

CTCN TECHNICAL ASSISTANCE

Pre-Feasibility Study Report

Ocean Energy focusing on Salinity Gradient Energy and Electrochemical Ocean Thermal Energy Conversion in Papua New Guinea

**Salinity Gradient Energy (SGE) | Electrochemical Ocean Thermal Energy Conversion (e-OTEC)
| Blue Battery Storage**

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Executive Summary

This pre-feasibility study assesses the technical, socio-economic and financial feasibility of three frontier marine renewable energy technologies: Salinity Gradient Energy (SGE / Reverse Electrodialysis), Electrochemical Ocean Thermal Energy Conversion (e-OTEC), and Blue Battery seawater storage, for the coastal waters of Papua New Guinea (PNG). It was prepared by the Korea Institute of Energy Research (KIER) under CTCN Technical Assistance Request 2024000020, and forms the principal technical annex (G.2) to the GCF Concept Note.

Headline resource findings

- **Salinity Gradient Energy.** The four target rivers near the demand center (Kemp Welch, Angabunga, Vanapa and Brown) contribute a combined mean flow of approximately 455 m³/s (historical gauge records, 1957–1996, compiled in the CCDA Technical Review, Appendix 11); at a gross specific energy of about 0.75 kWh/m³ this represents a gross (theoretical) potential of ≈1.2 GW, of which ≈360–368 MW is technically feasible at ~30% membrane-system efficiency.
- **Ocean thermal (e-OTEC).** Port Moresby coastal waters a warm surface layer of ~29 °C (annual mean 28.6 °C). **The available thermal gradient depends on intake depth: ≈23–26 K with water from ~1,000 m (4–5 °C), but only ≈10–13 K with water from ~200 m (16–19 °C).** The electrochemical approach reaches ~13–15% of the Carnot limit in KIER laboratory tests, which corresponds to an absolute net efficiency of ≈1% in KIER's 10 MW design, lower than conventional turbine OTEC (2–3%). Its potential advantages are the absence of turbine and working-fluid systems, modular stacks and potentially lower cost. KIER's 10 MW concept assumes a ~1,000 m cold-water intake reached 3–7 km offshore; a shallower (~200 m) intake would shorten the cold-water pipe substantially but reduce ΔT and power density by roughly a factor of three.
- **Vertical stability/intake depth.** Diurnal and seasonal HYCOM analysis confirms that, while the sea surface at Port Moresby is highly variable (thermally and during wet-season freshwater plumes), conditions stabilize rapidly with depth: salinity variability falls below ~1.8% at 4 m and below ~1% at 10 m, holding ≥34.4 PSU even in the wet season. A seawater intake at ≥10 m is therefore the recommended design basis for SGE feed-water stability and for minimizing thermal stress on membranes; this finding is based on ~9 km-resolution model data and is to be verified by in-situ profiling at the selected site.
- **Blue Battery storage.** KIER's seawater-based Blue Battery offers a non-flammable, low-cost storage option (LCOS 0.1–0.2 USD/kWh) well matched to firming intermittent renewables and to PNG's coastal/marine setting. KIER's target levelized cost of storage at commercial scale is 0.1–0.2 USD/kWh; the largest system operated to date is a 1 kW / 10 kWh pilot, so the 800 kWh pilot represents an ~80-fold scale-up.

Recommended pilot configuration (indicative)

The recommended configuration is a hybrid ocean-energy system combining Salinity Gradient Energy (SGE/RED), Electrochemical Ocean Thermal Energy Conversion (e-OTEC), and a Blue Battery, implemented in two stages. Stage 1 (from 2027, Korean R&D funding through the National Research Foundation, NRF) will demonstrate an e-OTEC pilot of about 10 kW with a shallow seawater intake, together with a Blue Battery (or seawater-based energy storage) of up to 100 kWh, to validate the technologies under PNG conditions. Stage 2 (GCF or other financing) will deploy the hybrid pilot described in the GCF Concept Note

(≈100 kW SGE, 50–100 kW e-OTEC, 800 kWh Blue Battery) as the first step toward a 10 MW-class integrated plant. **A deep cold-water intake, required for high-efficiency e-OTEC, will be included if a PNG partner can provide it.** The site will be on the Central Province coast near an electricity demand center; the Port Moresby coast outside the harbor and NMSA shipping lanes and the Kemabolo–Hula coastline identified by the CCDA Technical Review remain the candidate areas.

Indicative costs and economics

Table 1. Indicative costs and economics (Executive Summary).

Technology/source/Project phase	Indicative costs and economics	Note
Total indicative project cost	~USD 20.96 million	GCF Concept Note budget (grant request)
Pilot construction & commissioning	USD 20.5 million	SGE 100 kW ~4.0 M\$; e-OTEC 50–100 kW ~3.0–3.5 M\$; 800 kWh storage ~2.5–3.0 M\$ (itemized components sum to ~9.5–10.5 M\$; remaining ~10 M\$ to be itemized in the feasibility study)
SGE indicative LCOE	~USD 0.42/kWh	KIER cost model (Korean cost basis, undiscounted). Literature ranges of 0.05–0.10 (brine) and 0.2–0.3 (treated wastewater) do not apply to a river-water feed.
e-OTEC indicative LCOE	~USD 0.12–0.18/kWh (preliminary targets)	KIER 10 MW-class design with ~1,000 m intake; not yet validated at pilot scale. Hybrid Solar + heat pump + thermal storage variant ~0.15/kWh.
Blue Battery LCOS	USD 0.1–0.2/kWh	KIER seawater-battery / Blue ESS; commercial-scale target
PNG benchmark: Port Moresby grid (marginal generation)	≈ USD 0.17–0.19/kWh (gas); up to ≈ USD 0.58/kWh (diesel/gas peaking)	PNG Power purchase rates K0.68–0.75 and up to K2.31/kWh (Section 7.1), converted at ≈ 0.25 USD/PGK
PNG benchmark: diesel / off grid	USD 0.25–0.50+/kWh	Off-grid diesel generation; domestic average tariff ~USD 0.25/kWh
PNG benchmark – solar PV	USD 0.07 – 0.22 /kWh	Reference renewable

The headline message of the economics is two-sided and is stated transparently. KIER's existing SGE cost-and-evaluation model returns an LCOE of approximately 560 KRW/kWh (~USD 0.42/kWh) and a negative ROI, even though it credits revenue at ~520 KRW/kWh (130 KRW/kWh wholesale price × REC weighting of 4, ≈USD 0.39/kWh), a value already within PNG's diesel cost range. The model output (6,000 kWh/day) corresponds to a plant of ~260 kW; its LCOE is undiscounted, and it does not yet include membrane-replacement capital. A higher avoided-cost benchmark in PNG therefore does not by itself make the pilot

viable; the case for the pilot rests on GCF concessional grant support absorbing first-of-a-kind capital and technology risk. A site-specific, PNG-based financial model remains a feasibility-stage deliverable.

Beneficiaries, climate alignment and conclusion

The project is classified as GCF ESS Category B (indicative, pending ESIA), split 60% mitigation / 40% adaptation. The Concept Note cites 756,754 people, the population of Port Moresby; direct beneficiaries of the pilot itself are much fewer and will be estimated from the connected load. It supports PNG's Enhanced NDC commitment to energy-sector carbon neutrality by 2030 and to lifting the grid renewable share toward national 2030 targets, and it aligns with PNG's National Adaptation Plan resilience priorities. The resource assessment establishes that PNG has substantial marine energy potential and that the candidate technologies are technically applicable on the Central Province coast, subject to in-situ verification. The demand case is equally clear: Port Moresby peak demand is projected to grow from about 120 MW (2016) to roughly 271 MW by 2030 at around 6% per year, requiring on the order of 10–13 MW of new reliable generation annually, a gap that a phased, drought-resilient e-OTEC base-load block is well positioned to help fill alongside the existing Rouna and Edevu hydro assets.

List of Abbreviations

Abbreviation	Definition
AE	Accredited Entity
AHP	Analytic Hierarchy Process
CAPEX	Capital Expenditure
CCDA	Climate Change and Development Authority (PNG NDE)
CEPA	Conservation and Environment Protection Authority
CF	Capacity Factor
CTCN	Climate Technology Centre and Network
CWP	Cold-Water Pipe
e-OTEC	Electrochemical Ocean Thermal Energy Conversion
EE	Executing Entity
ESIA	Environmental and Social Impact Assessment
ESS	Environmental and Social Safeguards
FPIC	Free, Prior and Informed Consent
GCF	Green Climate Fund
HYCOM	Hybrid Coordinate Ocean Model (reanalysis)
ICCC	Independent Consumer and Competition Commission
IRR	Internal Rate of Return
KIER	Korea Institute of Energy Research
LCOE	Levelised Cost of Electricity
LCOS	Levelised Cost of Storage
MCDA	Multi-Criteria Decision Analysis
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NEA	National Energy Authority
NISIT	National Institute of Standards and Industrial Technology
NPV	Net Present Value
O&M	Operations and Maintenance
OGCM	Ocean General Circulation Model
OPEX	Operating Expenditure
OTEC	Ocean Thermal Energy Conversion

Abbreviation	Definition
PPA	Power Purchase Agreement
PPL	PNG Power Limited
PSC	Project Steering Committee
PSU	Practical Salinity Unit
RED	Reverse Electrodialysis
SGE	Salinity Gradient Energy
SIDS	Small Island Developing State(s)
SST / SSS	Sea-Surface Temperature / Sea-Surface Salinity
TES	Thermal Energy Storage
UPNG	University of Papua New Guinea
Unitech	PNG University of Technology

1. Introduction

1.1 Background

Papua New Guinea is a Pacific Small Island Developing State (SIDS) of approximately 10 million people dispersed across a mainland and hundreds of islands, with a vast Exclusive Economic Zone of some 2.4 million km². Electrification remains low, with on the order of 15–20% of the population connected to the national grid, and many coastal and island communities depend on high-cost diesel generation, resulting in high tariffs, unreliable supply, and rising greenhouse gas emissions. PNG is simultaneously highly exposed to climate hazards (sea-level rise, coastal inundation, coral bleaching, and intensifying extreme weather) and rich in marine resources. Its extensive coastline and river systems offer largely untapped potential for ocean-based renewable energy.

This pre-feasibility study was commissioned under CTCN Technical Assistance to assess whether Salinity Gradient Energy, Electrochemical Ocean Thermal Energy Conversion and Blue Battery storage are technically, socio-economically and financially feasible under PNG conditions, and to establish the technical and financial groundwork for a follow-on project financed through the Green Climate Fund (GCF).

1.2 Objectives

- Assess the marine renewable energy resource potential in PNG (salinity-gradient and ocean-thermal).
- Evaluate the technical applicability of SGE, e-OTEC and Blue Battery technologies at the selected site.
- Conduct socio-economic and financial analysis of the candidate technologies under PNG conditions.
- Apply a Multi-Criteria Decision Analysis (MCDA) to recommend a preferred technology configuration.
- Provide recommendations for a pilot/demonstration project and the follow-on GCF financing pathway.

1.3 Scope

The study covers the Central Province coastline between Port Moresby and the Kemabolo–Hula area, including the Kemp Welch, Angabunga, Vanapa and Brown river systems as SGE freshwater sources. It addresses resource assessment, technology overview, technical pre-feasibility, socio-economic and financial analysis, MCDA, stakeholder consultation and risk assessment. Detailed engineering design, a full Environmental and Social Impact Assessment (ESIA), and an investment-grade financial model are explicitly outside the scope of a pre-feasibility study and are to be conducted at the feasibility / Funding Proposal stage.

1.4 Alignment with national and GCF policy

Under its Enhanced (Second) Nationally Determined Contribution, submitted to the UNFCCC on 17 December 2020, PNG commits to carbon neutrality within the energy industries sub-sector by 2030 and to increasing the share of renewables in grid-connected installed capacity to 78% by 2030. The project is aligned with these commitments and with the resilience priorities of PNG's National Adaptation Plan.

Within the GCF results framework, it is a cross-cutting project, split 60% mitigation / 40% adaptation, addressing reduced emissions from energy access & generation and increased resilience of livelihoods, communities, and built infrastructure, and is screened as ESS Category B.

1.5 Implementing arrangements

The technical assistance is implemented by KIER (Distributed Energy Team, Jeju Global Research Center), with Dr. Hanki Kim as project lead and the marine resource analysis led by Assoc. Prof. Changhyun Jun (Korea University). In the GCF Concept Note the Executing Entities are named as KIER and the PNG National Energy Authority (NEA), with CCDA acting as the National Designated Entity (NDA) and the Accredited Entity still to be confirmed. Governance is provided by a Project Steering Committee comprising CCDA, NEA, ICCC, CEPA, PPL, NISIT, UPNG, Unitech and Water PNG, with oversight from UN CTCN. 2. Methodology

2.1 Overall approach

The assessment combines three complementary data streams to characterize the marine renewable energy resource and feasibility under PNG conditions:

- **Ocean model analysis (OGCM / HYCOM).** The HYCOM ESPC-D-V02 global 1/12° (~8–9 km) analysis on the GLBy0.08 grid, produced by the U.S. Fleet Numerical Meteorology and Oceanography Center, was used for temperature, salinity and current profiles across PNG waters. It provides a 3-hourly, depth-resolved (40 vertical levels, 0–5,000 m) gap-free time series, overcoming the cloud-cover gaps that limit satellite-only analysis in PNG's wet season, for the period August 2024 to August 2025 (the product is available from 10 August 2024, which sets the start of the record). The analysis presented covers 0–10 m; temperatures at intake depths of 200 m and 1,000 m have not yet been extracted.
- **AI-based satellite interpretation.** High-resolution satellite products were interpreted to provide spatial assessment of sea-surface temperature (SST) and salinity (SSS) and to validate the reanalysis outputs.
- **In-situ measurement.** Seawater and freshwater samples and spot salinity/temperature measurements were collected at Kalo (Central Province) on 27 May 2025 during the in-country mission (RBR CTD instrumentation).
- **River flows.** Mean, minimum and maximum flows for the four target rivers are taken from historical gauge records (1957–1996) compiled in the CCDA Technical Review (April 2026), Appendix 11.

2.2 Resource assessment methodology

SGE potential was estimated from the salinity gradient between seawater and river freshwater, the available river flow, and the achievable membrane power density. The per-river calculation applies a net specific energy of 0.22 kWh/m³ of freshwater, which corresponds to the gross mixing energy (~0.75 kWh/m³) multiplied by a practical membrane-system efficiency of ~30% (membrane technology currently approaching commercialization); no further efficiency factor is applied. Power is reported as mean continuous power (24-hour basis), and annual energy allows for 22 operating hours/day (1 hour maintenance, 0.5–1 hour ramp-up). e-OTEC potential was estimated from the vertical temperature gradient between the warm surface (~29 °C) and the cold-water intake, which depends on intake depth

(Sec Sub-surface temperature 4.2), and the electrochemical conversion efficiency achievable at that gradient, using an effective Seebeck coefficient of 2.2–2.8 mV/K.

2.3 In-situ measurement campaign

During the 25–30 May 2025 mission, seawater and freshwater samples were collected, and salinity/conductivity and temperature were measured using RBR CTD instrumentation at Kalo on 27 May 2025. This was a single-day sampling campaign rather than a moored deployment. The Response Plan (Output 2) foresaw deployment of pressure sensors, current meters and CTD instruments for a specified duration; this was not carried out and is carried forward to the feasibility stage (Section 12.5).

2.4 Limitations

As a pre-feasibility study, the assessment relies on one year of model analysis (2024–2025) supplemented by a single day of in-situ sampling. Consequently: (i) long-term inter-annual variability (e.g. ENSO cycles) is not captured by a single-year dataset; (ii) HYCOM's ~9 km resolution cannot fully resolve complex estuarine dynamics or narrow salinity-gradient structures, and downscaling/interpolation may smooth fine-scale features; (iii) site-specific bathymetry, wave climate, full-year monitoring, suspended-sediment/biofouling characterization, and detailed environmental baselines were not in scope; (iv) no in-situ freshwater flow, temperature or salinity data were collected, and river flows rely on historical gauge records ending in the mid-1990s; (v) sub-surface temperatures at e-OTEC intake depths have not been measured or extracted. These are identified as feasibility-stage requirements (Section 12) and are reflected in the roadmap (Section 12.4).

3. Site Selection and Validation

3.1 Site-selection criteria

Candidate locations were assessed against six groups of criteria: (i) technical suitability – bathymetry, freshwater inflow, thermal gradient, and water quality and turbidity; (ii) proximity to electricity demand and to the existing grid; (iii) access and logistics, including port access for heavy equipment; (iv) climate resilience and seismic exposure; (v) social and environmental considerations, including navigational safety, Coral Triangle Initiative (CTI) areas and customary marine tenure; and (vi) land availability. Two of these criteria carry particular weight for the follow-on project. First, a 10 MW-class integrated plant requires about 5 ha (~50,000 m²) of land, based on a conservative land-use density of about 200 W/m². Second, the plant should be located close to electricity consumers: investment in new transmission infrastructure is not included in the project budget, and maximizing local use of the electricity produced by the SGE and e-OTEC units and stored in the Blue Battery increases the project's impact.

3.2 Selected area: Central Province coast (Port Moresby to Kemabolo–Hula)

The regional analysis identifies the Central Province coast around Port Moresby as the best-fit area, for reasons that are well evidenced:

- **Broad, relatively shallow continental shelf** – unlike PNG's steep northern coast, providing a stable, cost-effective foundation for marine structures and enabling strategic intake placement (surface freshwater plus stable deeper seawater in close proximity).

- **Environmental stability** – situated away from the massive, fluctuating freshwater plumes of the major rivers (Fly, Sepik-Ramu), giving reliable, long-term seawater salinity. The Sepik-Ramu and Fly systems were assessed and found lower-suitability for stable intake because of dramatic seasonal current reversals, mining-sediment-laden plumes, lack of a protective delta and steep submarine canyons.
- **Strategic grid connectivity** – proximity to PNG's largest power-demand center and existing grid and substation infrastructure.
- **Port access and lower seismic exposure** relative to the most active 'Ring of Fire' zones, protecting capital-intensive assets.

Within-area siting – CCDA Technical Review (April 2026). The CCDA Technical Review, prepared by the NDE with PSC member institutions, concludes that the Port Moresby Harbour transit corridors and the sectors extending west toward Napa Napa conflict with NMSA shipping lanes (including LNG traffic) and intersect CTI boundaries, and classifies these urban maritime zones as technically and environmentally non-viable for permanent barge mooring. It identifies an optimal deployment zone at approximately 10°S, 147.5°E between Kemabolo and Hula villages (Rigo District), ~88 km east of Port Moresby, subject to FPIC and a full ESIA under the Environment Act 2000. The Kemabolo–Hula area reduces navigational conflicts and lies next to the Kemp Welch river mouth, the largest SGE freshwater source considered here. The CCDA map (Figure 1) locates the candidate e-OTEC site offshore between Kemabolo and Hula, with a cold-water pipe of about 6–8 km to the 1,000 m depth contour, a marine cable of about 14 km to a coastal substation near Kemabolo, and a connection of about 88 km to Port Moresby via the existing PPL grid network. **If confirmed with PNG Power, no new transmission line would be required.** Both candidate areas lie within the Coral Triangle Initiative area, so habitat surveys are required at either site. The indicative depths shown on the CCDA map, derived from GEBCO data, must be confirmed by bathymetric survey. Both footprints are carried forward to the feasibility stage, with NMSA and the Marine Environment Division of CEPA consulted before selection.

Applying the land and demand criteria favors the Port Moresby coast, which offers the greatest demand and existing grid infrastructure; however, the harbor itself and the sectors used by NMSA shipping lanes are excluded. A coastal location outside these areas will be identified with NMSA and CCDA. The Kemabolo–Hula coastline remains the alternative recommended by the NDE.

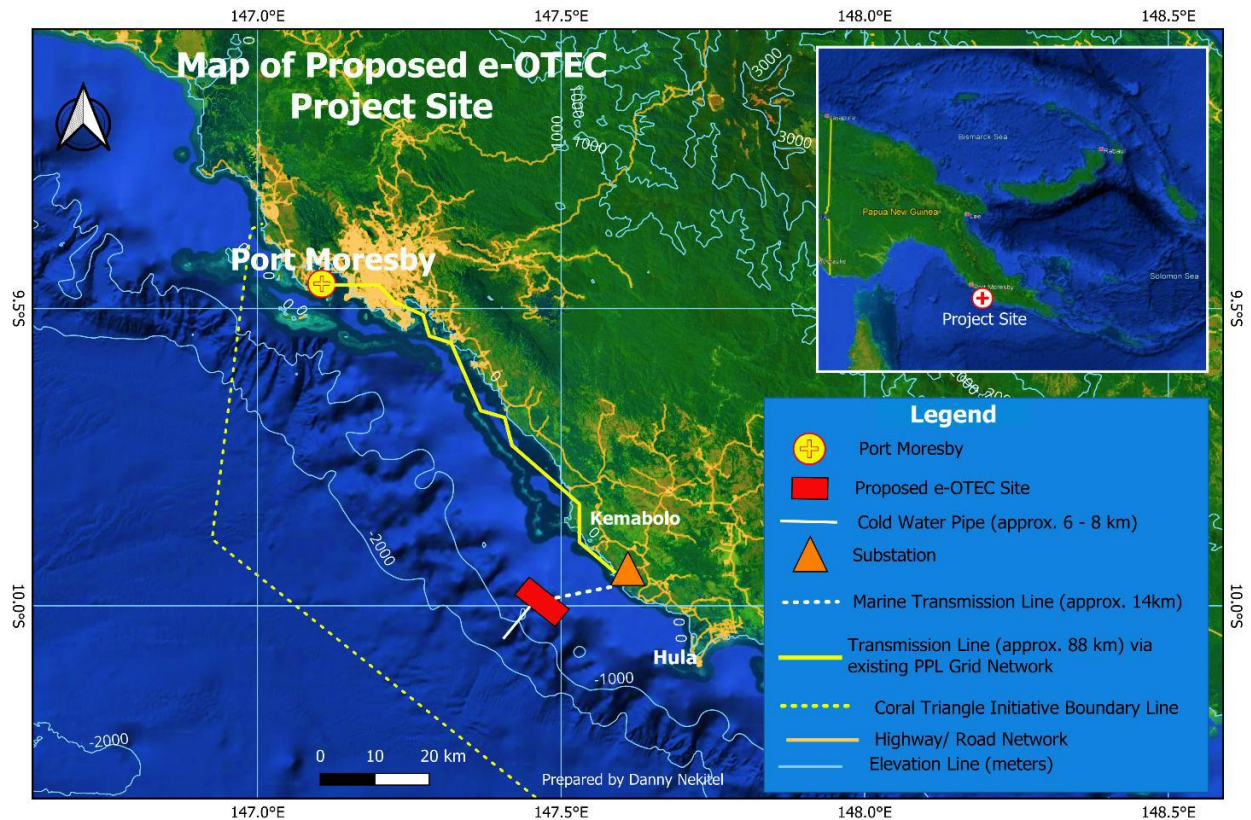


Figure 1. Candidate site for the e-OTEC component between Kemabolo and Hula (Central Province), with cold-water pipe, substation and grid connection. Source: CCDA, Technical Review of Marine Energy Data (April 2026).

3.3 Site characteristics

Table 2. Candidate area site characteristics.

Parameter	Value/status
Location	Central Province coast: Port Moresby margin and Kemabolo–Hula (site to be confirmed); Central Province rivers (SGE freshwater)
Continental shelf	Wide, relatively shallow – favorable foundation for marine structures
Sea-surface temperature	~26.4–31.5 °C seasonal at surface; annual mean ~28.6 °C; deep water ~4 °C ($\Delta T \approx 25$ K) (HYCOM, Aug 2024–Aug 2025)
Sub-surface temperature	~16–19 °C at ~200 m; ~4–5 °C at ~1,000 m (regional profiles, CCDA Technical Review, Table 25; site values to be measured)
Salinity at 10 m depth	≥ 34.4 PSU (stable; halocline confirmed even when surface salinity is variable in the wet season) – model result
Combined river flow (4 rivers)	~455 m ³ /s mean (historical gauge records 1957–1996)
Recommended SGE intake depth	≥ 10 m (stable, high-salinity feed)

Parameter	Value/status
e-OTEC cold-water intake	~200 m (electrochemical approach) vs ~1,000 m conventional – KIER 10 MW concept: ~1,000 m, 3–7 km cold-water pipe, ~4 m diameter. Kemabolo–Hula: cold-water pipe ≈ 6–8 km to ~1,000 m depth (CCDA map)
Thermal gradient	≈23–26 K with ~1,000 m intake; ≈10–13 K with ~200 m intake
Detailed bathymetry	Feasibility-stage survey required – interim regional GEBCO data used
Wave climate/tidal range/currents	Feasibility-stage site survey required for marine structural design
Kemp Welch / river-specific flow	Mean ~117.75 m ³ /s at Bannan Bridge (1967–1995) (Kemp Welch); see Section 4.1

3.4 Alternative sites

The inception mission (November 2024) visited the Basu and Markham rivers near Lae (Morobe Province). Both were found to present difficult, remote access without infrastructure and high sediment loads, and were not retained. The study subsequently screened and rejected the major river systems (Fly and Sepik-Ramu) as less suitable for stable intake operation. The comparison in Section 9 is therefore between technology configurations on the Central Province coast, with the choice between the Port Moresby margin and Kemabolo–Hula made at the feasibility stage (Section 3.2).

4. Marine Energy Resource Assessment

This section presents the substantive findings of the Marine Energy Potential Assessment (Activity 3.1), combining HYCOM analysis (2024–2025), AI-based satellite interpretation, historical river-gauge records and a single in-situ sampling day. These findings were presented to the PSC and at the March 2026 CTCN workshop and form the core analytical output of the technical assistance to date.

4.1 Salinity Gradient Energy potential

- **Gross potential of the four target rivers:** combined mean flow ~455 m³/s at a gross specific energy of ~0.75 kWh/m³ (≈2.7 MJ/m³), equating in theoretical terms to ~1.2 GW.
- **Technically feasible potential:** approximately 360–368 MW, applying the efficiency of currently commercializing membrane technologies (~30%).
- **Peak-flow values:** at the maximum recorded flows the instantaneous technical potential would reach ~3.8–4.1 GW, but such flows occur only briefly during floods and are not representative of usable potential.

The per-river breakdown (net specific energy 0.22 kWh/m³) is summarized below.

Table 3. Per-river Salinity Gradient Energy potential (four target rivers)

River (gauge)	Mean flow (m ³ /s)	Mean energy capacity (kWh/day)	Mean continuous power (kW) Annual-average output at 22 h/day (kW)
Kemp Welch (Bannon Bridge, 1967–1995)	117.75	2,238,230	93,258 85,486
Angabunga (Yaiufa Bridge, 1983–1996)	113.80	2,163,129	90,130 82,619
Vanapa (Peto Island, 1957–1992)	138.78	2,637,968	109,914 100,754
Brown (Karema Bridge, 1981–1996)	84.81	1,612,126	67,170 61,572
Markham (gauge record 1958–1976 without usable data; not included)	–	–	–
Total (4 rivers)	~455	~8.65 million	~360,471 (≈ 360 MW) ~330,432 (≈ 330 MW)

Source of flows: CCDA Technical Review (April 2026), Appendix 11. Flows are historical; current flows and seasonal minima must be verified by gauging at the selected river.

4.2 Ocean thermal (e-OTEC) potential

- **Thermal gradient:** Port Moresby maintains a warm surface layer (~29 °C, seasonally ~26.4–31.5 °C). Water at ~1,000 m is ~4–5 °C ($\Delta T \approx 23\text{--}26$ K), while water at ~200 m is ~16–19 °C ($\Delta T \approx 10\text{--}13$ K). The usable gradient therefore depends directly on intake depth.
- **Conversion efficiency:** conventional turbine OTEC at a 25 K ΔT has a Carnot limit of ~8.3% and a net efficiency of ~2.5–3.0%. In KIER laboratory tests, the electrochemical cycle reached ~13–15% of the Carnot limit (up to ~30% at very low flow rates, decreasing at higher flow). This relative efficiency corresponds to an absolute net efficiency of ~0.9–1.1% in KIER's 10 MW design, i.e. lower than conventional OTEC. The advantage of e-OTEC lies in the absence of turbines and working fluids and in modular construction, not in higher conversion efficiency.
- **Energy density:** at $\Delta T \approx 25$ K and an effective Seebeck coefficient of ~2.2 mV/K, cycle-extractable energy density is on the order of ~550 J/m² of electrode per cycle; at $\Delta T \approx 10\text{--}12$ K the same KIER relationship gives ~220–265 J/m².
- **Power density:** KIER laboratory data (linear fit: power density $\approx 2.95 \times \Delta T - 12.1$ mW/m², $R^2 = 0.43$) give ~61 mW/m² at 25 K but only ~17–23 mW/m² at 10–12 K, so a shallow-intake plant would need roughly three times more electrode area for the same output.
- **Intake-depth trade-off:** the cold-water pipe (CWP) typically represents 40–50% of OTEC construction cost. A ~200 m intake would cut CWP length by more than 80%, but at the cost of a much lower temperature difference ($\Delta T \approx 10\text{--}13$ K instead of $\approx 23\text{--}26$ K at ~1,000 m) and power

density; KIER's 10 MW concept therefore retains a ~1,000 m intake. At the Kemabolo–Hula candidate site, the CCDA map indicates a CWP of about 6–8 km to reach the 1,000 m depth contour. In Stage 1, budget constraints do not allow a deep intake: the ~10 kW e-OTEC pilot will use a shallow intake as a technology demonstration. The optimum depth, and the net output at a shallow intake after pumping loads, must be established by calculation and confirmed by in-situ temperature profiles.

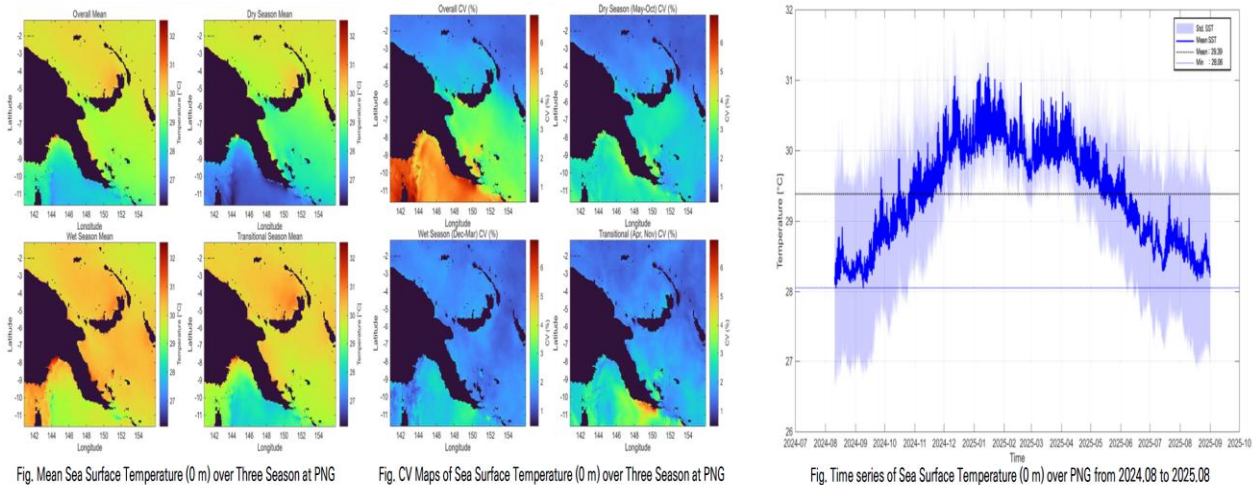


Figure 2. Spatiotemporal patterns in sea-surface temperature.

4.3 Salinity profile and intake depth

Diurnal and seasonal vertical analysis at Port Moresby (HYCOM, 0–10 m) confirms a strongly stratified, depth-stabilizing structure:

- **Surface (0 m):** highly variable – diurnal SST swings of 4.5–6% in the shallow coastal layer (driven by solar heating/nocturnal cooling), and wet-season salinity volatility of 4.0–5.0% from the nearby Laloki River freshwater discharge.
- **4 m (halocline):** variability falls sharply – salinity already down to ~1.5–1.8%; a strong, shallow halocline traps low-density freshwater at the surface and prevents downward mixing.
- **10 m:** a stable, high-salinity environment – salinity variability <1%, holding ≥ 34.4 PSU through the wet season, buffered from both diurnal thermal cycles and short-term surface pulses (tides, rain, river discharge).

Design conclusion: the seawater intake should be located at ≥ 10 m to secure a stable, high-salinity feed and to minimize thermal and salinity stress on the membranes – decisive for plant efficiency, durability and economics. This conclusion should be verified by in-situ profiling at the selected site, since the model resolution (~9 km) is coarse relative to nearshore features.

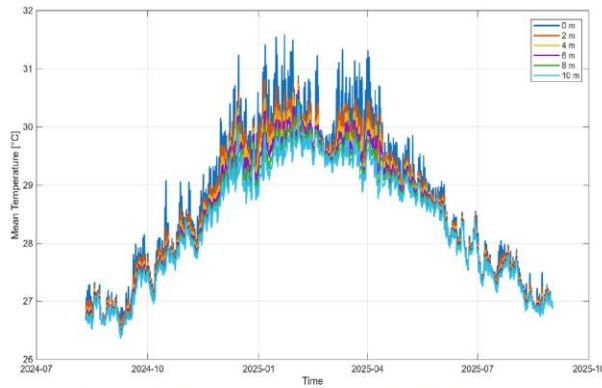


Fig. Depth-dependent time series of seawater temperature in Port Moresby from 0 to 10 m.



Fig. Depth-dependent time series of mean salinity in the Port Moresby from 0 to 10 m.

Figure 3. Depth-dependent time-series analysis.

4.4 Resource assessment summary

Table 4. Marine energy resource assessment summary.

Resource metric	Value	Basis
SGE gross (4 rivers)	~1.2 GW	~455 m ³ /s × ~0.75 kWh/m ³
SGE technically feasible	~360–368 MW	~30% membrane system efficiency
Combined river flow	~455 m ³ /s	4 target rivers (Central Province); gauge records 1957–1996
Sea-surface temperature range	~26.4–31.5 °C	Seasonal; annual mean ~28.6 °C
Vertical thermal gradient (ΔT)	~23–26 K (1,000 m) / ~10–13 K (200 m)	Depends on intake depth
e-OTEC efficiency	~13–15% of Carnot; ~1% absolute	KIER lab tests and 10 MW design
e-OTEC energy density	~550 J/m ² per cycle (25 K); ~220–265 J/m ² (10–12 K)	ΔT ≈ 25 K, Seebeck ~2.2 mV/K
Stable salinity at 10 m	≥34.4 PSU	Halocline / vertical-stability analysis (model)

5. Technology Overview

5.1 Salinity Gradient Energy / Reverse Electrodialysis (RED)

SGE generates electricity from the chemical-potential difference between seawater and freshwater. In RED, alternating cation- and anion-exchange membranes separate seawater and freshwater compartments; selective ion transport across the membranes generates an electrochemical potential that is converted to electricity at the electrodes. The chemical potential of mixing is approximately 2.7 MJ/m³ of river water, equivalent to roughly 270 m of hydraulic head.

- **Power density:** >200 W/m² of electrode; 0.5–1.0 W/m² of membrane; KIER record 1.9 W/m² with patterned ion-exchange membranes.
- **Maturity / operating record:** KIER 5 kW RED pilot in Jeju (operational since 2018; the first RED plant in Korea) – net energy efficiency 29.2%, availability 20/24 hours, ~80% stability over 60 days continuous operation, using treated municipal wastewater and seawater. Performance with turbid tropical river water is not yet demonstrated; lab-scale RED capability established at UPNG under this TA.
- **Stability and footprint:** SGE is a stable, dispatchable (no-ESS-required) renewable source – unlike weather-dependent PV/wind, with low CO₂ intensity (~18 gCO₂e/kWh) and land use of ~500–3,000 m²/MW.
- **Indicative LCOE:** USD 0.05–0.10/kWh with desalination brine and 0.2–0.3/kWh with treated wastewater (KIER); for a river-water feed the only available model result is ~USD 0.42/kWh (Section 8.3).

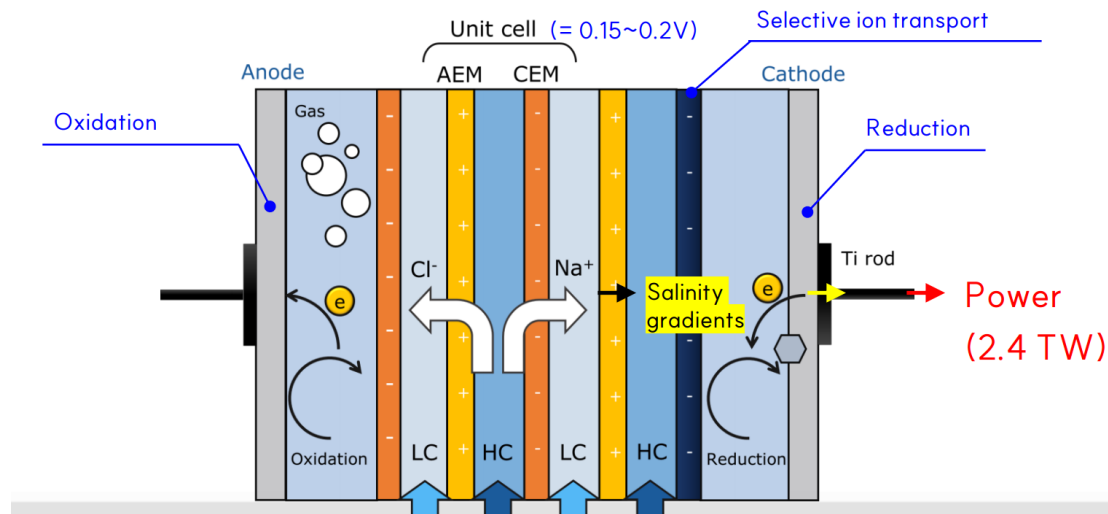


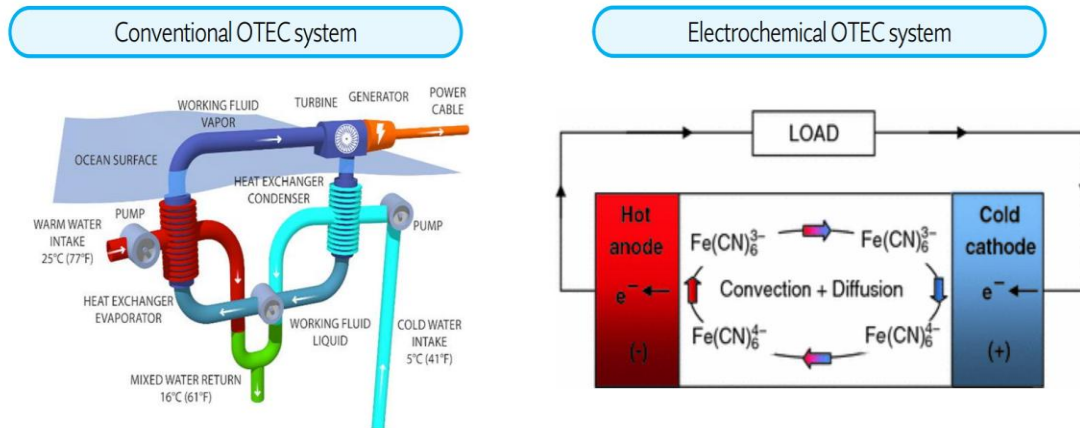
Figure 4. Schematic diagram of Reverse Electrodialysis (RED).

5.2 Electrochemical Ocean Thermal Energy Conversion (e-OTEC)

e-OTEC generates electricity through electrochemical reactions (a thermally regenerative electrochemical cycle using, for example, an $\text{Fe}(\text{CN})_6^{3-}/4^-$ redox couple with foam-type Cu/Ti electrodes and ion-exchange membranes) driven by the temperature gradient between warm surface seawater and cooler deep seawater. It requires no turbine or working-fluid cycle.

- **Efficiency:** effective Seebeck coefficient ~2.5–2.8 mV/K; efficiency relative to the Carnot limit ~13–18% in laboratory tests (depending on flow rate and supporting electrolyte), corresponding to an absolute net efficiency of ~1% (0.87–1.08% in KIER's 10 MW design), versus ~2.5–3.0% for conventional turbine OTEC.
- **Cold-water intake depth:** the 10 MW concept uses ~1,000 m; a ~200 m option is under evaluation (Section 4.2).

- **Configuration:** modular Cu-foam bipolar stacks; suited to a floating/nearshore barge. The 10 MW concept requires an electrode area of $\sim 70\text{--}117\text{ km}^2$.
- **Maturity:** laboratory scale; no field demonstration reported to date.



How: Running Turbine to generate electricity

Problem: Low heat efficiency (2.5 ~ 3.0%)

How: Using electrochemical reaction to generate

electricity (High efficiency 10 ~ 15%)

Figure 5. Conventional vs. electrochemical OTEC comparison.

5.3 Blue Battery Technology

Blue Battery is a seawater-based energy-storage technology with an intrinsically non-flammable design (seawater cooling avoids the thermal-runaway pathway of lithium-ion), suited to firming intermittent renewables and protecting critical loads.

- **Cost / density:** LCOS 0.1–0.2 USD/kWh (Blue ESS, commercial-scale target); volumetric energy density 5–7 Wh/L (Blue ESS) up to $\sim 150\text{ Wh/L}$ (seawater secondary battery).
- **Maturity:** KIER 10 kWh Blue Battery pilot operated with PV + grid input (3:7) for 30 days continuously without significant issues; container-scale (1 kW / 10 kWh) pilot also demonstrated. The proposed 800 kWh unit is an ~ 80 -fold scale-up.
- **Energy-storage principle:** acid–base junction plus concentration gradient ($\sim 57.6\text{ kJ/mol}$; equivalent hydraulic head $\sim 2,500\text{ mH}_2\text{O}$), with a domestic (Korean) supply chain (Toray membranes, Wesco electrodes, KIER/Innomeditech/Lapinion stacks).

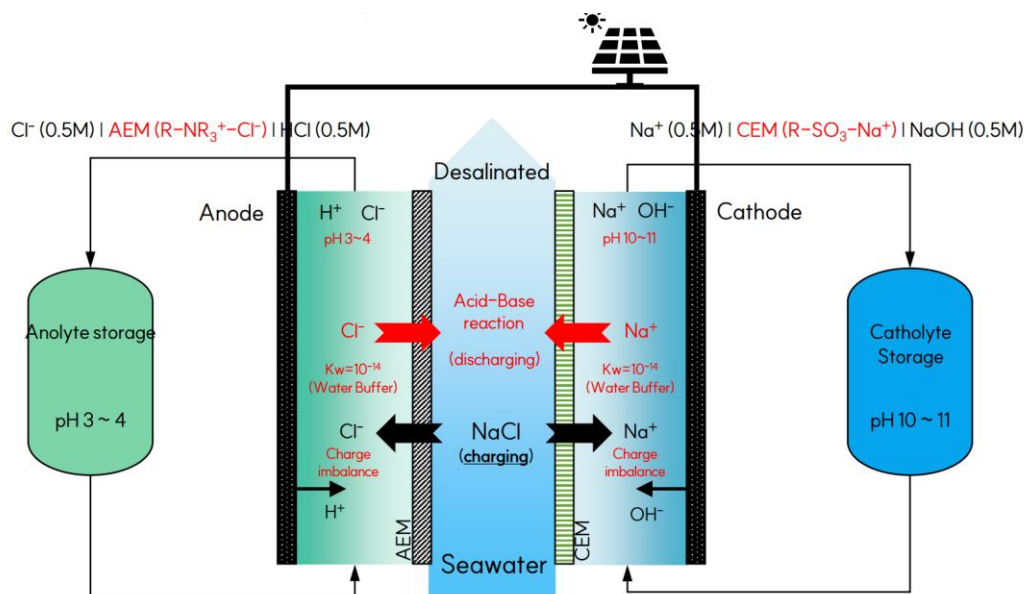


Figure 6. Blue Battery principle diagram.

5.4 Technology comparison

Table 5. Technology comparison: SGE / RED, e-OTEC and Blue Battery.

Attribute	SGE / RED	e-OTEC	Blue Battery
Function	Generation	Generation	Storage
Efficiency	29.2% net (Jeju pilot, wastewater feed)	~13–18% of Carnot; ~1% absolute	n/a (storage)
Indicative cost	LCOE ~0.42 USD/kWh (KIER model, river-type feed)	LCOE 0.12–0.18 USD/kWh (10 MW target)	LCOS 0.1–0.2 USD/kWh (target)
CO ₂ intensity	~18 gCO ₂ e/kWh	Very low (no fuel)	n/a
Dispatchability	Stable, no ESS needed	Stable (24/7) base-load	Firming / load-shifting
Maturity (KIER)	5 kW pilot, 2018–	Laboratory scale	10 kWh & container pilot
PNG applicability	High (rivers + sea)	High with deep intake; to be confirmed for shallow intake	High (supporting role)
Maturity	TRL 5–6; KIER 5 kW pilot (2018–); no demonstration above 100 kW reported globally	TRL 4 (laboratory scale)	10 kWh and container (1 kW/10 kWh) pilots

6. Technical Pre-Feasibility

This section translates the resource assessment and technology overview into a conceptual design for a pilot/demonstration installation on the Central Province coast.

6.1 Selected pilot configuration

The recommended pilot configuration, consistent with the GCF Concept Note budget and the KIER business concept, is a hybrid ocean-energy pilot:

- **SGE / RED unit: ~100 kW**, fed from a Central Province river (Kemp Welch or another target river, depending on the site) and a ≥ 10 m seawater intake.
- **e-OTEC unit: 50–100 kW**, on a floating/nearshore barge at the selected site, with a cold-water pipe to the depth confirmed under Section 4.2.
- **Blue Battery: 800 kWh (4-hour)** seawater-based storage, firming output and supporting critical loads (port, desalination, hospital, cold-chain).
- **Phasing:** pilot (100 kW class) > demonstration > 10 MW-class commercial e-OTEC plant, with grid integration to the Port Moresby network.

6.2 Conceptual plant layout

The conceptual block flow is: (i) **seawater intake at ≥ 10 m** with screening and pre-treatment; (ii) **freshwater intake from the selected river** with screening and pre-treatment; (iii) **SGE membrane stacks/electrode chambers (RED)** and **e-OTEC Cu-foam bipolar stacks/heat exchangers** fed by a cold-water pipe (CWP); (iv) **electrical conversion** (low-voltage DC > step-up DC-DC converter > grid-tie inverter > three-phase AC); (v) **Blue Battery ESS** for firming; and (vi) **off-take** via an onshore connection to the local distribution network.

Major equipment groups: membrane stacks (Toray membranes; KIER/partner stacks); Cu/Ti foam electrodes; peristaltic/seawater pumps; heat exchangers and CWP; DC-DC converter, grid-tie inverter and transformer; Blue Battery packs and balance-of-plant; SCADA/EMS and ocean-environment monitoring.

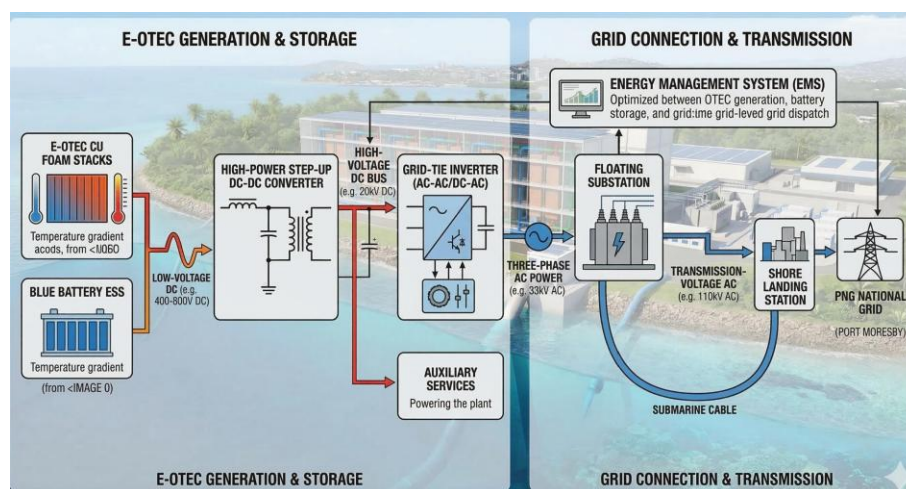


Figure 7. Generation/storage to grid block-flow schematic - illustrative concept.

6.3 Major equipment specifications

Indicative SGE specifications scaled from the KIER cost model: net specific energy ~ 0.1 kWh/ton; membrane power density ~ 1 W/m²; unit stack 1,000 cell-pairs, ~ 180 W/stack, ~ 0.045 m³/stack; plant design life 30 years, with membrane replacement expected about every 10 years (the cost model restores output in years 12 and 22 but does not yet include the replacement cost); pre-treatment and balance-of-system sized for the river/seawater feed. e-OTEC specifications follow the Cu-foam modular bipolar stack with Fe(CN)₆^{3-/4-} redox couple, ~ 4 m diameter CWP, and a $\sim 9,300$ kg/s flux at the 10 MW commercial scale (KIER 10 MW concept, $\sim 1,000$ m intake; electrode life 7–10 years).

6.4 Marine intake and cold-water pipe

For SGE: a seawater intake at ≥ 10 m and a freshwater intake from the selected river, both with screening and pre-treatment to manage suspended solids and biofouling. For e-OTEC: a cold-water pipe to the confirmed intake depth is the major engineering item; its length (from ~ 200 m to $\sim 1,000$ m depth) drives both cost and available ΔT . **At the Kemabolo–Hula candidate site, the CCDA map indicates a pipe length of about 6–8 km to the 1,000 m depth contour.** The Stage 1 pilot will use a shallow intake, and a deep intake will be considered in Stage 2 (see Section 4.2). A nearshore barge configuration is noted to reduce pumping losses by more than 15% relative to a fully offshore layout. **Intake screening and velocity limits must be designed to minimize entrainment and impingement of plankton, fish larvae and other organisms. Discharges will be released below the photic zone, and the thermal and salinity plume will be modelled in the ESIA, to limit effects on coral reefs.**

6.5 Performance prediction at PNG site conditions

Performance can be projected from KIER's Jeju operating data (29.2% net efficiency; 20/24 h availability; $\sim 80\%$ stability over 60 days) re-based to PNG's stable ≥ 34.4 PSU feed at 10 m. For a 100 kW SGE unit at 20/24 h availability, start-of-life output is $\sim 2,000$ kWh/day (~ 0.73 GWh/year). The KIER cost model assumes 6,000 kWh/day (~ 2.19 GWh/year), which corresponds to a plant of ~ 260 kW; its figures must be rescaled to the pilot size. Performance degrades by $\sim 5\%$ /year between membrane replacements. For e-OTEC, **output depends on intake depth (Section 4.2)**; seasonal surface cooling to $\sim 27^\circ\text{C}$ in the dry season reduces ΔT by ~ 2 K and must be included in a season-resolved performance model.

6.6 Grid connection and electrical balance-of-system

At pilot scale (~ 150 – 200 kW generation plus 800 kWh storage), the generation units and Blue Battery connect on a low-voltage DC bus (~ 400 – 800 V) through a grid-tie inverter and step-up transformer to the local 11 or 22 kV distribution network. The high-voltage architecture presented earlier (~ 20 kV DC bus, 33 kV AC, 110 kV transmission and floating substation) applies only to the 10 MW-class concept. An Energy Management System optimizes dispatch between generation, storage, and the grid.

6.7 Operations and maintenance plan

Indicative O&M, scaled from the KIER cost model: a two-shift, two-operator staffing basis; routine maintenance at ~ 1 hour/day plus annual servicing; membrane replacement scheduled within the design life (to be added to the cost model); a spare-parts inventory weighted toward membranes, electrodes and pump components; and a split between locally-delivered routine O&M (with PNG Power and trained local

technicians, supported by remote monitoring) and imported specialist components (membranes from Toray; electrodes; stacks). Capacity-building and a graduate-exchange program (KIER–UPNG) underpin local O&M capability.

7. Socio-Economic Analysis

7.1 Demographic and energy-access context

The Port Moresby / Central Province demand area is PNG's largest load center. National electrification is low (~15–20% grid access) and the average domestic electricity cost is approximately USD 0.25/kWh, with off-grid and diesel-backed supply substantially higher. Critical facilities: the port, cold-chain and fish processing, logistics, hospitals and water-treatment plants rely on diesel back-up during the frequent outages, producing high per-unit emissions and cost. The population of Port Moresby exceeds 756,754 (CCDA Technical Review); this figure describes the demand area, not the direct beneficiaries of the pilot.

Grid-demand outlook and the supply gap the pilot addresses. The Port Moresby grid is the country's fastest-growing system. Drawing on PNG Power Limited's 15-Year Power Development Plan (2016–2030), peak demand on the Port Moresby system is projected to rise from about 120 MW in 2016 to roughly 271 MW by 2030 at a sustained compound annual growth rate of about 6%, implying that the utility must add on the order of 10–13 MW of new reliable generation each year through 2030 to keep pace with the national 70%-electricity-access target. This growth profile is the demand-side rationale for the recommended phasing toward a 10 MW-class commercial e-OTEC plant: a drought-resilient, 24/7 base-load block fits squarely within the annual capacity-addition requirement and complements the existing Rouna and 54 MW Edevu hydro assets, whose dry-season output is vulnerable to ENSO-driven flow reductions. (These figures derive from a 2015 utility plan and should be refreshed against current PNG Power data at the feasibility stage.)

Current Port Moresby generation mix. Of 311 MW nominal capacity (261 MW available), hydropower provides ~124 MW (Rouna 1–4, Sirinumu, Edevu), natural gas ~103 MW (NiuPower, Dirio), diesel and HFO ~77 MW (Moitaka, Kanudi) and solar PV ~7 MW (CCDA Technical Review, Appendix 18). New generation therefore displaces a mix of gas, diesel/HFO and, at times, hydro, not diesel alone.

Avoided-cost benchmark (off-taker tariffs). PNG Power purchases power from generators under individual power-purchase agreements rather than a single tariff. Indicative off-taker rates are approximately K0.40/kWh for hydropower, K0.68–0.75/kWh for natural-gas generation, and up to about K2.31/kWh for diesel/gas peaking supply. The feasibility-stage financial model should use the marginal generation actually displaced on the Port Moresby grid (predominantly gas and diesel/HFO) as the avoided-cost benchmark.

7.2 Differential impacts on women and men

Women in PNG coastal communities are typically responsible for household energy management, water collection and small-scale economic activity, and are disproportionately affected by unreliable electricity. Improved reliability through marine renewable energy, and the co-located freshwater/desalination benefit, is expected to deliver disproportionate benefits to women. A Gender Assessment and Gender Action Plan accompany the project.

7.3 Employment generation

Construction-phase employment spans marine works, civil and electrical installation; O&M-phase employment centers on plant operation, membrane/electrode servicing and monitoring. The two-shift / two-operator basis of the cost model implies a small permanent operating team per pilot unit, augmented by local technicians trained under the capacity-building component, with skilled specialist input (membranes, stacks) initially imported and progressively localized.

7.4 Co-benefits

- Freshwater production through co-located desalination (water-energy nexus).
- Decarbonized marine mobility – DC fast-charging for electric ferries, fishing boats, and tour boats from the pilot hub.
- Potential aquaculture co-location with ocean-energy installations.
- Reduced reliance on imported diesel and associated foreign-exchange savings.
- Improved energy reliability supporting healthcare, education and small-business activity.

7.5 Customary marine tenure and community consent

In PNG, coastal communities hold customary ownership of reefs and fishing grounds. Free, Prior and Informed Consent (FPIC) and customary marine-tenure agreements with the villages at the selected site are therefore a precondition for any marine installation, and should begin at the start of the feasibility stage rather than after design.

8. Financial Analysis

8.1 CAPEX

The indicative project cost follows the GCF Concept Note budget (USD, grant request):

Table 6. Indicative project CAPEX (GCF Concept Note budget).

Component	Item	Indicative cost (USD)
1. Project development	Detailed feasibility study (0.30 M); site survey & basic design (0.20 M); CEPA environmental permitting (0.05 M)	0.35 million (component total in budget sheet; items sum to 0.55 M)
2. Pilot – SGE	100 kW SGE/RED (install 2.5–3.0 M\$; operation 0.5–1.0 M\$/3 yr)	~4.0 million
2. Pilot – e-OTEC	50–100 kW e-OTEC (stack 1.2 M\$; BOP pump & pipe 0.8 M\$; OPEX 1.0–1.5 M\$)	~3.0–3.5 million
2. Pilot – storage	800 kWh / 4 h Blue Battery (pack 1.2 M\$; BOP 1.0 M\$; SAT 0.3 M\$)	~2.5–3.0 million
2. Pilot – not yet itemized	Detailed engineering, marine works, grid connection, contingency	~10.0–11.0 million

Component	Item	Indicative cost (USD)
2. Construction & commissioning (total)	Detailed engineering, on-site installation & integration, operation	20.5 million
3. Capacity building	Utility O&M training (0.02 M); community engagement (0.01 M); Korea knowledge-sharing (0.08 M)	~0.11 million
Total indicative project cost	GCF grant request	~20.96 million

8.2 OPEX

The KIER SGE cost model (effectively ~260 kW) carries annual OPEX of ~715 million KRW (~USD 0.54 M/yr at ~1,330 KRW/USD), comprising labor (~200 M KRW), maintenance at ~5% of CAPEX (~415 M KRW) and other (~100 M KRW). The model's CAPEX is ~8.3 billion KRW (~USD 6.2 M); membrane/electrode replacement capital is not yet included. e-OTEC OPEX is estimated at USD ~0.81 M/yr (~2% of profit) for the 10 MW concept, with an electrode-life-driven replacement cycle of 7–10 years.

8.3 LCOE

The candidate technologies position as follows against PNG benchmarks:

Table 7. Indicative levelised cost of electricity (LCOE) by technology and benchmark.

Technology/source	Indicative LCOE (USD/kWh)	Note
SGE (general KIER range)	0.05 – 0.10 (brine); 0.2 – 0.3 (wastewater)	Brine feed > low end; treated wastewater > high end; not applicable to river feed
SGE at KIER model (Korea cost basis)	~0.42 (~560 KRW/kWh)	Undiscounted (O&M + depreciation ÷ output); revenue credited at ~520 KRW/kWh; negative ROI
e-OTEC (KIER 10 MW-class)	~0.12 – 0.18	0.12 (~160 KRW/kWh) and 0.18 (optimized Cu foam) in two KIER estimates; ~1,000 m intake; CAPEX 40.86 M\$ for 10 MW
e-OTEC hybrid (Solar+HP+TES)	~0.15	Effective Seebeck 3.5 mV/K; ~53% reduction vs carbon-cloth case (0.32 > 0.15)
Blue Battery (LCOS)	0.10 – 0.20	Storage, not generation; commercial-scale target
Solar PV (PNG benchmark)	0.07 – 0.22	Reference renewable
Diesel / off-grid (PNG benchmark)	0.25 – 0.50+	Displaced generation (off-grid); Port Moresby grid mix – see 7.1

8.4 Financial returns (NPV / IRR / payback)

On its native Korean assumptions (130 KRW/kWh electricity with a REC weighting of 4, i.e. ~520 KRW/kWh, 30,000 KRW/tCO₂ carbon price, 15% discount rate applied only to the net-return indicator), the SGE model returns a negative ROI and a ~36-year simple payback, i.e. not bankable on a pure-merchant basis. Because the model already values output at ~USD 0.39/kWh, comparable to PNG diesel costs, a higher avoided-cost benchmark in PNG does not by itself change this result. The pilot is therefore justified as a grant-funded demonstration: GCF concessional finance absorbs the first-of-a-kind capital and technology risk, and commercial viability depends on cost reductions to be demonstrated. A long-term PPA with PPL provides revenue certainty.

8.5 Sensitivity analysis

Indicative sensitivities (to be quantified with the PNG model): LCOE/NPV are most sensitive to CAPEX (driven by membrane area and, for e-OTEC, electrode area and CWP), capacity factor, the displaced-generation price, and the discount rate. For e-OTEC, intake depth is the key trade-off between CWP cost and ΔT /power density; the hybrid Solar+HP+TES configuration is the principal CAPEX-reduction lever.

8.6 Financial assumptions

The feasibility-stage financial model will use the following conventions: costs in constant USD with a stated base year; a single PGK/USD exchange rate for local costs and a single KRW/USD rate for Korean costs (current KIER estimates use 1,330–1,480 KRW/USD and will be harmonized); a stated inflation treatment; and a project lifetime of 30 years, consistent with the GCF Concept Note (A.12), with implementation from 2029 to 2034. Component replacements will be included in the cash flow: SGE membranes about every 10 years and e-OTEC electrodes every 7–10 years. Costs and energy will both be discounted at an agreed rate, so that the LCOE is directly comparable with other technologies; the existing KIER SGE model uses 15% only for its net-return indicator, and its LCOE is undiscounted. Carbon revenue may be included where a credible price and crediting pathway exist.

8.7 Indicative greenhouse-gas emission reductions

Emission reductions are estimated as: annual generation (MWh) $\times$ grid emission factor of the displaced generation (tCO₂/MWh). The previous estimate (~970 tCO₂/yr per unit) used 2.19 GWh/yr and the Korean grid factor (0.4428 tCO₂/MWh) and is withdrawn.

Item	Value	Basis
SGE 100 kW generation	~730 MWh/yr	100 kW $\times$ 8,760 h $\times$ 20/24 availability
e-OTEC 50–100 kW generation		After intake depth is confirmed (Section 4.2)
Port Moresby grid emission factor		Mix of gas, diesel/HFO and hydro (Section 7.1)
Illustrative SGE reduction	~365–510 tCO ₂ /yr	At an emission factor of 0.5–0.7 tCO ₂ /MWh, for illustration only

The final estimate, and the 10 MW-class figure cited in the Concept Note, will be recalculated with the confirmed grid emission factor at the feasibility stage (MRV design).

9. Multi-Criteria Decision Analysis (MCDA)

9.1 Proposed framework

A transparent weighted-scoring approach is recommended. Each option is scored 1–5 against each criterion; criterion weights sum to 100%; the weighted total ranks the options. This is transparent, easily communicated to the PSC, and supports a sensitivity check on the weights.

9.2 Criteria and weighting (indicative)

Table 8. MCDA criteria and indicative weighting.

Criterion	Weight	Rationale
Technical readiness /	20%	Resource fit, KIER maturity, site stability
Economic performance (LCOE / bankability)	20%	Cost vs PNG benchmark; GCF additionality
Climate mitigation (CO ₂ displaced)	15%	Fossil displacement; 60% mitigation weighting
Climate-resilience / adaptation value	15%	Stable supply to critical loads; 40% adaptation
Environmental impact / ESS	10%	Marine ecosystem, fisheries, ESS Category B
Social / gender / local employment	10%	Beneficiaries, women's benefit, jobs
Replicability across Pacific SIDS	10%	Paradigm-shift / scale-up potential

9.3 Indicative scoring and result

Applying the framework with current evidence (1 = weak, 5 = strong) gives the following indicative ranking. This is illustrative pending the feasibility-stage financial model and a final PSC weighting exercise.

Table 9. MCDA indicative scoring and result.

Option	Tech	Econ	Mitig.	Adapt.	Env.	Social	Replic.	Weighted
SGE / RED (100 kW)	5	4	4	4	4	4	5	4.3
e-OTEC (50–100 kW →10 MW)	4	5	5	5	3	4	4	4.4
Hybrid SGE + e-OTEC + Blue Battery	5	4	5	5	3	5	5	4.6
Blue Battery only (support)	3	4	2	4	4	3	4	3.4

Weighted totals corrected (arithmetic). The scores themselves remain indicative: in view of Sections 4.2 and 8.3, the e-OTEC economic score (5) and the hybrid technical-readiness score (5, higher than its least mature component) should be reviewed by the PSC.

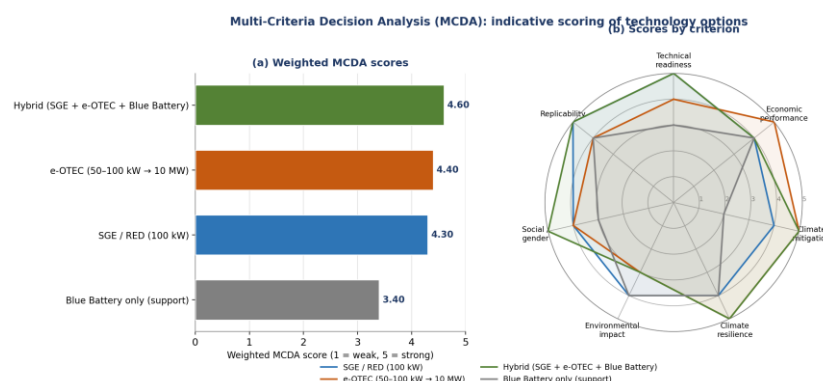


Figure 8. Indicative MCDA results: (a) weighted scores by option and (b) scores across the seven criteria. The hybrid configuration ranks highest. Weighted scores are computed from the criterion scores and the Section 9.2 weights (Technical 20%, Economic 20%, Mitigation 15%, Resilience 15%, Environmental 10%, Social 10%, Replicability 10%).

9.4 Sensitivity of the MCDA

Varying each criterion weight by –25%, 0 or +25% (2,187 combinations, renormalized), the hybrid option ranks first in every combination; e-OTEC ranks second in ~88% of combinations and SGE in the remainder. The recommendation is therefore robust to reasonable weight changes.

10. Stakeholder Consultation

Engagement during the TA included the Project Steering Committee meetings; the May 2025 in-country mission (with bilateral meetings with NEA, ICCC, CEPA and PPL); technical seminars at UPNG (May 2025); the KIER–UPNG young-professionals workshop; the CTCN cRD&D technical workshop in Seoul (11 March 2026); the wrap-up program in Korea (8–13 March 2026); the CCDA Technical Review of marine-energy data (April 2026); and the NDE comments on the ESRS and on the draft of this study, which are addressed in this report.

11. Risks and Risk Mitigation

The principal risks and indicative mitigations, aligned with the GCF Concept Note Section F risk table, are summarized below.

Table 10. Risks and risk-mitigation measures.

Risk	Likelihood / impact	Mitigation	GCF role
Permitting / regulatory delay (marine consents, tariff regulation, protected areas)	Med / High	Joint Coordination Committee (CCDA, NEA, CEPA, PPL); fast-track consultation; regulatory monitoring	Regulatory advisory & coordination funding
Electricity-tariff regulation change	Med / Med	Long-term PPA; government MOU	Financial-structure stabilization

Risk	Likelihood / impact	Mitigation	GCF role
Extreme waves/cyclones / SST variability/coral bleaching	Med / High	Climate-resilient marine structural design; real-time monitoring & early warning	Resilient-design cost & monitoring support
Community opposition / fisheries conflict / customary marine tenure	Med / High	FPIC from the start of the feasibility stage; customary marine-tenure agreements; benefit-sharing (local tariff, jobs); grievance redress; continuous engagement	Engagement-program funding
Technology performance uncertainty (frontier marine energy)	High / High	Phased pilot-before-scale-up; proven KIER base; performance-guarantee contracts; independent verification	Absorbs pilot-demonstration cost
e-OTEC thermal resource at shallow intake ($\Delta T \approx 10\text{--}13\text{ K}$ at $\sim 200\text{ m}$)	High / High	Net-output calculation including pumping loads; deeper-intake option; 12-month temperature profiling to 1,000 m before final design	Funds in-situ monitoring campaign
High upfront capital / long payback	High / High	GCF grant; long-term PPA; blended finance at scale-up	Lowers cost of capital; improves bankability
Limited local O&M capacity / low capacity factor	Med / Med	Capacity-building; co-operation model; remote monitoring; KIER–UPNG exchange	Capacity-building & technology-transfer support
Membrane fouling from high turbidity / TSS / organic load	Med / High	Site selection away from major-river plumes; $\geq 10\text{ m}$ intake; pre-treatment; biofouling management	Funds water-quality study & pre-treatment design
Marine pollution from anti-fouling agents and process fluids (chlorine, copper-based biocides, $\text{Fe}(\text{CN})_6$ electrolyte)	Med / High	Non-chemical or low-toxicity fouling control; closed electrolyte loops with leak detection; discharge limits in the ESMP; NMSA discharge permit	Funds ESIA and ESMP design
Entrainment/impingement and discharge-plume effects on Coral Triangle ecosystems	Med / High	Low intake velocities and screening; discharge depth below the photic zone; plume modelling; multibeam and side-scan habitat survey	Funds marine-spatial and habitat surveys
Data gaps (bathymetry, environmental baseline)	Med / Med	Feasibility-stage site survey & ESIA	Funds feasibility-stage studies

Risk	Likelihood / impact	Mitigation	GCF role
Navigational conflict with NMSA shipping lanes/proximity to Coral Triangle Initiative reef areas (barge mooring)	Med / High	Early NMSA and CEPA Marine Environment Division consultation; avoid harbor and western sectors classed as non-viable by the CCDA review; Kemabolo–Hula avoids the shipping lanes; both candidate areas lie within the CTI area and require habitat surveys. (Section 3.2)	Funds navigation-safety & marine-spatial study
Marine heatwave/ENSO subsurface warming deepens the warm layer, reducing available ΔT at the design intake depth	Low / High	Deploy 12-month in-situ temperature profilers before final design; size intake with margin and allow a deeper (e.g. ~250–300 m) intake option; verify ΔT across a full ENSO cycle	Funds in-situ monitoring campaign

12. Recommendations and Next Steps

12.1 Summary of findings

The resource assessment establishes that PNG has substantial marine renewable energy potential (~1.2 GW gross / ~360–368 MW technically feasible SGE from four Central Province rivers; a thermal gradient for e-OTEC of ~23–26 K with a deep (~1,000 m) intake, or ~10–13 K with a ~200 m intake) and that the candidate technologies are technically applicable on the Central Province coast, subject to in-situ verification. The TA has delivered the resource assessment, site screening, vertical-stability intake design, technology benchmarking against KIER's operating pilots, an indicative pilot configuration, an indicative financial framework, an MCDA, and a lab-scale RED capability at UPNG.

12.2 Items completed vs remaining

Completed: resource quantification and per-river breakdown (Section 4); HYCOM methodology documentation (Section 2); ≥ 10 m intake design basis (Section 4.3); e-OTEC and Blue Battery costs and the technology comparison (Section 5); the indicative pilot configuration and conceptual layout (Section 6.1–6.2); the CAPEX framework, LCOE table and financial assumptions (Section 8); and the MCDA framework, indicative scoring and sensitivity (Section 9).

Remaining for the feasibility / Funding Proposal stage: site selection between the Port Moresby margin and Kemabolo–Hula; in-situ temperature/salinity profiles to ~1,000 m and river gauging; confirmation of the e-OTEC intake depth and pilot output; detailed marine-structural and cold-water-pipe engineering with site survey data; a PNG-cost-rebased investment-grade financial model (NPV/IRR with PPL tariff, including membrane and electrode replacement); **quantified GHG reductions** with the PNG grid emission factor; a full ESIA and environmental baseline; the FPIC process, **customary marine-tenure agreements**

and community-consultation record; and a season-resolved performance model and quantified employment estimate.

12.3 Recommended pilot (indicative)

A hybrid pilot on the Central Province coast (site to be confirmed, Section 3.2) – ~100 kW SGE + 50–100 kW e-OTEC + 800 kWh Blue Battery, at a total indicative cost of ~USD 20.96 million (GCF grant), phased toward a 10 MW-class commercial e-OTEC plant, with seawater intake at ≥ 10 m and an e-OTEC cold-water intake at the depth confirmed under Section 4.2, integrated to the local grid.

12.4 Pathway to GCF financing

This pre-feasibility study is the principal technical annex (G.2) to the GCF Concept Note. The Concept Note is delivered to CTCN as a TA deliverable and, with this study, will be submitted to the GCF once an Accredited Entity is identified. Next steps: confirmation of the Accredited Entity; the PNG NDA Non-Objection Letter through CCDA; completion of the feasibility-stage engineering and financial items; and development of the full Funding Proposal (with detailed feasibility study, full ESIA and investment-grade financial model) for an implementation/investment period of 2029–2034.

12.5 Indicative roadmap

Table 11. Indicative implementation roadmap.

Phase	Focus	Indicative timing
Phase 1 – High-resolution observation	Satellite + in-situ fusion; on-site vertical observation with moored buoys profiling temperature and salinity to ~1,000 m for 12 months; river gauging; tidal currents; multi-year monitoring (incl. ENSO)	Pre-FP / early FP
Phase 2 – Fouling & water-quality analysis	Suspended-sediment (TSS) & organic-load analysis; biofouling potential; basic pre-treatment design	FP preparation
Phase 3 – Geotechnical & infrastructure stability	Seismic-risk assessment; offshore/onshore ground survey (multibeam bathymetry and side-scan sonar habitat mapping); intake-pipe stability review	FP preparation
Final goal – Optimal site & feasibility	Derive the practically realizable optimal site; enter Front-End Engineering Design (FEED)	FP / pre-construction

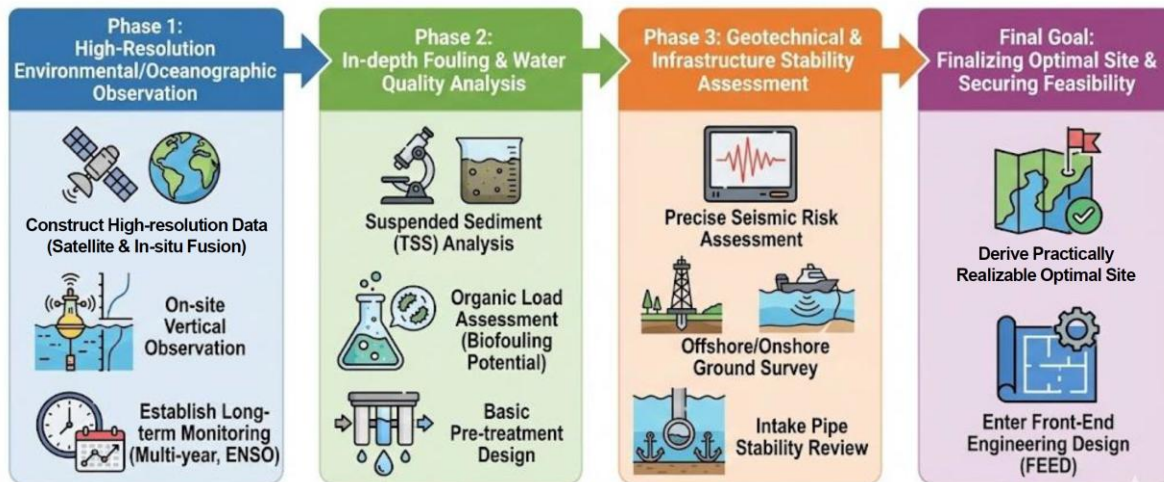


Figure 9. Implementation framework for SGE site selection.

13. Conclusion

This pre-feasibility study confirms that Papua New Guinea possesses substantial, largely untapped marine renewable energy resources and that Salinity Gradient Energy and Electrochemical Ocean Thermal Energy Conversion, supported by Blue Battery storage, are technically applicable to PNG conditions, with the Central Province coast offering favorable characteristics for a pilot/demonstration installation. The resource assessment, conducted through HYCOM analysis, AI-based satellite interpretation, historical river-gauge records and initial in-situ sampling, provides a credible preliminary foundation, and the vertical-stability analysis gives a clear ≥ 10 m intake design basis for SGE, to be confirmed in situ.

With this revision, the engineering concept, indicative costs, LCOE positioning and MCDA recommendation are in place. The remaining items: site selection, the e-OTEC intake depth, detailed marine engineering, a PNG-cost-rebased investment-grade financial model, a full ESIA, and FPIC, will be appropriately addressed at the feasibility / Funding Proposal stage. At current cost levels the technologies are not yet commercially competitive; the pilot is justified as a first-of-a-kind demonstration whose capital and technology risk is well matched to GCF concessional finance, with commercial viability depending on the cost reductions it is designed to test. The study positions PNG to pursue follow-on GCF financing and to become an early mover in marine renewable energy demonstration among Pacific SIDS.