Feasibility of Ocean Energy Capture along the South African Coast

For:

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Disclaimer

This document, **Feasibility of Ocean Energy Capture along the South African Coast**, is a desktop study intended to provide a preliminary assessment of the technical, economic, environmental, and socio-economic viability of Marine Renewable Energy (MRE) in South Africa.

The analysis, conclusions, and recommendations presented in this report are heavily dependent on the accuracy and reliability of the online and peer-reviewed sources consulted (including academic papers, industry reports, and publicly available policy documents). This report does not contain new, primary research data.

A significant limitation was encountered with the costing information: Costing data (Levelised Cost of Electricity - LCOE) for Wave and Ocean Current technology was especially difficult to confirm given the low level of international commercialisation and the proprietary nature of existing pilot project data. The economic projections for these technologies are therefore based on international trends and modelling assumptions, which are subject to high uncertainty.

Generative AI was utilised in the compilation and structural formatting of this report. However, to ensure the highest standards of integrity and factual accuracy, all content, data, and technical assertions were meticulously fact-checked and cross-referenced against the consulted published resources. The authors assume responsibility for the final content.

Executive Summary

This report critically evaluates the potential, regulatory landscape, environmental, and socio-economic implications of deploying Marine Renewable Energy (MRE) off the South African coast. A comprehensive review of all available marine renewable energy options was conducted, and Offshore Wind, Wave, and Ocean Current conversion were identified as the only feasible technologies to pursue due to their abundant available resource. The analysis is framed within the context of achieving a Just Energy Transition (JET) that prioritises sustainable development and coastal community livelihoods.

South Africa possesses significant offshore energy potential. However, the technologies to exploit this potential are at varying stages of maturity: Offshore wind energy is the most commercially viable MRE option globally, leading to the conclusion that it is currently the only MRE technology potentially economically feasible for near-term, large-scale deployment along the South African coast. Nevertheless, the current cost of offshore wind remains higher than established onshore renewables such as solar PV and onshore wind. In contrast, wave and ocean current conversion remain at the pilot scale, and their current cost is significantly higher than readily available onshore renewables. While wave and current devices offer valuable predictable baseload power that can enhance national energy security and grid stability, their cost must decrease to compete in the local market.

Deployment is governed by a complex set of regulations spanning Energy (e.g., Electricity Regulation Amendment Act, NERSA permits), Environment (NEMA, Marine Living Resources Act), and Coastal & Offshore Management (Integrated Coastal Management Act). The primary logistical bottleneck is the severe inadequacy of existing South African port infrastructure, which currently lacks the heavy-lift capacity and specialised quayside space required for the fabrication and assembly of massive Floating Offshore Wind (FOW) platforms and large current devices.

Beyond these physical constraints, the lack of local supply chains represents a broader national bottleneck. Developing these domestic capabilities requires significant time and investment, underpinned by long-term certainty regarding market demand and the "off-take" for such services and supplies.

In addition, the specialised vessels required to install these systems are not available in South Africa and must be mobilised from Europe or other global hubs at significant cost, further impacting project economics.

There are concerns regarding negative social and environmental impacts of exploiting ocean energy, but these can be mitigated by appropriate measures.

<u>Environmental concerns</u>: Construction activities generate significant underwater noise (pile driving) which is a major concern for marine mammals, but occurs once off and for a relatively short duration and measures like bubble curtains and soft-start piling can reduce this risk. Operational risks include the low, continuous noise and weak Electromagnetic Fields (EMF) from cables, and collision/entanglement risks for seabirds and whales, all of which are managed through deep cable burial, quieter components, and careful site selection away from migration paths.

<u>Socio-economic impacts</u>: The largest social risk is the displacement of commercial and small-scale fishers from traditional grounds due to exclusion zones, which threatens their livelihoods

and cultural heritage. Conversely, MRE creates substantial opportunities for high-value job creation, local supply chain development, and contributes to energy security.

The report recommends prioritising offshore wind deployment in the near term while investing in targeted research for wave and ocean current technologies to lower costs and understand their impact on the Agulhas Current's hydrodynamics. Crucially, development must be underpinned by inclusive governance. The final report will serve as a comprehensive baseline for communities and civil society to utilise when participating in energy planning, empowering them to ensure that all MRE projects contribute to a just, equitable, and sustainable energy future.

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Acronyms and abbreviations

AHTS	anchor handling tug supply
CTV	crew transfer vessel
EIA	environmental impact assessments
EMF	electromagnetic field
FOW	floating offshore wind
FSP	floating solar photovoltaics
HVAC	high voltage alternating current
JET	just energy transition
LCOE	levelised cost of electricity
MRE	marine renewable energy
OCEC	ocean current energy conversion
OTEC	ocean thermal energy
OWC	oscillating water column
PRO	pressure-retarded osmosis
RED	reverse electrodialysis
RRMSE	relative root mean square error
SGE	salinity gradient energy
SIDS	small island developing states
SWAC	seawater air-conditioning
SWL	still water level
WEC	wave energy converter

1 Introduction

1.1 Problem statement

In the context of the global climate crisis and unsustainable industrial development practices, South Africa urgently requires a just energy transition (JET) that prioritises affordable, accessible, carbon-neutral renewable energy over new, expensive, high-carbon fossil fuels while limiting the economic and social impact on the people who currently rely on the fossil fuel industry for their livelihoods. However, the shift towards ocean-based energy generation—including offshore wind, wave energy, and ocean currents—must be carefully scrutinised. The core problem is the need for independent, accessible evidence to understand the full environmental, social, and economic costs and benefits of these technologies to ensure they do not endanger the climate or undermine the livelihoods of vulnerable coastal communities, such as fishers, who depend on the ocean. The current knowledge base is insufficient to empower grassroots communities to effectively participate in decision-making processes regarding ocean-based energy development.

1.2 Proposed methodology

To address this knowledge gap and support policy change towards sustainable practices, a desktop study was conducted, reviewing available evidence to produce a comprehensive baseline report. The methodology includes the following steps:

1. **Literature review and desktop study**: A thorough review of available evidence was conducted to examine the socio-economic impacts and benefits of various ocean-based energy technologies (offshore wind, wave energy and ocean currents) and the associated necessary infrastructure (cables, harbours, and breakwaters). This process highlighted actions detrimental to the environment and ocean-dependent livelihoods, providing critical insights into the sustainability and scalability of these technologies.
2. **Consulting with experts in the field**: The research team engaged with experts to gather nuanced and specific data not readily available in public literature.
3. **Identifying operational case studies**: Relevant operational case studies was identified to provide practical evidence of the real-world costs, benefits, and impacts of these diverse technologies.
4. **Compiling the report**: The findings was compiled into a comprehensive baseline report, structured to be accessible for communities and civil society to utilise when participating in decision-making. The report provides evidence supporting policy change towards an equitable and sustainable energy future.
5. **Developing a synopsis**: To ensure maximum accessibility and utility for stakeholders, a concise synopsis of the final report was developed as a PowerPoint presentation.

2 Ocean energy

The oceans of the world contain an abundance of unutilised energy in various forms which, if effectively captured, can greatly contribute to the global demand for energy.

2.1 Global resource

Ocean energy, encompassing diverse technologies like offshore wind, wave, tidal, ocean current, Ocean Thermal Energy Conversion (OTEC), and salinity gradients, represents a vast and largely untapped resource with the capacity to provide significant, predictable power globally. Offshore wind stands out for its colossal resource size, with a global technical potential estimated to be in the tens of thousands of terawatt-hours (TWh) (more than 300 times South Africa's energy generation in 2024 of 194 TWh (Enerdata, 2024)), offering high-capacity factors in deeper waters (capacity factor is a measure of an electrical generating plant's actual energy output over a period, compared to the maximum possible output if it ran at full power continuously, expressed as a percentage or ratio). OTEC has the single largest potential among the marine hydrokinetic resources, with estimates suggesting up to 44 000 TWh/yr could be generated in tropical regions. Wave energy also presents a significant global technical potential, often estimated at around 29 500 TWh/yr. The energy harnessed from the predictable movement of tides is estimated to have a resource potential of around 1 200 TWh/yr, while salinity gradient energy has a practical potential ranging up to 625 TWh/yr where large, consistent river flows meet the sea. Overall, the combined suite of ocean energy resources offers a very large, reliable, and diverse portfolio of renewable power crucial for stabilising future electricity grids.

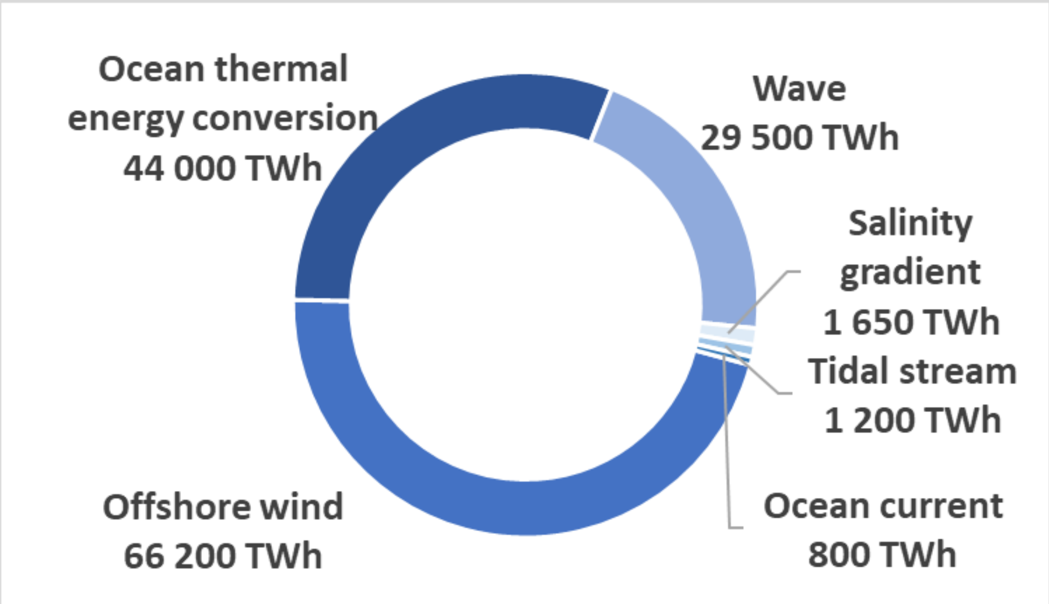


Figure 1: Global marine energy technical potential (IRENA & OEE, 2023) & (Satymov, Bogdanov, & Breyer, 2025)

2.2 Tidal energy

Tidal energy is a form of hydropower that converts the energy from the natural rise and fall of oceanic tides, and the ensuing flow of water, into usable electricity. The ultimate source of tidal energy is the powerful, predictable gravitational interaction between the Earth, Moon, and Sun.

The Moon's gravitational pull is the primary driver, causing the ocean water to bulge on both the near and far sides of the Earth, creating two high tides and two low tides approximately every 24 hours and 50 minutes. This gravitational action results in both the potential energy of a difference in water level (tidal range) and the kinetic energy of strong, flowing tidal currents (tidal streams).

There are two types of tidal energy extraction technologies:

1. **Tidal barrages (range):** Functioning similarly to a river dam, a tidal barrage is constructed across a bay or estuary to harness the *potential energy* created by the vertical difference in water levels. While simpler designs generate electricity only as the tide recedes (ebb generation), more sophisticated systems are engineered for two-way generation on both the ebb and flood tides.
2. **Tidal stream generators (current):** Underwater turbines, resembling submerged wind turbines, are placed in areas of fast-flowing tidal currents. The flow of water turns the blades, generating electricity. This harnesses the *kinetic energy*.

2.2.1 Global distribution

The commercial viability of tidal power plants, especially barrages, requires a large tidal range, typically 5 m or more, although 3 m is often cited for economic viability (US Energy Information Administration, 2024). The most energetic sites are generally found in specific coastal geometries (bays, estuaries, and narrow straits) that naturally amplify the tidal range or velocity.

Notable locations with high tidal energy potential and existing large-scale projects include (refer to Figure 2 below):

- **Bay of Fundy, Canada:** Known for having some of the highest tidal ranges in the world.
- **La Rance Estuary, France:** Home to one of the world's first and largest tidal barrage power plants (240 MW).
- **Sihwa Lake, South Korea:** Currently the world's largest tidal power station (254 MW).
- **The UK (e.g., Severn Estuary, Pentland Firth):** Significant potential for both tidal range and stream projects.

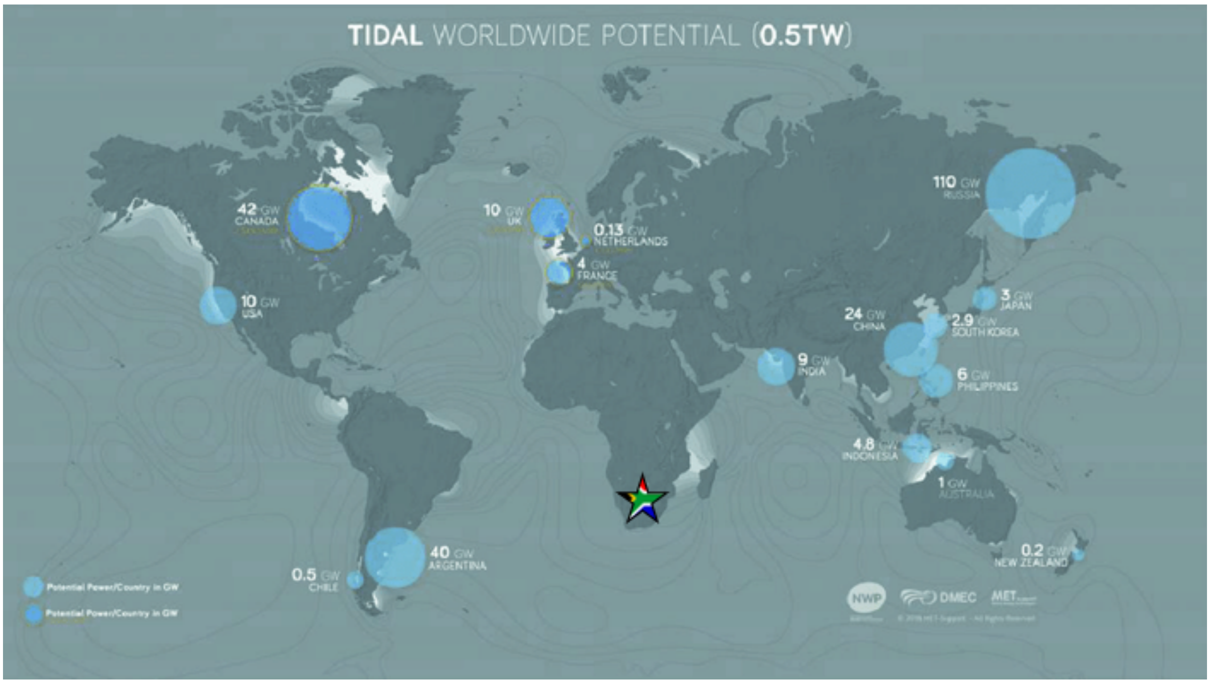


Figure 2: Global tidal energy potential (Wani, Dong, & Polinder, 2020)

2.2.2 Tidal energy potential in South Africa

The technical and economic prospects for large-scale tidal energy utilisation in South Africa are extremely limited due to the insufficiency of tidal resources. The coastline is characterised by a generally low tidal range (micro-tidal), often less than 2 meters, which falls well below the minimum threshold required for economically viable tidal barrage projects. Furthermore, while tidal stream potential has been investigated, the country lacks the globally significant tidal current speeds necessary for cost-effective, utility-scale generation. Finally, the few coastal areas with slightly increased tidal flows, such as the Langebaan Lagoon and between the Knysna Heads, are ecologically sensitive, and developing the necessary tidal power infrastructure there would pose unacceptable risks, including the disruption of estuarine ecosystems, impacts on fish migration, and detrimental changes to sedimentation and water quality.

2.3 Salinity gradient

Salinity Gradient Energy (SGE), also known as Osmotic Power or Blue Energy, is a clean, renewable energy source that captures the energy released when two water streams with different salt concentrations—typically freshwater and seawater—are mixed.

The driving mechanism for Salinity Gradient Energy (SGE) is chemical potential difference, which is naturally released when water bodies of different salinities spontaneously mix. Engineered systems control this mixing process to generate power, primarily using advanced membrane technologies (International Renewable Energy Agency, 2014):

- **Pressure-Retarded Osmosis (PRO)**: A semi-permeable membrane separates the high-salinity water (e.g., seawater) from the low-salinity water (e.g., river water). Due to osmosis, the freshwater naturally moves through the membrane towards the seawater side. This influx of freshwater increases the pressure in the high-salinity channel. This pressurised flow is then directed through a hydro-turbine to generate electricity.

- **Reverse Electrodialysis (RED)**: This system uses a stack of alternating cation-exchange and anion-exchange membranes placed between alternating channels of fresh and salt water. The difference in salt concentration drives the positively and negatively charged ions (cations and anions) in the salt water to migrate in opposite directions across the membranes, creating an electrical potential (a voltage) that is then harnessed as an electric current.

2.3.1 Global energy distribution and potential

The global potential for Salinity Gradient Energy (SGE) is concentrated at river mouths and estuaries where large, consistent volumes of freshwater meet the ocean - refer to Figure 3 below. The theoretical potential of this mixing process, when considering all global river water discharge, is massive, estimated at about 15 000 TWh/year, a figure comparable to the world's wave energy potential. However, the practical potential is significantly lower, estimated to be around 625 TWh/year (about 2% of global electricity consumption), after accounting for critical factors like technical limitations (membrane efficiency and fouling), environmental constraints, and the necessary preservation of environmental flow in rivers (Lin, Wang, Wang, & Elimelech, 2023). Consequently, SGE is most viable in key locations with large, stable river flow rates, such as major river systems in North America, South America (e.g., the Amazon), Asia, and Europe.

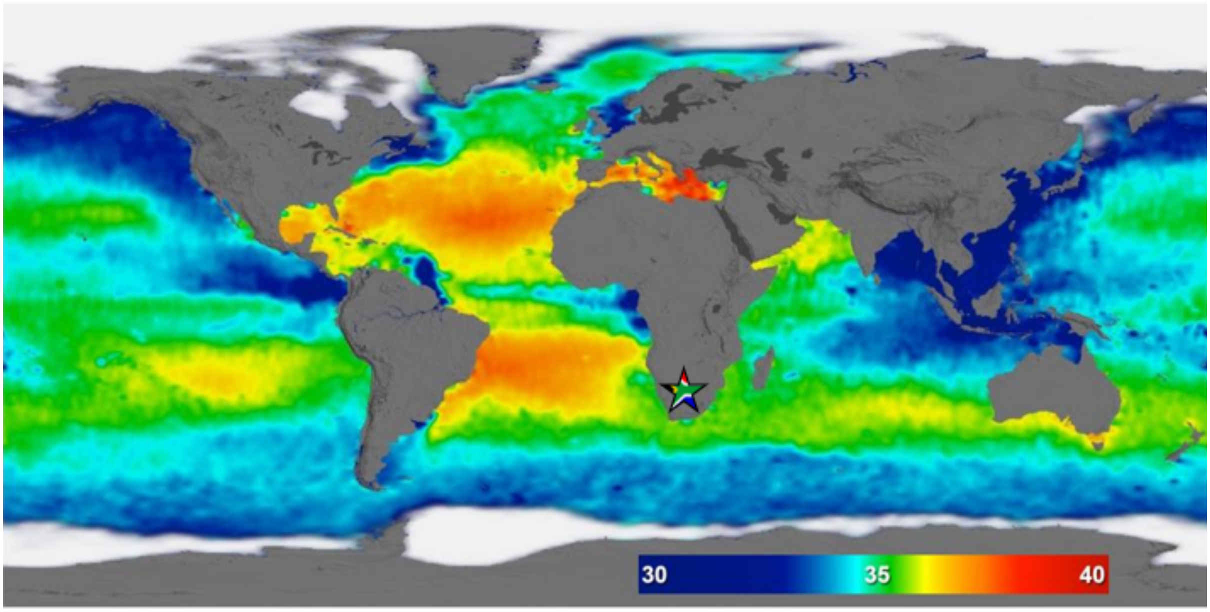


Figure 3: Example of synoptic, near-global salinity coverage from satellite observations showing annual mean sea surface salinity patterns based on observations from the Aquarius mission during 2011–2014 (NASA, 2019)

2.3.2 Salinity gradient energy potential in South Africa

Salinity Gradient Energy (SGE) is not a viable option for large-scale power generation in South Africa primarily due to water scarcity and inconsistent river flow; as a water-stressed country, prioritising limited freshwater resources for human, sanitation, and agricultural use makes diverting the large, continuous river water volumes needed for SGE economically and socially untenable. Furthermore, the majority of the nation's river network is characterised by seasonal or ephemeral flow, which makes the freshwater discharge at estuaries highly variable and unreliable for the efficient, consistent operation required of SGE base-load power plants. Lastly, South

Africa lacks utility-scale coastal estuaries suitable for the massive industrial infrastructure (like extensive membrane surfaces and large water intake/discharge structures) needed for commercial SGE, and introducing such developments would pose an unacceptable risk to the numerous small, ecologically sensitive coastal habitats that exist along the coastline.

2.4 Ocean thermal

Ocean Thermal Energy Conversion (OTEC) is a form of renewable energy that uses the temperature difference between warm surface seawater and cold deep seawater to drive a heat engine and generate electricity.

The core principle of OTEC relies on the thermodynamic Rankine cycle and a minimum temperature differential of 20°C between the water layers.

1. **Heat Engine Cycle:** OTEC uses the warm surface water (e.g., 27°C to 29°C) as the heat source and the deep cold water (found at ~ 1 000 meters, e.g., 4°C to 7°C) as the heat sink (EBSCO, 2025).
2. **Conversion (Closed-Cycle)**: The most common design is the Closed-Cycle OTEC. Warm surface water is pumped through a heat exchanger called an evaporator which vaporises a working fluid with a low boiling point (typically ammonia). The expanding vapor then drives a turbine connected to an electrical generator. The vapor is finally condensed back into a liquid using the cold deep-sea water in a second heat exchanger (condenser), and the cycle repeats.
3. **Byproducts**: A significant benefit of OTEC is its ability to operate continuously (providing baseload power) and its potential to produce freshwater (via open-cycle systems) and support aquaculture using the nutrient-rich deep water.

2.4.1 Global energy distribution

OTEC's viability is strictly limited by geography to the tropical and equatorial regions (~20°N to 20°S latitude – refer to Figure 4 below).

- **Viable Zone:** Ideal OTEC conditions—a sustained temperature difference year-round between the surface and 1 000-meter depth—are found primarily within this tropical belt.
- **Locations:** These conditions are prevalent in areas like the Caribbean Sea, the Pacific Ocean near Hawaii and small island developing states (SIDS), and specific areas in the Indian Ocean.
- **Potential:** The global theoretical energy potential is vast, but the sustainable, practically extractable potential is estimated to be as high as 10 000 Terawatt-hours per year (TWh/yr) without significantly disrupting the ocean's thermal structure, making it a powerful resource for island nations with high energy and freshwater needs (Jing, Wang, Mei, & Tian, 2025).

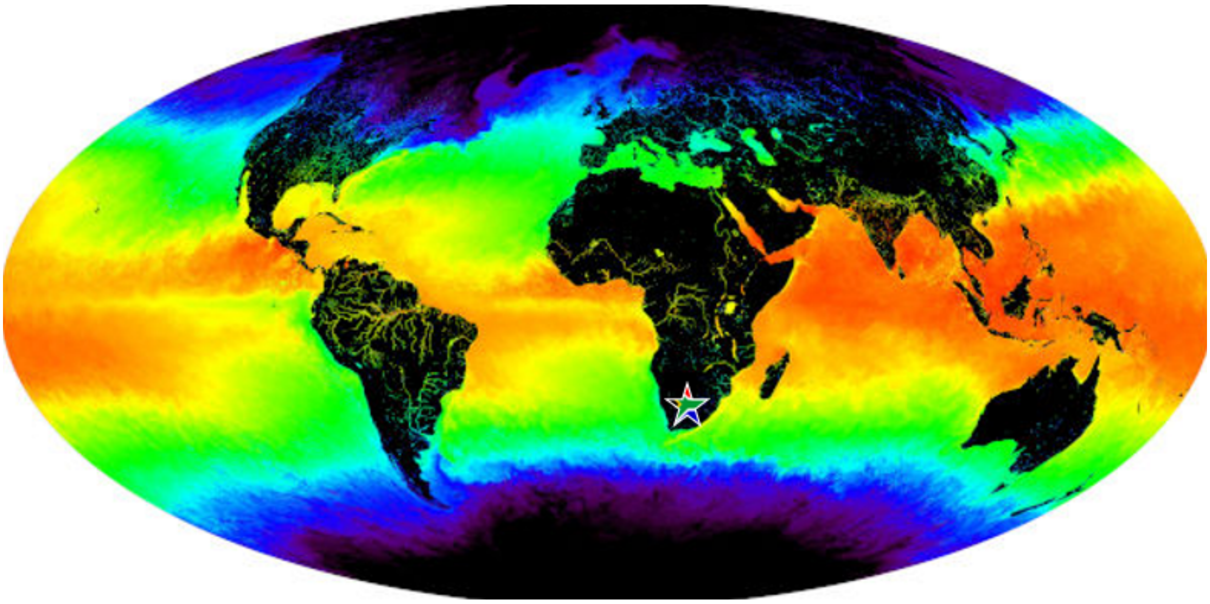


Figure 4: Global sea surface temperature (MODIS Ocean Group, NASA GSFC, University of Miami, 2001)

2.4.2 Ocean thermal energy conversion potential in South Africa

Despite South Africa's lengthy coastline, Ocean Thermal Energy Conversion (OTEC) isn't a viable option for large-scale power generation because the country simply lacks the necessary, consistently large, stable thermal gradient along most of its shores.

This inadequacy is driven by the influence of two major ocean current systems. Along the West Coast (Atlantic), the cold Benguela Current flows northward, causing frequent, persistent upwelling of deep, cold water right to the surface. This drastically reduces the surface water temperature, minimising the overall temperature difference available for OTEC. Conversely, along the South and East Coast (Indian), the warm Agulhas Current provides high surface temperatures, but this region is south of the ideal equatorial belt. The resulting thermal gradient to the deep water is generally not consistent or large enough throughout the year to guarantee the minimum 20°C differential needed for economic efficiency, and seasonal cooling further diminishes the resource.

Even if marginally suitable areas, such as parts of the KwaZulu-Natal coast, were found, the engineering challenges remain prohibitive. Due to the inherently small temperature difference, OTEC systems operate at a very low efficiency (less than 7%), which necessitates moving extremely large volumes of water. This requires constructing enormous, costly infrastructure, most notably the deep cold water pipes that can be up to 10 meters in diameter and 1 000 meters long. This high capital expenditure combined with a suboptimal resource base makes the resulting Levelised Cost of Energy (LCOE) utterly non-competitive when compared to South Africa's abundant and accessible solar, wind, and wave energy resources. Therefore, the cold-water dynamics in the west and the sub-optimal thermal gradient in the east reliably preclude OTEC from being a meaningful part of the country's energy mix. However, the cold water dynamic does support the successful implementation of Seawater Air-Conditioning (SWAC), which is currently being utilised at the V&A Waterfront in Cape Town, and this climate control technology holds significant potential for further deployment in other large commercial buildings along the country's coastline. For more information on the resource saving potential of the V&A's SWAC systems, refer to (Joubert, Owen, Hassan, & Haasbroek, 2024)

2.5 Wave energy

Ocean wave energy originates from the wind's friction as it blows across the water's surface, transferring the kinetic energy of the moving air into the water. Winds result from air moving from colder to hotter parts of the globe which is why wave power is ultimately considered a form of solar energy. This fundamental linkage exists because wind itself is generated by the uneven heating of the Earth's atmosphere by the Sun; as the Sun warms different parts of the globe at varying rates, it creates atmospheric pressure differences that drive air movement (wind), and this wind, in turn, creates the waves. The resulting size and power of these waves depend on three primary factors: the wind speed, the time duration the wind has been blowing, and the fetch, which is the distance over which the wind acts upon the water. The waves then travel vast distances, carrying this stored energy as a combination of potential and kinetic energy until they dissipate, making wave energy an indirect yet powerful manifestation of solar radiation.

2.5.1 Available resource

The distribution of significant wave energy resources is heavily concentrated in specific oceanic regions, primarily those with long stretches of open water (large fetch) exposed to persistent, strong prevailing winds and vast storm tracks – refer to Figure 5 below.

- **Mid-Latitude Zones (30° to 60° North and South):** The most energetic regions globally occur between these latitudes. These zones are frequently swept by mid-latitude storm systems, generating powerful and consistent ocean swell.
- **High-Potential Regions:** Coastlines bordering the eastern sides of large oceans, which receive waves generated from thousands of kilometres away, exhibit the highest technical potential. These include:
    - The Western Seaboard of Europe (particularly the northern coast of the UK, Ireland, and Portugal).
    - The Pacific Coasts of North and South America.
    - The Southern Coasts of Australia and New Zealand.
    - The Southern African coastline.
- These premium sites can often have annual average wave power densities exceeding 30 kW per meter (kW/m) of wave crest, with some locations reaching 70 kW/m or higher. The worldwide theoretical potential for wave energy is massive, estimated to be around 29 500 TWh/yr.

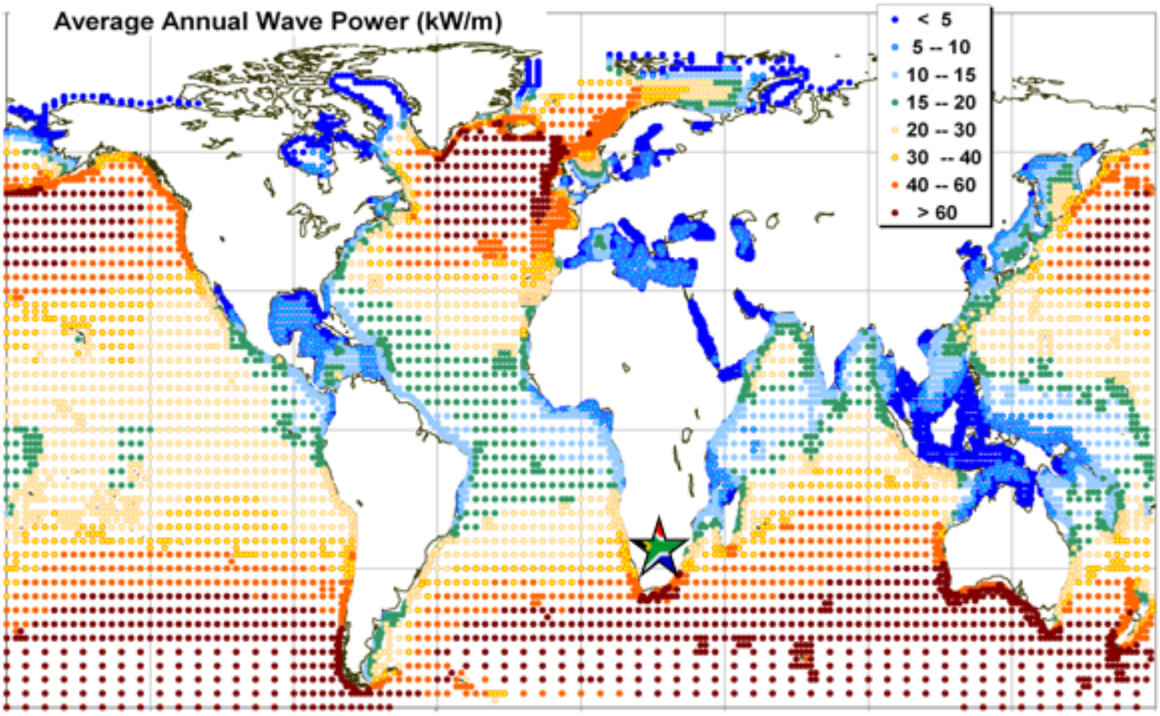


Figure 5: Global annual mean wave power estimates in kW/m (data from the ECMWF WAM model archive; calibrated and corrected by Fugro OCEANOR against a global buoy and Topex satellite altimeter database) (Cruz, 2008)

2.5.2 Wave energy potential in South Africa

South Africa's extensive coastline, which stretches for over 2 800 kilometres, holds a substantial and genuinely promising wave energy resource, particularly along its southern and western reaches. This isn't just a marginal resource; the estimated total wave energy available along the entire coast sits at roughly 56 800 MW (Department of minerals and energy, 2002), with a practical, technically recoverable potential capable of contributing 8 to 10 GW to the national electricity grid (Fourie & Johnson, 2017).

The most energetic zone is undeniably the south-west coast, extending roughly from Cape Point up to Port Nolloth. This area is directly and consistently exposed to the large, powerful swells generated by the prevailing westerlies and deep-ocean storm tracks in the South Atlantic and Southern Ocean. This exposure translates into an exceptionally high average power density, frequently reaching 40 kW per meter of wave crest, which ranks this section among the most energetic coastlines globally – refer to the top-right image in Figure 6. While the rest of the coastline offers more moderate, yet still significant, power density, typically averaging between 15 kW/m and 30 kW/m, the strategic value is clear.

This marine resource offers a key advantage: consistency and high predictability. Unlike the intermittent nature of solar and standard wind power, wave patterns can be forecast accurately days in advance, making wave energy highly valuable for grid balancing and providing a more stable foundation than variable renewables. Recognising this potential, South Africa has been actively exploring and validating the resource. This includes detailed resource assessment studies by (Geustyn, 1983) who analysed wave data measured along the South African coast, updated by (Joubert J. , 2008) and expanded to include an in-depth investigation of the wave energy resource on the South African southwest coast and lastly (Joubert J. , 2013) conducted a detailed analysis of the available resource in Table Bay – refer to Figure 6.

Ultimately, the substantial and reliable energy flux along its western and southern shores makes wave energy one of the most viable and strategically important marine renewable energy resources for South Africa to pursue.

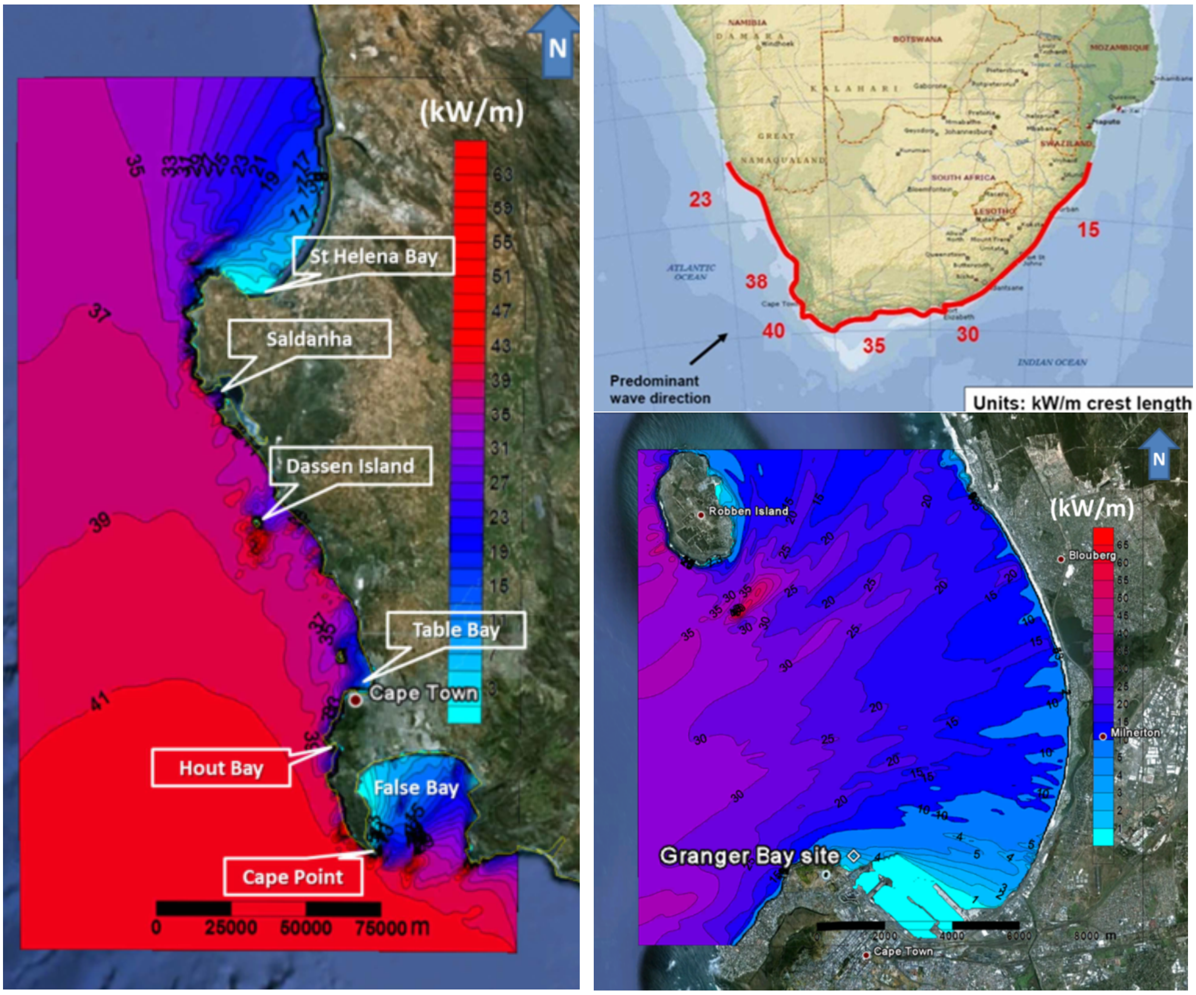


Figure 6: Spatial distribution of wave power on the South African southwest coast based on 10 years of hindcast wave data (Joubert J. , 2008) *(left), nearshore wave power levels based on measured wave data* (Retief, 2007) *and* (Joubert J. , 2008) *(top-right) and mean annual average wave power distribution (kW/m) of Table Bay based on 11 years of hindcast NCEP wave data (bottom-left)*

2.5.3 Wave energy theory

Linear Wave Theory, also known as Airy Wave Theory, is the simplest mathematical description of water waves. It is built upon the assumption that the wave amplitude is very small compared to both the wavelength and the water depth, allowing the equations of motion to be linearised (Dean & Dalrymple, 1991). This theory treats the wave as a progressive, periodic, and sinusoidal disturbance traveling over a fluid layer of uniform depth.

The description below defines the key geometric and temporal parameters necessary for the theory:

- **Wavelength (*L*):** The horizontal distance between two successive wave crests or troughs.
- **Wave Period (*T*):** The time it takes for one complete wavelength (*L*) to pass a fixed point.

- **Wave Height (*H*):** The vertical distance between a wave crest and the preceding trough.
- **Water Depth (*d*):** The vertical distance from the seafloor to the Still Water Level (SWL).

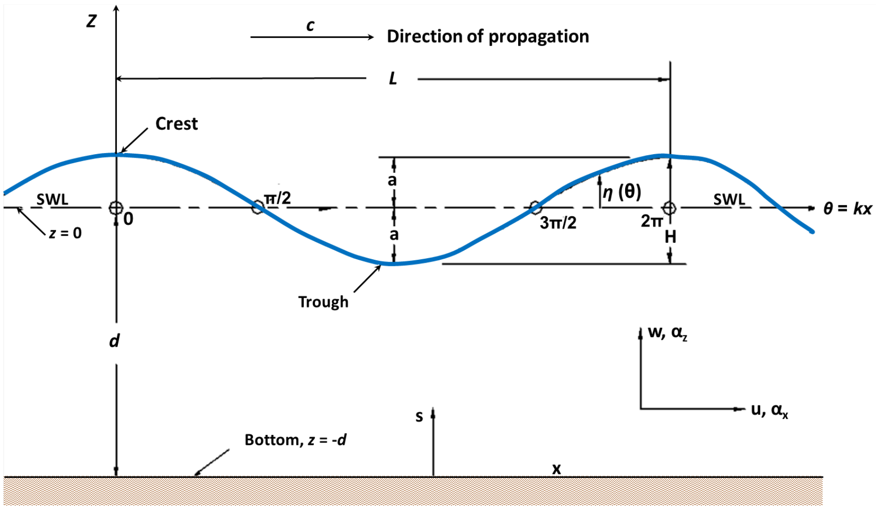


Figure 7: Basic wave parameters (US Army Corps, 2006)

Ocean waves propagate energy across the water's surface through the orbital motion of individual water particles, not by the linear transport of the water itself. As a wave passes, the water particles near the surface move in nearly circular or elliptical orbits (Dean & Dalrymple, 1991). At the wave crest, particles move in the direction of wave travel, and in the trough, they move opposite to it. This orbital diameter is greatest at the surface (approximately equal to the wave height) and diminishes rapidly with depth. In deep water, the orbital motion essentially ceases at a depth of about half the wavelength (*L*/2), meaning waves only disturb the water within that limit (US Army Corps, 2006). It is this synchronized, oscillating motion of water particles that transmits the wave's energy horizontally across the ocean.

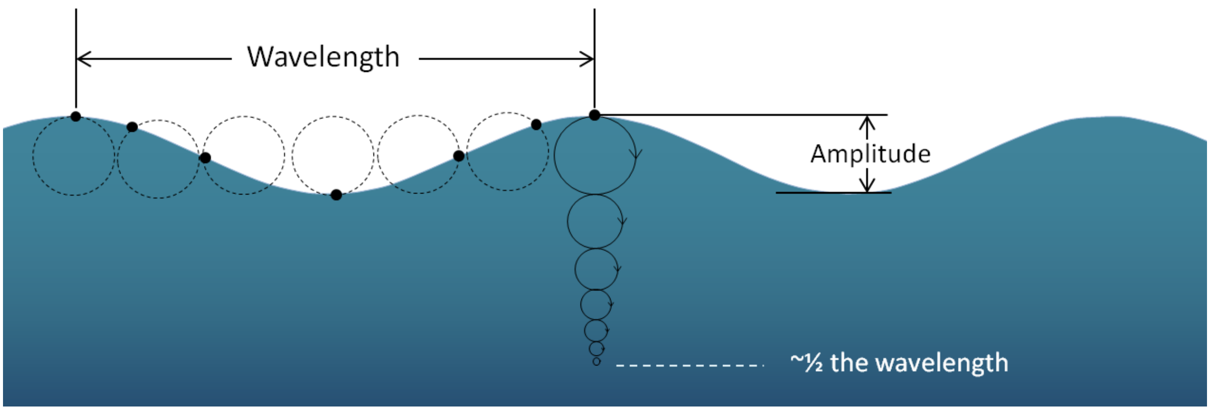


Figure 8: Orbital motion of a water particle (black dot) as a wave propagates across the surface (BC Campus, 2015)

In shallow water (where the water depth, *d*, is less than half the wavelength, *L*/2), the seafloor increasingly interferes with the orbital motion of the water particles (Dean & Dalrymple, 1991).

This friction prevents the deeper part of the orbit from closing, causing the circular orbits to become increasingly elliptical as the particles are squeezed into a flatter motion near the seabed (Holthuijsen, 2007). As the wave moves into progressively shallower water, this friction causes the wave to slow down, while the wave energy remains constant, leading to a dramatic increase in wave height (a process known as shoaling) (US Army Corps, 2006). Eventually, the wave's crest outruns the base and the water particle velocity in the crest exceeds the wave speed, causing the crest to become unstable, spill forward, and break (Dean & Dalrymple, 1991). This typically occurs when the wave height approaches approximately times the water depth ($H \approx 0.8d$) (US Army Corps, 2006)

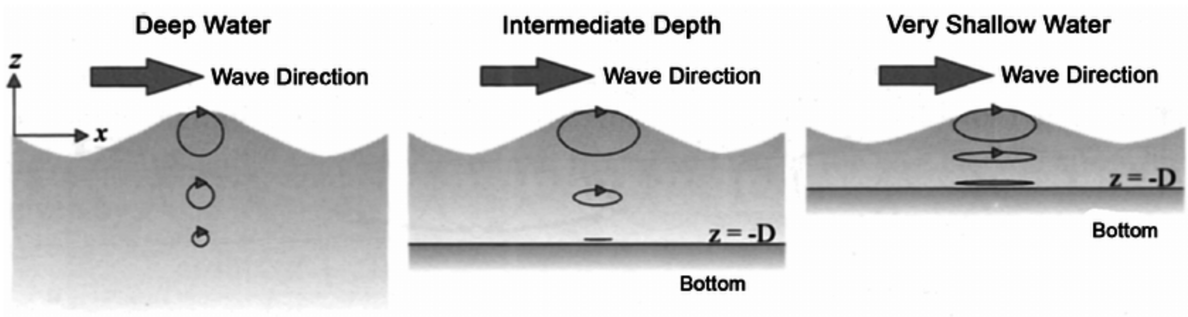


Figure 9: The orbital motion in deep water, intermediate-depth water and very shallow water (Holthuijsen, 2007)

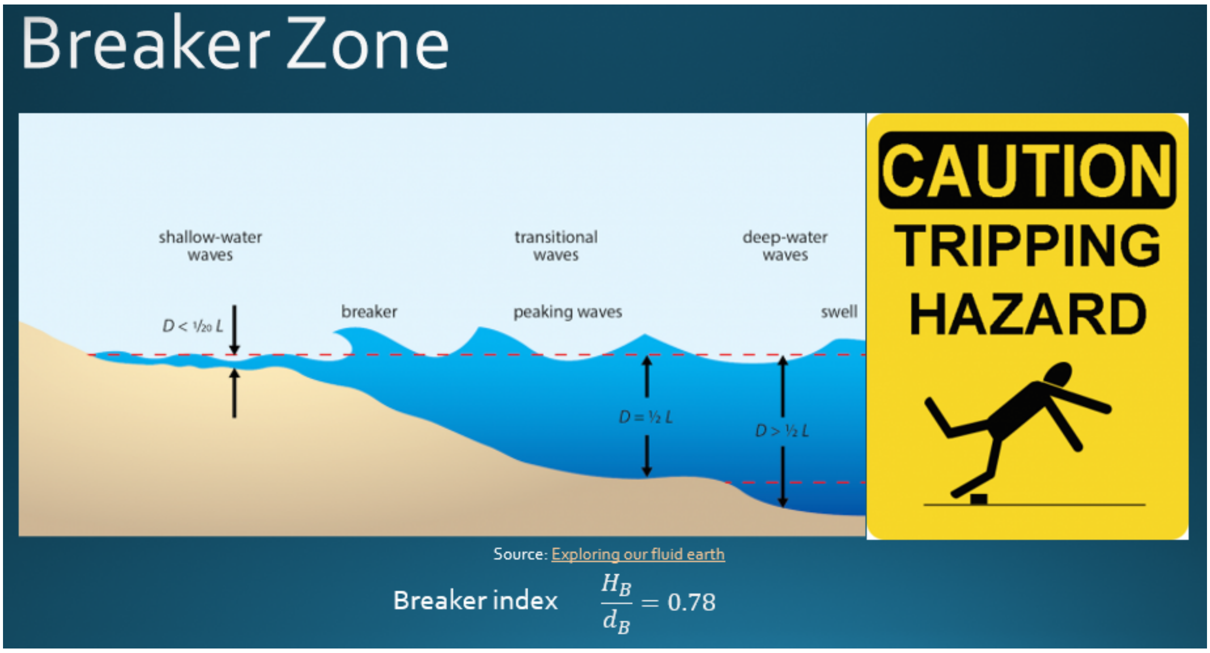


Figure 10: Wave propagation from deep water to shore (Joubert J. , 2025)

The total incident wave power per unit width of a linear wave at any water depth is given by:

$$\overline{P} = \frac{\rho g H^2}{8}\frac{1}{2}\left[1 + \frac{4\pi d/L}{sinh(4\pi d/L)}\right]\frac{gT}{2\pi} tanh(2\pi d/L) \quad (1)$$

Eq (1) shows that wave power is most strongly dependent on wave height, as the power is proportional to the square of the wave height (*H*). Doubling the wave height quadruples the available power. This factor accounts for the potential energy stored in the elevated water mass of the wave crest. Power is also directly proportional to the wave period (*T*). The period is a measure of the wave's velocity and influences the kinetic energy component of the wave, representing how frequently the energy is delivered.

Water depth becomes a critical factor as waves approach the shore (in intermediate and shallow water). In these depths, the seafloor interferes with the wave's motion, causing the group velocity (the speed at which the energy travels) to decrease, which in turn affects the amount of power transported.

2.5.4 Opportunities of wave energy

Wave energy offers several key advantages for power generation: it is an abundant resource, and in many regions, it is relatively evenly distributed along the coastline. Crucially, wave conditions are highly predictable, often allowing for accurate forecasting up to about 3 days in advance, which provides grid operators with valuable planning time. This predictability allows wave energy to effectively augment the variability of other renewables, as wave power can remain substantial at night and even when wind energy may be negligible, thus stabilising the overall supply. Finally, wave energy systems can also be deployed to provide reliable power to remote, coastal, and island communities.

2.5.5 Challenges of wave energy

All ocean energy technologies face significant challenges related to the harsh and corrosive marine environment, which complicates materials science and maintenance. Currently, the technology for many ocean energy types remains at a low level of commercial readiness, requiring substantial further investment in R&D to prove reliability and economic viability. A major factor driving up costs is the need to design systems for extreme conditions (such as the 1-in-100 year storm event), which demands robust, expensive components to ensure survivability against huge hydrodynamic forces. Furthermore, the deployment of large-scale arrays presents potential environmental impacts, including changes to sedimentation processes, risks to marine life, and posing hazards to shipping and navigation.

2.5.6 Wave energy technology

The idea of extracting energy from ocean waves is not new. Girard, a French inventor, mathematician & engineer, obtained a patent for a machine he and his son had designed in 1799 to capture the energy in ocean waves by attaching wooden beams to docked ships which used the vessel's bobbing motion to operate the beams as levers against fulcrums on the shore. Significant conceptual progress was made when Yoshio Masuda patented the first oscillating water column (OWC) device in 1940, marking a key shift towards functional prototypes. Global interest surged following the 1973 Oil Crisis, which catalysed serious research into renewable energy. This led directly to Stephen Salter's pioneering work at Edinburgh University in 1974 on the 'Salter's Duck', one of the most famous early wave energy concepts. South African research began when Stellenbosch University started studying wave energy potential in 1982. Commercialisation efforts ramped up with Richard Yemm's founding of Pelamis Wave Power in 1998, leading to the world's first multi-machine wave farm in Portugal. The timeline closes with Dr. Stig Lundbäck co-founding CorPower Ocean in 2012 to commercialise highly resonant, point-absorber technology, highlighting the ongoing global pursuit of commercial readiness – refer to Figure 11 below.

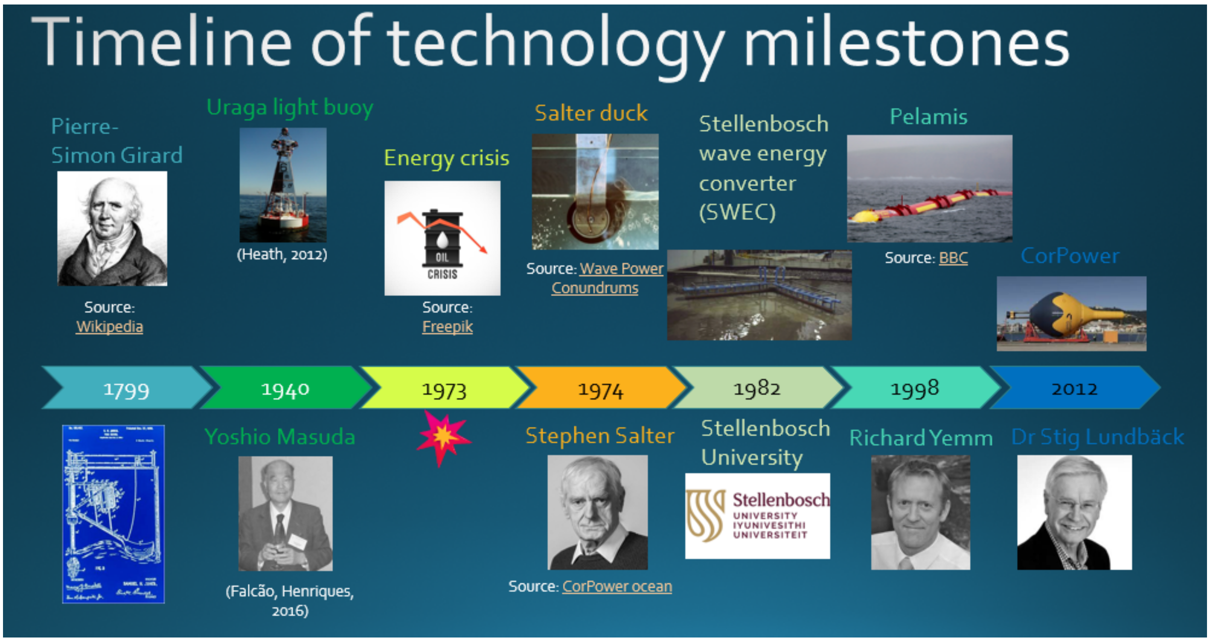


Figure 11: Timeline of key milestones in wave energy conversion technology, highlighting major conceptual and commercial prototypes and their inventors from 1799 to the present

Based on (Falcão, 2010)'s review, Wave Energy Converters (WECs) are fundamentally classified by their operating principle and their location relative to the shore. The primary principles of operation include **Oscillating Water Columns (OWCs)**, which use an air turbine driven by the oscillation of an internal water surface; **Oscillating Bodies** (including point absorbers and attenuators), which convert the kinetic energy from their motion, either relative to a fixed point or between two internal components; and **Overtopping Devices**, which convert the wave's potential energy by channelling water into a reservoir above sea level to drive a low-head hydro turbine. These devices are then categorized by deployment location as **shoreline/onshore**, **nearshore** (typically fixed to the seabed), or **offshore** (often utilizing floating platforms to access the most powerful deep-water resource).

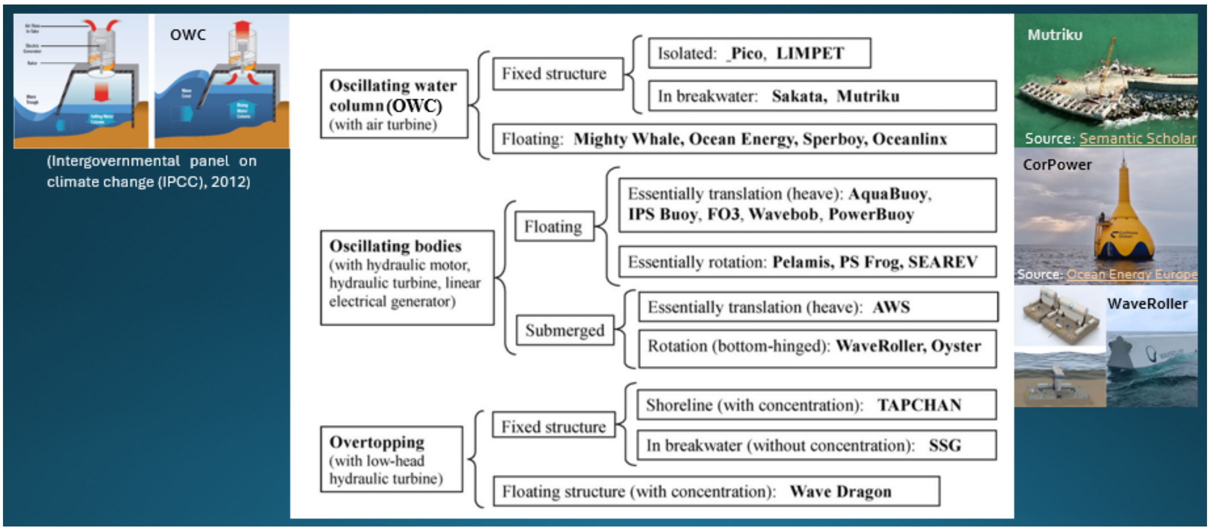


Figure 12: Wave energy converter device classification (Falcão, 2010)

In the following sections case study examples of leading wave energy converters are presented which could be suitable for deployment along the South African coast.

2.5.6.1 Example case study: Eco Wave Power

Eco Wave Power's wave energy converter (WEC) operates on the principle of a shore mounted float system. The device utilises large, buoyant floats or "floaters" fixed to breakwaters, jetties, or other coastal structures. As waves roll in, the movement of the water causes the floats to rise and fall, translating the wave's energy into hydraulic pressure. This pressure is then transmitted through hydraulic pistons to shore-based accumulators and generators, which are protected from the harsh marine environment (Eco Wave Power, 2022). Notably, this innovative system was named one of the Best Inventions of 2025 by TIME Magazine. Regarding development in South Africa, Eco Wave Power signed an agreement with Africa Great Future Development Ltd to conduct a feasibility study for a potential wave energy power station in the Port of Ngqura, Eastern Cape (Eco Wave Power, 2025).

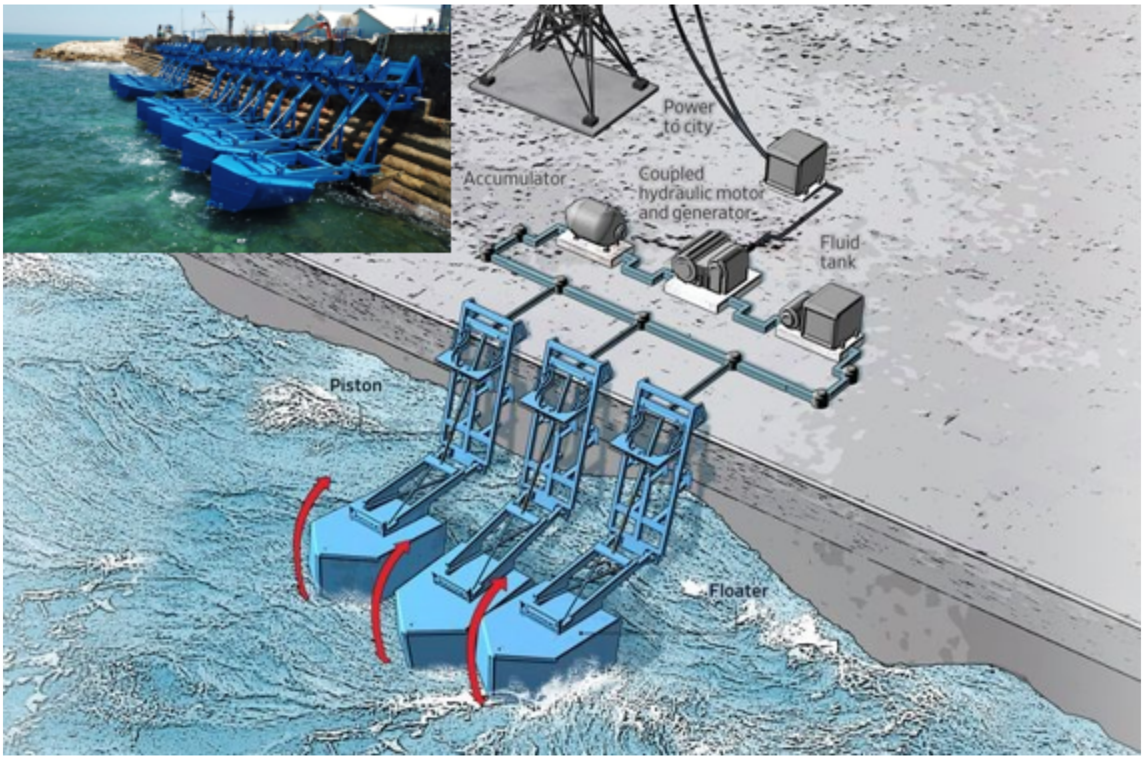


Figure 13: Schematic of Eco Wave Power shore-based system comprising of floating pontoons, pistons, accumulator, motor & generator and fluid tank (Eco Wave Power, 2022) & (WIPO Magazine, 2023)

The power matrix for Eco Wave Power's system (as shown in Table 1) indicates that the device operates most effectively under short wave period conditions. Consequently, at South Africa's predominant wave conditions, which have a lower characteristic frequency than the device's current resonant frequency, the system's output is limited to only 34% of its total capacity. This significant performance deficit necessitates that the device's resonant frequency must be adjusted to perform optimally in South African waters. Since the resonant frequency is dictated by the floater dimensions (mass and geometry), this adjustment would primarily require modifications to the floater dimensions to tune the device to the dominant wave periods found along the South African coast.

Table 1: 1 MW power matrix for a 100 floater system with floater dimensions of 2.8m x 3.6m x 1.5m (Eco Wave Power, 2020)

Wave height (m)	Wave period (s)											
	4	5	6	7	8	9	10	11	12	13	14	15
0.5	59	47	39	34	29	26	24	21	20	18	17	16
1	235	188	157	134	118	105	94	86	78	72	67	63
1.5	529	424	353	303	265	235	212	193	176	163	151	141
2	941	753	627	538	471	418	376	**342**	314	290	269	251
2.5	1 000	1 000	980	840	735	654	588	535	490	453	420	392
3	1 000	1 000	1 000	1 000	1 000	941	847	770	706	652	605	565
3.5	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	941	869	807	753
4	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	941
4+	Storm protection											

2.5.6.2 Example case study: CorPower

The CorPower Ocean Wave Energy Converter (WEC) is a type of point absorber that utilises a buoy tethered to the seabed, optimised to oscillate in resonance with incoming waves. Its operational principle relies on a highly advanced, patented phase control system and a unique pneumatic spring to ensure the buoy consistently oscillates with maximum amplitude, even when the wave frequency shifts, thereby boosting power output by up to five times compared to conventional point absorbers (Dickson, Pennock, Todalshaug, & Rebenius, 2025). This resonant operation makes the CorPower device potentially well-suited for deployment in South Africa's high-energy coastal waters. The system can be tuned to the specific low characteristic frequency (longer periods) prevalent along the South African coast, allowing it to efficiently capture the substantial power flux available, particularly along the South-West Coast, and achieve high capacity factors.

Figure 14: CorPower unit deployed at sea (Ocean Energy Europe, 2024) and in the process of deployment (The European Marine Energy Centre LTD, 2018)

2.6 Ocean current

Ocean current energy is a form of marine renewable energy that harnesses the kinetic energy stored in the continuous, flowing movement of ocean currents. Similar to wind turbines, underwater turbines convert the mechanical energy of the moving water into electricity.

Ocean currents are generated and influenced by a complex interplay of forces, which can be broadly categorized into surface-driven and density-driven circulation:

- **Surface Currents (Wind-Driven):** These currents, generally confined to the upper few hundred meters of the ocean, are primarily generated by **wind friction** acting on the sea surface. The steady pattern of global winds (like the trade winds and Westerlies) pushes the water, but the direction is modified by the **Coriolis effect**, which deflects currents to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
- Deep Currents (Density-Driven/Thermohaline Circulation): These currents are generated by differences in water density, which are primarily controlled by temperature (thermo) and salinity (haline). Cold, salty water is denser than warm, fresh water. As water masses cool in polar regions and ice forms (increasing salinity), the denser water sinks and drives a slow, global "conveyor belt" of deep ocean circulation.
- **Other Influences:** Current velocity is locally influenced by factors such as the **coastal topography** (forcing currents into narrower, faster flows) and **tidal forces**, which can create powerful, localized tidal streams near shore (NOAA, 2022).

2.6.1 Global distribution and high-velocity areas

The most significant resources for energy capture are found in persistent, **high-velocity currents** that flow close to continental shelves or through narrow straits. These areas naturally focus the flow, increasing the kinetic energy density – refer to Figure 15.

- **Gulf Stream (USA):** Perhaps the most famous high-velocity resource. It flows along the coast of the southeastern United States and can achieve speeds necessary for viable energy capture.
- **Kuroshio Current (East Asia):** The Pacific equivalent of the Gulf Stream, flowing off the coast of Japan, which is another major target for current energy development.
- **Straits and Channels:** Strong, reliable currents are found in narrow geographical features, such as the **Florida Current** (a segment of the Gulf Stream).

These current systems are attractive because they provide a highly **predictable baseload** resource, as their flow is continuous and largely unaffected by daily weather changes (Sadoughipour, VanZwieten, & Tang, 2025).

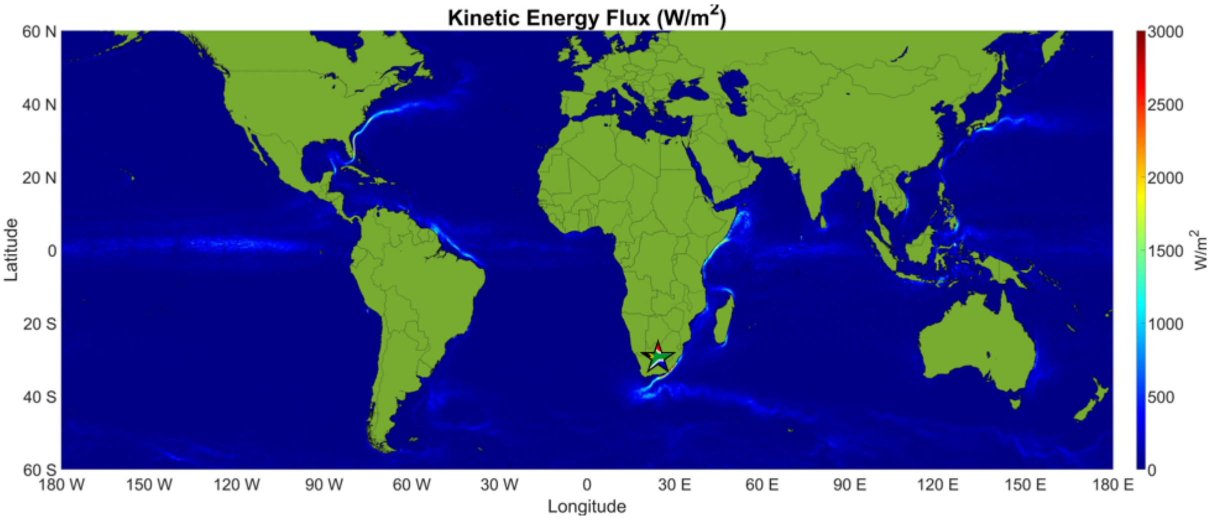


Figure 15: Global average power density calculated using drifter data in watts per square meter (Sadoughipour, VanZwieten, & Tang, 2025)

2.6.2 Ocean current energy potential in South Africa

South Africa possesses one of the world's most impressive ocean current resources in the Agulhas Current, which flows south-westward along the South and East Coasts (KZN and Eastern Cape) with significant speed and volume – refer to Figure 16. Its high energy density, primarily found off the continental shelf, boasts velocities that can exceed 2.0 m/s (or ≈4 knots) in the current's core (refer to Figure 17), leading to an enormous theoretical energy potential. However, capturing this resource faces major hurdles: the strongest flow occurs far offshore, demanding costly deep-water moorings and long transmission cables; the current's instability, marked by turbulence and large meanders (known as Natal Pulses), complicates turbine placement and maintenance; and finally, deploying large-scale current farms raises environmental concerns about impacts on marine life, navigation, and the current's own thermal dynamics (Meyer, Reinecke, Roberts, & van Niekerk, 2013)

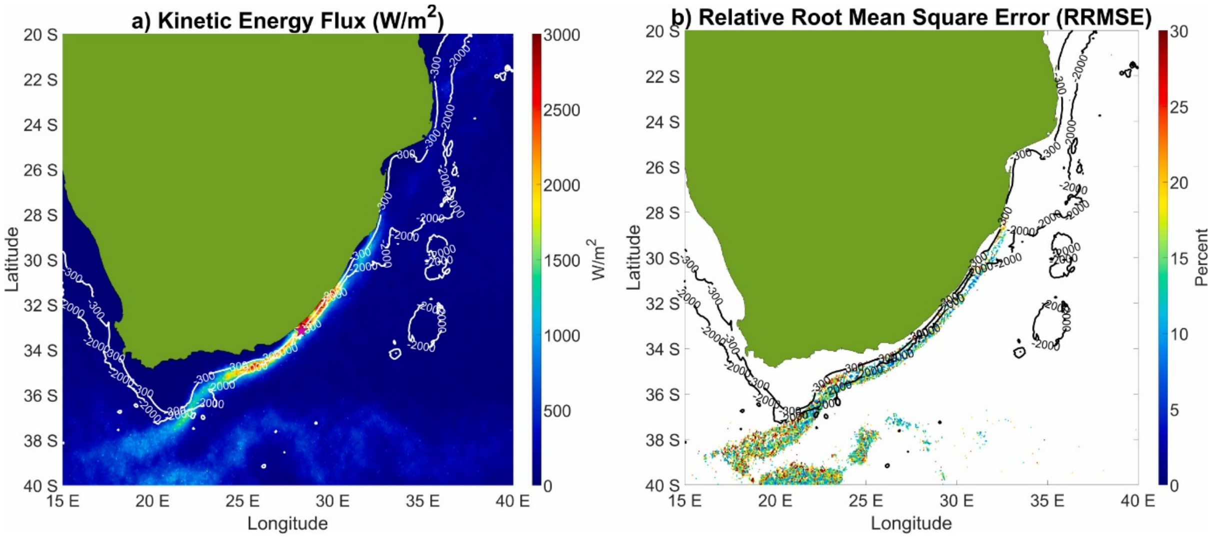


Figure 16: Calculated average power density in South Africa and the corresponding RRMSE (Sadoughipour, VanZwieten, & Tang, 2025)

While the Agulhas Current offers a significant and powerful resource for Ocean Current Energy, the high technical costs associated with deep-water deployment and the navigational and environmental complexities mean that South Africa's focus remains primarily on the more accessible offshore wind and wave energy resources in the near to medium term.

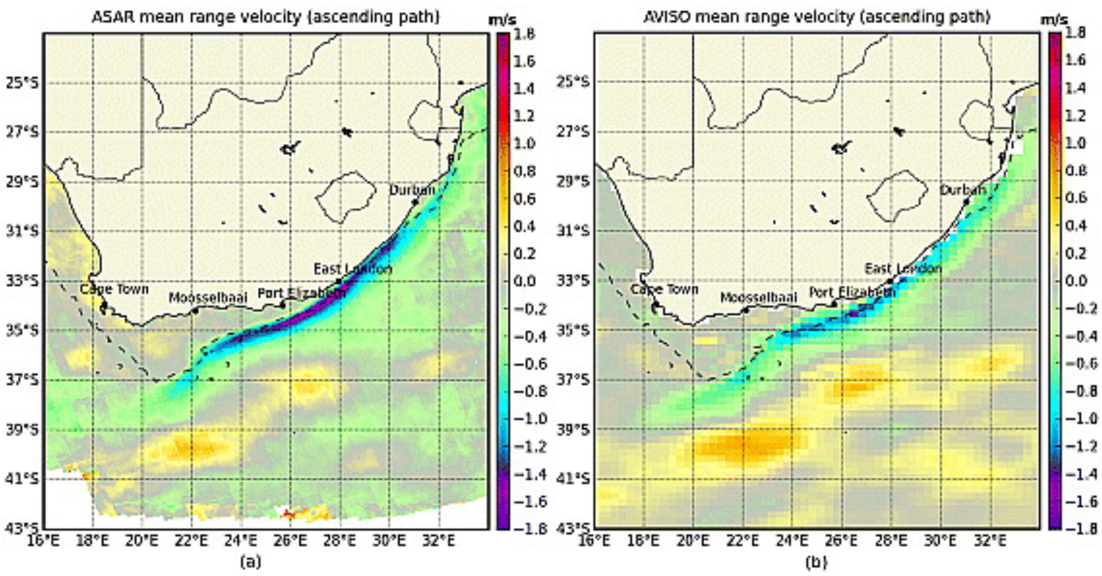


Figure 17: Mean range-directed surface current velocity (in m/s) in an ascending path configuration for (a) ASAR and (b) AVISO. Positive values indicate a flow toward the northeast, about 75° from the north (Rouault, Mouche, Collard, Johannessen, & Chapron, 2010)

2.6.3 Ocean current theory

The equation for the theoretical power available from ocean currents is derived from the kinetic energy of the moving fluid, which is essentially the same formula used for wind power. This power is expressed as the total kinetic energy flux passing through the cross-sectional area swept by the energy converter (like a turbine).

The total incident power (P) available in a free-flowing ocean current is given by:

$$P = C_P \times \frac{1}{2} \times \rho \times A \times v^3 \qquad (2)$$

Where:

- P is the **power** available in the current (in Watts, W).
- C_p is the power coefficient, a dimensionless measure of the **efficiency** of the turbine itself. Theoretically limited by the Betz limit to 0.593 for unbounded, free fluid flow, but the blockage effect of the seafloor fluid flow for ocean current turbines, can see the Betz limit exceeded.
- ρ(rho) is the **density of the seawater** (typically ≈ 1 025 kg/m^3).
- A is the cross-sectional area swept by the turbine rotor (in square meters, m^2).
- v is the **velocity** or speed of the ocean current (in meters per second, m/s).

2.6.4 Opportunities of ocean current energy

The main advantages of ocean current energy conversion are rooted in the physical properties of water and the nature of global ocean currents. Ocean current energy provides highly predictable baseload power because major currents are continuous and stable, driven by large-scale forces rather than transient weather patterns. This continuity translates into a high capacity factor for the turbines, often exceeding 50%. Furthermore, because water is approximately 830 times denser than air, even slow currents carry immense kinetic energy density, allowing ocean current devices to be smaller and slower-moving than wind turbines for the same output. Finally, since the systems are deployed entirely underwater, they have minimal to no visual impact on the coastline.

2.6.5 Challenges of ocean current energy

Ocean current energy conversion in South Africa is plagued by challenges despite the enormous theoretical potential of the Agulhas Current. The strongest flow occurs far offshore, requiring the deployment of turbines in deep water with complex, costly deep-water moorings and the installation of very long, expensive subsea transmission cables. Furthermore, the current is highly unstable, known for generating turbulence and large meanders (Natal Pulses), which complicates turbine placement and subjects the infrastructure to extreme and unpredictable loads. Finally, there are significant environmental concerns, including potential impacts on critical marine life, the risk of biofouling (marine growth) severely reducing efficiency, and the added concern of devices posing a hazard to shipping and navigation in offshore operational areas.

2.6.6 Ocean current technology

Ocean Current Energy Conversion (OCEC) is a marine renewable technology that captures the kinetic energy stored in the steady, continuous flow of major ocean currents and localised tidal streams. The core technology involves adapting principles from wind power, using horizontal- or vertical-axis hydrokinetic turbines submerged underwater. Technology development has been focused on creating robust, efficient devices capable of operating in the harsh marine environment. Key development stages include achieving high efficiency (C_P) in water, creating durable anti-fouling materials, and engineering cost-effective mooring and foundation systems suitable for deep-water and high-velocity flows. Unlike wind, the high energy density of water (over 800 times that of air) means development can focus on smaller, slower-moving turbines to provide a highly predictable baseload resource.

2.6.6.1 Example case study: Minesto

The Minesto Deep Green technology is a type of underwater kite or hydrofoil that generates energy from tidal and ocean currents. Its operational principle is unique: instead of relying solely on the velocity of the ambient current, the tethered kite, equipped with a turbine, performs pre-programmed figure-eight trajectories (or "flying patterns"). This manoeuvre allows the kite to move through the water at a speed several times higher than the actual average current speed, effectively multiplying the flow velocity relative to the turbine blades. A primary advantage is that this design permits energy generation in low-velocity currents (as low as 1.2 m/s), which are typically uneconomical for conventional fixed-turbine technologies (Minesto, 2025). For South Africa's powerful Agulhas Current, which is fast but located in deep water far offshore, the Minesto system's capability for deep-water deployment and efficient energy capture in the lower velocity edges of the current could be advantageous. However, the system would need rigorous testing to withstand the extreme turbulence and strong eddies (Natal Pulses) characteristic of the Agulhas Current core.

Figure 18: The Minesto Deep Green underwater kite tidal energy converter. The left image illustrates the key components, including the hydrofoil wings, turbine, and tether, while the right image shows the device pre-deployment (Minesto, 2025)

2.6.6.2 Example case study: Orbital Marine Power

The Orbital Marine Power (formerly Scotrenewables) O2 is a second-generation, floating tidal stream turbine. Its operational principle involves anchoring a long, catamaran-like platform in a high-velocity tidal current, allowing two large, submerged rotors—which are mounted on strut legs at either end of the platform—to harvest kinetic energy from the flow. Key advantages include its low-cost installation and maintenance, as the entire platform can be easily towed to port, eliminating the need for specialised dive vessels. Its flagship achievement is the O2 device currently deployed at the European Marine Energy Centre (EMEC) in Scotland, which is the world's most powerful operational tidal turbine (Tethys, 2025). While the technology is designed for strong tidal flows, its robust, surface-piercing design and easy maintenance access could make it technically adaptable for South Africa's fast-flowing Agulhas Current. However, the Agulhas current flows in deep water far offshore, necessitating significantly longer mooring systems, very long subsea cables, and greater turbulence resistance compared to the typical nearshore tidal environments for which the O2 was optimised.

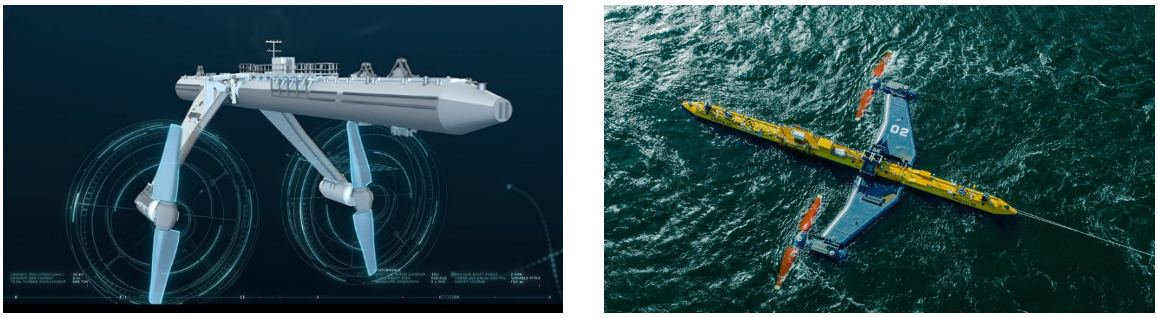


Figure 19: The left schematic shows the dual-rotor vessel design (European Union, 2020), while the right image provides an aerial view of the device deployed at sea (Orbital Marine Power).

2.7 Offshore wind

Offshore wind energy is generated by harnessing the kinetic energy of wind flowing over bodies of water, primarily seas and oceans, using turbines fixed to the seabed or mounted on floating structures.

The wind itself is an indirect form of solar energy. It originates from the differential heating of the Earth's surface by the Sun. Air masses over the equator are heated more intensely than those over the poles, creating pressure differences. Air flows from areas of high pressure to areas of low pressure, generating wind.

For offshore wind, the resource is often superior to onshore wind due to three key factors:

1. Reduced Friction: Over the open sea, there are less physical obstructions, (trees, buildings, hills) than on land. This drastically reduces the surface friction, allowing wind speeds to be higher and more consistent, and therefore the capacity factor for offshore wind is larger than for onshore wind.
2. Thermal Stability: The ocean's large thermal mass moderates temperature fluctuations, reducing the diurnal (day-night) variation in wind speed that is common over land (Foody, Coburn, Aird, Barthelmie, & Pryor, 2024).
3. Nocturnal Jets: Over the sea, winds often accelerate at night, creating low-level nocturnal jets that deliver strong, steady power when solar generation is offline (Quint, Lundquist, & Rosencrans, 2025).

Offshore wind power is the most mature and commercially proven technology among all marine renewable energy sources, standing distinctly ahead of wave, tidal, and ocean current power. While other marine technologies are still scaling up prototypes and operating at demonstration level, global offshore wind has reached gigawatt-scale deployment, boasting a total installed capacity exceeding 83 GW (Global wind energy council, 2025). This substantial deployment, particularly using fixed-bottom foundations in shallow waters, confirms its status as a technically proven and bankable technology, having successfully transitioned from an emerging technology to a key component of the global energy transition.

2.7.1 Global distribution of offshore wind

The global offshore wind resource is vast, but the commercially viable areas are concentrated where high, consistent wind speeds occur relatively close to large population centres and where water depths allow for installation.

- Northern Europe (High Potential): The shallow waters of the North Sea and the Baltic Sea possess immense, consistent wind resources due to their location in the path of the Westerlies. These regions currently lead the world in offshore wind capacity and density.
- North America and East Asia (Emerging Potential): The East Coast of the United States and the waters off the coasts of Japan, Korea, and China are rapidly developing, capitalising on strong coastal winds and are also starting to utilise floating offshore wind technology to access deeper waters further from shore.
- Deep Water Resource: The theoretical potential for offshore wind, especially when considering floating turbines for areas deeper than 60 meters, is enormous, with estimates suggesting the global technical potential could exceed 420 000 TWh/year (International Energy Agency , 2019). Refer to Figure 20 below for the global distribution of offshore wind speed.

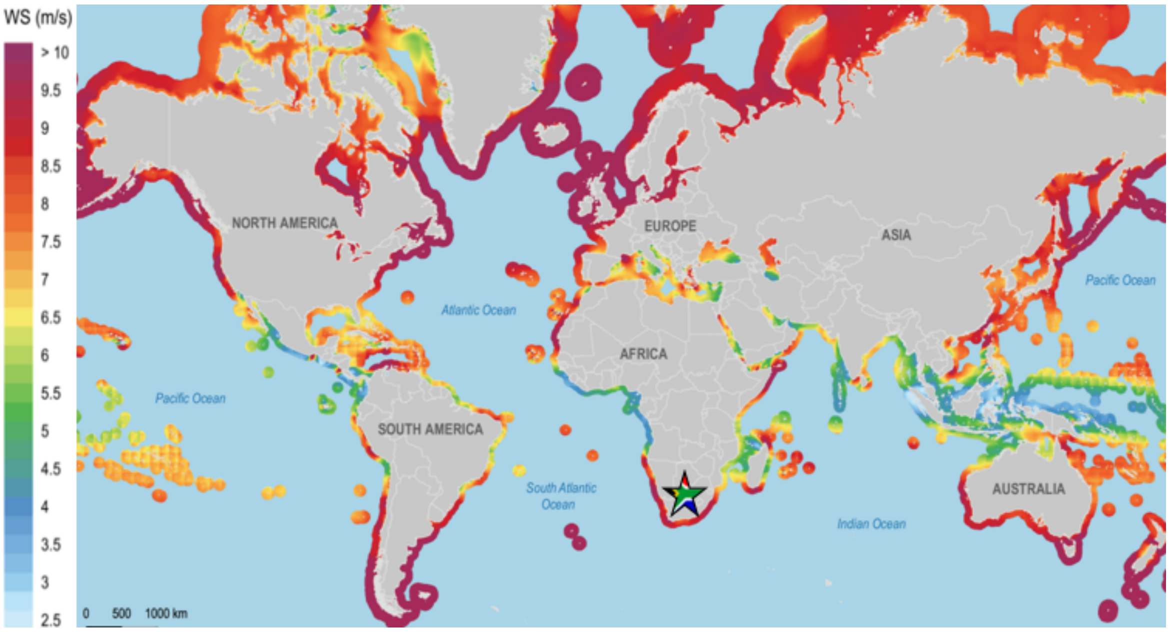


Figure 20: Global offshore wind speeds (Technical University of Denmark, World Bank Group, n.d.)

2.7.2 South Africa's offshore wind resource

South Africa possesses a significant and strategically important offshore wind resource, presenting a major opportunity for diversifying its energy mix. The resource magnitude is noteworthy, generally being stronger than the national average onshore wind resource. The greatest potential is concentrated in two primary areas: the West Coast (Atlantic), where the strong South Atlantic High-Pressure system drives particularly high wind speeds and high potential for both fixed-bottom and floating turbines, and the South Coast (Indian Ocean), particularly along the Southern Cape and Eastern Cape, which also shows robust potential, especially in deeper waters. Due to the steep drop-off of the continental shelf around South Africa, a substantial portion of the high-quality resource is located in water depths exceeding 60 meters. Consequently, floating offshore wind (FOW) technology is considered the most promising long-term option for large-scale deployment, rather than traditional fixed-bottom turbines. This resource offers high strategic value as it provides crucial complementary generation to the country's solar power, often generating electricity most strongly during the evening and winter months when national grid demand typically peaks. Therefore, offshore wind is viewed as essential for meeting South Africa's ambitious long-term renewable energy targets (Rae & Erfort, 2020).

Figure 21: Offshore wind speeds of the coast of South Africa (Technical University of Denmark, World Bank Group, n.d.)

2.7.3 Offshore wind theory

The theory for offshore wind power is fundamentally the same as the kinetic energy flux equation used for ocean currents: Equation (2) of 2.6.3 Ocean current theory. The primary difference lies in two crucial parameters: fluid density (ρ) and the power coefficient (C_p). Since the density of air is approximately 800 times less than that of water, the power coefficient (C_p) for wind turbines cannot exceed the Betz limit for unbounded, free fluid flow. Due to the vast difference in density, significantly stronger wind speeds are required to generate the same amount of power as a hydrokinetic turbine, or, alternatively, a significantly larger turbine rotor area (A) is needed for an offshore wind device compared to a tidal turbine to produce equivalent power.

2.7.4 Opportunities of offshore wind

The main advantages of offshore wind power stem from harnessing the powerful, stable winds over the open sea. Offshore wind resources are of superior quality because the lack of surface friction minimises turbulence and allows for higher, more consistent wind speeds than onshore. This results in a significantly higher capacity factor than typical onshore wind farms – 40 to 50% versus 30 to 40% for onshore wind (International Renewable Energy Agency, 2019). Furthermore, because the technology is well established and commercially available, it offers rapid scalability. Final benefits include reduced visual and noise impact due to deployment far from the coast, and the potential for cost and infrastructure synergy (shared cabling, vessels) through co-location with other marine energy technologies. Examples of potential co-location opportunities include combining these with fish farming and seaweed harvesting operations (Miranda, Rosa-Santos, Taveira-Pinto, Guan, & Fazeres-Ferradosa, 2025).

Co-locating floating solar photovoltaic (FPV) systems with offshore wind farms optimises marine space and enhances energy yield through resource complementarity; solar peaks during the day while wind energy is often higher at night or during storms. This hybrid model significantly lowers the Levelised Cost of Energy (LCOE) by sharing expensive infrastructure like offshore substations and subsea cables (Ramanan, King, & Jundika, 2025). Furthermore, the natural cooling effect of the water increases solar panel efficiency by 5–10% (Himan, Rabby, Hassan, Ahmed, & Khalil, 2025), creating a more stable and cost-effective renewable energy hub.

2.7.5 Challenges of offshore wind

The challenges facing offshore wind power are dominated by high capital costs, making it uncompetitive with cheaper land-based renewables despite being the cheapest ocean technology. This expense is compounded in places like South Africa, which currently lacks a local supply chain, necessitating the costly importation of turbines, cables and foundation structures, as well as specialised vessels. Furthermore, the marine environment is harsh and corrosive, leading to expensive and complex maintenance. Construction activities, particularly pile-driving, generate intense noise pollution harmful to marine life, while the vast turbine arrays introduce environmental concerns related to migratory birds and create hazards for shipping and fishing.

2.7.6 Offshore wind technology

Offshore wind technology utilises wind turbines installed in the sea to harness the stronger and more consistent wind speeds found away from the coast, where there is less friction from land features. These installations consist of massive turbines that convert the wind's kinetic energy into electricity via a generator housed in the nacelle. As illustrated in the schematic (Figure 22), the primary technical components include the rotor assembly—comprising the aerodynamic blades and the central hub—and the tower, which elevates the turbine to access higher wind speeds. The hub houses the pitch system to optimise energy capture by adjusting blade angles, while the tower supports the nacelle, which contains the drivetrain (including the generator and often a gearbox) and the yaw mechanism that aligns the rotor with the prevailing wind direction.

To give an idea of scale in terms of size and capacity of onshore and offshore wind turbines and how this is predicted to increase towards to 2035, refer to Figure 23. For shallow water (typically less than 50 m), turbines are secured using fixed-bottom foundations like monopiles or jackets; for the vast deep-water resource, Floating Offshore Wind (FOW) systems are used, which are tethered to the seabed. The electricity generated is then collected by an offshore substation and sent to shore via subsea export cables for connection to the grid – refer to Figure 24.

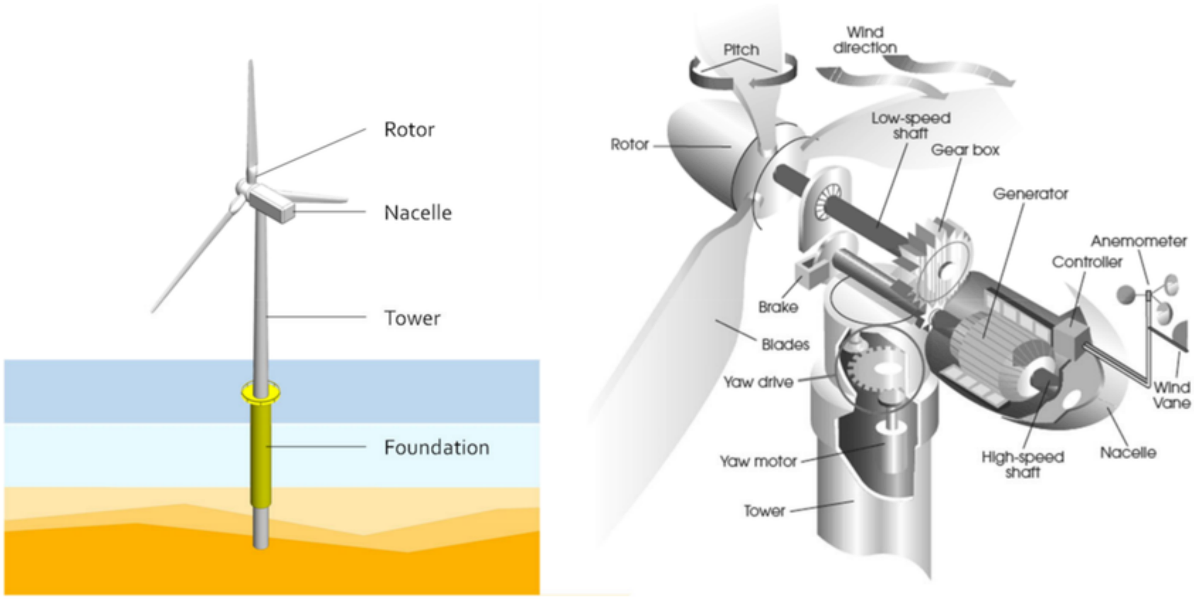


Figure 22: Main components of an offshore wind turbine (Oliveira, et al., 2024)

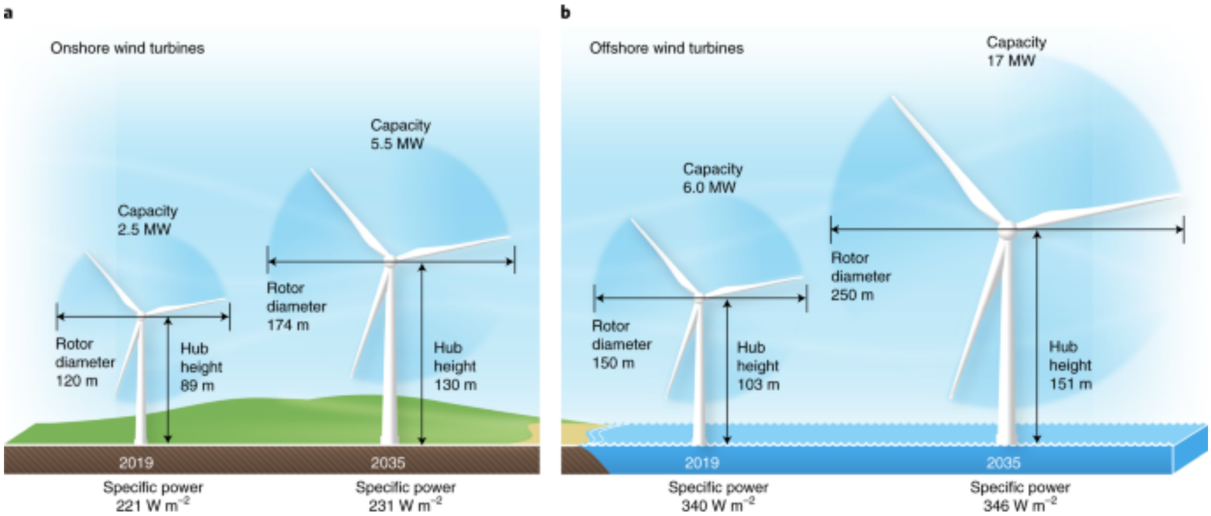


Figure 23: Predicted progression of wind turbine size for onshore and offshore applications (Wiser, et al., 2021)

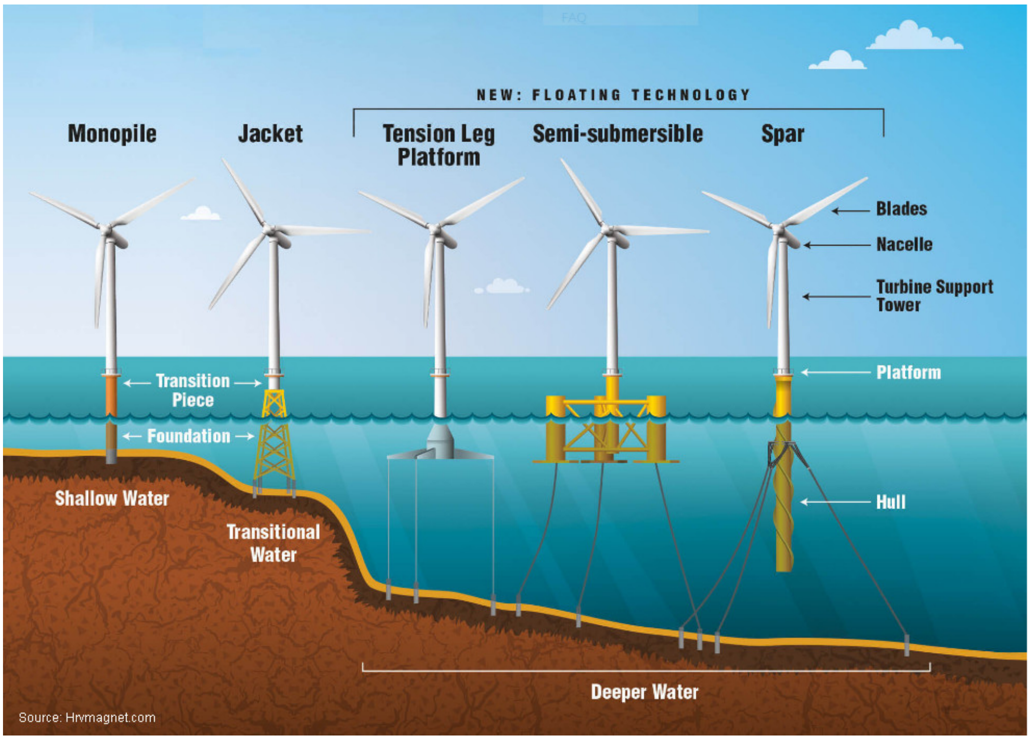


Figure 24: Types of offshore wind turbines (Blue Horizon, n.d.)

2.7.6.1 Example case study: WindFloat Atlantic

Located 20 km off the coast of Viana do Castelo, Portugal, WindFloat Atlantic is a suitable case study for South Africa as it represents the world's first semi-submersible floating wind farm. Commissioned in 2020, the project consists of three 8.4 MW turbines operating in water depths of approximately 100 meters, a profile that closely matches the deep-shelf conditions found off the South African coast where fixed-bottom foundations are not viable (Memija, 2024).

This project is particularly relevant to the South African context because it offers a direct solution to the country's current logistical and infrastructure bottlenecks. Unlike traditional offshore wind projects that require massive heavy-lift vessels—which are currently unavailable in South Africa and prohibitively expensive to mobilise—the WindFloat technology allows the entire unit to be assembled onshore in a dry dock. Once assembled, the units are simply towed to the site by standard tugboats, a capability that aligns with the existing ship-handling and towing expertise found in major South African ports like Durban and Cape Town.

Furthermore, the site is exposed to the powerful swells of the Atlantic Ocean, mirroring the high-energy environments of the Western and Eastern Cape. The platforms have successfully withstood extreme weather conditions, including waves of up to 20 meters, proving the technology's durability in sea states similar to those of the "Roaring Forties" (Windfloat Atlantic, 2024). Beyond technical resilience, WindFloat Atlantic has served as a global pilot for the coexistence of offshore wind and commercial fisheries. The project provides critical data on managing exclusion zones and protecting local livelihoods, which is a primary concern for ensuring a Just Energy Transition (JET) for South Africa's coastal communities.

Figure 25: WindFloat Atlantic pilot project (Ocean Winds)

2.7.6.2 Example case study: Kincardine offshore wind farm

The Kincardine Floating Offshore Wind Farm (FOWF), located in Scottish waters, is another appropriate case study for South Africa's offshore wind ambitions because it directly tackles the challenges of deep-water deployment. Situated in depths of 60 to 80 meters, Kincardine validated the use of Floating Offshore Wind (FOW) technology, which is essential for South Africa as its high-potential wind resource lies beyond the rapidly dropping continental shelf. The project demonstrated the feasibility of assembling and towing massive turbines to site, confirming the logistical and technical pathway required for South Africa to access its best wind resources where fixed-bottom turbines are not practical. Kincardine therefore serves as a crucial blueprint for the FOW technology and specialised supply chain South Africa needs to develop (Statkraft, 2021).

Figure 26: The schematic (left - By Untrakdrover - Own work, CC BY-SA 3.0) of the floating foundation and turbine components of Kincardine floating wind farm, while the right image shows an aerial photograph of the a single turbine fully deployed in the North Sea site (Statkraft, 2021).

2.7.6.1 Future case studies in South Africa: The Gagasi project & PetroSA

The Gagasi Offshore Floating Wind Farm is currently the leading commercial-scale offshore wind prospect in South Africa and serves as a vital local case study for the industry. Developed by GenesisHexicon—a joint venture between the South African firm Genesis Eco-Energy Developments and the Swedish floating wind specialist Hexicon—the project is situated approximately 5 to 17 km off the coast of Richards Bay, KwaZulu-Natal. Designed with a planned capacity of 810 MW, the facility is expected to feature up to 54 wind turbines mounted on floating foundations, a technology specifically chosen to tap into the high-energy, deep-water wind resources (>50 m) that characterize the South African shelf. Currently in the Environmental Impact Assessment (EIA) phase, the project aims to feed clean power directly into the national grid at the Richards Bay industrial hub, representing a significant capital investment of approximately ZAR 55 billion and a major step toward diversifying South Africa's energy mix through its vast marine potential (TGS | 4C, 2025).

As part of its strategic shift toward South Africa's energy transition, PetroSA is actively exploring the feasibility of developing offshore wind farms within its existing offshore rights. In early 2024, the state-owned entity launched a call for a comprehensive technical and economic study focusing on the southern and western coastal regions, specifically targeting Offshore Blocks 9 and 11A near Mossel Bay. A central component of this initiative is the potential re-use of existing offshore infrastructure, such as the FA Platform and its subsea network, for electricity generation and transmission to reduce decommissioning liabilities and capital costs. While acknowledging the current lack of high-altitude wind data and specialised local regulations, PetroSA aims to identify suitable floating technologies and develop a roadmap for commercial-scale production, potentially beginning with a pilot project to test impact and integration in deep-water environments (Maritime Review Africa, 2024).

3 Infrastructure requirements

The successful deployment of Marine Renewable Energy (MRE)—including offshore wind, wave, and ocean current devices—depends on establishing complex, specialised infrastructure both onshore and offshore. This infrastructure represents a significant upfront cost but is essential for project viability and long-term operation.

3.1 Port infrastructure and logistics

The sheer size and weight of modern MRE components necessitate substantial upgrades to coastal ports, transforming them into dedicated offshore energy industrial hubs.

3.1.1 Specialised port facilities

A conventional commercial port is not suitable for MRE construction. Key specialised port infrastructure requirements include:

- Quayside space: Vast, high-load-bearing quayside and laydown areas are needed for component staging, storage, and assembly (refer to Figure 27 for an example of offshore wind turbine storage). This is particularly critical for Floating Offshore Wind (FOW) platforms, which are often fabricated or fully integrated onshore before being towed out to sea.
- Heavy-lift cranes: Ports must be equipped with specialised, super heavy-lift cranes capable of handling multi-megawatt nacelles, lengthy blades (exceeding 100 meters), and foundation segments, often requiring lifts in excess of 1 500 tonnes.
- Manufacturing and fabrication: Establishing local manufacturing facilities within the port area, especially for FOW platforms and components, is vital for developing a domestic supply chain and reducing reliance on costly imports. However, investment in developing the local resources will only be done if there is a pipeline of projects supported by national policy in place.

Figure 27: Jacket foundations for ground-mounted offshore wind turbines stored on the quayside in Port of Nigg (Offshore Engineering)

3.1.2 Specialised vessels and tugs

The construction and deployment phase requires a fleet of expensive, highly specialised marine assets:

- Deployment vessels: Specialised jack-up vessels (for fixed-bottom wind), large semi-submersible heavy-lift vessels, and anchor handling tug supply (AHTS) vessels are needed for installing foundations, towers, and mooring systems.
- Cable-Laying Vessels (CLVs): Highly sophisticated, dynamically positioned vessels are required for the precise laying and burial of subsea cables.
- Tugs and crew transfer vessels (CTVs): Powerful tugs are necessary for towing massive FOW structures and CTVs for transferring maintenance personnel and light cargo.

3.2 Subsea electrical infrastructure

The electrical infrastructure is the high-cost artery connecting the generation site to the grid.

3.2.1 Subsea cabling

- The cable system comprises two main components, both of which are expensive and require specialised deployment:
- Inter-array cables: These cables link individual generating devices (turbines, wave converters, current devices) within the farm to the central offshore substation.
- Export cables: The main high-voltage cable transmits the aggregated power from the offshore substation to the onshore grid connection point. These cables must be buried beneath the seabed for protection against fishing gear, anchors, and environmental scour.
- AC vs. DC: The choice between High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC) for the export cable depends on distance and capacity. HVAC is cheaper for short distances but suffers from high losses over long routes. HVDC is preferred for long-distance projects (typically over 100 km) and requires expensive converter stations at both ends, but results in lower energy losses – refer to Figure 28 below.

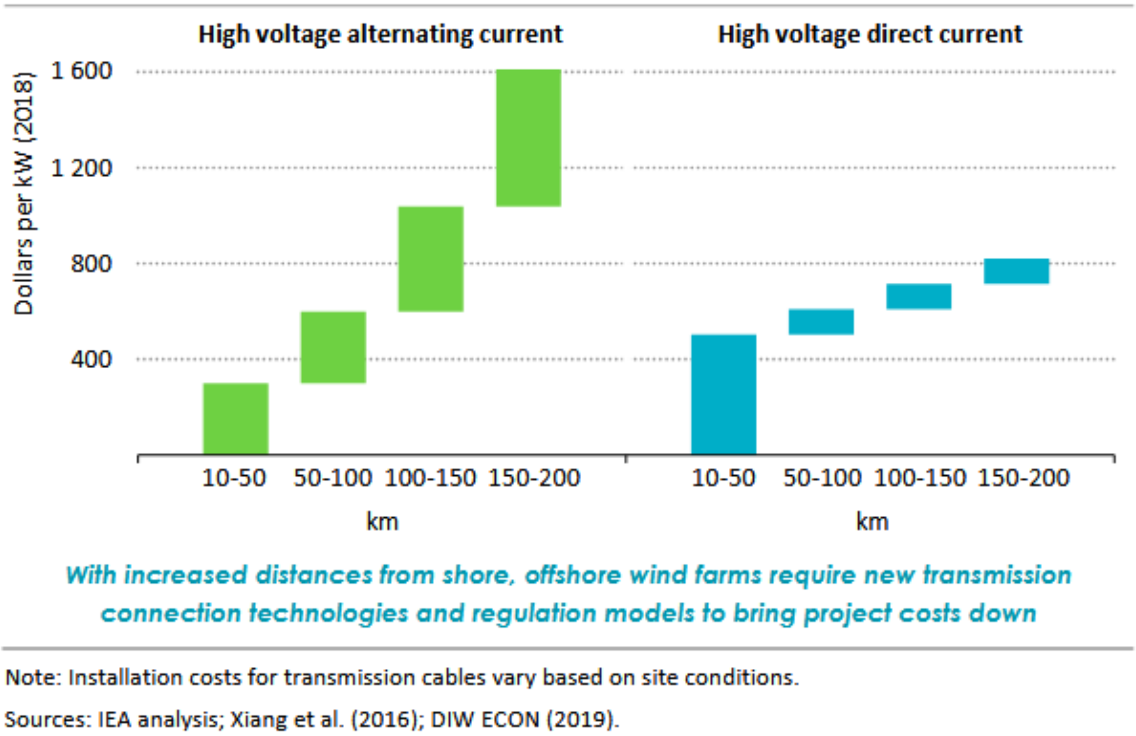


Figure 28: Indicative upfront capital coast for high-voltage transmission cables by and distance from shore (International Energy Agency , 2019)

3.2.2 Offshore and onshore substations

- Offshore Substation (OSS): This structure collects the lower voltage power from the inter-array cables, transforms it to a higher voltage (to minimise transmission losses), and then feeds it into the main export cable (refer to **Error! Reference source not found.** which s hows an example of an offshore substation)
- Onshore substation (grid connection): The cable lands onshore and connects to a substation where the power is further conditioned, converted (if HVDC is used), and connected to the national high-voltage transmission network, requiring compliance with the local Grid Code.

3.3 Operations and Maintenance (O&M) infrastructure

Long-term project viability depends on efficient and cost-effective O&M infrastructure.

3.3.1 O&M base and vessels

- O&M base: A dedicated port facility is typically required to house maintenance personnel, spare parts, and equipment.
- Service vessels: This includes specialised crew transfer vessels (CTVs) for personnel, and larger service operation vessels (SOVs) which house technicians for extended periods offshore, particularly for sites further from the coast.

3.3.2 Future Cost Reduction through Advanced Tools

The O&M phase is typically the most expensive component of an MRE project over its lifespan. However, the cost of O&M for offshore wind is expected to keep on decreasing due to rapid technological advancements (refer to Figure 29 below which shows how O&M costs are expected to decline due to economies of scale and industry synergies, along with technology advancement):

- Predictive maintenance with AI: The use of Artificial Intelligence (AI) analyses real-time sensor data from turbines (vibration, temperature, noise) to predict component failure before it occurs. This allows for scheduled, proactive repairs rather than costly, reactive emergency fixes, dramatically improving uptime.
- Robotics and drones: Specialised robots and Remotely Operated Vehicles (ROVs) are increasingly used for routine inspections, repair of underwater foundations and moorings, and subsea cable integrity checks. Drones are used for inspecting turbine blades and towers, replacing reliance on costly rope access teams and improving technician safety.

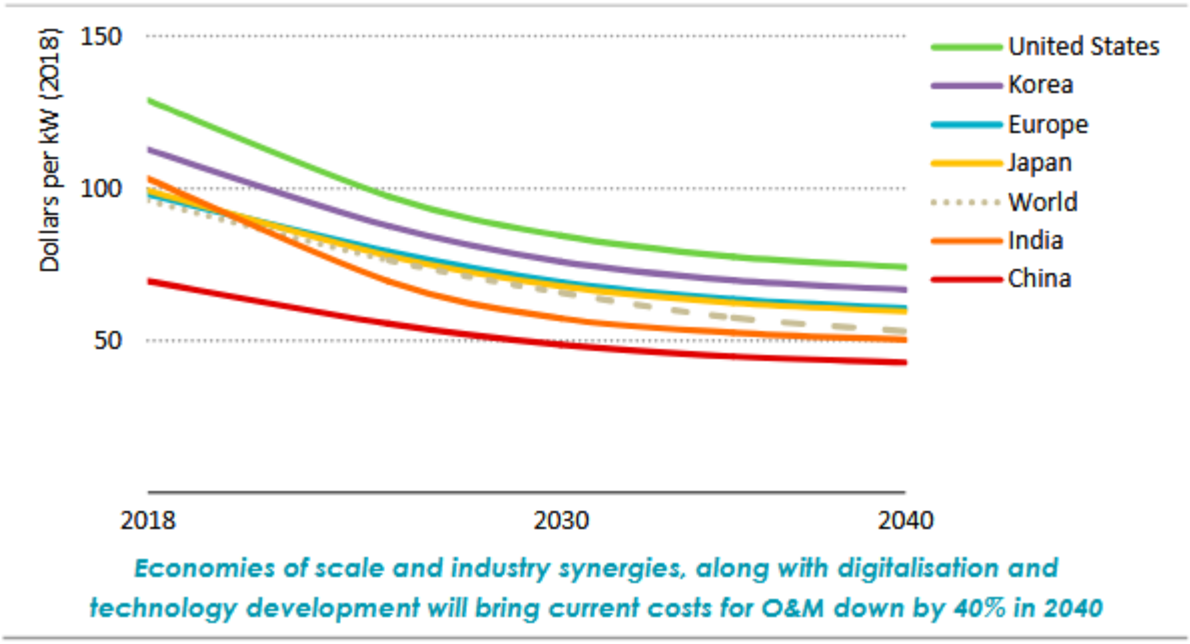


Figure 29: Regional average annual O&M costs for new projects (International Energy Agency , 2019)

South Africa's port infrastructure is currently not adequately equipped to provide the necessary specialised support for the emerging MRE industry, particularly for large-scale offshore wind projects. While ports like Durban, Cape Town, and Port Elizabeth possess general maritime capacity, they lack the extensive, high-load-bearing quayside space required for the simultaneous staging and assembly of massive Floating Offshore Wind (FOW) platforms. Furthermore, they generally lack the specialised heavy-lift cranes and equipment needed to handle the immense weight and dimensions of modern turbine components. This deficit is compounded by the absence of a localised manufacturing supply chain, meaning specialised components and vessels must be imported, significantly increasing project costs and logistical complexity. Developing the MRE sector requires strategic and substantial upgrades to other available ports, such as Saldanha Bay and the Port of Ngqura, to transform them into dedicated offshore energy industrial hubs.

4 Potential environmental, social & economic impacts

The development of marine renewable energy (MRE) technologies—offshore wind, wave, and ocean current converters—presents a critical balance for South Africa: utilising vast, clean energy resources while safeguarding its unique, highly sensitive coastal and deep-sea ecosystems, which include the Benguela Current Marine Ecosystem and the powerful Agulhas Current. Environmental Impact Assessments (EIAs) must be meticulously conducted across the project lifecycle, from construction through operation and decommissioning, with particular attention paid to socio-economic consequences for coastal communities.

4.1 Environmental impacts

Environmental impacts are generally categorised by the phase in which they occur, with unique considerations for South Africa's rich marine biodiversity, including migratory whales (e.g., Southern Right Whale, Humpback Whale) and endangered seabirds (e.g., African Penguin) (World Wildlife Fund). Refer to a depiction of potential environmental impacts of offshore wind during construction and operation below in Figure 30.

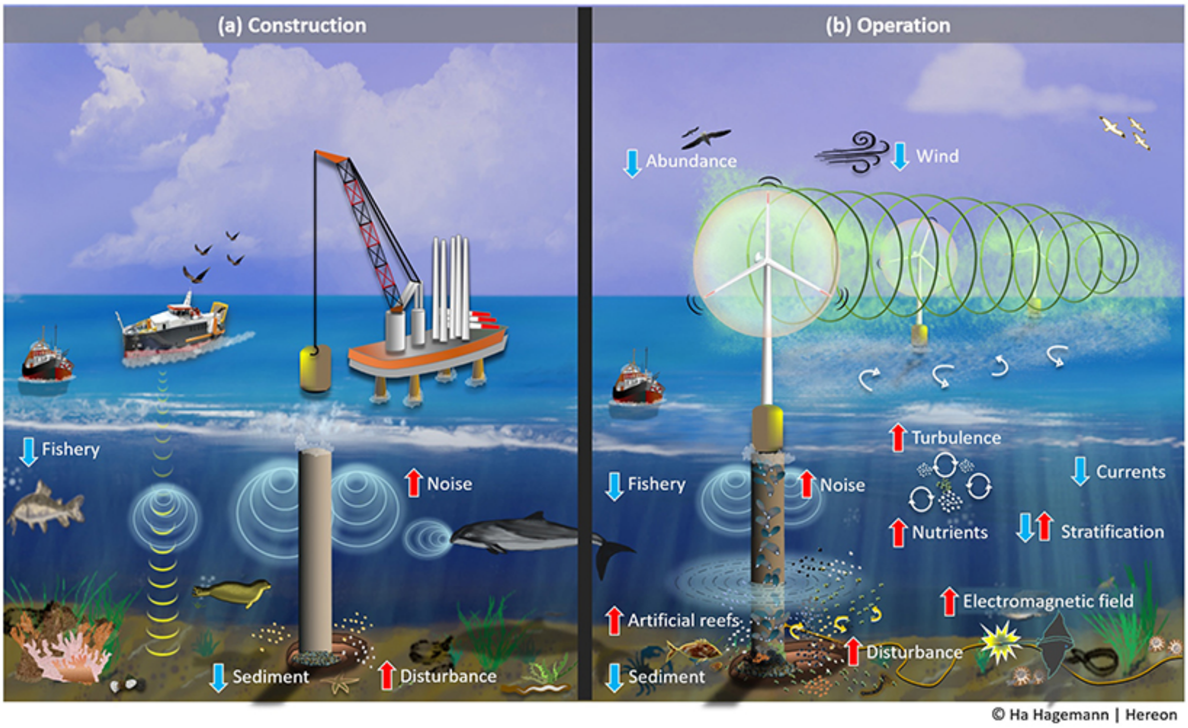


Figure 30: Offshore wind turbines have effects on the environment and ecosystems during (a) their construction, and (b) when they are in operation. Blue arrows represent a decrease in a specific process and red arrows indicate an increase (Benkort, Christiansen, Ho-Hagemann, Daewel, & Gilles, 2024)

4.1.1 Impacts during construction (Acoustic and physical disturbance)

Construction is the shortest phase but generates the most intense and acute impacts on the immediate environment.

4.1.1.1 Underwater noise

The most significant environmental impact during the construction of fixed-bottom offshore wind and nearshore wave devices is underwater noise, which largely originates from the intense, impulsive sound generated by pile driving for foundations, supplemented by noise from seabed preparation and cable trenching. High-intensity noise poses a direct threat, potentially causing physical injury such as barotrauma or permanent hearing loss in marine mammals and fish (Bonar, Bryden, & Borthwick, 2015). Critically, even non-injurious noise levels cause behavioural changes, leading to species displacement, disrupting vital activities like feeding, mating, and navigation, a major concern along the migration routes of cetaceans in South African waters (Ocean Energy Systems, 2022). Mitigation measures are essential and include employing acoustic bubble curtains to dampen sound (), utilising vibratory or drilling methods instead of percussive piling, and implementing Soft Start/Ramp-up procedures alongside Marine Mammal Observers (MMOs) who halt work when protected species are detected (Offshore coalition for energy and nature, 2024).

Figure 31: Noise mitigation measure of using a bubble curtain during foundation installation of offshore wind turbines (left) (Offshore engineer, 2023) and caisson suction foundations have a smaller footprint and reduced contact area with the seabed(right) (Rui & et al, 2023)

4.1.1.2 Habitat and Seabed Alteration

The installation phase of marine renewable energy devices inevitably involves the physical disturbance and alteration of the seabed. The primary sources of this impact are the placement of foundation footprints for fixed structures, anchor points for floating systems (wind, wave, and ocean current), and trenching or dredging required for laying subsea power cables (Bonar, Bryden, & Borthwick, 2015). The resultant impact is two-fold: dredging temporarily increases turbidity (sediment suspension), which can smother benthic (seabed) organisms; and the permanent presence of foundations causes a direct loss of existing habitat, a critical concern in the soft-bottom environments characteristic of the Agulhas Bank (Nelson Mandela University, n.d.). To mitigate these effects, developers must undertake detailed geophysical surveys to avoid sensitive habitats, ensure full cable burial to prevent scour, and utilise minimal footprint foundation designs, such as suction anchors, to reduce the contact area with the seabed (Foglia & et al, 2025).

4.1.2 Impacts During Operation (Chronic and Continuous Effects)

4.1.2.1 Collision risk and entanglement

Operational impacts are continuous and chronic, often related to the permanent infrastructure. During the operational phase of marine renewable energy devices, collision risk and entanglement pose a direct physical threat to marine fauna (Bonar, Bryden, & Borthwick, 2015). The primary sources of risk include the turbine blades of offshore wind devices (above water), the submerged rotors of ocean current turbines, and the extensive network of mooring lines and tethers used by wave and floating systems (Bonar, Bryden, & Borthwick, 2015).

Figure 32: Entangled whale (The marine mammal center, 2025)

The impact is critical for specific South African species: avian species like African Penguins and Cape Gannets risk lethal collision with wind turbine blades, while marine mammals, particularly migrating whales, face a high risk of entanglement in submerged mooring lines and tethers (Ocean Energy Systems, 2022). A crucial mitigation measure is the careful selection of site location to actively avoid areas with high concentrations of marine animals and established migration paths. Further mitigation includes slowing rotor tip speeds for ocean current devices, optimising turbine spacing in wind farms to maintain safe flight corridors for birds, and using taut mooring lines or protective casing to significantly reduce entanglement opportunities Mitigation Measures: Slowing rotor tip speeds where possible, optimising turbine spacing to allow for safe flight corridors, and using taut mooring lines or protective casing to reduce entanglement risk.

4.1.2.2 Underwater Noise and Electromagnetic Fields (EMF)

During operation, marine renewable energy devices are carefully managed to minimise environmental disturbance, focusing on controlling underwater noise and Electromagnetic Fields (EMF). While operational noise, generated continuously by components like generators and rotors, can cause acoustic masking, interfering with marine life communication, this is successfully mitigated using acoustic isolation and quieter direct-drive generators (Tougaard, Hermannsen, & Madsend, 2020). Regarding EMF, the energised subsea AC and DC cables generate only weak fields, and current research suggests the likelihood of significant negative impact on marine life is small (Ocean Energy Systems, 2022). Nonetheless, because elasmobranchs (sharks and rays) off the South African coast rely on electroreception, developers proactively deploy robust mitigation strategies: the primary defence involves the deep burial of all cables and the use of shielded or armoured cables. These measures effectively contain the fields, ensuring the technology's long-term environmental compatibility (Hutchinson, Gill, & Sigray, 2021).

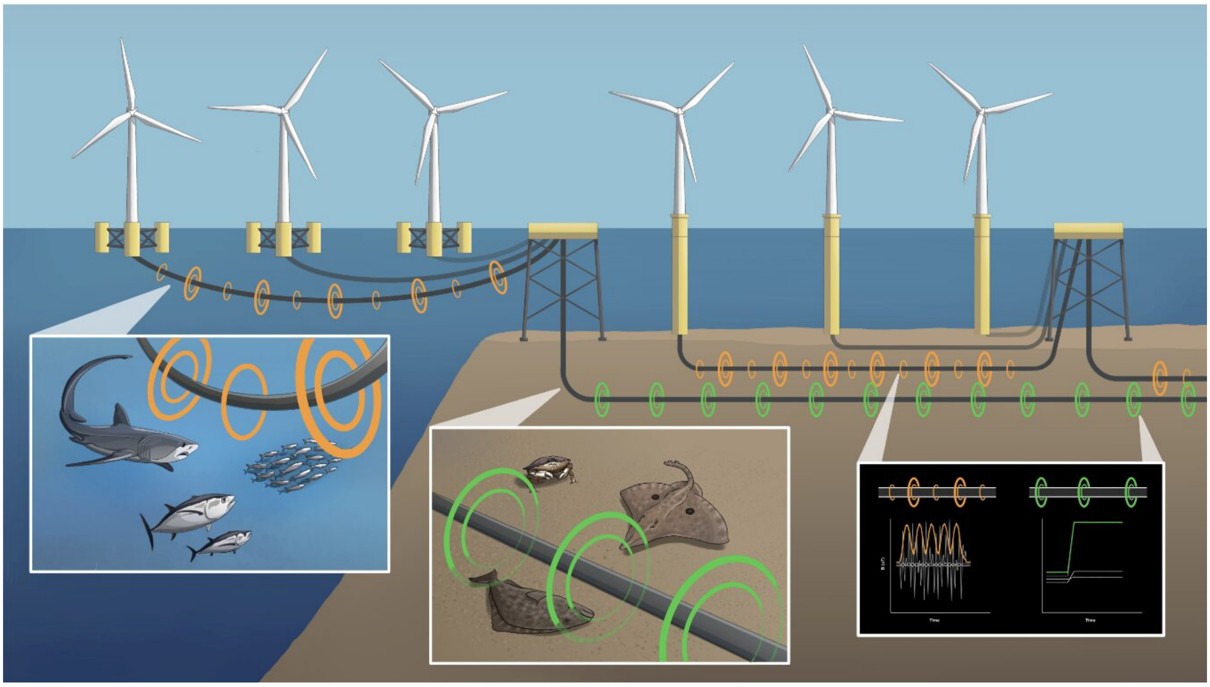


Figure 33: Diagram demonstrating the electromagnetic fields (EFS) that are emitted from electrical wires, such as deep-sea cables, which have the potential to impact marine creatures. Diagram © Kyle Newton (Save our seas foundation, 2025)

The sheer scale of marine renewable energy infrastructure can significantly alter the physical and ecological environment. One key impact is the 'Reef Effect', where foundations and anchors act as artificial reefs, attracting new benthic communities and mobile species, which, while potentially increasing local biomass, carries the risk of introducing invasive species and fundamentally altering the existing food web (Ocean Energy Systems, 2022). Furthermore, large arrays can induce changes in oceanographic systems: Wave Energy Converters (WECs) create a wave "shadow," potentially altering coastal sediment transport and leading to shoreline erosion down-wave or accretion (refer (Moradi, Chertouk, & Ilinca, 2022)), while massive energy extraction from ocean current arrays in the Agulhas could theoretically cause measurable current slowing and mixing, impacting thermal dynamics crucial for regional weather and fish stocks. Mitigation strategies are essential, involving the implementation of Marine Management Plans to monitor biological shifts and the use of advanced hydrodynamic modelling to precisely set array spacing and limit energy extraction thresholds in the Agulhas Current to negligible levels.

4.2 Social and Economic Impacts

The success of MRE in South Africa is reliant on achieving social license, meaning the industry must deliver economic benefits while addressing impacts on coastal communities.

4.2.1 Potential Impacts on Coastal Communities

The largest potential social impact of Marine Renewable Energy (MRE) deployment is the direct conflict with existing maritime activities, primarily affecting fishing and shipping. The requirement for safety and exclusion zones around MRE arrays leads directly to the displacement of commercial and small-scale fishers, resulting in reduced catch, increased operating costs due to longer transits, and, critically, threatening the socio-cultural fabric and heritage associated with fishing as a traditional way of life (Trifonova, et al., 2025). Furthermore, MRE deployment creates shipping and navigation hazards, forcing vessels to deviate from established international and domestic shipping lanes, which increases both operational time and cost (Maritime and coastguard agency, 2024). On land, the massive scale of MRE construction strains coastal infrastructure, as the influx of construction crews and specialised vessels, coupled with the high demand for storage and fabrication, can severely overwhelm the capacity of local port facilities (such as Saldanha Bay and Port of Ngqura) and place undue pressure on essential coastal town services such as housing and utilities.

4.2.2 Economic Benefits and Opportunities

Marine Renewable Energy (MRE) deployment represents a massive opportunity for economic diversification and enhancing national energy security for South Africa. The sector promises substantial job creation in high-value roles across engineering, specialised maritime maintenance, project management, and local component fabrication, which is critical for reducing reliance on costly international contractors – refer to the number of direct and indirect jobs create by the offshore wind industry in Europe in Figure 34 below. This demand for large floating offshore wind (FOW) platforms and other specialised components provides a powerful incentive for upgrading existing port infrastructure and establishing a robust local manufacturing supply chain, thereby generating sustainable, long-term economic activity (National Renewable Energy Laboratory; Moffat and Nichol, 2023). Furthermore, the predictable, high-capacity factor power generated by MRE sources directly contributes to grid stabilisation and supports the country's necessary just transition away from coal. Finally, although initial displacement of fishing is a concern, the exclusion zones around MRE arrays could potentially function as de facto marine protected areas, creating a "Refuge Effect" that leads to increased fish stock biomass and subsequent spill-over benefits for surrounding fishing waters (European commission, 2018).

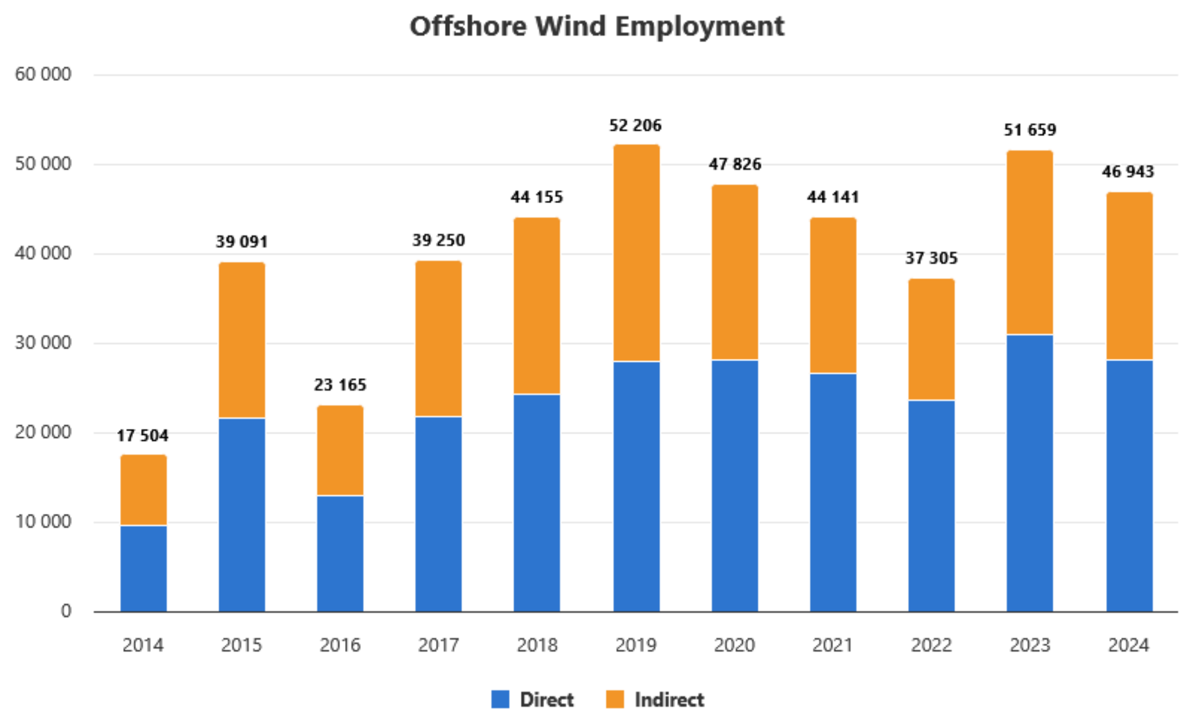


Figure 34: Employment in the offshore wind energy subsector, 2014–2024 (European commission, 2025)

4.3 Conclusion and Mitigation Strategy

The path for MRE deployment in South Africa requires a commitment to Best Available Technology and a collaborative, multi-sectoral approach. EIAs must move beyond standard compliance to include robust, long-term monitoring programs focused on the unique risks to the African Penguin, migrating whales, and the turbulent Agulhas Current. Crucially, the mitigation of socio-economic impacts requires early and inclusive consultation with fishing communities, transparent benefit-sharing mechanisms, and strategic public investment to transform coastal ports into integrated energy and industrial hubs. Only through this holistic approach can South Africa successfully harness its marine energy wealth while ensuring environmental and social sustainability.

5 Ocean energy deployment in South Africa

Marine Renewable Energy (MRE)—including offshore wind, wave, and ocean currents—represents a powerful, underutilized resource that can significantly contribute to South Africa's just energy transition (JET). However, its successful deployment requires navigating a complex local energy market and regulatory environment.

5.1 Local energy market and competition

The South African energy market is dominated by coal, but the policy shift towards renewables presents both opportunities and stiff competition for emerging marine technologies.

South Africa's JET aims to shift government decision-making towards evidence-based choices that prioritise ecosystem integrity and people's health and livelihoods over extractive, profit-driven economic growth. MRE can contribute to this by offering carbon-neutral generation alternatives. However, the immediate local market is highly sensitive to price and scalability, factors where established land-based renewables (solar and onshore wind) currently hold a significant advantage.

However, marine energy sources offer a unique competitive edge through resource predictability and high capacity factor:

- Ocean currents: These sources provide a predictable, reliable baseload resource because ocean currents flow continuously, which is crucial for grid stability.
- Offshore wind and wave: The resources are typically stronger and more consistent away from shore, offering a higher capacity factor than most terrestrial wind and solar farms.

Successful integration into the local market will therefore depend on demonstrating MRE's superior grid stability benefits and reducing the high initial costs through economies of scale and local supply chain development.

5.2 Regulatory requirements

MRE deployment in South Africa is subject to stringent, multi-layered regulatory requirements designed to protect the environment and ensure sustainable development. These regulations are categorised into key areas: **Environment**, **Energy**, **Climate Change**, and **Coastal & Offshore Management**.

5.2.1 Power generation permits and energy legislation

Generating electricity from the ocean with a capacity greater than 100 MW falls under the Electricity Regulation Amendment Act 38 (2024), necessitating a generation permit from the National Energy Regulator of South Africa (NERSA). NERSA requires general project information, including the project's name, location, type, capacity, energy efficiency, and expected lifespan. More detailed information must also be provided, covering:

- Maintenance and decommissioning costs and schedules.
- Expansion or modifications planned during the lifespan.
- Customer profiles.
- Financial information of the project.

Further energy compliance is mandated by the National Energy Act (Act 34 of 2008).

5.2.2 Environmental and coastal legislation

Environmental Impact Assessments (EIAs) are mandatory, governed primarily by the National Environment Management Act (Act 107 of 1998) (NEMA). The unique marine location necessitates compliance with several acts concerning coastal and marine resource management:

- Integrated Coastal Management Act (2008).
- Sea-shore Act (Act 21 of 1935).
- Marine Living Resources Act (Act 18 of 1998).
- Sea Birds and Seals Protection Act (Act 46 of 1973).
- Maritime Zones Act (Act 15 of 1994).
- Marine Pollution (Control and Civil Liability) Act (Act 6 of 1981).
- National Monuments Act (Act 28 of 1969).
- The South African Marine Safety Authority (1998).

Future planning will also need to align with the Marine Spatial Planning Act (under development).

5.2.3 Climate change and policy alignment

MRE projects must demonstrate alignment with national and provincial climate and policy frameworks:

- Integrated Resource Plan (2019).
- Western Cape Climate Change Response Strategy (2022).
- Climate Change Adaptation Response plan for South Africa’s Coastal Sector (2025).
- Draft National Greenhouse Gas Carbon Budget and Mitigation Plan Regulations (2025).

5.2.4 International conventions

Compliance extends to international agreements that govern marine activities and biodiversity conservation:

- United National Convention on the Law of the Sea (1982).
- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972).
- Convention on Biological Diversity (1992) and the Conservation of Biological Diversity White Paper (1997).

The overall regulatory environment ensures that development takes place only when people are empowered to participate in decision-making about their environment.

5.3 Opportunities

Despite the challenges, MRE offers significant opportunities to address core developmental, economic, and energy security issues in South Africa.

5.3.1 Security of supply

MRE contributes directly to national energy security. Ocean currents, in particular, provide a predictable, high-capacity baseload that can stabilise the grid and complement the inherent intermittency of solar and conventional wind.

5.3.2 Decentralised generation

Marine energy can support decentralised generation, allowing projects to be strategically sited closer to dense coastal population centres or remote coastal communities. This reduces the need for costly, long-distance terrestrial transmission infrastructure, contributing to overall system resilience.

5.3.3 Job creation and local economic growth

Developing the MRE sector is a potent engine for job creation and local economic diversification. The demand for specialised engineering, maintenance, and fabrication of components (especially for Floating Offshore Wind platforms) creates powerful incentives for:

- Upgrading port infrastructure.
- Establishing a local manufacturing supply chain.
- High-value employment in specialized maritime maintenance, engineering, and project management.

This investment aligns with the government's goal of empowering local communities and fostering social change by creating opportunities for employment and participation in sustainable economic development.

5.3.4 Informed Decision-Making

The research into MRE is intended to produce evidence that supports policy change towards sustainable practices. Making a comprehensive baseline report accessible for communities and civil society empowers them to participate actively in decision-making around energy planning, ensuring a just, equitable, and sustainable energy future.

6 Cost of ocean energy

The economic viability of Marine Renewable Energy (MRE) is fundamentally determined by its cost competitiveness against established energy sources. This cost is standardised using the Levelised Cost of Electricity (LCOE).

The Levelised Cost of Electricity (LCOE) represents the average cost to build and operate a power-generating facility over its entire lifetime, divided by the total energy it is expected to produce over that lifetime. It is typically expressed in currency per unit of energy, such as US Dollars per Megawatt-hour ($/MWh) or South African Rands per Kilowatt-hour (R/kWh).

Mathematically, the LCOE takes into account the time value of money through a discounted cash flow analysis, incorporating:

- Capital expenditure (CAPEX): Initial construction costs.
- Operational expenditure (OPEX): Fixed and variable maintenance costs.
- Fuel costs: (Zero for most renewables).
- Financing costs: The cost of capital (discount rate).
- Total lifetime energy production (influenced by the capacity factor).

The primary benefit of LCOE is that it provides a standardised, "apples-to-apples" basis for comparing highly disparate technologies—from coal-fired power plants to solar farms to wave energy converters—on an equal financial footing. This allows policymakers and investors to make informed decisions about the least-cost mix of new generation capacity, balancing factors such as cost, reliability, and emissions.

In 2015, global data clearly illustrated the economic challenge facing nascent marine technologies. Analysis by (Taveira-Pinto, Rosa-Santos, & Fazeres-Ferradosa, 2020) and others, presented in relevant reports at the time, showed a dramatic disparity in LCOE:

- Wave and tidal energy was significantly more expensive than established renewable options. At the time, wave projects often had LCOE estimates in the range of €0.6/kWh to over €1.1/kWh and tidal energy between €0.54/kWh to over €0.71/kWh.
- In contrast, onshore wind and solar photovoltaics (PV) were already achieving costs well below €0.1/kWh.

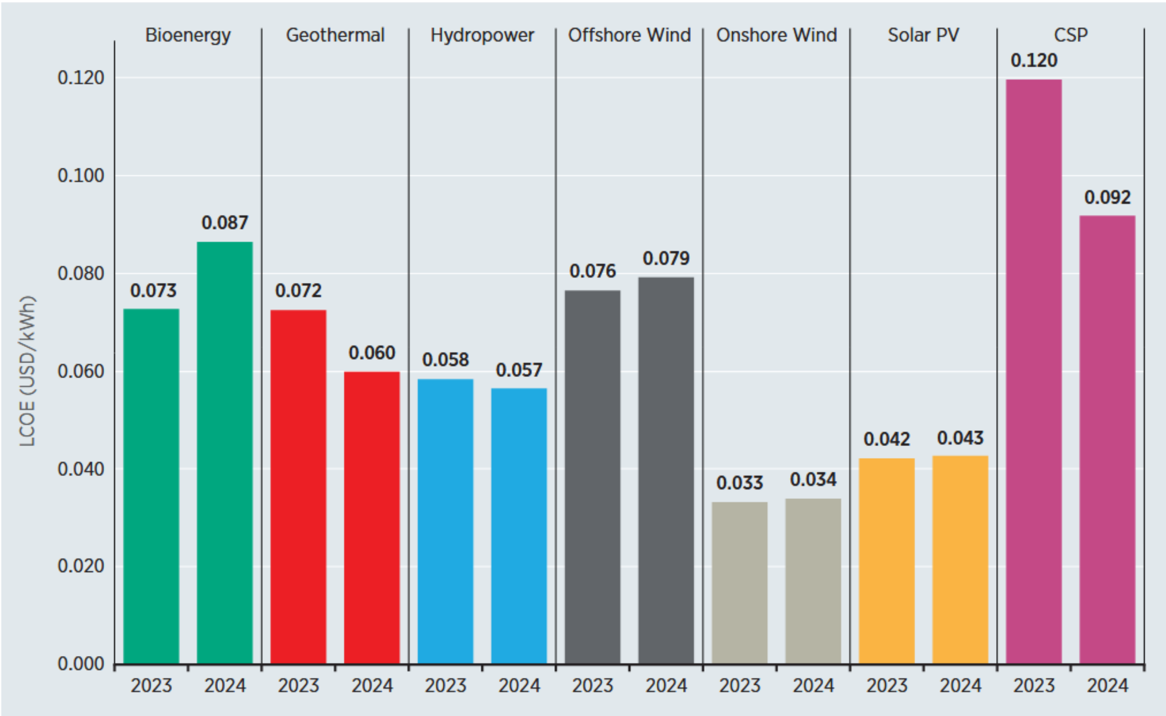
This massive cost gap underscored the fact that in 2015, wave and tidal conversion were too expensive to compete against other, more readily available renewable energy technologies, limiting them to research and demonstration projects.

More recent international assessments confirm the continued cost dominance of onshore technologies while highlighting the rapid decrease of the cost of offshore wind. Reports from the (International Renewable Energy Agency, 2025) provide a clearer picture of this trend for 2023 & 2024:

- **Solar PV and onshore wind:** These technologies remain the cheapest sources of new bulk electricity globally. In 2024, the global weighted average LCOE for new utility-scale **Solar PV** was approximately ($0.043/kWh), and onshore wind was even lower at about ($0.034/kWh).

- **Offshore wind:** The LCOE for offshore wind has fallen dramatically over the last decade, but it is still more than double that of the cheapest onshore alternatives. In 2024, the global weighted average LCOE for newly commissioned offshore wind projects was significantly higher, often hovering around ($0.079/kWh) or more.

It is important to note that global IRENA reports often do not include LCOE figures for wave and tidal/ocean current energy in their primary cost summaries (as these technologies are not yet commercially available), reinforcing the fact that they remain pre-commercial.



Notes: CSP = concentrating solar power; kWh = kilowatt hour; LCOE = levelised cost of electricity; PV = photovoltaic; USD = United States dollar.

Figure 35: Global weighted-average LCOE, 2023-2024 (International Renewable Energy Agency, 2025)

The same fundamental cost hierarchy holds true when LCOE is calculated using South African-specific financial parameters and expressed in South African Rands (R/kWh).

- Local studies and industry data show that onshore solar PV and wind projects procured under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) have achieved remarkably low tariffs, with LCOE values often falling well below 100 cents/kWh.
- In contrast, techno-economic models for MRE in South Africa indicate that wave and ocean current energy LCOE figures are expected to be significantly higher in the short-to-medium term. Wave energy, in particular, remains prohibitively expensive.

This domestic analysis underscores the major finding: while South Africa's offshore resource is vast, the current LCOE of wave and tidal MRE makes them not commercially competitive against other readily available renewable energy technologies. Therefore, current deployment efforts must be restricted to the most mature technology, offshore wind, while continued research is conducted to drive down the cost of wave and current energy.

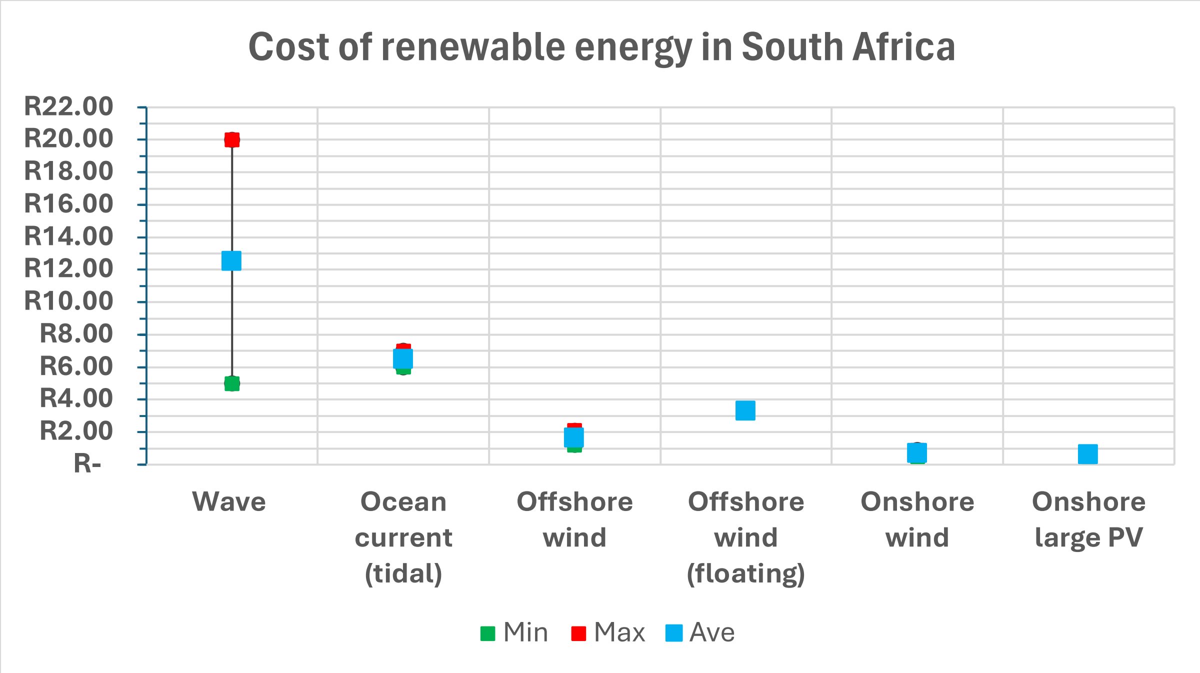


Figure 36: Cost of renewable energy in South Africa (Presented costs based on (Meridian Economics , 2020), (International Renewable Energy Agency, 2025) and engagement with technology developers)

7 Conclusions

Based on the evidence reviewed, the following conclusions are drawn regarding the prospects of MRE deployment in South Africa:

7.1 Technical maturity and economic feasibility

- Offshore wind dominance: At this time, only offshore wind energy has been successfully exploited commercially in other parts of the world, benefiting from years of large-scale deployment, particularly with fixed-bottom technologies. This maturity makes it the most ready-to-deploy MRE option available for South Africa.
- Wave and ocean current status: Wave and ocean current conversion technologies remain at the pilot or demonstration scale globally. The cost of energy derived from these nascent technologies is currently significantly higher and much less confirmed than other readily available onshore renewable energy conversion (such as solar PV and onshore wind).
- Economic feasibility: Given the substantial cost differential, at this time only offshore wind energy may be economically feasible for near-to-medium-term large-scale deployment along the South African coastline, particularly if deep-water Floating Offshore Wind (FOW) costs continue to decline internationally.

7.2 Environmental and social impact management

- Mitigation of concerns: There are legitimate concerns regarding the negative social and environmental impacts of exploiting ocean energy (including underwater noise, collision risk, habitat alteration, and displacement of fishers). However, the research confirms that these impacts can be mitigated by appropriate measures (e.g., careful site selection, cable burial, noise dampening).
- Informed decision-making: The core challenge lies not in the inability to mitigate, but in the necessity of shifting government decision-making towards evidence-based choices that prioritise ecosystem integrity and people's health and livelihoods over purely extractive, profit-driven growth.

7.3 Local market alignment

- The high predictability and stability (high capacity factor) offered by MRE—particularly ocean current and offshore wind—provide a unique competitive advantage over intermittent land-based renewables for grid stability and security of supply, provided the cost barriers can be overcome.
- The required infrastructure (cables, harbours, vessels) presents an immediate opportunity for job creation and local supply chain development, supporting a just, equitable, and sustainable energy future.

8 Recommendations

To enable South Africa to responsibly harness its vast offshore energy potential and achieve a just energy transition, the following recommendations are put forth:

8.1 Prioritise offshore wind development

The government and private sector should prioritise offshore wind energy in the near term due to its comparative technical maturity and potential economic feasibility. This should involve:

- Strategic site allocation: Focus initial efforts on identifying sites where Floating Offshore Wind (FOW) is most viable, aligning with areas of high resource quality while ensuring strategic exclusion from sensitive marine habitats and major fishing grounds.
- Accelerated policy clarity: Finalise the Marine Spatial Planning Act and integrate offshore wind targets into future iterations of the Integrated Resource Plan (IRP) to provide the regulatory certainty required to attract private investment.

8.2 Conduct focused research on nascent technologies

Given the long-term potential of wave and ocean current resources (especially the predictable nature of the Agulhas Current), sustained, targeted national funding is recommended for:

Hydrodynamic modelling: Invest in advanced hydrodynamic modelling specific to the Agulhas Current and high-energy wave sites to accurately determine maximum sustainable energy extraction limits before any significant negative change in oceanographic systems occurs.

Pilot scale monitoring: Establish local pilot projects for wave and current technologies focused primarily on environmental and social monitoring to generate South African-specific baseline data on noise, EMF, and ecological interactions, reducing uncertainty for future commercial phases.

8.3 Localise infrastructure and supply chain development

Public-private partnerships must be leveraged to address the critical lack of specialised port infrastructure:

- Port upgrades: Dedicate resources to upgrading key port facilities (e.g., Saldanha Bay, Port of Ngqura) to handle the heavy-lift capacity and extensive quayside staging areas required for FOW fabrication and assembly.
- Skill development: Develop targeted skills development programmes in partnership with technical institutions to localize expertise in specialized maritime maintenance, engineering, and subsea cabling required for all MRE technologies.

8.4 Empower community participation and ensure social justice

For MRE deployment to align with the principles of a Just Energy Transition, community participation must be central:

- Accessible evidence: The comprehensive baseline report resulting from this research must be actively disseminated and translated into accessible formats (such as the synopsis in a PowerPoint presentation) to empower coastal communities and fishers to actively participate in environmental governance.

- Benefit sharing: Regulatory frameworks must mandate transparent benefit-sharing mechanisms that genuinely compensate displaced fishers, support the creation of alternative sustainable livelihoods, and allow affected communities to have a voice in decisions that impact their lives. This requires shifting policy away from extractive practices towards models that prioritise people and their livelihoods.

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Appendix A – Presentation on ocean energy