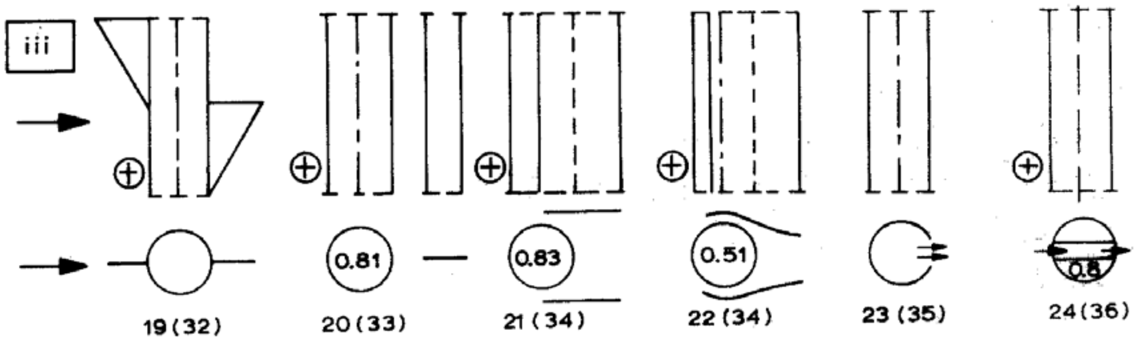

Figure 9: Near-wake stabilisers for VIV suppresion. Source: [51].

4. **Fairings:** Fairings are free-rotating, teardrop-shaped devices that are attached to pipelines to passively align with ocean currents. They reduce vortex shedding caused by the pipe and decrease the hydrodynamic drag significantly. The main advantages are: optimal choice for simultaneously reducing both VIV and drag; their passive rotation allows for self-adjustment according to changing current directions; and energy-efficient because they do not require active control or an external power source.

Figure 10 presents a fairing solution provided by Lankhorst Offshore.

Figure 10: Lankhorst fairings for VIV suppression. Source [53].

5. **Hybrid Suppression Strategies:** Given the unique challenges of OTEC cold-water pipes, a hybrid approach combining multiple VIV suppression techniques is often necessary. For example: helical strakes may be used in sections where high risk of VIV is expected, or fairings could be installed at deeper sections to reduce drag and stabilise the flow. VIV suppression is a critical design consideration for OTEC cold water intake pipes, as excessive vibrations can lead to fatigue failure and compromised efficiency. While helical strakes, fairings, and near-wake stabilisers are commonly used in offshore applications their practical implementation for ultra-deep, large-diameter OTEC pipes is still under research [54-56]. A combination of passive suppression methods, tailored to the specific hydrodynamic conditions at different depths, is likely the best approach for ensuring the long-term reliability of OTEC infrastructure.

4

KEY RECOMMENDATIONS: STRATEGIC PRIORITIES

4.1 ENHANCING OTEC RELIABILITY THROUGH INNOVATION AND TECHNICAL ADVANCEMENTS

1 Optimizing Site Selection for OTEC Deployment

To improve the identification of suitable locations for OTEC deployment, decision-makers should enhance GIS-MCDA (Geographic Information Systems - Multi-Criteria Decision Analysis) frameworks by integrating high-resolution oceanographic, geophysical, and environmental datasets. This would allow for more precise site selection while ensuring economic and environmental feasibility. Additionally, developing standardized oceanographic modeling tools will help assess long-term thermal gradients, seabed stability, and exposure to extreme weather events. Establishing comprehensive environmental impact assessment (EIA) guidelines is also crucial to balance ecological preservation with project viability.

2 Enhancing Cold Water Pipe (CWP) Materials and Installation Strategies

Selecting optimal cold water pipe (CWP) materials and installation strategies is essential for ensuring the longevity and reliability of OTEC systems. The use of advanced composite materials, such as high-density polyethylene (HDPE) and fiber-reinforced polymers (FRPs), can enhance durability, reduce weight, and minimize biofouling. Flexible pipe-laying strategies that adapt to varying seabed topographies, including modular segmented construction and dynamic positioning techniques, should be implemented to facilitate deep-sea installation. Additionally, real-time monitoring systems must be adopted to track structural integrity and detect early-stage pipe degradation.

3 Developing Resilient Anchoring and Mooring Systems

The diversity of seabed characteristics at potential OTEC sites requires adaptable and resilient anchoring solutions. Advancing numerical modeling tools will allow for more precise simulations of mooring behavior under varying environmental conditions, including wave impacts, strong currents, and extreme weather. Standardizing mooring and anchoring guidelines is essential to align OTEC platform requirements with best practices from offshore wind and floating structures, ensuring structural resilience and regulatory consistency.

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4 Mitigating Vortex-Induced Vibrations in Cold Water Pipes

Vortex-Induced Vibrations (VIV) present a significant fatigue risk for OTEC cold-water intake pipes due to their large diameter, unsupported spans, and exposure to ocean currents. To mitigate these risks, passive VIV suppression techniques should be implemented. Furthermore, developing real-time structural health monitoring systems will help detect excessive vibrations and dynamically optimize suppression measures.

5 Scaling OTEC from Demonstration Projects to Commercial Deployment

Securing financial support for scaling OTEC technology beyond small-scale demonstration plants remains one of the most significant barriers to commercialization. Government-backed financial incentives, such as R&D grants, production-based subsidies, and investment tax credits, must be expanded to reduce initial costs and encourage private sector participation. Promoting international collaboration through pooled funding from national governments, regional development banks, and climate financing mechanisms can help de-risk large-scale OTEC projects. Engaging the private sector by fostering partnerships with venture capital firms, utilities, and offshore engineering companies will allow for greater industry expertise and financial backing. Additionally, standardizing performance metrics and regulatory pathways for OTEC projects will provide clearer guidelines for permitting, financing, and risk assessment, ultimately improving investor confidence.

6 Investing in Research and Development for Technical Advancements

Governments and industry stakeholders should prioritize investment in research and development (R&D) to develop cost-effective mitigation strategies for addressing key technical challenges in OTEC deployment. This includes advancing computational modeling techniques, conducting experimental testing, and integrating new materials and technologies into OTEC system designs. Collaboration with marine engineers, oceanographers, and offshore energy experts is also crucial to refining deployment strategies and improving system efficiency. Incorporating these advancements into OTEC infrastructure planning and regulatory frameworks will enhance system resilience and contribute to reducing long-term maintenance costs, improving OTEC's competitiveness in the offshore renewable energy sector. Establishing technical guidelines and monitoring protocols will further support the scalability of OTEC by ensuring that engineering best practices are applied across different deployment sites.

4.2 ADOPTION OF OTEC IN SIDS

To enable the effective implementation of OTEC in SIDS, a comprehensive and forward-looking strategy is required. These recommendations are based on insights gathered through stakeholder engagements conducted during 2024 by Islands Innovation in the context of PLOTEC project. A stakeholder mapping exercise was carried out to identify key experts from civil society, academia, the energy industry, the private sector, and government across the Caribbean, Pacific, and Atlantic, Indian Ocean and South China Sea (AIMS) regions. The recommendations focus on enhancing energy security, reducing reliance on imported fossil fuels, and aligning OTEC with national climate goals. The following structured approach addresses both immediate priorities and long-term sustainability.

1 Establishing a Clear Policy Framework

A robust and transparent policy framework is essential to support the development of OTEC. Governments should define a strategic vision that aligns OTEC adoption with national energy and climate objectives while establishing regulatory requirements and incentives to attract investment. Ensuring that OTEC integrates seamlessly with other renewable energy initiatives will create a cohesive and supportive energy transition.

2 Raising Public Awareness and Engaging Stakeholders

Public support and stakeholder involvement are critical for the success of OTEC projects. Raising awareness through targeted public campaigns will help communities understand the benefits and address any concerns. Transparency and trust can be fostered by organizing stakeholder engagement initiatives, including workshops and information sessions, allowing communities to participate in the decision-making process.

3 Strengthening International Collaborations

Developing OTEC technology and ensuring its successful deployment requires international partnerships. Collaboration with global organizations and countries experienced in OTEC and renewable energy will provide valuable insights and resources. Sharing best practices from successful OTEC projects will help overcome common implementation challenges. Additionally, engaging with regional SIDS intergovernmental institutions, such as the OECS, CARICOM, and PIFS, will facilitate the harmonization of policies and foster collective efforts toward sustainable energy development.

4 Investing in Infrastructure and Capacity Building

For OTEC to be effectively implemented, national energy infrastructure must be upgraded to accommodate its integration. Alongside infrastructure development, investment in technical training and capacity-building programs will ensure a skilled local workforce capable of operating and maintaining OTEC systems. This long-term commitment to workforce development will create new economic opportunities and drive the sustainability of OTEC projects.

5 Supporting Research and Innovation

Ongoing research and development are necessary to enhance the feasibility of OTEC. Governments and industry stakeholders should provide funding to support technological advancements tailored to the unique challenges of SIDS. Establishing partnerships with academic and research institutions will encourage innovation and continuous improvements in OTEC efficiency, helping to reduce costs and expand deployment opportunities.

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6 Steps for OTEC Implementation in SIDS

To move from planning to execution, specific steps must be taken. Establishing a dedicated national OTEC task force with representatives from government, industry, and local communities will ensure that efforts are coordinated and aligned with national goals. Financial incentives should be introduced to encourage private-sector investment and offset high capital costs. The implementation of pilot projects in key locations will provide real-world data to validate the technology's feasibility and build confidence among stakeholders. Updating regulatory frameworks will streamline approval processes and environmental impact assessments while providing clear guidelines for project permits, operational standards, and long-term sustainability. Furthermore, knowledge-sharing initiatives, such as regional and international forums, workshops, and training sessions, will promote best practices and build local capacity for OTEC deployment.

7 Prioritizing Short-Term and Long-Term Actions

In the next one to two years, priority should be given to reviewing and updating policy and regulatory frameworks to accommodate OTEC projects. Public awareness campaigns should be launched to educate stakeholders and the general population about the benefits of OTEC. Establishing international partnerships will enable SIDS to access the technical expertise and financial resources necessary to accelerate implementation.

Over the next three to five years, infrastructure development should be prioritized to facilitate the seamless integration of OTEC into national energy systems. Research and development must continue to improve efficiency, reduce costs, and address emerging technical challenges. Capacity-building programs should be expanded to ensure a trained workforce capable of supporting OTEC operations. A robust monitoring and evaluation framework should be developed to track project performance and long-term sustainability, ensuring that OTEC contributes to energy security and climate resilience in SIDS.

Implementing these recommendations will accelerate the adoption of OTEC in SIDS, reducing dependency on imported fossil fuels, enhancing energy security, and contributing to climate resilience. A strategic approach that combines policy development, stakeholder engagement, technological innovation, and international collaboration will position OTEC as a viable and sustainable renewable energy solution for island communities.

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5

CONCLUSION

ADVANCING OTEC AS A SUSTAINABLE ENERGY SOLUTION

OTEC's path to large-scale deployment. Refining site selection methods, advancing engineering solutions for cold water pipes and moorings, mitigating VIV effects, and securing financial pathways will make OTEC a commercially viable and sustainable energy solution. This is particularly crucial for Small Island Developing States (SIDS) and coastal regions that require reliable renewable energy sources to enhance their energy security and economic resilience.

As OTEC projects move toward commercialization, ensuring responsible and sustainable deployment will require comprehensive environmental and social impact assessments. While previous studies suggest that OTEC's risks are manageable, long-term field studies are essential to validate these assumptions and assess potential ecological impacts. Governments, research institutions, and industry stakeholders should invest in developing robust environmental monitoring frameworks to track and mitigate any disruptions to marine ecosystems. Adaptive management strategies, similar to those applied in other renewable energy sectors, should be integrated into regulatory processes to ensure that OTEC deployment evolves in response to emerging scientific findings. Establishing standardized environmental guidelines and best practices for site selection, resource use, and ecosystem protection will contribute to the long-term sustainability and public acceptance of OTEC technology.

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BIBLIOGRAPHY

[1] IEA-OES (2024), Self-Sustained Desalination Technologies Powered by Ocean Energy

[2] Freeman, M.C., Garavelli, L., Wilson, E., Hemer, M., Abundo, M.L., Travis, L.E. 2022. Offshore Aquaculture: a Market for Ocean Renewable Energy. Report for Ocean Energy Systems (OES). April 2022. www.ocean-energy-systems.org

[3] IEA-OES (2022), Using sea water for heating, cooling and power production. www.ocean-energy-systems.org

[4] Rivera, G., Felix, A., & Mendoza, E. (2020). A Review on Environmental and Social Impacts of Thermal Gradient and Tidal Currents Energy Conversion and Application to the Case of Chiapas, Mexico. *International Journal of Environmental Research and Public Health, 17*(21), 7791. https://doi.org/10.3390/ijerph17217791

[5] Coastal Response Research Center. (2010). Ocean Thermal Energy Conversion: Assessing Potential Physical, Chemical and Biological Impacts and Risks (p. 39). University of New Hampshire, Durham, New Hampshire.

[6] Rivera, G., Felix, A., & Mendoza, E. (2020). A Review on Environmental and Social Impacts of Thermal Gradient and Tidal Currents Energy Conversion and Application to the Case of Chiapas, Mexico. *International Journal of Environmental Research and Public Health, 17*(21), 7791. https://doi.org/10.3390/ijerph17217791

[7] OES. (2021). *White Paper on Ocean Thermal Energy Conversion (OTEC).* www.ocean-energy-systems.org

[8] Giraud, M., V. Garçon, D. delaBroise, S. L'Helguen, J. Sudre, and M. Boye. 2019. Potential effects of deep seawater discharge by an Ocean Thermal Energy Conversion plant on the marine microorganisms in oligotrophic waters. Sci. Total. Environ. 693: 133491.

[9] Garduño, E.P.; García, A.; Rodríguez, Y.; Bárcenas, J.F.; Alatorre, M.A.; Cerezo, E.; Guadalupe, J.; Romero, V.M.; Silva, R. Conversión de Energía Térmica Oceánica (OTEC), Estado del Arte; CEMIE-O, Universidad Autonoma de Campeche: Mexico City, Mexico, 2017; p. 136.

[10] Copping, A.; Farr, H. (2024). *Feasibility of Ocean Thermal Energy Conversion (OTEC) Development for U.S. Islands*. Paper presented at Pan American Marine Energy Conference (PAMEC 2024), Barranquilla, Colombia.

[11] Devault, D. A., and Péné-Annette, A. (2017). Analysis of the environmental issues concerning the deployment of an OTEC power plant in Martinique. Environmental Science and Pollution Research, 24(33), 25582–25601. doi:10.1007/s11356-017-8749-3.

[12] Grandelli, P., Rocheleau, G., Hamrick, J., Church, M., and Powell, B. (2012). Modeling the Physical and Biochemical Influence of Ocean Thermal Energy Conversion Plant Discharges into their Adjacent Waters (DOE/ EE0003638-1). Makai Ocean Engineering, Inc. doi:10.2172 /1055480.

[13] Lu, S.; Yu, J.; Golmen, L.; Wesnigk, J.; Papandroulakis, N.; Anastasiadis, P.; Delory, E.; Quevedo, E.; Hernández, J.; Llinás, O. (2014). *Environmental aspects of designing multi-purpose offshore platforms in the scope of the FP7 TROPOS Project*. Paper presented at OCEANS 2014 Taipei, Taipei, Taiwan.

[14] Auvray, C., Ledoux, S., Diaz, B., Yvon, C., and PougetCuvelier, A. (2015). Environmental impact assessment for an OTEC plant in Martinique Island. La Houille Blanche, 2, 60–66. doi:10.1051/lhb/20150020.

[15] Langer, J., Quist, J., & Blok, K. (2020). Recent progress in the economics of ocean thermal energy conversion: Critical review and research agenda. *Renewable and Sustainable Energy Reviews*, 130, 109960. https://doi.org/10.1016/j.rser.2020.109960.

[16] IEA-OES. (2024). Ocean Thermal Energy Conversion (OTEC) Economics: Updates and Strategies. www.ocean-energy-systems.org

[17] The Barbados Light & Power Company Limited, "Billing Under the Renewable Energy Rider : The Barbados Light & 560 Power Company Limited. https://support.blpc.com.bb/support/solutions/articles/42000060966-billing- 561 under-the-renewable-energy-rider.

[18] The Barbados Light & Power Co. Ltd. Fuel Clause Adjustment. https://www.blpc.com.bb/index.php/customer-care/fuel-clause-adjustment

[19] Light & Power Holdings, "Annual Report 2013," 2014. [Online]. Available: https://www.emeracaribbean.com/docs/librariesprovider11/stakeholder-documents/lphareport2013.pdf?sfvrsn=d92ab7b0_2

[20] Emera Caribbean, "2015 Annual Report," 2016. [Online]. Available: https://www.emeracaribbean.com/docs/librariesprovider11/stakeholder-documents/emera-17-final-approved-(opt).pdf?sfvrsn=8d67a0d6_2-
Fair Trading Commission, "2017 Annual Report," 2018. [Online]. Available: https://www.ftc.gov.bb/library/2017_ftc_annual_report.pdf

[21] The Barbados Light & Power Company Limited, "Non-consolidated Financial Statements ," 2019. [Online]. Available: https://www.ftc.gov.bb/library/blip_app/appl/2020-06-19_exhibit_rj3_blpc_financials_nonconsol_2019.pdf

[22] Inter-American Development Bank, "Energy Transition in Barbados: Opportunities for Adaptation of Energy Taxes to Mitigate Loss of Government Revenue," 2022. https://publications.iadb.org/publications/english/document/Energy-Transition-in-Barbados-Opportunities-for-Adaptation-of-Energy-Taxes-to-Mitigate-Loss-of-Government-Revenue.pdf

[23] Ministry of Energy and Water Resource, "Barbados National Energy Policy 2019 - 2030," 2019. [Online]. Available: https://energy.gov.bb/publications/barbados-national-energy-policy-bnep/

[24] Our World Data, "Barbados: CO_2 Country Profile." [Online]. Available: https://ourworldindata.org/co2/country/barbados

[25] Our World Data, "Barbados: CO_2 Country Profile." [Online]. Available: https://ourworldindata.org/co2/country/barbados

[26] Galparsoro I, Liria P, Legorburu I, Bald J, Chust G, Ruiz-Minguela P, Pérez G, Marqués J, Torre-Enciso Y, González M, Borja A. A Marine Spatial Planning Approach to Select Suitable Areas for Installing Wave Energy Converters (WECs), on the Basque Continental Shelf (Bay of Biscay). Coastal Management 2012; 40:1-19.

[27] Hall, Kashawn & Kelly, Solange & Henry, Legena, 2022. «Site selection of Ocean Thermal Energy Conversion (OTEC) plants for Barbados,» Renewable Energy, Elsevier, vol. 201(P2), pages 60-69.

[28] Garduño-Ruiz, Erika Paola, Rodolfo Silva, Yandy Rodríguez-Cueto, Alejandro García-Huante, Jorge Olmedo-González, M. Luisa Martínez, Astrid Wojtarowski, Raúl Martell-Dubois, and Sergio Cerdeira-Estrada. 2021. "Criteria for Optimal Site Selection for Ocean Thermal Energy Conversion (OTEC) Plants in Mexico" Energies 14, no. 8: 2121. https://doi.org/10.3390/en14082121

[29] Eastman JR, Jin W, Kyem PAK, Toledano J. Raster procedures for multi-criteria/multi-objective decisions. Photogrammetric Engineering and Remote Sensing 1995; 61: 539-47.

[30] Diamond JT, Wright JR. Design of an integrated spatial information system for multiobjective land-use planning. Environment and Planning B: Planning and Design 1988; 15(2): 205 -14.

[31] Janssen R, Rietveld P. Multicriteria analysis and geographical information systems: an application to agricultural land use in the Netherlands. In Scholten HJ, Stillwell JCH (Eds.) Geographical Information Systems for Urban and Regional Planning 1990, 129-39.

[32] Church RL, Loban SR, Lombard K. An interface for exploring spatial alternatives for a corridor location problem. Computers and Geosciences 1992; 8: 1095-1105.

[33] Jankowski P, Richard L. Integration of GIs-based suitability analysis and multicriteria evaluation in a spatial decision support system for route selection. Environment and Planning B 1994; 21: 323-40.

[34] Rashed T, Weeks J. Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas. International Journal of Geographical Information Science 2003; 17: 547-76.

[35] Malczewski J. GIS-based multicriteria decision analysis: a survey of the literature. International Journal of Geographical Information Science 2006; 20(7): 703-26.

[36] Nobre A, Pacheco M, Jorge R, Lopes M, Gato L. Geo-spatial multi-criteria analysis for wave energy conversion system deployment. Renewable Energy 2009; 34 : 97-111.

[37] Tammi I, Kalliola R. Spatial MCDA in marine planning: Experiences from the Mediterranean and Baltic Seas. Marine Policy 2014; 48: 73-83.

[38] M. Lynch *et al.*, 'Corewind D3.1 - Review of the state of the art of dynamic cable system design', 2020.

[39] '66 kV Submarine Cable Systems - Static and Dynamic Solutions for Bottom Fixed and Floating Offshore Wind', Prysmian Group.

[40] R. T. Pinto and P. Bauer, 'The Role of Modularity Inside the North Sea Transnational Grid Project: Modular Concepts for the Construction and Operation of Large Offshore Grids.', 2011.

[41] C. Patton, 'Dynamic Power Cable Layout Solutions', presented at the Floating Wind Solutions, The Westin Houston, Memorial City, 2021.

[42] R. Adiputra and T. Utsunomiya, 'Stability based approach to design cold-water pipe (CWP) for ocean thermal energy conversion (OTEC)', *Applied Ocean Research*, vol. 92, p. 101921, Nov. 2019, doi: 10.1016/j.apor.2019.101921.

[43] Vryhof (2018), Vryhof Manual - The Guide to Anchoring.

[44] F.A. McHale, W. Lloyd Jones, and H.M. Horn. 1980. "Deployment and Operation of the 50KW Mini-OTEC Plant." Paper presented at the Offshore Technology Conference, Houston, Texas, May. https://doi.org/10.4043/3686-MS.

[45] Coastal Response Research Center. 2010. Technical Readiness of Ocean Thermal Energy Conversion (OTEC). University of New Hampshire, Durham, NH. Available at https://coast.noaa.gov/data/czm/media/otec_nov09_tech.pdf.

[46] R. Taylor, D. True, and F. Arnold. 2010. "Anchoring and Mooring Considerations for an OTEC Pilot Plant." In OCEANS 2010 IEEE Conference, 1–7. Sydney, NSW, Australia, May. https://doi.org/10.1109/OCEANSSYD.2010.5664437.

[47] M. Somoano, A. Rodríguez-Luis, D. Blanco, and R. Guanche. 2024. "Effect of Bathymetry Irregularities on the Energy Dissipation of a Mooring Line." Ocean Engineering 296: 116932. https://doi.org/10.1016/j.oceaneng.2024.116932.

[48] J.H. Lienhard. Synopsis of Lift, Drag, and Vortex Frequency Data for Rigid Circular Cylinders, 1966.

[49] C.H.K. Williamson and R. Govardhan. A brief review of recent results in vortex-induced vibrations. Journal of Wind Engineering and Industrial Aerodynamics, 96:713–735, 2008.

[50] R. D. Gabbai and H. Benaroya. An overview of modeling and experiments of vortex-induced vibration of circular cylinders. Journal of Sound and Vibration, 282:575–616, 2005.

[51] M.M. Zdravkovich. Review and classification of various aerodynamic and hydrodynamic means for suppressing vortex shedding. Journal of Wind Engineering and Industrial Aerodynamics, 7:145–189, 1981.

[52] Lankhorst Offshore. LM VIV Strakes Brochure. Accessed February 27, 2025. https://www.lankhorst-offshore.com/files/6/3/9/5/LM%20VIV%20strakes.pdf.

[53] Lankhorst Offshore. LM VIV Fairings Brochure. Accessed February 27, 2025. https://www.lankhorst-offshore.com/files/5/2/8/5/LM%20VIV%20fairings%20fldr.pdf.

[54] Y. Zhang, J. Tan, and H. Li, "Investigation of dynamic behavior of ultra-large cold-water pipes for ocean thermal energy conversion," J. Mar. Sci. Eng., vol. 3, no. 3, p. 25, 2023. https://doi.org/10.3390/jmse11072093

[55] J. Tan, Y. Zhang, and L. Wang, "Vibrational responses of an ultra-large cold-water pipe for ocean thermal energy conversion: A numerical approach," J. Mar. Sci. Eng., vol. 11, no. 11, p. 2093, 2023. https://doi.org/10.3390/jmse11112093

[56] H. K. Shivanand and A. Sajjan, "Computational study of VIV suppression devices for marine pipelines," Int. J. Eng. Res., vol. 4, no. 3, pp. 393–402, 2023. https://tijer.org/tijer/papers/TIJER2304393.pdf

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