Marine Aquaculture, Renewable Energy, Reefs & Ecotourism for Ecosystem Services (TA6619)

Strategic Summary of Project Research and Initial Recommendations for The Republic of the Marshall Islands

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The summary information presented is a result of the initial analysis made to identify key sectors of interests relating to Marshall Islands, to understand local context and prepare ground for further research on potential multi-function marine and maritime projects.

The analysis presented in this summary is a starting point and will help to guide further in-country engagement.

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Abbreviations and Units and Measure

ADB	Asian Development Bank
EEZ	exclusive economic zone
FPV	floating photovoltaic
LCOE	levelized cost of energy
LCOH	levelized cost of hydrogen
MARES	Marine Aquaculture, Reefs, Renewable Energy, and Ecotourism for Ecosystem Services
NREL	National Renewable Energy Laboratory
OTEC	ocean thermal energy conversion
PV	photovoltaic
RMI	Republic of Marshall Islands
TA	technical assistance

Units and Measure

GW	gigawatt
GWh	gigawatt-hour
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour
m	meter
m^2	square meter
m/s	meter per second
MW	megawatt
TWh	terawatt-hour
W	watt
yr	year

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1.0 Headline overview

Coastal and Small Island Developing States such as the Republic of the Marshall Islands (RMI) can maximize the potential of their vast exclusive economic zones (EEZs) by encouraging multi-function marine projects that leverage several capabilities holistically. Such activities will enable nations to tackle the climate change challenge and achieve a regenerative marine environment.

The Asian Development Bank's (ADB) technical assistance (TA) project (TA 6619) entitled Marine Aquaculture, Reefs, Renewable Energy, and Ecotourism for Ecosystem Services (MARES)[1] is exploring the combination of marine renewable energy capabilities relevant to RMI with local research of potential in-country sites suitable for multi-function initiatives which can be integrated therein.

The project team has developed a set of criteria to enable the selection of appropriate initiatives that blend marine renewable energy with marine aquaculture; nature-based tourism; alternative fuels and maritime transport; and/or restoration and regeneration of coral reefs or other ecosystems and regeneration. These criteria combine collectively to define a MARES-type project.

Offshore wind and marine solar have been identified as being highly likely to be viable in the waters of the Marshall Islands; a further four types of marine renewable energy including Ocean Thermal Energy Conversion (OTEC)] have been identified as being potentially viable.

Sites within the RMI, Majuro, Rongrong and Eneko Island have all been identified as having the right range of characteristics to support and benefit from MARES multi-function pilot projects.

RMI is well suited for MARES pilot projects. There are a number of maturing and scalable innovations that align well to the needs of the country and its communities. This is especially so as RMI may be a Small Islands Developing State But it is most definitely a large ocean state.

The project team seeks guidance from the Government of RMI on the further development of this report. The project team will analyze candidate technologies and identify pilot projects to participate in the ADB High-Level Investor Forum on 7 February 2023 in Kuala Lumpur.

2.0 The MARES concept

The world's seas and oceans – and the ecosystems, economies and livelihoods that depend on them – are under great stress. Climate change; ocean acidification; marine pollution; natural disasters; overfishing, destructive fishing and illegal, unreported and unregulated fisheries; coastal and population growth resource pressures; sea level rise; and the collapse of marine ecosystems all present significant issues.

There is growing understanding of the breadth of positive outcomes a well-managed seaspace can support – not just targets related to jobs, economic growth and environmental protection, but broader agenda such as the Sustainable Development Goals, Nationally Determined Contributions for climate change action, among others.

[1] ADB. Regional: Marine Aquaculture, Reefs, Renewable Energy, and Ecotourism for Ecosystem Services.

The MARES TA 6619 analyzes how three potential blue economy opportunities can be harnessed:

- The **first is the harnessing of marine renewable energy.** The opportunity here is considerable, especially for large ocean states. Studies suggest that wave energy alone could power the entire world but the pace of change is still lagging behind expectation. A review of marine renewable opportunities illustrates that there are many ways forward, as technologies mature and more research is undertaken on potential sites for implementation. Governments are also grasping the nettle on policy commitments and creating enabling environments for investment and operational implementation.
- The second opportunity is created by the potential of **marine green hydrogen.** This allows large ocean states to utilize their seaspaces not only to meet local electricity demands, but also to convert renewable electricity to green hydrogen/ammonia, and then to export that to existing markets such as refinery, steel, fertilizer that currently use grey hydrogen (produced from fossil fuels) or to entirely new markets such as transportation fuels (a 'Power-to-X' capability). Both policy and commercial drivers are demanding alternative marine fuels, for example, which creates significant new commercial possibilities in this realm. This, then, is the second potential game changer: financial investment will flow into regenerative marine activities because there is a promising market model that simply didn't exist before.
- The third set of opportunities is **to develop a much broader set of multi-functional projects** that make the most effective use of available seaspace, to provide the greatest positive effect on local communities (including ensuring that any resulting prosperity is justly transitioned and equitably distributed) and results in the lightest environmental impact. The uses of marine renewable energy as charging platforms in the shipping industry, seawater air conditioning (SWAC) technology for cooling, ocean energy systems for more cost-effective aquaculture industries and more efficient desalination systems for more sustainable water supply in the future, among others, make possible the fostering of a blue economy, both addressing the economic and environmental challenges of today.

The MARES follows such approach There are many exciting emerging innovations in marine aquaculture, cultivated reefs and nature-based marine tourism, but the tangible added benefits when they all come together need to be ascertained and how countries can plan for that.

3.0 What the MARES project is looking for

In order to support the Marshall Islands and other island states to maximize the potential of their blue economies, the MARES project aims to find capabilities, innovations, technologies or infrastructure that can be combined with one or more technologies and/or infrastructure to create a multi-function capability with a viable, scalable business model. This enables island states to maximize the socio-economic benefits of their blue economies and large EEZ resources to create and equitably distribute greater prosperity for all.

The MARES initiative is seeking to shortlist six to eight candidate projects that:

- Support and align to existing **national aims and objectives**.
- Are **multi-function**, **technically sound** and **scalable**.
- Are **financially viable**.
- Are **sensitive to local conditions and stakeholders**.

- Are **future-proofed**.

4.0 Marine renewable energy options relevant to RMI

The Division of Energy within the RMI Ministry of Resources and Development is responsible for National Energy Policy Coordination and some implementation. This includes responsibility for energy efficiency and renewable energy. The Framework for the National Energy Policy includes a 20% improvement in energy efficiency and 100% or complete renewable energy utilization or zero emissions.

The 2009 Marshall Islands National Energy Policy calls for "An improved quality of life for its people through clean, reliable, affordable, accessible, environmentally appropriate, and sustainable energy services." [2]

Table 1 provides an overview of ocean energy options for the Marshall Islands. Options are then described in more detail.

4.1 Offshore wind (high likelihood of viability in RMI)

Offshore wind energy is powered via wind turbine-based propulsion, similar to onshore systems but with fixed or floating windmill-based technology infrastructure out at sea. Instead of occupying vast land space to develop onshore wind farms, offshore wind power utilizes the marine coastal landscape which is far from any populated or residential areas.

The average wind speed in the Republic of Marshall Islands is 7.09 meters per second (m/s) at 100-meter (m) elevation with a corresponding power density of 310.69 watts per square meter (W/m^2).[3] The wind speeds are higher in the northernmost islands while assessment could be worthwhile for Majuro and Ebeye[4] including utility scale (>500 kilowatt [kW]) offshore turbines in their lagoons.[5] However, data is still limited due to less than 20 years of meteorological records,[6] though past measurements done by the United States show average wind speeds of 6-7 m/s.[7] An offshore wind turbine was used as Biorock shore protection in Arno Atoll with the base being grown as an artificial reef.[8] However, reef-mounted wind turbines may also affect the reef ecosystem (footnote 6). The Global Status Report states that a 1.5- to 7.5-megawatt (MW) wind turbine has a capacity factor of 35-45 %.[9]

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[2] M.D. Conrad. 2016. *Republic of the Marshall Islands Pursuing a Sustainable and Resilient Energy Future*. National Renewable Energy Laboratory. 16 July.
[3] Technical University of Denmark. *Global Wind Atlas*.
[4] IRENA. 2013. *Pacific Lighthouses - Renewable energy opportunities and challenges in the Pacific Islands region The Republic of the Marshall Islands*. Abu Dhabi. International Renewable Energy Agency.
[5] Republic of the Marshall Islands Energy Future. 2018. *Navigating our Energy Future : Marshall Islands Electricity Roadmap*. Republic of the Marshall Islands.
[6] IRENA. 2015. *Renewables Readiness Assessment: Republic of the Marshall Islands*. Abu Dhabi. International Renewable Energy Agency.
[7] The Government of the Republic of the Marshall Islands. 2016. *National Energy Policy and Energy Action Plan*. Republic of the Marshall Islands.
[8] K. Jormelu et al. 2010. *Shore protection in the Republic of the Marshall Islands: Pilot project report*.
[9] REN21. 2015. *Renewables 2015 Global Status Report*. REN21. Paris.

Table 1. RMI Martine Renewable Energy Options and Indicative Estimates (e.g., Potential, Costs, Levelized cost of Energy (LCOE)

							Levelized Cost of Hydrogen [LCOH] ($/kg)	
Technology	**Potential [Installed] Capacity (GW)**	**Technical Resource (GWh/year)**	**Capital Cost (Million $/MW)**	**Capital Cost (Billion $)**	**Operational Turnover (Billion $ / year)**	**Levelized Cost of Energy ($/kWh)**	**LCOH (based on LCOE) ($/kg)**	**Reference LCOH by 2030 ($/kg)**
Marine Solar	2,290.77 – 22,907.66[a][b][c]	3,207,072.86 – 36,652,261.26[f]	$1.50 - $1.88	$4,295.19 - $34,361.49[g]	$160.35 - $3,665.23[h]	$0.094 - $0.134	7.81 - 11.16	1.55 - 2.5[i]
Wave	0.037 - 0.605[a][b][c][d][e]	38.94 - 2,492.54[f]	$2.7 - $9.1	$0.337 - $1.635[g]	$0.002 - $0.249[h]	$0.066 - $0.866	5.46 - 72.14	Not Available
OTEC	12.83 - 128.28[a][b][c]	183,444.57 - 1,834,445.68[f]	$3.00 - $13.00	$166.77 - $384.85[g]	$9.17 - $183.44[h]	$0.021 - $0.091	1.75 - 7.58	6.79 - 9.51 [j]
Offshore Wind	4,982.03 - 49,820.27[a][b][c]	21,821,279.72 - 218,212,797.25[f]	$3.00 - $4.00	$19,928.11 - $149,460.82[g]	$1,091.06 - $21,821.28[h]	$0.069 - $0.091	5.71 - 7.61	3.50 - 6.14 [k][l]
Marine Bioenergy	4.58 - 45.76[a][b][c]	40,088.41 - 400,884.11	$3.50 - $4.50	$20.59 - $160.17[g]	$2.00 - $40.09[h]	$0.040 - $0.051	3.33 - 4.28	Not Available
Tidal/Current	67.35 - 673.49[a][b][c]	29,498.66 - 589,973.12[f]	$3.30 - $5.60	$377.15 - $2,222.50[g]	$1.475 - $59.00[h]	$0.377 - $1.279	31.39 - 106.54	Not Available
Salinity Gradient[m]	No data	No data	$27.50 - $35.00	No data	No data	No data	No data	No data

* NB Underpinning assumptions (listed as alphabets in the table) for these calculations are available in Appendix 1.

Abbreviations: GW = gigawatt, GWh = gigawatt-hour, kg = kilogram, kWh = kilowatt-hour, LCOE = levelized cost of energy, LCOH = levelized cost of hydrogen, MW = megawatt, OTEC = ocean thermal energy conversion

Sources: ADB.2014. *Wave Energy Conversion and Ocean Thermal Energy Conversion Potential in Developing Member Countries*. Manila; A. S. Kim and H. J. Kim, eds. 2020. *Ocean Thermal Energy Conversion (OTEC) Past, Present, and Progress*. London; Central Intelligence Agency. The World Factbook; Pacific Islands Ocean Observing System. Global Wind Atlas; IRENA. 2022. *Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green hydrogen cost and Potential*. International Renewable Energy Agency. Abu Dhabi, 2022; N. Dinh. 2022. *Projections of levelised costs of hydrogen (LCOH)*. MARES Report. Manila. ADB. S. Banerjee, M. N. Musa and A. B. Jaafar. 2017. Economic assessment and prospect of hydrogen generated by OTEC as future fuel. *International Journal of Hydrogen Energy*. Volume 42, Issue 1. pp 26-37; The World Bank. 2021. The Offshore Wind Roadmap for the Philippines.

4.2 Marine solar (high likelihood of viability in RMI)

Marine solar systems may be attached to a fixed structure or floating on the body of water. This is perhaps the most promising of all the types of marine renewable resources available to the Marshall Islands. According to studies, RMI's solar resource is greatest in the northern islands and the least in the middle islands. The average solar potential is at 5 kilowatt-hour per square meter per day (kWh/m^2-day).[10] Floating solar photovoltaic (PV) is being explored, with a pilot in the Majuro lagoon (footnote 5). A pilot project for Biorock shore protection in Majuro Atoll was also commissioned (footnote 8).

4.3 Ocean Thermal Energy Conversion (potentially viable in RMI)

OTEC uses the temperature difference between the ocean surface (warm) and the deep seawater (cool), which can be used to drive a heat engine (Global potential: 10,000 terawatt-hour per year [TWh/yr]).[11] The tropical oceans act as a vast solar collector and the OTEC process allows this to be converted to clean electricity without interruption, 24/7. A 10-MW floating OTEC is considered to be technically achievable in locations such as Japan and Hawaii but is not yet fully commercial. However, the present state of proven pipeline technology is such that an island-based 2.5 to 5 MW system is considered achievable today and 10 to 50 MW by 2050 if not sooner. The OTEC Foundation has confirmed the significant potential for OTEC globally, at least for a 30-MW plant facility or equivalent combination of smaller plants, for Kwajalein Atoll. The Organisation for the Promotion of Ocean Thermal Energy Conversion and GEC Co Ltd of Japan proposed an OTEC plant for Kwajalein Atoll (footnote 4).

Estimated generation of 1,430 gigawatt-hour per year (GWh/yr) for a 100 MW plant exists from a previous study.[12] Many OTEC systems have multi-user capacity potential, for example for underwater data centers, ocean cooling, mariculture, research centers and artificial reefs, none of which have been fully explored and which could generate further economies of scale.

Studies made by the National Renewable Energy Laboratory (NREL) show that the resource potential for OTEC, once plants established in RMI, is 380 GWh per year. Kwajalein Island which houses a US Military base is considered as the location for a 20-MW OTEC power plant to provide electricity and fresh water to the military facility. But operating OTEC plants also poses multiple operational challenges, aside from the environmental impacts and the associated land requirements.

At present, the biggest barrier to more widespread adoption of OTEC technology is financial, not technical, particularly at a scale below 10 MW. The electricity generation process system is simple and has proven to be reliable at both the Hawaii Natural Energy Laboratory and the Okinawa Deep Seawater Research Center. What is missing is the financial guarantee to move beyond small demonstration plants to pre-commercial prototype units, to provide key operational performance data to encourage investment in larger commercial-scale facilities.

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[10] National Renewable Energy Laboratory. *RE Data Explorer.*

[11] IEA Ocean Energy Systems. 2021. *White Paper on Ocean Thermal Energy Conversion (OTEC).* IEA Technology Programme for Ocean Energy Systems (OES).

[12] ADB. 2014. *Wave Energy Conversion and Ocean Thermal Energy Conversion Potential in Developing Member Countries*. Manila.

4.4 Tidal flows and currents (potentially viable in RMI)

The movement of ocean water volumes, caused by the changing tides, creates tidal current energy. Tides cause kinetic movements, i.e., reversing current flows, which can be accelerated near coasts, where there is constraining topography, such as straits between islands. Tidal stream energy has a global potential of more than 800 TWh/yr.

The Marshall Islands Government has not mentioned tidal energy in the National Energy Policy (footnote 7) and they also stated it is unsuitable in the short term (footnote 5). A tidal-powered Biorock shore protection project was planned but cancelled due to manufacturer's delays (footnote 8). There may be specific sites or island groups that have potential for tidal energy (e.g., harnessing tidal range and/or currents) but further investigation is needed.

The potential for ocean as well as for tidal current energy remains experimental globally, unproven globally with relatively few pilot projects and no examples of commercialization. No previous studies have yet to be conducted specifically for the Marshall Islands.

4.5 Wave energy (potentially viable in RMI)

Wave energy utilizes the movement of the ocean surface caused by wind systems and the resulting pressure fluctuations from below the ocean surface can also be exploited. Due to the development of floating wave energy converters (attenuator devices), the potential of this system increases rapidly since it can be deployed basically anywhere on the surface of the world's ocean where wave resources are present (Global potential: 80,000 TWh/yr [footnote 11]).

A 10-kilowatt per meter (kW/m) wave energy potential was assessed for Mauro Atoll.[13] It was considered for Gugeegue Island the 1990s but never developed (footnote 4). A wave-powered Biorock shore protection project was undertaken in Arno Atoll (footnote 8). However, there were no well-tested commercial wave energy systems (footnote 6) at the times of previous studies and it is mostly deemed unsuitable until 2025 (footnote 5). Nevertheless, the potential for wave energy exploitation is clear and since the wave energy resource is present in RMI, further investigation may lead to possible projects. In the past few years, more innovative efforts and technological innovations have surfaced, several of which have been detailed as possible solutions by the MARES team, especially in combination with other sources.

4.6 Marine bioenergy (potentially viable in RMI)

Bioenergy refers to organic derived, electrical energy being produced from sources such as algae (macro and micro); seaweed; kelp; algae; biomass, bacteria and other compounds. Production processes involve harvesting, extraction, pyrolysis, gasification, liquification, processing and anaerobic digestion.

The Marshall Islands Office of Commerce, Investment and Tourism stated that algae grown in a controlled environment may be a candidate technology to increase the country's renewable energy share.[14] There may be potential associated to mass scale growth of kelp forests; seagrass meadows; seaweed; utilization of sargassum from extended protected areas or ecosystem restoration; and algae, seaweed or kelp.

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[13] A. Lauranceau-Moineau,2019. *Blue Energy: Renewables in the Pacific Ocean.* Presented during the workshop on Incorporating the Ocean in NDCs. Fiji. 9 May 2019.

[14] Marshall Islands Office of Commerce & Investment. n.d. Renewable Energy for Marshall Islands.

4.7 Salinity gradient (may be unviable in RMI)

Salinity gradient uses the difference in salt concentration between seawater and freshwater (chemical potential) to allow ion movements from high to low concentration (Global potential: 10,000 TWh/yr [footnote 11])

There is no specific literature for salinity gradient energy for RMI. The NREL and RE Data Explorer also do not provide data for the said resource (footnote 10). The country also does not have large freshwater bodies to provide a salinity gradient resource.

4.8 The potential of Green Hydrogen

In order to reduce reliance on fossil fuels, electricity energy can now be converted into hydrogen, which can thus be viewed as another form of energy carrier. Hydrogen can be produced using various methods; from use of conventional energy sources like natural gas or coal, from nuclear energy and, most importantly, from renewable energy sources like wind, solar and biomass

Currently the most basic industrial process to produce the purest form of hydrogen is water electrolysis, the process of splitting water molecules to give hydrogen and oxygen by circulating electricity directly through it. Hydrogen produced with electrolysis using the electricity made from renewable energy sources has low global warming potential. The most important advantage of electrolysis of water is the production of extremely pure hydrogen, with the only by-product being oxygen. There is potential to create a new global commercial opportunity where excess marine renewable energy is converted to exportable hydrogen which could unlock the financing required to speed up adoption of these technologies and secure a key regenerative cornerstone of many nations' blue economies.

5.0 Potential investable projects

Innovations investigated by the MARES team that are potentially relevant to the Marshall Islands include:

- **A 'digital living reef'** that mimics the natural barrier behavior of coral reefs (i.e., reducing the power of larger waves that are typically bad for the shoreline), at the same time as accelerating regenerative coral growth and converting wave power to energy.[15]
- **A floating offshore OTEC** system that is designed to be affordable and manageable within coastal and smaller island states, in order to help decarbonize at a lower unit cost than incumbent fossil fuels.[16]
- **A floating offshore solar energy system** that provides clean, hybrid PV electricity for ports and coastal communities, including nearshore aquaculture farms. [17]
- A project testing how **locally produced hydrogen can be used as fuel for a ferry** that runs between the mainland and local islands, to shift from diesel power to renewable energy.

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[15] ADB. 2022. *Paddling to Create Cultured Reefs for New Habitats and Coastal Protection.* *ADB Knowledge Events*. Manila. 6 May.

[16] ADB. 2022. *Ocean Thermal Energy Conversion (OTEC) Viability as a Catalyst for Transformative Island Development*. ADB Knowledge Events. 30 September.

[17] ADB. 2022. ACEF 2022 Deep Dive Workshop: *The Future of Ocean Energy and Hydrogen - Just Transition to a Safer World*. ADB Knowledge Events. 16 June.

- **An aquaculture project** that is working with the local coastal community so that it **can be featured as an eco-tourism asset**, rather than a disturbance. It has done so by specifically designing its infrastructure to be a destination for scuba diving tours.[18]

Further investigation of down-selected initiatives will continue.

6.0 Potential pilot sites in the Marshall Islands

The site selection process aimed to identify the top three project areas in the Marshall Islands that would best support the testing of each technical concept to strengthen the regenerative blue economy and, hopefully, provide sufficient evidence for full commercial scalability of solutions. The target activities in the pilot sites will generally fall within the four key categories of renewable energy, marine aquaculture, nature-based marine tourism and coral reefs.

6.1 Majuro

Majuro is one of RMI's 29 atolls and home to about half of the entire population as well as the international airport. It covers a land area of 9.2 square kilometers. Majuro is the site of most tourism accommodations and commercial infrastructure. There is potential for any MARES project to support existing offerings that rely on the electrical grid.

6.2 Rongrong

Rongrong is the largest islet on the Northwest corner of Majuro lagoon. It is close to the international airport and a short boat ride inside the lagoon to the population center of Majuro. There are also safe anchorages on the south side of the island inside the lagoon. There is a high school and the island is powered exclusively by diesel generators. It is thus far enough to operate off-grid as a case study for off-grid islands, but close enough to easily resupply with the labor and materials.

6.3 Eneko Island

Eneko, on Majuro's northern shore is 9 kilometers from the international airport and is a short boat ride away. The island offers pristine beaches; clear, shallow waters; and a few underwater relics from World War II. The area is popular with snorkeling fans thanks to the colorful fish and coral. It is known locally as the 'conservation island', as it offers significant potential for eco and/or nature-based tourism initiatives.

7.0 Conclusion and next steps

Offshore wind and marine solar have been identified as being highly likely to be viable in the waters of the Marshall Islands; OTEC, tidal and/or current, wave and marine bioenergy are all potentially viable. Salinity gradient is, at this stage, not considered suitable for deployment. Majuro, Rongrong and Eneko Island have all been identified as having the right range of characteristics to support and benefit from MARES pilot projects.

The project team will now:

- Review local legislations and regulations to recommend enabling action, if any.

[18] ADB. 2022. *How Singapore is Modernizing Fish Farming with Low Carbon Alternative Methods*. ADB Knowledge Events. 6 August.

- Review social and cultural aspects of RMI and how multi-modal projects might be suitable with appropriate safeguards and capacity development.
- Progress towards prefeasibility review of select multi-function projects.
- Provide comment on thresholds and triggers for feasibility for such projects including innovation in financing structures, colocation of downstream activities and opportunity for enhance viability through colocation.

Appendix 1

Footnotes:

(a) The area of computation for the Low Scenario is 1% of the total available area (10% of the total available area for the High Scenario). For tidal/current, low scenario is 0.5 m/s in 0.1% of the total available area while high scenario covers velocities 1 m/s in 1% of the total available area.

(b) The perimeter of the EEZ of RMI is 1,603,536.43 km^2 (EEZ US and associated territories data from http://geo.pacioos.hawaii.edu/geoexplorer/). The value for the EEZ No-take zone is 80% of the EEZ.

(c) The rated output used are the following: marine solar energy – 7 sqm/kW; wave energy – 10 MW/km; OTEC – 0.8 MW/km^2 (https://library.oapen.org/bitstream/handle/20.500.12657/43849/external_content.pdf?sequence=1); offshore wind – 310.69 W/m^2 (wind atlas @ 100 m; globalwindatlas.info); marine biomass – 2,500 MWh/km^2-yr (annual yield); tidal/current – 42 MW/km^2.

(d) The coastline length is 370.4 km (https://www.cia.gov/the-world-factbook/field/coastline/). The final value used is the value for the low scenario.

(e) The final value used is the value for the low scenario.

(f) The following capacity factor values are used: marine solar – 1,400 (low scenario yield) to 1,600 (high scenario yield) kWh/kWp/yr is used (Decherong, G. (2002). The Project for Ocean Thermal Energy Conversion (OTEC) and its Multi-purpose Utilization in the Republic of Palau); wave energy – 0.12 (low scenario) and 0.47 (high scenario) (Asian Development Bank. (2014). Wave Energy Conversion and Ocean Thermal Energy Conversion Potential in Developing Member Countries. https://doi.org/10.1007/BF02929925); OTEC – 14.30 GWh/MW (annual production) (Asian Development Bank. (2014). Wave Energy Conversion and Ocean Thermal Energy Conversion Potential in Developing Member Countries. https://doi.org/10.1007/BF02929925); offshore wind – 0.5 (https://globalwindatlas.info/area/Marshall%20Islands, IEC Class III); tidal/current – 0.1 (high scenario) and 0.05 (low scenario).

(g) The capital cost values are used, as listed: marine solar – Under the ADB floating solar project, low installed capacity scenario capital cost uses USD15M/8 MW CAPEX per MW while high installed capacity scenario capital cost uses USD12M/8MW CAPEX per MW; wave energy – USD9.1M/MW CAPEX per MW (low installed capacity scenario capital cost) and USD2.7M/MW CAPEX per MW (high installed capacity scenario capital cost) (USD2.7-9.1M/MW, https://www.ocean-energy-systems.org/documents/16823-international-levelised-cost-of-energy-for-ocean-energy-technologies-2015-may-2015.pdf/); OTEC – USD13M/MW CAPEX per MW (low installed capacity scenario capital cost) and USD3M/MW CAPEX per MW (high installed capacity scenario capital cost) (3-13M USD/MW, https://www.ocean-energy-systems.org/documents/16823-international-levelised-cost-of-energy-for-ocean-energy-technologies-2015-may-2015.pdf/); offshore wind – USD4M/MW CAPEX per MW (low installed capacity scenario capital cost) and USD3M/MW CAPEX per MW (high installed capacity scenario capital cost) (3-5M USD/MW); marine bioenergy – USD4.5M/MW CAPEX per MW (low installed capacity scenario capital cost) and USD3.5M/MW CAPEX per MW (high installed capacity scenario capital cost) (Early TRL Cost of Seaweed farm ($70,000), biomass plant ($3,500,000 to $4,500,000 per MW) but anticipated to become cheaper based on land equivalents, IRENA); tidal/current – USD5.6M/MW CAPEX per MW (low installed capacity scenario capital cost) and USD3.3M/MW CAPEX per MW (high installed capacity scenario capital cost) (https://www.ocean-energy-systems.org/documents/16823-international-levelised-cost-of-energy-for-ocean-energy-technologies-2015-may-2015.pdf/).

(h) Electricity price assumed for revenue: USD0.05/kWh (low scenario turnover) and USD0.10/kWh (high scenario turnover)

(i) IRENA, “Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green hydrogen cost and,” International Renewable Energy Agency, Abu Dhabi, 2022.
(j) S. Banerjee, M. N. Musa and A. B. Jaafar, “Economic assessment and prospect of hydrogen generated by OTEC as future fuel,” International Journal of Hydrogen Energy, p. https://doi.org/10.1016/j.ijhydene.2016.11.115, 2017.
(k) World Bank, “Offshore Wind Roadmap for The Philippines,” World Bank, Washington, DC. License: Creative Commons Attribution CC BY 3.0 IGO, 2021.
(l) N. Dinh (2022), Projections of levelised costs of hydrogen (LCOH), MARES Report: ADB
(m) Salinity gradient research and technologies in RMI need more exploration, investigation, and feasibility studies.