STRENGTHENING THE PACIFIC BLUE SHIPPING PARTNERSHIP

Zero-carbon transition plan

For official use only

11 August 2023

WORLD BANK GROUP
Transport

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Preamble

This analytical work aiming at "Strengthening the Pacific Blue Shipping Partnership (PBSP)" was undertaken as part of the World Bank's wider regional advisory services and analytics (ASA) "A Blue Transformation for Pacific Maritime Transport.

For transparency, it is important to note that this analytical work faced significant challenges in the research process. These included, for instance, the Covid-19 pandemic with the impossibility of in-person consultations and site visits, the unavailability or limited availability of governmental officials due to shifts in priorities, or the reassignment of consultants and related analytical responsibilities as the work evolved.

This analytical work aims to make a significant contribution to decarbonizing regional maritime transport in the Pacific. It strengthens the analytical foundation of the PBSP, it outlines potential key options (e.g., governance, technical, operational, or financial) to consider moving forward, and it provides a basis for discussion. However, given the challenges mentioned, it should not be considered as fully conclusive or exhaustive, and can benefit from existing complementary analytics by other experts as well as further research.

Acknowledgments

The preparation of this Transition Plan working paper was led by the World Bank, with the expert support of GHD Group.

The World Bank task team responsible for this paper was led by Dominik Englert and comprised Jennifer Brown, Yoomin Lee, Isabelle Rojon, and Michael Wilson. Peter Nuttall provided strategic expert guidance and advice. The GHD team was led by Guy Reynolds.

The World Bank team would like to express its great appreciation to Fei Deng for her managerial guidance and constructive suggestions during the planning, development, and finalization of this research work. Her willingness to give her time and support was highly valued.

Support from the NDC Support Facility is gratefully acknowledged.

Acronyms and abbreviations

The following acronyms and abbreviations have been used in the Report.

Acronym / abbreviation	Meaning
BAU	Business as usual
CAPEX	Capital Expenditure
CCS	Carbon Storage and Capture
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DWT	Deadweight of a vessel (ship/craft)
e-fuel	CO_2-neutral alternative fuels
FSHIL	Fiji Ships & Heavy Industries Ltd
GHD	GHD Pty Ltd
GHG	Greenhouse Gas
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MCA	Multi-Criteria Analysis
NDC	Nationally Determined Contribution
OPEX	Operational Expenditure
PBSP	Pacific Blue Shipping Partnership
PIC	Pacific Island Countries
PID	Propulsion Improving Device
PV	Present Value
RMI	Republic of Marshall Islands
SSD	Slow Speed Diesel
t	Tonne (metric)
UNDP	United Nations Development Program
UNSW	University of New South Wales
USD	United States Dollars
WASP	Wind-assisted ship propulsion

Executive Summary

Introduction

GHD has been engaged by the University of New South Wales (UNSW), as part of UNSW's work for the World Bank on the Pacific Blue Shipping Partnership (PBSP), to provide advice on two components of UNSW's service to the World Bank:

1. Technical Solutions and Decarbonization Pathways for domestic and regional shipping to transition from a current baseline to a 40% reduction in CO_2 emissions by 2030 and zero CO_2 emissions by 2050.
2. A Blended Finance Roadmap, which outlines, at a high-level, the scale, scope and needs of financing the proposed Decarbonization Pathways for the PBSP.

This Report covers the **Technical Solutions and Decarbonization Pathways** work component and is the **Final** version issued by GHD on 31 October 2022.

GHD has been instructed by the World Bank to use a specific revised dataset (spreadsheet dated 17 October 2022). As per this baseline, the six PBSP island countries covered in this Report are **Fiji, Kiribati, Marshall Islands, Solomon Islands, Tonga, and Tuvalu**. As inventory baseline data for other PBSP nations are currently unavailable, country-specific decarbonization transition pathways for **Samoa** and **Vanuatu** are not provided. Discussions around the work have been presented at three online PBSP Open Forums (25 May 2022, 22 June 2022 and 29 July 2022).

Approach

The proposed Zero-Carbon Transition Plan is based on the same GHG abatement measures and timings across all PBSP nations. These are distinguished by ongoing/instant, short-term and long-term measures. Even though the measures and their timings are assumed the same across the PBSP member countries, countries may still have different GHG emissions savings opportunities for each abatement measure. For example, the GHG abatement potential of wind-assisted ship propulsion (WASP) technologies in PBSP member countries closer to the equator with lower wind resources (e.g., Kiribati) may be less attractive than in countries with higher wind resources (e.g., Fiji). Furthermore, the individual country's policy and roll-out of supporting mechanisms will influence how effective and how well adopted each abatement measure will be. Ongoing collaboration across the PBSP member countries will also be key to achieve economies of scale and develop inter-country trade and knowledge-sharing opportunities surrounding each abatement measure. Details on the methodology can be found in the complementary World Bank working paper "Zero-Carbon Transition Plan (working title)".

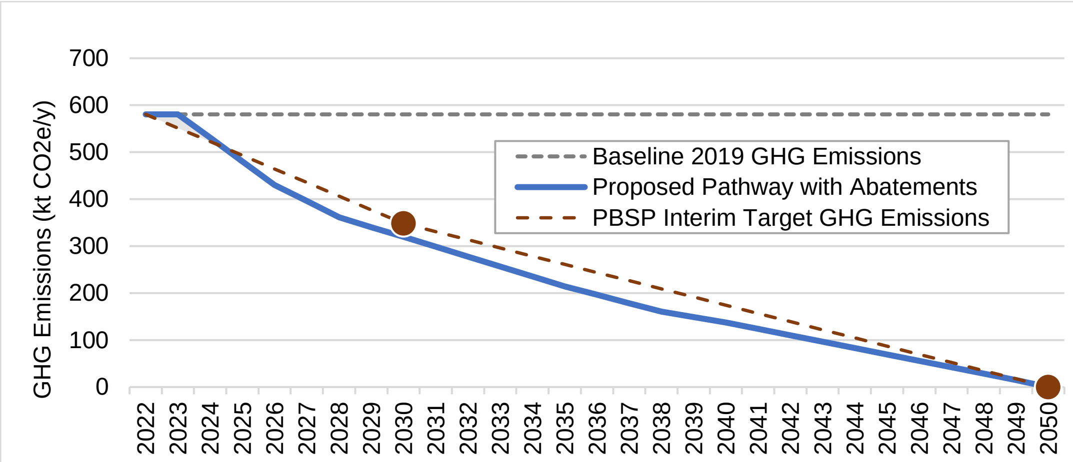
Furthermore, the Zero-Carbon Transition Plan should not be considered in isolation from other sectors, particularly given the competing needs of land for agricultural production and renewable energy generation. The goal is to achieve self-sustaining value chains and minimize the reliance on energy imports from outside the Pacific Island Countries (PICs).

Overview

This report outlines plausible technological and operational pathways that the Pacific Blue Shipping Partnership (PBSP) could envisage as immediate, short-term, and long-term measures to achieve its GHG emissions reduction goals. The analysis is based on the outcomes of the 'High-Level Baseline Assessment' report and is adapted for the types of ships and routes associated with the region.

Several greenhouse gas (GHG) emission measures potentially applicable to the PBSP member countries' fleet have been assessed using a Multi-Criteria-Analysis (MCA). Based on this MCA, a possible 2050 decarbonization pathway has been developed, which is hereafter referred to as 'Zero-Carbon Transition Plan'. It factors in a range of criteria including the maturity of technology, socio-economic drivers, and the local readiness of each GHG abatement measure. Given the evolving nature of several abatement measures, the Zero-Carbon Transition Plan proposed in this report should be reviewed and updated periodically (e.g., every two to five years). Using data from the High-Level Baseline Assessment, a model has been developed to inform the potential GHG emissions reductions and costs for each abatement measure for each country and for the region as whole. Figure 1 shows the emissions trajectory under the Zero-Carbon Transition Plan, illustrating that this plan would not only meet, but even slightly exceed the emissions reduction targets of the PBSP.

Figure 1: Greenhouse gas emissions trajectory under the Zero-Carbon Transition Plan



Key findings

From the assessment of potential GHG abatement measures and the modeling of a decarbonization pathway, several key findings can be identified.

Ongoing/instant and short-term GHG abatement measures

Operational measures in ship operations

Ongoing/instant and short-term (2023–2030) abatement measures seek to address immediate challenges in technical vessel designs, logistics, marine infrastructure, and data gathering by improving operational efficiencies. They include improved maintenance programs, demand-supply management, data systems, supporting infrastructure, WASP retrofitting[1], engine derating, propulsion improving devices (PIDs), blended biofuels, and motor switching.

If successfully implemented, these ongoing/instant and short-term GHG abatement measures have the potential to achieve 40 percent GHG emissions reductions by 2030 and will 'buy' time for long-term abatement measures involving electrification and green e-fuels to mature. This is clearly illustrated in Figure 2 which shows the contribution of, in particular, operational efficiency measures and WASP retrofitting in reducing GHG emissions by more than 40 percent by 2030.

It is also possible that due to these measures the fossil fuel import dependence could be reduced by around 40 percent in the same period. This would result in significant savings to the economies of the PBSP member countries in terms of imports. However, as fuel expenses reduce due to improved efficiencies, there is also a risk that operators will consume more fuel based on the savings achieved (i.e., the so-called "rebound effect"[2]).

[1] It must be noted that the benefits associated with WASP technologies are location specific as they are dependent on local wind conditions. This means that WASP solutions will need to be hybrid technologies in their approach, based on trialling/proof of concepts in each PBSP member country.
[2] University Maritime Advisory Services. 2019. Reducing the Maritime Sector's Contribution to Climate Change and Air Pollution. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816020/potential-role-targets-economic-instruments.pdf

Land-based infrastructure

Operational measures, especially maintenance and retrofitting, are critically dependent on slipways and ship lifts in the region. A high-level check of the slipway capacity across PBSP countries has indicated a significant shortfall of slipways across the PBSP member countries. Therefore, it is recommended to prioritize initial investment in these facilities and systems and to implement a rigorous three-to-five-year maintenance cycle. Furthermore, a more detailed understanding of the capability and condition of existing slipway assets is needed to determine the extent of additional investment required. Further integration of landside logistics with freight route efficiency measures such as warehousing, information systems, and electronic data visibility may also be beneficial.

Biofuels

The analysis has identified that blended biofuels could play a temporary role in the decarbonization of maritime transport within the PBSP member countries (see Figure 2). However, it must be noted that there are various risks associated with the large-scale use of biofuels. They include, among other things, competition with local food supplies as well as continued dependence on imports where there are shortfalls in local production. It will be critical that potential conflicts with food production on arable land are well managed.

It is estimated that a regional amount of 1,500 tons of coconut oil as a 20 percent blend in total of 7,500 tons of blended fuel could be produced locally to reduce GHG emissions. This would require the redirection of five to ten percent of existing coconut oil exports to maritime transport within the region. At the same time, this could offer an opportunity for PICs such as the Solomon Islands, Papua New Guinea, and Vanuatu to enhance their exports as they could become the primary suppliers of coconut oil to other PICs.

After blended biofuel will be phased out, conservatively the remaining coconut used to blend could play a minor role as a 100 percent (i.e., non-blended) biofuel without creating a need for additional imports at higher costs or massively invest in growing and processing by the PICs for biofuel use versus more lucrative value-added uses.

Long-term GHG abatement measures

Electrification and green e-fuels

Long-term (2031–2050) GHG abatement measures are likely to include a mix of electrification, and green e-fuels which include liquid hydrogen, liquid ammonia and methanol produced using renewable energy. As shown in Figure 2, the uptake of electrification and green e-fuels increases continually from 2031 and contribute to achieving full decarbonization of the domestic maritime fleet by 2050.

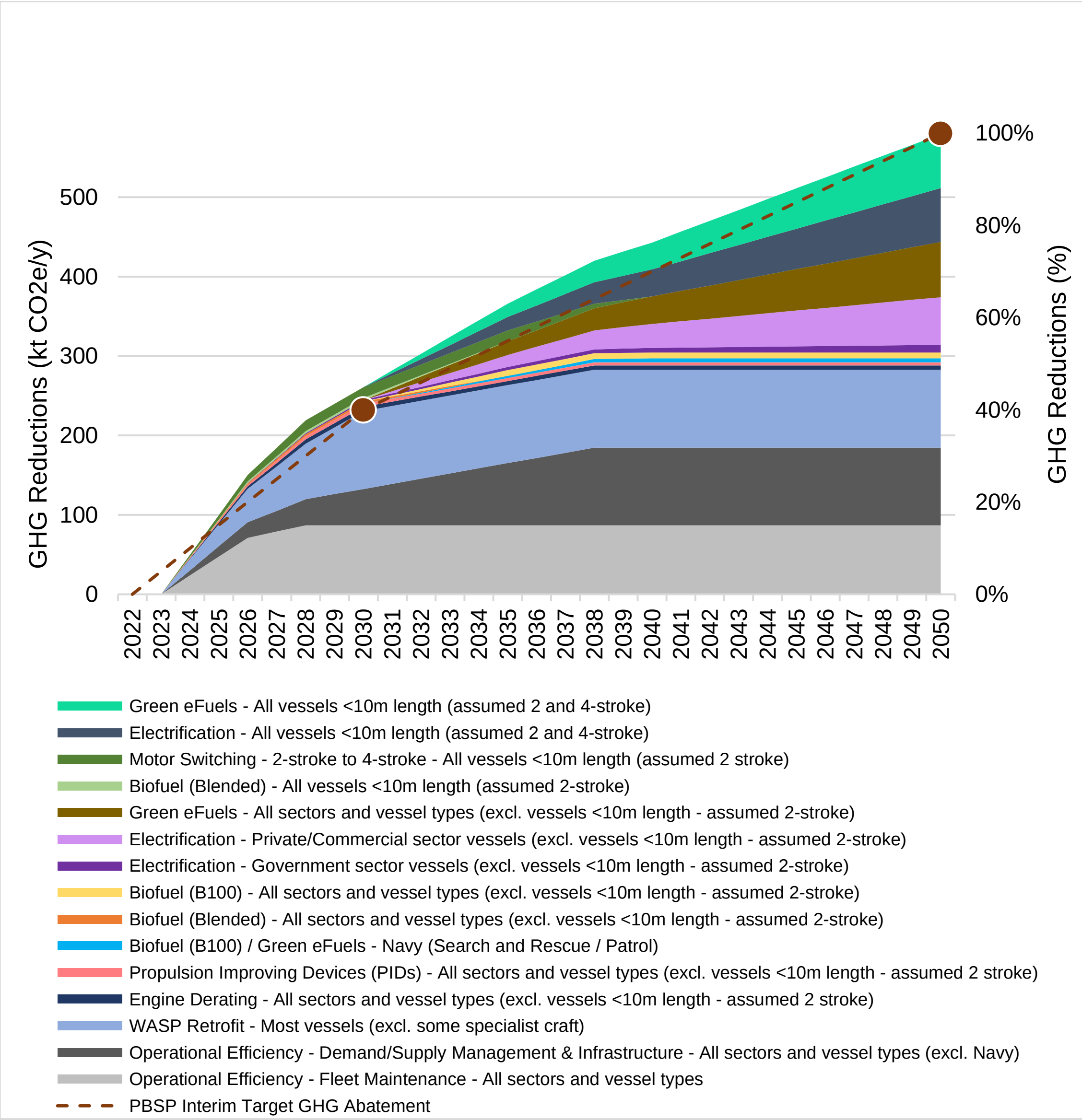
These measures will need to be reviewed and confirmed following an implementation assessment of ongoing/instant and short-term abatement measures over the next two to three years, and a review of the mix of solutions best suited and available to PBSP member countries in 2030–2050. The proportion of fleet electrification compared to green e-fuels will depend on the outcome of local pilot programs, technology development and maturity, development of supporting infrastructure, and overcoming e-fuels handling and storage concerns.

The uptake of long-term GHG abatement measures will require the establishment of long-term alternative green e-fuel supplies including all supporting infrastructure. As such, these measures require decisive underlying policy with sufficient lead times to enable effective roll-out. It is recognized that in some PBSP member countries, several major constraints and barriers may hinder the uptake of some of these GHG abatement measures. This could, for example, happen due to the absence of an integrated energy policy, the lack of development of alternative local renewable electricity supply, limited funding, and limited technical and labor capacity. Therefore, any long-term GHG abatement measures cannot be considered in isolation from the broader national challenges and must be implemented in an integrated manner.

For those future measures that involve green e-fuels and require large-scale industrial facilities and large investments into production capacities, it would be advisable for PBSP member countries to monitor developments in the Pacific-Rim area (i.e., plans in Australia/New Zealand, Papua New Guinea, Asia, and North America) with regard to the likelihood and opportunity of PICs obtaining early, guaranteed supply at affordable prices of these types of future green e-fuels. One way could be to link a local trial (proof of concept) of a technology to an existing pilot supply from overseas to also test future supply chains and local infrastructure needs.

A few GHG abatement measures involving new technologies and/or alternative fuels are still globally emerging with proof of concepts (pilots) underway. This implies that in the longer term (post-2030), one or more current abatement measures with future potential may still emerge as leaders in the long-term mix of abatement measures and transition pathways. Alternately, some of the currently proposed GHG abatement measures may become less prominent as whole-of-system/national network, cost, and economic performance become better known by 2030.

Figure 2: Uptake of GHG abatement measures under the Zero-Carbon Transition Plan



In any case, it is important to ensure that some GHG abatement measures are phased in and out in coordination with other GHG abatement measures to minimize redundancy and waste of funds. For example, there is a clear need to identify which existing vessels should be retrofitted or which should be scrapped and replaced with purpose-built new builds (running electric or green e-fuel). Likewise, investments will need to be made in GHG abatement measures that are compatible and complementary to each other.

Recommendations

The proposed next steps for the technical aspects of the decarbonization pathway include:

- **Further monitor and review relevant pilot studies and conduct additional regional specific pilot studies**, e.g., on WASP, ammonia fuel/hydrogen/electric craft/ charging and storage/handling and identify the next steps to allow for expansion and commercialization of these technologies.
- **Identify specific training needs and delivery requirements for GHG abatement measures**, including for improved fleet maintenance, WASP retrofit, engine derating and PIDs, biofuel production, electrification, and green e-fuels.
- **Further refine the MCA process** considering social and economic aspects, along with any new and emerging developments.
- **Enhance the understanding of the viability of the different technical GHG abatement measures in the PBSP member countries** by also assessing factors such as likely wind conditions for WASP, land availability to install solar panels, the size of the port area required for infrastructure, and availability of means and routes to deliver equipment, materials, and fuels to the PBSP member countries.
- **Infrastructure and information systems:** A survey of routes is required to enable safe and efficient navigation along with a detailed inventory of vessel maintenance facilities and slipway conditions and capabilities.
- **Pathway iteration:** Continually review, update, and adapt the pathway at a country level to account for the different policy settings and technology developments. This is best undertaken centrally so that the PBSP's climate targets for the Pacific region are achieved.

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1 Introduction

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1.1 Scope and limitations

This report: has been prepared by GHD for The University of New South Wales (UNSW) and may only be used by The University of New South Wales (UNSW) for the purpose agreed between GHD and The University of New South Wales (UNSW).

GHD otherwise disclaims responsibility to any person other than The University of New South Wales (UNSW) arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

The Scope of the proposed decarbonization is primarily the domestically operating maritime fleets (including small/artisanal craft with 2-stroke outboard engines), but also includes those vessels and maritime trades between the six PBSP island countries (i.e., Inter-PBSP island country maritime trade). For national accounting consistency, and the avoidance of double counting, the importing PBSP island country involved in the Inter PBSP island country maritime trade has been allocated the resulting CO_2e emissions in the Baseline determinations.

The identification of the various current domestic maritime fleets, their likely CO_2e emissions, and the inter-PBSP island country trades have been researched and estimated by UCL (engaged by UNSW). This Baseline work was then integrated into GHD's technical decarbonization pathways modelling.

The Report (this Report) has been prepared for UNSW for the purpose of facilitating discussion of the PBSP and to provide focus on matters that may require further investigation or consideration.

GHD has not been involved in the preparation of the associated UNSW reports for the Task A (Baseline Assessment) and Task D (Advisory and Capacity Support for Multi-Country NDC Enhancement and Governance) and has had no contribution to, or review of the associated reports other than in this report. GHD shall not be liable to any person for any error in, omission from, or false or misleading statement in, any other part of the Governance of the PBSP report.

GHD will be preparing the preliminary Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) estimates set out in this report ("Cost Estimate") using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD.

The Cost Estimate has been prepared for the purpose of this project and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the PBSP transition pathways can or will be undertaken at a cost which is the same or less than the Cost Estimate.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

GHD has prepared this report on the basis of information provided by The University of New South Wales (UNSW) and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.2 Assumptions

1.2.1 General assumptions

– GHD has based our analysis on current "commercially available" and/or "in proof of concept" technologies. GHD cannot predict developments in alternative technologies and energy supplies that can and will occur in the future.
– A zero-carbon emissions pathway has been assumed without the use of carbon offsets. The use of carbon offsets may be used as a means to help fund individual carbon abatement measures; however, this is discussed in Section 3.6 of GHDs accompanying Blended Finance Roadmap.
– GHD has based our analysis on the following countries: Fiji, Solomon Islands, Kiribati, Republic of Marshall Islands, Tuvalu, and Tonga. These are the countries which had baseline data provided by UCL.
– Extent of the study – GHD's analyses are focused on the known domestic vessel fleets of the PBSP countries along with immediately associated maritime infrastructure. GHD is only providing a short review (screening), based on publicly available information, of the energy resource or the upstream components that will be required to be in place for the transition pathways at the country-level (see section 4.2). This short review allows for input into a rapid assessment of the appropriateness of the identified abatement measures for the PBSP.

1.2.2 Emissions reductions model assumptions

– The emissions reductions model is based on the maritime fleet in the inventory data, including vessel count, type, size, operation type, fuel type, engine power, fuel consumption, and total annual greenhouse gas emissions. Where data are incomplete or missing, assumptions have been made based on similar vessels within the inventory. In some cases, information on government vessels have been updated based on government ship listing websites.

- This model is based on the carbon dioxide equivalent (CO_2e) emissions of the inventory. Percentage reductions in CO_2e emissions are applied per applicable vessel. Some abatement measures will be more effective in reducing emissions for some vessel types than others based on a range of factors, including how the vessels are currently maintained, operated, and designed. Therefore, this model takes a simplified averaging approach of emissions abatement across the applicable vessels.
- Each abatement measure has a start and end year (unless the measure is considered ongoing past 2050). Abatement measure start and end years are based on GHD's understanding of the requirements to action these abatement measures and the readiness for roll-out. Each abatement measure is also coordinated with the timing of other abatement measures to meet the short-term or long-term targets, with consideration of the compatibility of each abatement measure.
- For this assessment, abatement measures are modelled to phase-in and phase-out linearly over the nominated respective periods and does not consider potential acceleration of roll-out that may occur. Where it is expected that an abatement measure is unlikely to reach all applicable vessels, the total reduction in emissions is reduced by a factor based on GHD's understanding which is informed by stakeholder feedback.
- A number of abatement measures assumes 100% coverage across the applicable vessels. This is based on the underlying target for the PBSP fleet to achieve zero emissions by 2050. This means that each vessel (including small craft) has a target of zero emissions by 2050.
- Actual wind resource energy used across the countries will inevitably be different to those used as a basis to estimate the efficiency gains for WASP technology. The effectiveness of this technology varies based on a range of variables including, local available wind resource, vessel type, specific WASP technology, and vessel loading. Accordingly, the outputs of the model cannot be relied upon to represent actual conditions without due considerations of the inherent inaccuracies.
- For battery charging requirements of electrified vessels, battery capacity is presented in terms of kilowatt-hours (kWh), with cost estimates made based on this. Energy generation, including renewable energy supply such as solar irradiance (for photovoltaic energy supply), wind, wave, and hydro resource energy, has only been shortly reviewed at a high-level in terms of its general availability at a PBSP country level and consequential impact on the applicability of a particular identified abatement measure (see section 4.2).
- It is acknowledged that area requirements for energy generation, including biofuel feedstock production represents a significant challenge for the PBSP nations and are reflected in the applicability of the respective abatement measure in the model and discussed for each abatement measure.
- Specific assumptions made for each abatement measure is discussed in more detail in Appendix C – Model Assumptions.

1.2.3 Cost model assumptions

- CAPEX and OPEX estimates (Cost Estimate), are based on the inventory parameters indicated in this report, using information reasonably available to the GHD employee(s) who prepared the Report; and based on assumptions and judgments made by GHD and documented in the Report.
- The Cost Estimate is a strategic level Class 5 Order of Magnitude estimate as defined in the International, Cost Estimate Classification System of the Association for the Advancement of Cost Engineering with an expected accuracy range of -20% to -50% (Low) and +30% to +100% (High). It is intended for the purpose of screening of abatement options and the identification of potential sources of funding as part of the Blended Finance Roadmap. These costs are not suitable for budgetary purposes.
- All cost related information is presented in USD (per 2022) based on information from a range of sources and countries as best applicable to the PBSP nations. No allowance for price escalation,

inflation, or price reduction due to technological and market maturity has been made. Present Values (PVs) are discounted to an assumed PBSP abatement projects start year of 2023.

- The Cost Estimate is high-level and informs the modelling but is not suitable for budgeting purposes. The assumptions of the costing information are specified in Appendix C but are obtained from a mix of publicly available information (studies, PBSP government agencies, international agencies) and GHD industry-knowledge acquired through industry consultations and the use of a GHD subscription to a third-party (Clarkson's SIN) maritime database.
- The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in the Report, no detailed quotation has been obtained.

1.3 Qualifications

The Report was prepared subject to your acknowledgement that GHD is not qualified and/or accredited to give advice in relation to legal issues, contractual issues, accounting issues, currency issues, human resources, industrial relations, native title, land tenure, climate change, or taxation issues or to make financial forecasts that would require any of these areas of expertise.

1.4 Material received after the date of the Report

The opinions, conclusions and any recommendations in the Report are based on conditions encountered and information reviewed at the date of preparation of the Report.

[Client] acknowledge that GHD has not, and GHD accepts no obligation to, update the Report for events subsequent to the date that the Report was signed.

1.5 GHD's quality systems

This engagement has been conducted under GHD's Quality Management System, which has been certified by Lloyds as complying with AS/NZS ISO 9001.

GHD's quality system procedures are applied to all GHD projects and include a requirement to prepare quality plans to verify compliance with the technical and commercial requirements of the project.

A key component of the GHD's quality system is the requirement to have each report independently reviewed by experienced personnel in that area before it is delivered to *[Client]*.

2 Presentation of analytical framework

2.1 What are the abatement measures considered at a high level?

2.1.1 General approach

The technical assessment focuses on identifying those abatement measures for transitioning PBSP domestic maritime fleets to zero emissions. It includes those which are especially relevant to the PBSP island countries from a socio-economic-enviro perspective and can be potentially implemented in the short-term. It should be noted that a few abatement measures involving new technologies and/or alternative fuels are still globally emerging with proof-of-concepts (pilots) underway. This implies that in the longer term (post 2030) there are one or more current abatement measures with future potential which may still emerge as leaders in the long-term mix of abatement measures and transition pathways. Alternately, some of the currently proposed abatement measures may become less prominent as whole-of-system/national network, cost and economic performance becomes better known by 2030.

As an assessment tool, a Multi-Criteria Analysis (MCA) has been developed with, as output, a set of suggested short-term and long-term abatement measures considered to be relevant to the PBSP island countries (as at the time of report submission). There may also be technical solutions presented which will be excluded in the MCA as either not relevant or out-of-scope for technical/risk reasons.

A proposed general strategy of PBSP abatement measures follows, outlining the hierarchy of measures, emissions reduction sector-focus, exceptions needing specific measures, and suggested timeframes for implementation. A key goal of the proposed strategy is to ensure that an abatement measure does not become redundant with high cost of CAPEX and effort incurred with minimal time for economic recovery.

For example, a careful approach to electrification has been assumed recognizing that primary ports (coastal population centers) are more likely to have the ability (with appropriate levels of local/national grid investments) to support electric vessels and engines, while secondary ports (more remote coastal/island communities dependent on essential services and supplies) are more likely to have the ability to support craft powered by traditional means (i.e. WASP) and locally produced fuels where available. This means that risk of wider system failures and wasted investment can be better managed through a flexible, adaptive mix of abatement measures in the long-term given the many unknowns facing all countries globally as they transition to zero emissions.

The emissions model is based on a set of assumptions and generates a set of proposed abatement measure pathways for each PBSP country using the baseline fleet inventory and strategic settings presented for the period 2023 to 2030 (Short-Term) and 2031 to 2050 (Long-Term).

2.1.2 Basis of assessment

To guide the development of the decarbonization strategy, a carbon management hierarchy (Figure 3) has been adopted as a basis for assessing individual abatement measures. This hierarchy places greater emphasis on first understanding the baseline and ensuring no activities increase upon the agreed emissions levels. In the context of the PBSP countries, this critical first step sets the foundation for policy setting surrounding all new and existing (second-hand) vessels joining the fleet, particularly for donated vessels from other countries and international agencies.

The issue of safeguarding vessel procurement requirements in the context of improving fuel efficiency and stabilizing or reducing emissions levels has historically been a key issue for PICs due to the lack of available funds for both governments and the private sector to purchase new purpose-built replacement vessels. The result has been the replacement or addition of domestic vessels to government fleets which are typically donated and accepted without pre-agreed conditions on fuel efficiency and emissions levels. A number of these donated vessels are several years old when received by the PIC government. Increasingly, donated specialized vessels, such as border control (navy) vessels and some Ro-Ro/PAX ferries, are newly built. Replacement or additional vessels acquired by PIC private sector operators have been typically end-of-life second-hand vessels in poor condition sold by overseas operators who are replacing their end-of-life vessels with newbuilds. It is therefore imperative that part of the decarbonization transition plans for the PBSP domestic fleets includes setting and monitoring pre-agreed required levels of fuel efficiency, emissions ceilings, age ceilings, minimum levels of asset condition and repair/maintenance, and the availability of certain pre-installed technologies for all vessel replacements and additions including donated vessels.

Once this baseline is safeguarded, the focus turns to reducing emissions, primarily through the identification of operational measures that improve efficiencies or avoid fuel use where possible. Where fuel must be consumed, the next step is to consider alternative fuel products that have reduced or zero GHG emissions. Finally, to address remaining emissions that cannot be easily eliminated, emission offset schemes may be available to achieve a zero-carbon strategy. However, based on project feedback, this assessment will not consider carbon offsets to demonstrate a decarbonization pathway and has therefore been excluded from the technical abatement measures available.

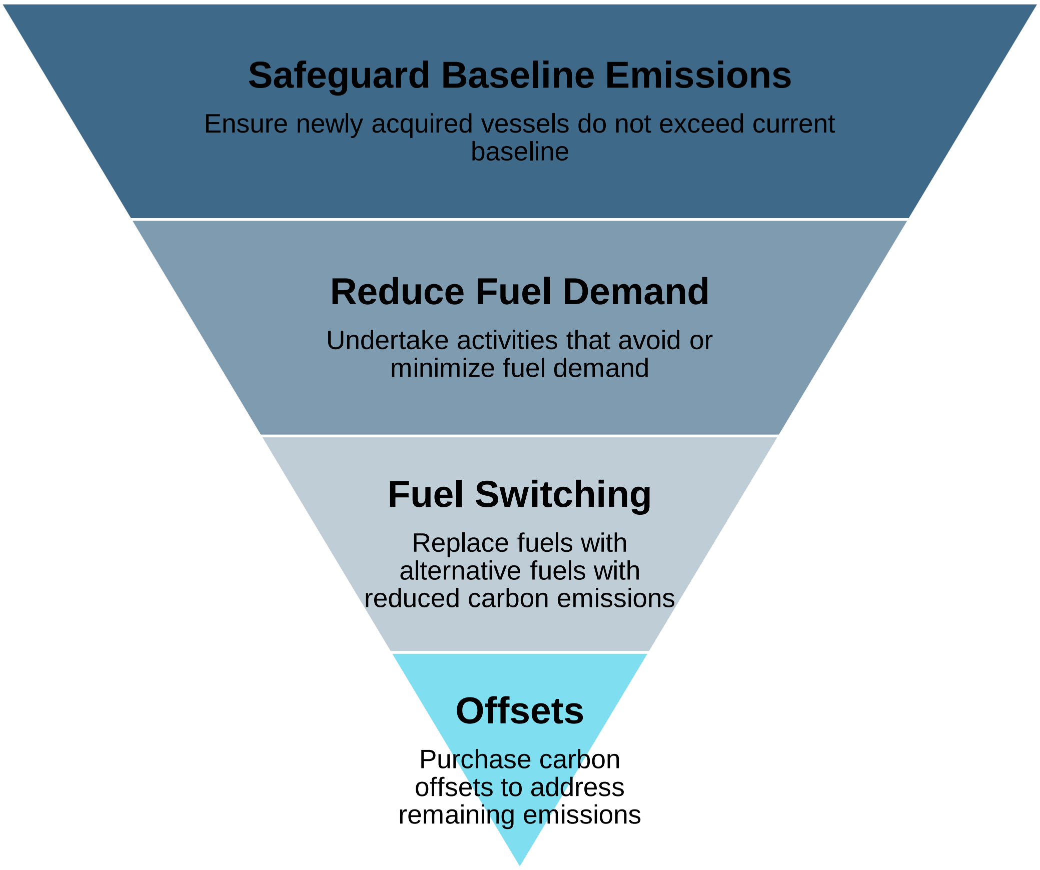

Figure 3: Carbon management hierarchy adopted for PBSP decarbonization strategy

2.1.3 Overview of abatement measures globally

There has been extensive research by numerous parties (of which a few key relevant sources are referenced below [3] [4] [5] [6] [7] [8] [9] [10]) on existing, planned and concept abatement measures globally and in the Pacific Islands region for reducing GHG emissions. Some are more relevant to large ocean-going vessels as opposed to small domestic vessels and engines/outboards, or specific regions of the world. When considering each abatement measure, applicability to the PBSP nations and long-term viability and sustainability are essential regardless of the measure's success in other world markets. Decarbonization options for the maritime sector include a number of abatement measures that can be applied to a vessel level, such as vessel modifications to improve efficiency and switching to a sustainable fuel source. Sector-wide abatement measures such as improving operational systems and behavior must also form part of the decarbonization strategy. Figure *4* shows some examples of abatement measures (current and under development/pilot testing) involving technology and alternative fuels.

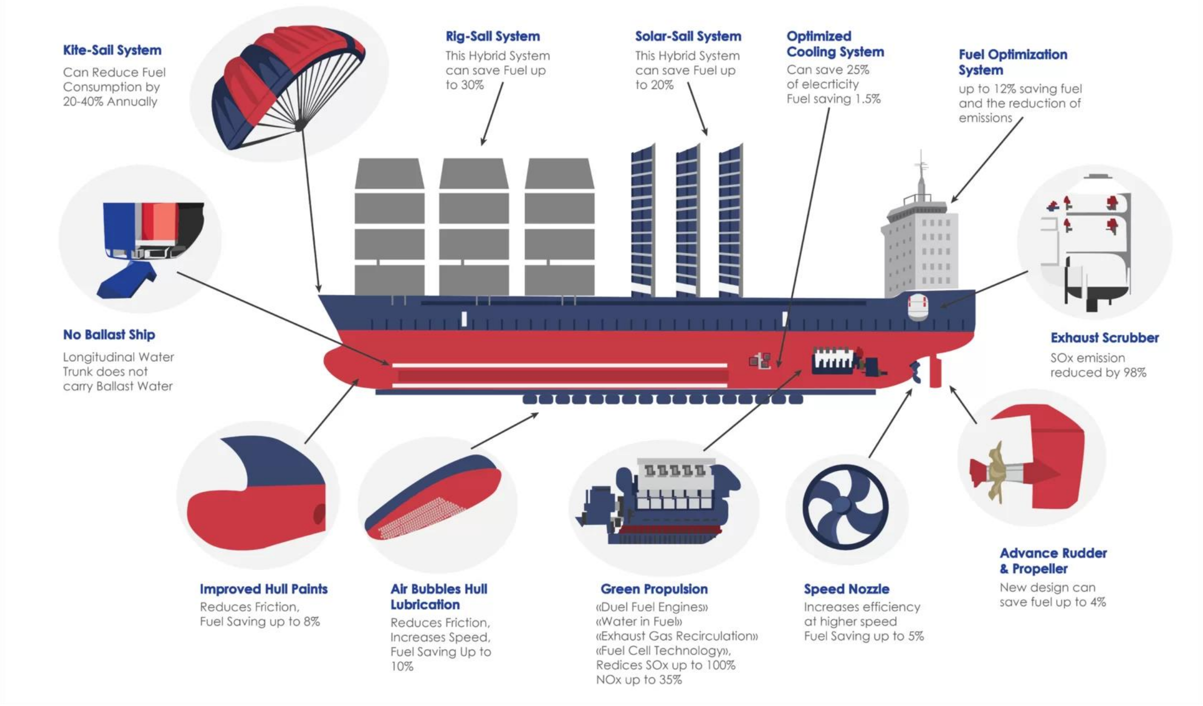

Figure 4: Examples of GHG abatement measures at a vessel level, and other measures to improve environmental performance

(Source: Marine Digital)

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[3] Rehmatulla, N., Calleya, J., Smith, T., 2017. The implementation of technical energy efficiency and CO2 emission reduction measures in shipping. *Ocean Engineering,* vol. 139, 2017, pp 184-197. https://www.sciencedirect.com/science/article/pii/S0029801817302160

[4] Nuttall, P., Newell, A., Rojon, I., Milligan, B. & Irvin, A., 2021. Pacific island domestic shipping emissions abatement measures and technology transition pathways for selected ship types. *Marine Policy*, vol. 132, 2021, https://doi.org/10.1016/j.marpol.2021.104704.

[5] Nuttall, P., 2022. Technical Abatement Pathways – Pacific Blue Shipping Partnership – MCST PBSP TWG Working Paper #4, Draft, June 2022.

[6] Lupoae, L.A., 2022. Development of a Sustainability Impact Method for Inter-Island Maritime Transport (Masters Thesis – TU Delft and supervised by USP-MCST, Dr. P. Nuttall).

[7] GIZ, 2022. Marshalls Islands Maritime Transport Roadmap – stakeholder workshop 9 May 2022.

[8] IRENA, 2021. A pathway to decarbonize the Shipping Sector By 2050.

[9] Nordic West Office (NWO), 2022. Practical Playbook for Maritime Decarbonisation – Value chain-based pathways towards zero-emission shipping.

[10] IMO, 2021. IMO Action to Reduce Greenhouse Gas Emissions from International Shipping (IMO GHG Strategy to 2050).

2.1.4 Review of PBSP country policies

A high-level review of each country's Nationally Determined Contributions (NDC) as listed on the UN Climate Change NDC Registry as of July 2022[11], NDC Implementation Roadmaps (where available), and other policies/strategies regarding climate change (where available) was conducted to better understand what abatement measures have already been identified within government policy. Table 1 below provides an overview of domestic climate change policies and how they support the decarbonization of domestic shipping and the specific abatement measure identified in this report. A summary of each country's NDC and other relevant documents with respect to the potential abatement measures can be found in Appendix E – Summary of Country NDCs and related documents.

Table 1: Summary of PBSP country relevant policy statements on domestic maritime decarbonization

Country	Relevant Policy Statement on Domestic Maritime Decarbonization
Fiji	The Fiji NDC[12] sets a target for 100% renewable energy generation by 2030, which will be achieved predominately with a combination of biomass energy generation, waste to energy, hydropower, and photovoltaic power. The NDC sets a target to reduce domestic maritime shipping emissions by 40% by 2030. The Fiji NDC Implementation Roadmap (2021)[13] identifies the following abatement measures for emissions reduction: • fleet maintenance; • renewable energy driven sea vessels as an option, including wind, it is however, unclear if this is WASP or wind generated electricity; and • switching from inefficient 2-Stroke to either direct injection 2-Stroke or 4-Stroke outboards.
Kiribati	The Kiribati NDC[14] sets targets to unconditionally reduce 12.8% of BAU greenhouse gas emissions and conditionally reduce 49% of BAU greenhouse gas emissions by 2030, compared to 2014 levels. The Kiribati NDC Implementation Roadmap (2021)[15] commits to investing in low carbon mini-container ship and a small low carbon cargo/passenger freighter both of which may use wind-hybrid propulsion. The following abatement measures for emissions reduction are identified: • the use of imported biofuels for marine vessels as a possible abatement method; and • commitment to replacing 2010 2-stroke outboards to either 4-stroke (1,560) or electric outboards (450) by 2030.

[11] https://unfccc.int/NDCREG
[12] https://unfccc.int/sites/default/files/NDC/2022-06/Republic%20of%20Fiji%27s%20Updated%20NDC%2020201.pdf
[13] https://www.economy.gov.fj/images/CCIC/uploads/Mitigation/Brief__Fiji_NDC_Implementation_Roadmap_Policy.pdf
[14] https://unfccc.int/sites/default/files/NDC/2022-06/INDC_KIRIBATI.pdf
[15] https://gggi.org/report/kiribati-ndc-implementation-roadmap-2021/

Country	Relevant Policy Statement on Domestic Maritime Decarbonization
Republic of the Marshall Islands (RMI)	RMI's NDC[16] was updated in December 2020. The following documents were available: • Update Communication on the Marshall Islands Paris Agreement NDC (30 December 2020). • Tile Til Eo 2050 Climate Strategy "Lighting the way" (September 2018)[17]. • RMI Electricity Road Map[18] The RMI has committed through its NDC (referenced in the above documents) to reduce emissions 45% from 2010 levels by 2030 with the NDC stating that domestic shipping (through the PBSP) is committed to a 40% emissions reduction. The RMI has committed, in the RMI Electricity Road Map, to reduce electricity sector emissions and the use of diesel for electricity generation by 50% by 2025. This would be achieved using wind and solar energy generation, and potentially switching to biodiesel. The RMI 2050 Climate Strategy identifies the following: • changes to operations and improved docking facilities as an abatement method for emissions reduction • changes in shipping design as a possible abatement method, and this could include WASP; and • fuel switching, or fuel mixing. This is highlighted as an option for reducing domestic shipping emissions in the 2050 Climate Strategy and biofuel is mentioned as an option. It is noted that supply of coconut to generate biofuels would be limiting.
Solomon Islands	The 2030 reductions target in the Solomon Islands NDC[19] is 30% compared to 2015 levels. In addition, the Solomon Islands committed to 45% reduction of emissions by 2030 on the condition that international financial and technical resources were available. While electrification of maritime vessels is not specifically addressed in the NDC, however, there are a number of renewable energy options proposed for conditional and non-conditional emissions reductions options.
Tonga	The Tongan NDC[20] commits to a 13% reduction in energy related emissions by 2030, compared to 2006. While not specifically addressed in the NDC in relation to domestic shipping, however, the NDC sets a target of 70% of electricity being generated from renewables by 2030, using a mix of solar, wind and battery storage. There may be further internal policy settings not yet in the public domain, particularly on motor-switching, as advised by the PBSP Technical Forum (29th July 2022).
Tuvalu	The Tuvalu NDC[21] provides an indicative target of 60% reduction in emissions below 2010 levels by 2025. While electrification of maritime vessels is not specifically addressed in the NDC, however, the NDC commits Tuvalu to transitioning to 100% renewable energy generation by 2025, primarily by improved energy efficiency and installation of photovoltaic arrays.

[16] https://unfccc.int/sites/default/files/NDC/2022-06/RMI%20NDC-UpdateUPDATED_01.20.2021.pdf
[17] https://policy.asiapacificenergy.org/node/3754/portal
[18] https://rmi-data.sprep.org/dataset/rmi-electricity-roadmap
[19] https://unfccc.int/sites/default/files/NDC/2022-06/NDC%20Report%202021%20Final%20Solomon%20Islands%20%281%29.pdf
[20] https://unfccc.int/sites/default/files/NDC/2022-06/Tonga%27s%20Second%20NDC.pdf
[21] https://unfccc.int/sites/default/files/NDC/2022-06/TUVALU%20INDC.pdf

2.2 How will they be analyzed?

Drawing upon research by others that detail emissions abatement measures appropriate to the Pacific Islands Countries[22] [23] [24], the proposed PBSP abatement measures will ideally need to meet a set of criteria which are deemed nationally and regionally important from a strategic and policy-settings perspective. Factors such as positive impacts for economic development and SMEs, technical readiness, low cost / ease of running / high abatement potential, energy self-reliance (local production), societies (communities), technical knowledge transfers (skills development), traditional values/cultures, and the marine environment, are considered of national and regional importance when assessing the various alternative abatement measures. Application of this sort of assessment lens will also, by definition, likely rule out certain global abatement measures as being applicable to the PBSP either in the near/short-term, and/or long-term.

Based on the review of national strategies, policies and general socio-economic concerns/issues for the PBSP island communities, a suggested set of 10 evaluation criterion (labelled C1 to C10), as shown in Table 2, is used as the design for the Multi-Criteria Analysis (MCA) of the various abatement measures identified globally (a long-list of abatement measures). The result of the MCA will be a proposed set of abatement measures (a short-list) which are deemed by the analysis as applicable (suitable) building-blocks for a PBSP transition plan (or pathway). For an MCA result to be obtained capturing the relative impact of each criterion, a suggested weighting has been applied to each criterion based on GHD's understanding of the strategic needs and policy goals of the PBSP nations, i.e., what is the importance of each criterion relative to each other from a whole-of-government and societal perspective.

The top three MCA criteria in terms of weightings (importance) are considered to be:

- Technical Readiness Level (TRL) (20%),
- CO_2e Emissions Abatement Capability (15%),
- Short-term and future potential availability of Local Alternative Energy Supplies, and Ease of Supply of Abatement Technology (15%).

Other criteria (each 10% weighting) considered important in assessing an abatement measure are the level of vessel fleet coverage; minimum CAPEX needs (i.e., the capital intensity of the abatement measure); and the level of socio-economic benefits. The remaining criteria used in the MCA (re. C5, C6, C7 and C8) are considered to have lesser importance (each 5% weighting).

The concept and definition of a technical readiness level is explained in more detail in the MCA below (see Section 4.1).

Table 2: Suggested set of 10 evaluation criteria

#	Evaluation Criteria	Description	Suggested Weighting
C1	Vessel Fleet Coverage Level	This criterion assesses the level of potential applicability of the measure across the Baseline vessel fleet to maximize CO_2e emissions abatement.	10%
C2	CO_2e Emissions Abatement Capability	This criterion assesses the potential effectiveness of the CO_2e reduction measure on each applicable vessel.	15%

[22] Nuttall, P., Newell, A., Rojon, I., Milligan, B. & Irvin, A., 2021. Pacific island domestic shipping emissions abatement measures and technology transition pathways for selected ship types. *Marine Policy*, vol. 132, 2021, https://doi.org/10.1016/j.marpol.2021.104704.

[23] Nuttall, P. Vahs, M., Morshead, J., Newell, A., 2018. The case for field trialling and technology/knowledge transfer of emerging low carbon maritime technologies to Pacific Island Countries. *Nova Science Publishers*. https://mcst-rmiusp.org/index.php/reference-library-main/download/26-usp-papers-low-carbon-shipping-pacific/725-nuttall-p-vahs-m-morshead-j-newell-a-2018-the-case-for-field-trialing-and-technology-knowledge-transfer-of-emerging-low-carbon-maritime-technologies-to-pacific-island-countries

[24] Nuttall, P., 2022. Technical Abatement Pathways – Pacific Blue Shipping Partnership – MCST PBSP TWG Working Paper #4, Draft, June 2022.

#	Evaluation Criteria	Description	Suggested Weighting
C3	Technical Readiness Level (TRL)	This criterion assesses the potential technical readiness level for local / regional implementation of the abatement measure.	20%
C4	Minimum CAPEX Needs	This criterion assesses the potential level of capital expenditure intensity required to adopt and implement the abatement measure.	10%
C5	OPEX Net Benefit Level	This criterion assesses the potential for ongoing savings in operational expenditure over the life of the measure (up to 2050).	5%
C6	PIC Environmental Whole-of-Life Benefits Level	This criterion assesses the potential reduced environmental impact to the PIC region on a "well-to-wake" basis.	5%
C7	PIC Fuel Overseas Supply Reduction	This criterion assesses the potential for the abatement measure to reduce reliance on imported fuel supply from outside the Pacific and supports fuel independence of the Pacific Islands region.	5%
C8	PIC Minimum Governance, Management and Training	This criterion assesses the potential ability for abatement measure to be successfully self-managed on an ongoing basis by the vessel owner.	5%
C9	PIC Socio-Economic Benefits Level	This criterion assesses the potential contribution of the abatement measure to improving the country's standard of living and economic vibrance, and social opportunity for alignment with traditional maritime knowledge.	10%
C10	Short-term and future potential availability of Local Alternative Energy Supplies, and Ease of Supply of Abatement Technology	This criterion assesses the presence of existing and potential availability of local renewable energy production, bio-fuels production, and the ease of supply of the assets/technologies of the abatement measure. It also implicitly covers the availability of supply chains needed to support the immediate local adoption and wide-scale roll-out of the abatement measure.	15%

A list of possible technical abatement measures as assessed against each of the above criteria are presented in the following section.

3 Detailed explanation of abatement measures considered in the MCA

3.1 Introduction

To inform the assessment of each abatement measure in the MCA, a long list of global abatement measures is proposed to achieve zero GHG emissions by 2050. The technical pathway proposed in this report is only one possible pathway and will change as technology matures, new research emerges, national policy adjusts, and supporting government programs evolve. Although an extensive list of abatement measures exists, it is emphasized that these abatement measures are unlikely to succeed or be adopted on a national or regional scale without an integrated systems approach to social, environmental, and economic sustainability.

Ongoing and short-term (2023-2030) abatement measures seek to address immediate challenges in vessel technical designs (i.e., technical modifications to vessels to improve energy efficiency including the use of wind to assist propulsion), logistics, marine infrastructure and data gathering all leading to improved operational efficiencies as a basis for all future abatement measures. Towards 2030, any short-term measures should begin to phase out, in favor of the nominated long-term measures identified in this report.

Long-term (2031-2050) abatement measures require establishment of long-term alternative green-fuel supplies including all supporting infrastructure. As such, these measures require decisive underlying policy with sufficient lead-times to enable effective roll-out. It is recognized that in some PBSP nations, there exists a number of major constraints and barriers that may hinder some abatement measures, including the absence of an integrated energy policy, the lack of development of alternative local renewable energy supply, limited funding (which the blended finance body of work seeks to address), and limited technical and labor capacity[25] [26]. Therefore, any long-term abatement measures cannot be considered in isolation of the broader national challenges and must be executed in an integrated manner.

A summary of the abatement measures is presented in the following section with details in Appendix A – Abatement Sheets.

3.2 Long-list of global abatement measures

The following section describes in more detail a long list of global abatement measures which will be inputted into the MCA (excluding those considered not relevant to the study as mentioned in section 3.2.10 below) to produce a short-list of ranked abatement measures relevant to the PBSP nations.

3.2.1 Improved maintenance programs

Improved maintenance programs can provide increased efficiencies from enhanced vessel performance.

<u>Key measures and assumptions</u>

- Applies to all vessels based on the minimum maintenance needs of all vessels for optimum efficiency.
- May achieve 15% average fuel consumption & emissions savings, however studies into the effect of biofouling on ship efficiency by GloFouling Partnerships in collaboration with the UNDP and the

[25] Khan, NA. 2019, *Terminal Evaluation Report of Fiji Renewable Energy and Power Project*, United Nationals Development Programme (UNDP) Pacific Office, Fiji.
[26] South Pacific Applied Geoscience Commission 2006, *An Evaluation of the Biofuel Projects in Taveuni and Vanua Balavu, Fiji Islands*. SOPAC Technical Report 392, Fiji.

International Maritime Organization (IMO) suggests a decrease of efficiency of up to 55% in extreme cases[27].

– Improved fleet maintenance and engine servicing and filter replacement.
– More regular hull inspection, cleaning programs and service regimes.

Key considerations

– Requirement for investment (CAPEX) and OPEX in local shipyards / slipways / ship-lifts
– Incentive programs for increased time vessels are out of service and enforcement of ongoing maintenance as a minimum requirement.
– Opportunity to further develop the regional maritime services economy and increase self-sufficiency.

Inclusion in Country NDCs and other supporting government policies

– Not specifically identified as an abatement method in the documentation reviewed for PBSP countries, but is recognized as being important (see Appendix E).

Figure 5: Diver performing underwater hull cleaning

(Source: Hydrex)

Figure 6: Biofouling of ship hull

(Source: safety4sea.com)

[27] GloFouling Partnerships, 2021. *Preliminary Results: Impact of Ships' Biofouling on Greenhouse Gas Emissions*. Global Environment Facility (GEF) – United Nations Development Programme (UNDP) –IMO. Available from: https://17616ec4-2b99-45ba-a5b5-7e2164091d97.filesusr.com/ugd/34a7be_470cd6f793f04eeb8e743d739a492265.pdf

3.2.2 Demand-supply management, data systems & supporting infrastructure

Demand-supply management, data systems, and supporting infrastructure can provide efficiencies through optimized routing, vessel specialization, passenger/cargo separation and improved information systems.

Key measures and assumptions

- Applies to all vessels based on the logistical aspect to all government and commercial vessels.
- May achieve at least 20% average fuel consumption & emissions savings however successful implementation can have the most effective improvement on maritime fleet efficiency of all abatement measures and will ease the transition to zero emissions significantly.
- Improved scheduling to improve overall efficiency and reduce unnecessary trips.
- Separation of cargo and passengers can provide opportunities for vessel and route specialization.
- Reduce port congestion and improve safety.
- Review of existing port and marina infrastructure and business models to identify factors limiting commercial growth, e.g. availability of warehousing and cold-storage, lease arrangements, connectivity with other services etc.

Key considerations

- Requirement for investment (CAPEX) and OPEX in dedicated port and marina developments / local shipyards / slipways / ship-lifts.
- Improved freight routing and alignment of major/minor freight routes with vessel.
- Capacity can provide significant fuel savings.
- Freight route improvements will require integration with land side logistics & infrastructure.
- CAPEX requirements to allow separation of cargo and passengers at the port
- Establishing data-gathering systems.

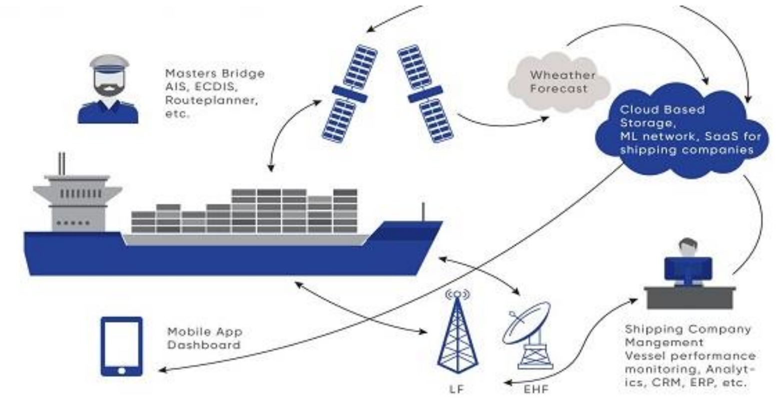


Figure 7: Fleet logistics and information systems

(Source: Marine Digital)

Inclusion in Country NDCs and other supporting government policies

- Not specifically identified as an abatement method in the documentation reviewed for PBSP countries (see Appendix E).

3.2.3 WASP retrofit

WASP retrofit, and supplemented by installation on new builds, can provide significant fuel savings. This technology caters for small local island vessels to large international cargo vessels.

A number of WASP vessels currently based on traditional designs use a hybrid of sails for propulsion, with an electric motor. The battery can be charged using a variety of renewable energy sources, including solar, wind, or hydro energy.

Local Pacific WASP pilot projects typically refer to small remote/inter-lagoon craft with limited passenger and cargo. WASP on large cargo vessels have been trialed and continue to be trialed overseas with some plans for turbines to be installed on PIC domestic cargo vessels.

Like with other abatement measures there is a need to have local proof of concept and trials to ensure confidence in future operation and the ability to attract finance.

Key assumptions

- May be applicable to all vessels excluding some specialist craft such as dredging, pleasure craft, pollution response boats, search and rescue/ patrol, tugboats, and yachts. This is primarily based on functionality requirements.
- Reduction in GHG emissions ranging from 20% to 30% depending on local country wind resource. Further efficiency can be achieved, however, voyage times and weather conditions will need to be factored. In the past, ships have relied wholly on wind energy, so some vessels have the potential to achieve full emissions abatement with WASP.
- Location-specific as it is dependent on local wind conditions, and some countries will have more favorable wind than others (on a typical basis) (refer Appendix C – Model Assumptions).
- Includes all forms of WASP, including soft sails, rigid and wing sails, towing kites, Flettner rotors etc. (noting that some WASP technologies perform better than others).
- Table 3 summarizes the fuel efficiency and savings for each WASP technology.

Table 3: Fuel efficiency and savings for each WASP technology

WASP Technology	Fuel efficiency and savings[28]
Soft sails	11-50%
Rigid sails	10-30%
Towing kites	10-15%
Suction wings	10-30%
Hull sails	Approx. 60%
Flettner rotors	5-33%

Key considerations

- Location-specific as it is dependent on local wind conditions
- Some countries will have more favorable wind than others (on a typical basis)
- Limited potential when navigating within ports or sheltered lagoons so will require supplementary or auxiliary power source.
- Reduces imported fuel supply needs
- Well suited to freight where steaming speeds are less critical

[28] L.A. Lupoae, 2022. Development of a Sustainability Impact Method for Inter-Island Maritime Transport (Masters Thesis – TU Delft and supervised by USP-MCST, Dr. P. Nuttall).

– Purpose designed new build expected to provide greatest savings but retrofit an option
– Supports training and skills development in ship building and retrofit, including traditional designs
– Retrofit can be carried out locally in main ports with appropriate facilities

<u>Inclusion in Country NDCs and other supporting government policies</u>

– The Fiji NDC identifies renewable energy driven sea vessels as an option, including wind. However, it is unclear if this is WASP or wind generated electricity (see Appendix E).
– The Kiribati NDC commits to investing in low carbon mini-container ship and a small low carbon cargo/passenger freighter both of which may use wind-hybrid propulsion (see Appendix E).
– The RMI 2050 climate strategy identifies changes in shipping design as a possible abatement method, and this could include WASP (see Appendix E).
– Not specifically identified as an abatement method in the documentation reviewed for other countries (see Appendix E).

Figure 8: Rigid sails for large vessels

(Source: Dalian Shipbuilding Industry Corporation)

Figure 9: WASP for small-medium vessels

(Source: Swire (left), Okeanos (right))

3.2.4 Motor-switching from 2-stroke to 4-stroke

Motor-switching from 2-stroke to 4-stroke allows the replacement of 2-stroke engines for more efficient and lower emissions 4-stroke.

Key assumptions

- May achieve 20% GHG emissions reduction due to reduced fuel wastage and cleaner fuel burning technology
- Applicable to most 2-stroke outboard motors. Exceptions may include some very small vessels (e.g. <5 meters length) and port trolling motors.
- Abatement measure can potentially begin phasing in immediately providing there are adequate incentives and funding mechanism to support the transition.

Key considerations

- Availability of 4-stroke motors to replace existing 2-stroke stock.
- Incentivizing transition to 4-stroke may be required (for example a subsidy for the price difference between 4-stroke and 2-stroke).
- Additional policy settings may be required to achieve rapid update of 4-stroke technology.
- Utilizes existing supply chain.
- Opportunities to improve regional population health and the marine environment.

Inclusion in Country NDCs and other supporting government policies

- The Fiji NDC identifies switching from inefficient 2-stroke to either direct injection 2-stroke or 4-stroke outboards as an abatement (see Appendix E).
- The Kiribati NDC commits to replacing 2010 2-stroke outboards to either 4-stroke (1,560) or electric outboards (450) by 2030 (see Appendix E).
- Not specifically identified as an abatement method in the documentation reviewed for other PBSP countries (see Appendix E).

3.2.5 Engine derating

Engine derating involves optimizing the vessel's engine to suit typical operating speed and reduce fuel consumption.

Key measures and assumptions

- Applies to all vessels not operating at engine design speed.
- May achieve 5-10% average fuel consumption & emissions savings.
- Efficiency gains are expected based on the assumption that the current operational speed is generally lower than what the engine has been originally designed for.
- This includes modifications to the existing engine and/or optimizing the propeller size to suit the typical operational speed which is covered under Propulsion Improving Devices (see Section –)

Key considerations

- Incentive programs and enforcement of ongoing motor derating as a minimum requirement.
- Opportunity for local training and further development of the regional maritime services economy.

Inclusion in Country NDCs and other supporting government policies

- Not specifically identified as an abatement method in the documentation reviewed for PBSP countries (see Appendix E).

3.2.6 Propulsion improving devices (PIDs)

This measure involves the retrofitting of propulsion improving devices (PIDs) to existing vessels with significant life remaining.

Key measures and assumptions

– Applies to all large, slow vessels with high block coefficient
– May achieve 5-10% average fuel consumption & emissions savings.
– Activities include installation of different ducts, pre-swirl fins, fin on hull, rudders, caps, contra-rotating propellers, or other modifications (such as hull air-bubble lubrication) to reduce turbulence and improve efficiency.
– A combination of multiple modifications can be made to a single vessel, however diminishing improvement is expected with each additional modification.
– Some modifications may only be appropriate for slower-moving vessels with high block coefficient, such as Contracted and Loaded Tip (CLT) propellers

Key considerations

– Requirement for investment (CAPEX) and OPEX in local shipyards / slipways / ship-lifts.
– Opportunity to further develop the regional maritime services economy.

Inclusion in Country NDCs and other supporting government policies

– Not specifically identified as an abatement method in the documentation reviewed for PBSP countries (see Appendix E).

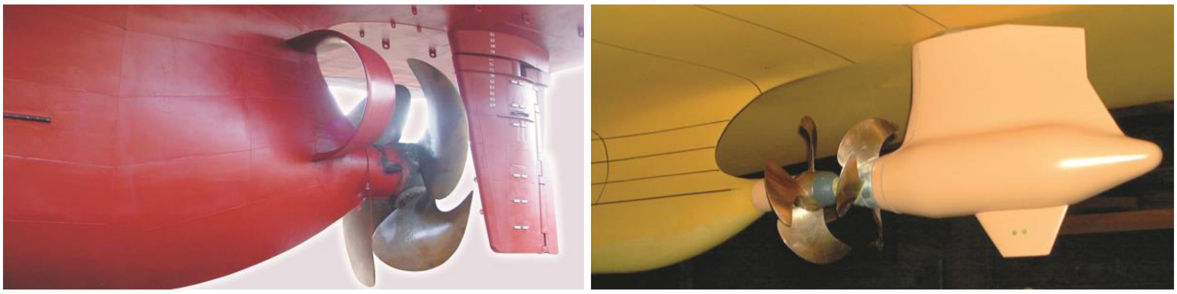


Figure 10: Propeller and duct modifications

(Source: Wartsila)

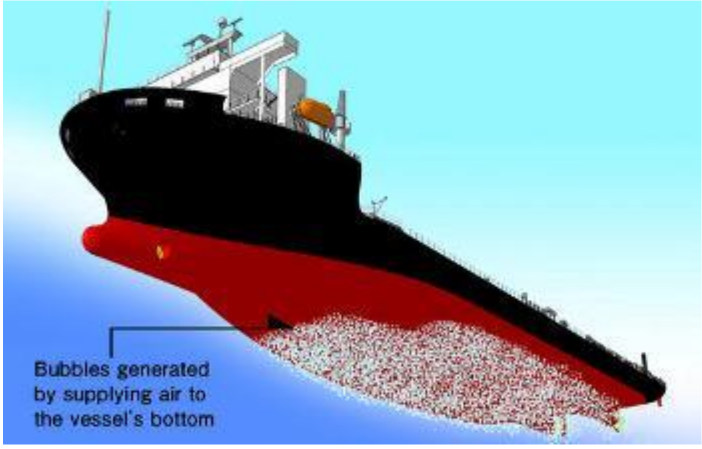


Figure 11: Hull air lubrication system

(Source: Marine Insight)

3.2.7 Biofuels (blended and 100%)

Blended and 100% (also called B100) biofuels offer a replacement 'drop-in' fuel for existing engines with the potential for significant emissions reductions. Blending, to create for example B20 biofuel (20% vegetable oil and 80% fossil fuel), is the mixing of existing marine engine fossil fuels with typically a ‘green’ (often waste product) vegetable oil. A 100% biofuel has no fossil fuel mixed component.

Key assumptions

- Blended biofuels (phased/temporary) are applicable to all vessel types including 2-stroke transition fuel for future electrification of 2 strokes
- 100% biofuels (ongoing) will require significant input to ensure a sustainable supply chain. Therefore, at this stage the model has assumed only 10% of vessels (excluding 2-stroke outboards) to be applicable for this abatement measure
- 100% biofuels are applicable to Navy vessels to maintain existing operational functionality, e.g., speed, range etc.
- Existing engines may only require minor upgrades to operate on blended biofuels.
- It is expected that some vessels will remain on 100% biofuel and not transition to electric or green e-fuels
- Biofuel feedstock includes copra, sugarcane, bagasse etc., however understanding the economic drivers and reasons for past failures is critical for future success
- Blended biofuels may reduce GHG emissions by 20% (assuming a 20% biofuel blend)
- 100% Biofuels may reduce GHG emissions by 100% (assuming sustainably sourced)

Key considerations

- What cannot be locally produced will need to be imported, which mirrors the current dependence of PBSP countries on imported fossil fuels.
- Further retrofits (modifications to engines) may be required for 100% biofuel.
- 100% biofuel is not applicable to 2-strokes due to technical issues.
- Local production of biofuels provides greater independence from imported fuel supply and provides for the further development of a regional biofuels production economy.
- Critical that any conflict with food production on arable land is well managed (i.e., conflict is prevented) – this being a significant risk which fundamentally undermines the sustainability of biofuels production and the well-being of regional populations (access to local, affordable foods).
- Requires further study on local production and supply chain capacity to meet needs.
- CAPEX required to scale up biofuel production.
- Need to overcome previous challenges faced by past biofuel production initiatives.

Inclusion in Country NDCs and other supporting government policies

- The Kiribati NDC identifies the use of imported biofuels for marine vessels as a possible abatement method (see Appendix E).
- The RMI identifies switching of fuels as an abatement method for domestic shipping but does not specify the fuel type (see Appendix E).
- Not specifically identified as an abatement method in the documentation reviewed for other PBSP countries (see Appendix E).

3.2.8 Electrification (full)

Electrification of the vessel fleet is based on newbuild full electric design vessels with batteries and retrofit with electric outboards and inboards.

Key assumptions

- Assumed approximately half Government and Commercial vessels will ultimately transition to electric, and approximately half will transition to green e-fuels.
- Assumed all 2 stroke motors (outboards) will eventually transition to electric or (green e-fuels) from blended biofuels due to inability of these motors (outboards) to easily run on 100% biofuel or transition to 4-stroke.
- Electrified vessels and vessels operating on green e-fuels will retain potential for WASP to further reduce battery charging and fuel demand.
- Source of energy may include onboard solar photovoltaics and onshore generation. Onshore energy to meet charging demand are likely to include a mix of solar photovoltaic, wind, hydro, wave, geothermal, and generation from 100% biofuel. It is recognized that this is a long-term abatement measure that requires further detailed analysis.
- GHG abatement of 100% (assuming renewable energy)

Key considerations

- Electrification of vessels requires supporting generation, transmission and charging infrastructure with significant infrastructure investment required including port charging.
- Larger and long-distance operated vessels require greater electric powering (battery storage) and CAPEX implying that small, short-distance vessels are better suited for electrification from a regional investment perspective in terms of both new vessels and supporting infrastructure.
- Majority electrification of fleet would provide significant progress towards fuel supply independence.
- Charging infrastructure may be limited to major port facilities in the medium-term with the view to expanding to smaller regional centers in the long-term.
- Shipping will need to compete with other renewable energy demands including other transport modes and other sectors.

Inclusion in Country NDCs and other supporting government policies

- The Kiribati NDC roadmap commits to replacing 450 older 2-stroke outboards with electric outboards by 2030 (see Appendix E).
- Not specifically identified as an abatement method in the documentation reviewed for other PBSP countries. However, Fiji, RMI, Solomon Islands, Tuvalu and Tonga have targets for switching to renewable electricity (see Appendix E).

Figure 12: Electric outboard motors

(Source: ePropulsion (left), E-Motion (right))

Figure 13: Electric cargo ships

(Source: Yara International)

Figure 14: Electric commuter ferries

(Source: Molslinjen)

3.2.9 Green e-fuels

Green e-fuels include liquid hydrogen (LH_2), liquid ammonia and methanol produced using renewable energy.

Key assumptions

- The long-term assumption of green e-fuels is currently modelled as being applicable to half the vessels that are not utilizing 100% biofuels (i.e., 45% of all large vessels and 50% of 2-stroke outboards by 2050).
- It is noted that as some 2-stroke motors transition to 4-stroke, the new 4-strokes will also have a similar fuel share as the larger vessels as they too will be able to operate on 100% biodiesel.
- GHG abatement of 100% (assuming sustainably sourced).

Key considerations

- Similar to energy supply for vessel electrification (see section – above), the green e-fuel supply chain is currently unclear and requires decisive, careful planning to ensure its success.
- Where possible, local supply chain independence is preferred. Any Pacific countries with future abundant, affordable renewable energy production would be potential candidates for the local production of green e-fuels and further supply to other non-producing Pacific Island Countries.
- The applicability of wide-scale green e-fuels will require additional review as new information emerges.

Inclusion in Country NDCs and other supporting government policies

– Not specifically identified as an abatement method in the documentation reviewed for maritime vessels for any of the countries (see Appendix E).

Figure 15: Liquid hydrogen cargo

(Source: Kawasaki Heavy Industries)

Figure 16: Hydrogen fuel cell ferry

(Source: Incat Crowther)

Figure 17: Vessel powered by ammonia

(Source: NYK Line)

Figure 18: Tugboat reconfigured to run on ammonia

(Source: NYK Group)

3.2.10 Other alternatives not considered in the study

Other alternatives[29] to the green e-fuels outlined in sections 3.2.1 to 3.2.9 not considered in the study as potential abatement measures for transitioning by the PBSP can be grouped into:

- 'grey' fuels, such as Liquefied Natural Gas (LNG) and Liquified Petroleum Gas (LPG) – these fuels (gases) are fossil fuels, only provide a limited reduction in emissions to marine diesel fuels, require significant investment in onboard vessel and shore-side facilities, and are likely to continue the dependence on fuel imports for the PBSP nations

- technical solutions handling the continued use of fossil fuels, such as the provision of shore-power to existing fossil-fueled vessels and the direct carbon capture and storage of emissions from vessels – these solutions are costly, likely to offer a limited reduction in emissions, and provide operational challenges for PBSP nations

- technical solutions involving perceived higher risks with operations and waste management when performed at a large-scale, such as nuclear energy.

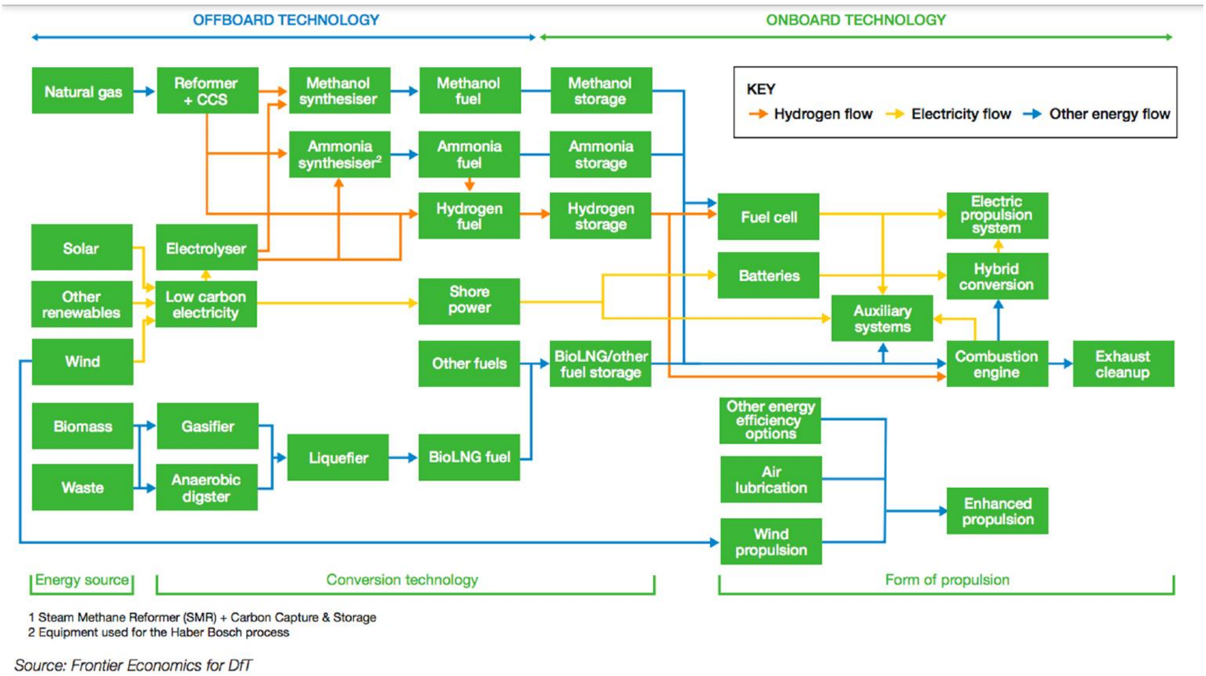


Figure 19: Technologies and fuels on a pathway to zero-emission shipping

(Source: Frontier Economics for DfT)

[29] Secondary source: Nuttall, P., Newell, A., Rojon, I., Milligan, B. & Irvin, A., 2021. Pacific island domestic shipping emissions abatement measures and technology transition pathways for selected ship types. *Marine Policy*, vol. 132, 2021, https://doi.org/10.1016/j.marpol.2021.104704.

4 Application of the analytical framework

4.1 Technology Readiness Level

For each of the abatement measures identified, the Technology Readiness Level (TRL) has been determined. The TRL definition adopted in this report uses the NASA technical readiness scale[30] (Figure 20) and ranges from 1 (basic principles observed and reported) to 9 (system ready for full scale deployment). The TRL for each measure is largely based on research by others in this sector[31].

Figure 20: Technology Readiness Level (TRL) using the NASA TRL scale

(Source: NASA)

An important part of TRL is the successful transition from TRL 4 to 6 which is often referred to as the "valley of death"[32] (see Figure 21). This aspect is also considered in the MCA process when evaluating the potential ease of availability of an abatement measure.

[30] NASA, 2021. Technology Readiness Level. Available from: https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level

[31] Nuttall, P., Newell, A., Rojon, I., Milligan, B. & Irvin, A., 2021. Pacific island domestic shipping emissions abatement measures and technology transition pathways for selected ship types. *Marine Policy*, vol. 132, 2021, https://doi.org/10.1016/j.marpol.2021.104704.

[32] Rossini, A., 2019. Bridging the technological "valley of death". PwC Norway. Available from: https://www.pwc.no/en/bridging-the-technological-valley-of-death.html

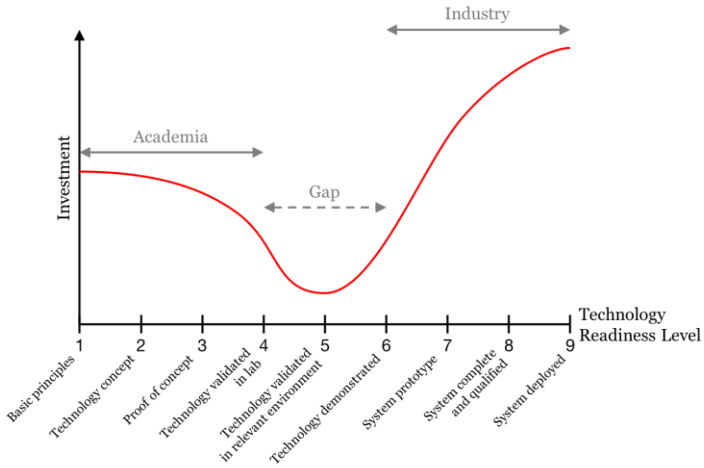


Figure 21: Technical readiness pathway with "valley of death"

(Source: PwC)

4.2 Renewable energy generation, biofuel production, and wind energy resources

To provide further context for the potential for each abatement measure, the current status of renewable energy supply and the available agricultural land for growing inputs for biofuels (incl. use of waste biomass) is presented below.

The current status of renewable energy generation for each PBSP nation indicates at a high-level the likely proportion of battery charging energy that could be potentially sourced from sustainable generation, which in turn informs the potential for decarbonization of the domestic maritime sector more broadly.

As shown in Table 4, 60% of Fiji's energy supply is currently from renewable sources, however the Marshall Islands and Solomon Islands only generate 2 and 6% respectively. This suggests that further uptake of renewable energy would need to occur within these two nations for fleet electrification to meaningfully contribute to maritime decarbonization. It is understood that some PBSP nations, including Fiji, have potential to supply geothermal energy but this would require significant future investment in infrastructure to realize. As future projects come online the renewable energy share of these nations should increase.

The availability of agricultural land for each PBSP nation also informs the potential for measures such as biofuel and some green e-fuels that require agricultural land to produce and therefore run the risk of competing with national food sources and the export trade in some agricultural products. As shown in Table 4, the Marshall Islands and Tonga have a vast majority of their available agricultural land area already planted with coconut, which suggests that further coconut planting for any future biodiesel use could potentially threaten the existing capacity to produce other foods locally.

The Pacific Islands region is currently a minor producer of coconut oil (less than 10% of global production) with the Philippines the world's largest producer (40% share). Within the Pacific Island region, PNG and Vanuatu are the largest producers and exporters of both copra and coconut oil with PNG exporting around 18,000 tonnes of coconut oil (2015) and Vanuatu around 7,000 tonnes of coconut oil (2015)[33]. The Pacific Islands region exported in total around 29,000 tonnes of coconut oil in 2015. Subject to the economics of export prices (global commodity markets) and the resulting margins for producers/processors versus selling for regional biofuel use, a theoretical 5% to 10% share of current coconut oil exports from the region would represent a regional availability of around 1,500 to 3,000 tonnes of coconut oil for biodiesel use (as a blend or 100% fuel). This level of potential (albeit

[33] SPC / Pacific Islands Farmers Organisation Network, 2017. An overview of the market for Pacific Island coconut products and the ability of industries to respond. https://pacificfarmers.com/wp-content/uploads/2018/02/CIDP_Report_Final_e-copy_resized.pdf

limited) availability, given adequate financial returns and support for local producers/processors, is taken into account in the development of the transition pathways and the role of the various abatement measures in this study.

Table 4: Summary of renewable generation status and available agricultural land for each PBSP nation

Country	Current Status of Renewable Energy Generation[34]	Available Agricultural Land (AAL)[35]	Current Land Area with Coconut Planting (2015)[36]
Fiji	60%	4,250 km² (23% of land area)	620 km² (15% of AAL)
Kiribati	17%	340 km² (42% of land area)	Not available
Marshall Islands	2%	86 km² (48% of land area)	80 km² (93% of AAL)
Solomon Islands	6%	1,170 km² (4% of land area)	380 km² (32% of AAL)
Tonga	10%	350 km² (49% of land area)	310 km² (89% of AAL)
Tuvalu	23%	18 km² (60% of land area)	Not available

4.2.1 Regional wind energy resource

The potential efficiency gains for WASP can be estimated based on data obtained from Global Wind Atlas[37]. Table 5 summarizes the Mean Power Density at 10 meters elevation for each of the PBSP nations. The proposed efficiency gains from WASP have been provisionally estimated by GHD to the nearest 5% between 20% and 30% [38] based on the corresponding lower and upper mean wind power densities of the PBSP nations (scaled linearly). A screenshot of the wind resource across the region is provided in Figure 22. For reference, Figure 23 shows the available wind resource at 200m and illustrate the upper range for wind energy generation potential. Nations around the equator, such as Kiribati and Tuvalu have the lowest annual wind energy resource, while wind resource tends to increase further north or south of the equator. While some vessels will be able to achieve significantly greater efficiencies than shown below, these numbers reflect the lower efficiency gains from other vessels across the fleet.

Table 5: Wind resource energy for each PBSP nation and corresponding efficiency gain assumed for WASP

Country	Mean Power Density (W/m²)	% Efficiency Gains Proposed
Fiji	100-330	30
Kiribati	60-70	20
RMI	100-200	25
SI	100-150	20

[34] The Secretariat of the Pacific Regional Environmental Programme (SPREP), 2020. *State of Environment and Conservation in the Pacific Islands: 2020 Regional Report.* Available from: https://library.sprep.org/content/state-environment-and-conservation-pacific-islands-2020-regional-report-indicator-27
[35] The World Bank Data. Available from: https://data.worldbank.org/indicator/AG.LND.AGRI.K2
[36] SPC / Pacific Islands Farmers Organisation Network, 2017. An overview of the market for Pacific Island coconut products and the ability of industries to respond. https://pacificfarmers.com/wp-content/uploads/2018/02/CIDP_Report_Final_e-copy_resized.pdf
[37] https://globalwindatlas.info/
[38] Lupoae, L.A., (2022). *Development of a Sustainable Impact Method for Pacific Inter-Island Maritime Transport*. Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Netherlands.

Tonga	150-220	25
Tuvalu	70-80	20

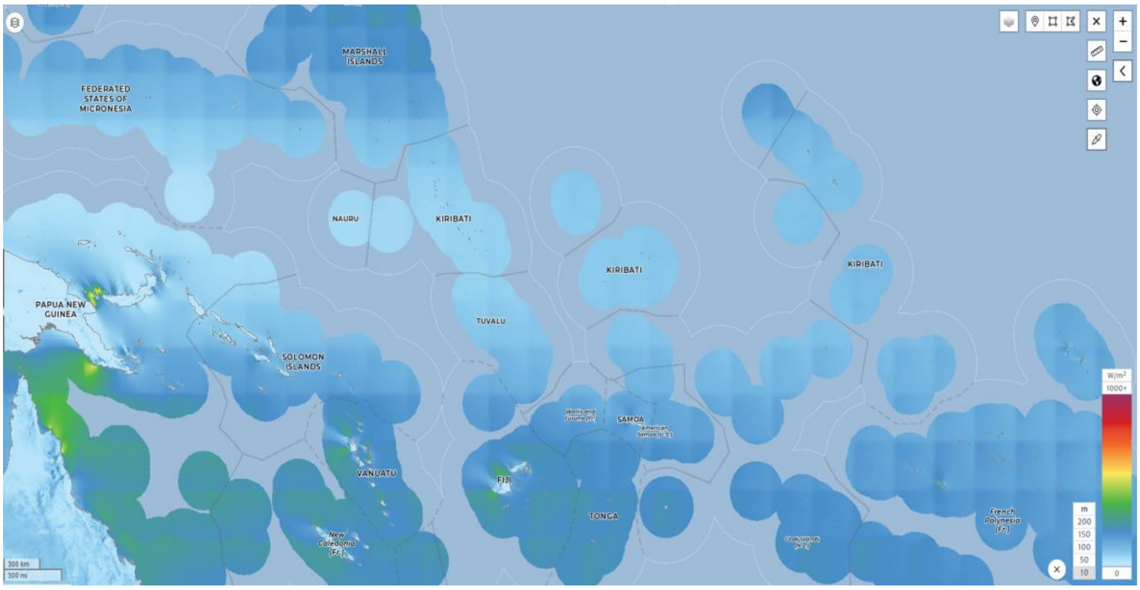


Figure 22: Wind energy resource (mean W/m²) for the PBSP region (10m elevation)

(Source: [https://globalwindatlas.info/)](https://globalwindatlas.info/)

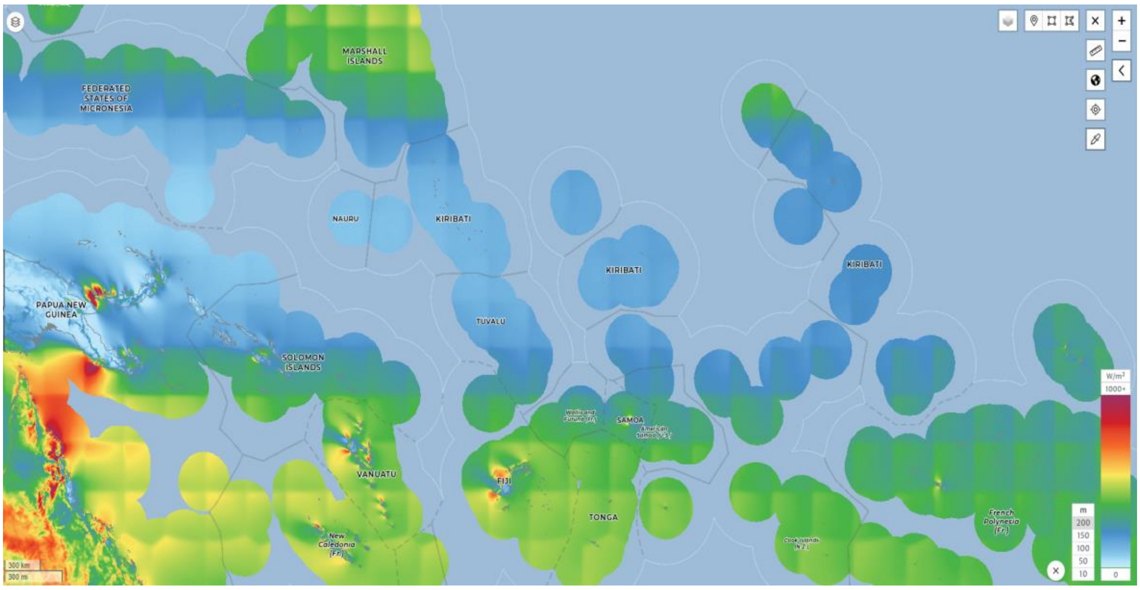


Figure 23: Wind energy resource (mean W/m²) for the PBSP region (200m elevation)

(Source: [https://globalwindatlas.info/)](https://globalwindatlas.info/)

4.3 Results of the MCA

The results of the MCA are detailed in Table 6 below which contains the list of identified abatement measures scored by criterion on a scale of 1 (low) to 5 (high), and the resulting overall weighted MCA score for each abatement measure.

The results, based on the assumptions used, indicate that:

- Relevant abatement measures for the PBSP are: Motor Switching – transitioning from 2-stroke to 4-strokes; WASP retrofits; Operating savings measures (Demand/Supply management optimization, and improved Maintenance programs); Engine Derating; the use of blended Biofuels; and the use of Propulsion Improving Devices.

- More technically/economically problematic (incl. infrastructure/energy resource/agriculture needs and issues), still maturing or uncertain measures, from a Pacific Islands perspective, are: 100% biofuels; full electrification of vessels; and the use of green e-fuels.

- Excluded abatement measures, mainly either for risk or policy-setting reasons, are: nuclear; LPG/LNG; cold-ironing of existing diesel-powered vessels; the use of carbon storage and capture (CCS) directly relating to the vessels; and offsets (unless under specially defined conditions, refer to the accompanying Blended Finance Roadmap).

- There is a set of short-term / ongoing abatement measures available to the PBSP to start now (2023+) and that there are globally evolving abatement measures which will have a role to play at some level from 2031 onwards to further transition to zero emissions by 2050. This implies that any decarbonization pathway tabled now for the period 2031-2050 is only one of many possible scenarios with these long-term pathways evolving and changing as technologies mature globally in terms of performance and cost.

Table 6: Multi-Criteria-Analysis of abatement measures

Summary Description of Available Abatement Measures						Assumed Assessment Criteria (MCA) - scored 1 (low) to 5 (high)											
Abatement Measure Groups	**Decarbonization Approach Focus**	**Technical Readiness Level (TRL)** [39]	**Assumed Baseline CO_2e Emissions Reductions Potential**	**Applicability to PIC Fleet Inventory**	**Landside &/or Port Needs**	**C1. Vessel Fleet Coverage Level**	**C2. CO_2e Emissions Abatement Capability**	**C3. Technical Readiness**	**C4. Min. CAPEX Needs**	**C5. OPEX Net Benefits Level**	**C6. PIC Enviro Whole-of-Life Benefits Level**	**C7. PIC Fuel Overseas Supply Reduction**	**C8. PIC Min. Gov., Mgt. & Training Level**	**C9. PIC Socio - Econ. Benefits Level**	**C10. Availability of Local Energy & Ease of Supplies**	**OVERALL MCA Weighted Score**	**Proposed Inclusion as Measure for PBSP**
1. Improved Maintenance Programs	Increased efficiencies (tech. performance & utilizations)	9 (available)	5-10%	All vessels (incl. 2-stroke outboards)	Access to local slipways / yards with lifters, and training	5	2	5	4	3	3	4	4	3	3	**3.65**	Yes (Ongoing)
2. Demand-Supply Management, Data Systems, Supporting Infrastructure	Efficiencies through optimized routing, vessel specialization, passenger/ cargo separation, improved information systems etc.	7-9 (available assuming appropriate system design)	10-20%	Entire Fleet	Data collection and sharing systems, regional port facilities, warehousing/ cold storage, training	5	3	4	1	5	5	5	2	5	3	**3.65**	Yes (Ongoing)
3. WASP Retrofit	Primarily retrofit, supplemented by installation on new builds	7-9 (dependent on technology)[40]	5-33%	Geography with wind potential and knowledge level	Access to local slipways / yards with lifters, and training	4	4	4	3	4	4	5	3	5	4	**4.00**	Yes (Ongoing)
4. Motor-switching from 2-stroke to 4-stroke	Replacement 2-stroke engines for more efficient and lower emissions 4-stroke	9 (available)	10-20%	Almost all 2-stroke outboards	No additional needs from existing 2-stroke	5	3	5	3	4	4	5	4	4	5	**4.25**	Yes (Initial phase / temporary)
5. Engine Derating	Optimizing engine to suit typical operating speed	9 (available)	5-10%	All vessels not operating at engine design speed.	Access to skilled personnel and training	3	2	5	4	4	4	5	4	3	3	**3.60**	Yes (Initial phase)

[39] Technical Readiness Level derived from Nuttall, P., Newell, A., Rojon, I., Milligan, B. & Irvin, A., 2021. Pacific island domestic shipping emissions abatement measures and technology transition pathways for selected ship types. *Marine Policy*, vol. 132, 2021, https://doi.org/10.1016/j.marpol.2021.104704.
[40] L.A. Lupoae, 2022. Development of a Sustainability Impact Method for Inter-Island Maritime Transport (Masters Thesis – TU Delft and supervised by USP-MCST, Dr. P. Nuttall).

Summary Description of Available Abatement Measures						Assumed Assessment Criteria (MCA) - scored 1 (low) to 5 (high)											
Abatement Measure Groups	**Decarbonization Approach Focus**	**Technical Readiness Level (TRL)** [39]	**Assumed Baseline CO_2e Emissions Reductions Potential**	**Applicability to PIC Fleet Inventory**	**Landside &/or Port Needs**	**C1. Vessel Fleet Coverage Level**	**C2. CO_2e Emissions Abatement Capability**	**C3. Technical Readiness**	**C4. Min. CAPEX Needs**	**C5. OPEX Net Benefits Level**	**C6. PIC Enviro Whole-of-Life Benefits Level**	**C7. PIC Fuel Overseas Supply Reduction**	**C8. PIC Min. Gov., Mgt. & Training Level**	**C9. PIC Socio - Econ. Benefits Level**	**C10. Availability of Local Energy & Ease of Supplies**	**OVERALL MCA Weighted Score**	**Proposed Inclusion as Measure for PBSP**
6. Propulsion Improving Devices (PIDs)	Retrofit to existing vessels with significant life remaining	8-9 (dependent on technology)	5-10%	All large, slow vessels with high block coefficient	Access to local slipways / yards with lifters, and training	2	2	5	4	3	4	5	3	3	3	**3.40**	Yes (Initial phase)
7. Biofuels (Blended)	Replacement 'drop-in' fuel for existing engines	9 (available but limited in scale)	10-20%	All vessels (incl. 2-stroke outboards)	Access to blended fuel bunkers / tanks / drums	5	3	5	4	4	3	2	4	3	2	**3.60**	Yes (Initial phase / temporary)
8. Biofuels (B100)	Replacement 'drop-in' fuel for modified engines	7 (available but limited in scale)	100% (sustainably produced)	Most vessels except for 2-stroke outboards	Access to biofuel bunkers / tanks / drums	1	5	3	3	3	3	1	3	2	1	**2.60**	Yes (To be further evaluated)
9. Electrification (full)	Newbuild Full Electric Designs with batteries	4-6 (ready for targeted applications, but requires reliable large scale electricity supply)	100% (renewables charging)	Most vessels except for Navy/Patrol op. needs	Access to renewables recharging facilities	4	5	2	1	2	4	5	2	3	2	**2.90**	Yes (To be further evaluated)
10. Green e-fuels (liquid hydrogen, ammonia, methanol, etc.)	Newbuild Fuel-cell Designs	3-5 (low maturity level, but rapidly developing internationally)	100% (incl. use of CCS)	Most vessels except for 2-stroke outboards / redundancy with electric fleet	Access to green e-fuel bunkers / tanks / drums	4	5	2	3	3	3	1	2	3	2	**2.90**	Yes (To be further evaluated)

Summary Description of Available Abatement Measures						Assumed Assessment Criteria (MCA) - scored 1 (low) to 5 (high)											
Abatement Measure Groups	Decarbonization Approach Focus	Technical Readiness Level (TRL) [39]	Assumed Baseline CO_2e Emissions Reductions Potential	Applicability to PIC Fleet Inventory	Landside &/or Port Needs	C1. Vessel Fleet Coverage Level	C2. CO_2e Emissions Abatement Capability	C3. Technical Readiness	C4. Min. CAPEX Needs	C5. OPEX Net Benefits Level	C6. PIC Enviro Whole-of-Life Benefits Level	C7. PIC Fuel Overseas Supply Reduction	C8. PIC Min. Gov., Mgt. & Training Level	C9. PIC Socio - Econ. Benefits Level	C10. Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Measure for PBSP
11. Other	Grey-fuels (gases) / At Port Cold-ironing of Diesel Vessels/ Nuclear / CCS / Ongoing Offsets	N/A (excluded)	<100% (varying according on technology adopted)	Minimal as these technologies are more applicable to international large vessels	Significant level of landside and port infrastructure required. Level varying according to technology adopted	2	2	2	2	2	2	2	2	2	2	**2.00**	No (excluded)
Assigned MCA Weightings:						10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	**100%**	-

4.4 Key messages from the MCA

The results of both the technical review and the MCA indicate that there are three distinct sets of abatement measures relevant to the PBSP which can be used in the development of transition pathways for the PBSP: one set for ongoing use, one set for the short-term (up to 2030, including some temporary transitioning measures), and the other set for long-term (2030+).

4.4.1 Short-term abatement measures

The temporary transitioning abatement measures, which have the capability to partially reduce GHG emissions but not to zero, cover motor switching and blended biofuels. For instance, with motor switching from 2-stroke to 4-stroke, the replacement4-strokes would need to be either further replaced by electric or green eFuels motors to achieve zero emissions. The same is true for blended biofuels. This implies that a balance will need to be struck between the short-term gains of temporary abatement measures and investing in measures that will be become increasingly redundant (obsolete) within 10 to 15 years if the target of zero emissions by 2050 is to be met.

4.4.2 Ongoing WASP abatement measure

The Pacific Islands have varying levels of continuous wind resources available both for renewables electricity generation and as wind assistance for vessels fitted with various technologies (i.e., traditional, rigid and rotor sails). The use of WASP technology and the variability of continuous wind resources around the Pacific Islands suggests that WASP technology will need to be used in a hybrid form with other green powering (i.e., electric/battery with solar and movement recharging, and back-up use of green eFuels and 100% biofuels where available and at affordable prices).

4.4.3 Long-term abatement measures

The use of biofuels, particularly as B100, will need to be carefully considered as a long-term abatement measure as its local production potentially has negative impacts on local land use, agricultural exports, and food supply. If local production of biofuels across all PBSP countries is insufficient, or cannot be achieved economically, which is currently the general case, then any supply shortfalls of biofuels would have to be met by overseas imports. Consequently, these imports would continue the existing PBSP country reliance on energy imports at high cost to their economies. The use of blended biofuel (i.e., B10-20) as a temporary measure has less demand on production levels and its production level may be more feasible to maintain with the equivalent blend input volumes converted to 100% biofuel use.

The long-term abatement measure of electrification, as one of the potential long-term measures next to green eFuels, will require an adequate level of local renewable energy generation and supporting infrastructure to cover both landside needs and the domestic maritime sector. The current level of renewables production by PBSP countries and the potential future use of geothermal in some countries has been discussed in section 4.2 above. If local renewable energy production and/or distribution is inadequate in the future, then either investments will have to be made in off-grid / localized production specifically for the domestic maritime sector (i.e., produced near to and supplied at ports), or shortfalls will need to be met by green eFuels (imported and/or locally produced).

A number of relevant abatement measures indicated in the MCA (i.e., vessel fleet maintenance, WASP retrofits and the installation of Propulsions Improvement Devices) are conditional upon the availability of local and/or regional slipway / ship-lift facilities. This aspect of required supporting second-level infrastructure, and its current availability, is discussed in section 6 below.

4.4.4 Requirement for integrated planning

There is a clear recognition relating to infrastructure needs that the long-term abatement measures will require significant lead-times to implement. This will require decisive, adaptive, careful planning, training and further research and development and local trialing (proof-of-concept) of measures. Key will also be regional fleet renewal thinking noting the earlier comments for the need for a proactive approach to procurement regarding gifted vessels to governments and the purchase of second-hand vessels from overseas by governments and the private sector, i.e., replacement or additional vessels will need to be supplied with emissions reducing capability before they can start operating domestically.

5 Modelling of transition pathways

5.1 Introduction

This section provides detail on the decarbonization pathway model and key outputs to inform the blended finance component of this study. The purpose of this model is to illustrate a possible 2050 decarbonization strategy with an interim target of 40% GHG reduction by 2030. Given the number of common themes applicable to the PBSP nations, including the necessity for sea travel as part of daily life, as well as the vast majority of emissions borne from small vessels, the model adopts a similar approach to each of these nations. Where appropriate the effectiveness of each abatement measure may vary between countries, particularly with respect to local wind availability and the assumed emissions reduction from WASP technologies[41] (refer section 4.2.1). Given the variability across the national (domestic) fleets, a number of assumptions have been made to simplify the model. Please refer to Section 1.2 and Appendix C – Model Assumptions for further details.

5.1.1 Baseline inventory data (domestic fleets)

The decarbonization pathway modelling is based on the updated baseline domestic fleets inventory developed by UCL dated 17th October 2022. The inventory includes information on each vessel, including country, size, ownership, age, voyage type, vessel type, engine size, fuel type, estimate annual fuel consumption, and annual GHG emissions.

Table 7 summarizes how the vessels in the baseline domestic fleets inventory have been categorized for the emissions abatement study. Other baseline data used to generate cost outputs include engine power, time at sea, and vessel length.

Table 7: Summary of vessel parameters used in the model from the baseline inventory

Ship Type
Barge
Bulk Carrier
Cargo
Container ships
Dredging
Fishing vessel
General Cargo
Landing craft
Medical boat
Oil tanker
Open Boat
Other
Passenger
Passenger and Cargo
Pleasure craft
Pollution response boat
Reefer
Research vessel
RoRo
Search and Rescue/Patrol
Small artisanal crafts
Small boats
Support vessel
Tug boat
Wet products
Work Boat
Yacht

Ownership
Government
Other – assumed Private/Commercial

Voyage Type
Domestic
International
N/A

Year Category
Before 1983
Between 1984 and 2000
2001 onwards

Vessel Length
<10m
10m-25m
25m-50m
50m-100m
>100m
N/A

Engine Type
SSD (Slow Speed Diesel)
MSD (Medium Speed Diesel)
HSD (High Speed Diesel)
Note: Petrol engines not indicated in baseline

Fuel Type
HFO
MDO
Petrol

[41] L.A. Lupoae, 2022. Development of a Sustainability Impact Method for Inter-Island Maritime Transport (Masters Thesis – TU Delft and supervised by USP-MCST, Dr. P. Nuttall).

GHD has not checked or verified the data in detail, but where data is incomplete, GHD has made appropriate assumptions based on similar vessel types or operational function from within the inventory. The following summarizes the changes made:

1. **Dumb Barges.** For barges that rely on being towed and therefore have zero emissions, zeroing the length to preserve the vessel count without applying additional costs to these vessels.
2. **kW Data.** Where missing, input kW data for vessels derived from the fuel consumption at sea, annual time at sea, specific fuel consumption, and engine load.
3. **Length Data.** Where missing, input length (m) data for vessels based on other similar vessels. This was generally the case of the Tuvalu inventory.

5.1.2 Unavailable data for Samoa and Vanuatu

Maritime fleet inventory and CO_2e emissions are not currently available in the baseline data for Samoa and Vanuatu, therefore no specific zero emissions pathway has been provided for these nations. However, as there are common carbon abatement themes applied all the other PBSP nations presented in this report, it is suggested that similar opportunities and challenges are present in Samoa and Vanuatu, assuming that the fleet make-up is similar to the other PICs and the vast majority of emissions are from small vessels. As with all the abatement measures discussed in this report, some country-specific variation is expected. In particular, the feasibility of cultivation of any biofuel feedstock given the limited availability of land, and the availability of wind resource to support WASP. As the cost outputs of the model are generally based on the number of vessels in the fleet, inventory data for Samoa and Vanuatu are required to inform the Blended Finance Roadmap. While similar PICs may be used as a proxy for these two nations to determine costs ranges, caution is advised.

5.1.3 Inter-PIC maritime trade and fleet, and other exclusions

Analysis of the UCL provided baseline data, with further research by GHD, shows that there is a small fleet of vessels involved in Inter-PIC trade (i.e., between PBSP countries) mainly involving fuel (over 70% share) distributed from a storage hub in Fiji to some other PBSP countries, as well some general cargoes (around 25% share) with Fiji as a transshipment location. Assessment of the possible CO_2e emissions from the vessels involved in the current Inter-PIC maritime trade shows that these inter-PIC trade CO_2e emissions account for only around 0.5% of the total regional baseline emissions from the domestic fleets, i.e., they are extremely minor. The current vessels involved in the inter-PIC trade are typically overseas flagged, chartered-in, and may also operate for periods outside of the Pacific Islands region.

Given these observations, it was decided to exclude the Inter-PIC maritime trade and fleet from further analysis noting that the international maritime CO_2e reduction pathways being developed and implemented by international shipowners and organizations (IMO etc.) should cover the existing inter-PIC vessels involved. If in the future domestically-owned and trading vessels are also used for emerging (future) inter-PIC maritime trade, then these vessels would be covered under the PBSP national CO_2e reduction pathways.

There is also some PBSP trade likely not captured in domestic maritime trade statistics involving the supply of fuel to national and overseas fishing fleets operating in the region's waters. However, if domestic vessels are involved in these fuel re-supply operations, then they should be captured in the Baseline domestic fleets inventory. The CO_2e emissions from the overseas fishing fleet operating in PBSP country waters have not been assessed and are therefore excluded from the analysis due to the vessels being part of overseas (other country) national fleets.

5.1.4 Summary of PBSP proposed abatement measures

Each abatement measure assumes a start and end year with phase-in and phase-out years that reflect its availability, broader system integrated requirements and/or challenges. Some abatement measures impact the entire fleet across the applicable vessel type, however, it is acknowledged that some abatement measures will have limited uptake depending on how the roll-out is supported and incentivized (e.g. WASP retrofits and motor switching from 2-stroke to 4-stroke). The model therefore includes a proportional uptake functionality as described in the previous sections (refer Appendix C – Model Assumption for further details).

Each abatement measure assumes a percentage reduction in emissions based on a range of factors that addressed fuel/motor switching, reduction in fuel use (e.g., WASP), improved maintenance/ logistics, or a combination. Improvements in efficiency have been based on research by others and is documented in Appendix C – Model Assumptions. GHD acknowledges that a significant body of work currently exists across the various technical solutions proposed in this report, upon which this model is based. Where necessary simplifications must be made for the model, some assumptions have been made based on GHD's experience in the energy and maritime sectors (refer Section 1.2 Assumptions).

The selection of abatement measure and timing are coordinated with other measures to allow for short-term abatement while providing additional lead-time for long-term measures to further establish and mature.

It is recognized that some abatement measures do not provide 100% emissions reductions, therefore must be phased out by 2050 to achieve fleet decarbonization. Often these short-term measures serve as a technological stepping-stone towards zero emissions technologies and are therefore paired in the model to reduce overlap and double counting of emissions abatement.

Model outputs include the emissions abatement of each measure expressed in tonnes of carbon dioxide equivalent (tCO_2e) and a range of indicators that describe the fleet, including the number of vessels the abatement measure applies to, the total tonnes of fuel consumed and saved, average vessel length, average engine power, and combined annual energy demand. This will inform CAPEX and OPEX investment requirements and enable operating cost savings to be indicated.

Table 8 provides a summary of the proposed abatement measures and the corresponding timing. As discussed earlier, each abatement measure is phased in and out over a nominated period. This is intended to allow sufficient time for transition and is assumed to be linear in the model. Refer to Appendix C – Model Assumptions for further details.

Table 8: Proposed abatement measures

#	Term	Start	Phase-in years	End	Phase-out years	Proposed abatement measure	Applicable vessels	Applicable vessel size	Applicable sector	Linked abatement measures
1	Ongoing	2023	3	-	-	Improved Maintenance Programs – All sectors and vessel types	Entire fleet	All vessel lengths	Both government and non-government sectors	-
2	Ongoing	2023	15	-	-	Demand-Supply Management, Data Systems, Supporting Infrastructure – All sectors and vessel types (excl. Navy)	All vessels except search and rescue / patrol (i.e., Navy)	All vessel lengths	Both government and non-government sectors	-
3	Ongoing	2023	7	-	-	WASP Retrofit – Most vessels (excl. some specialist craft)	All vessels except dredging, pleasure craft, pollution response boats, search and rescue / patrol (i.e., Navy), tugboats, yachts. Containerships also have deck-space that is used for containers which makes it difficult to find the appropriate space to install WASP technology.	All vessel lengths	Both government and non-government sectors	-
4	Ongoing	2023	5	-	-	Engine Derating – All sectors and vessel types (excl. vessels <10m length – assumed 2 stroke)	All medium-large vessels except barges, dredging, medical boats, open boats, pleasure craft, pollution response boats, search and rescue / patrol (i.e., Navy), small artisanal craft, small boats, tugboats, work boats, yachts.	>10m length	Both government and non-government sectors	-
5	Ongoing	2023	5	-	-	Propulsion Improving Devices (PIDs) – All sectors and vessel types (excl. vessels <10m length – assumed 2 stroke)	All large vessels except barges, dredging, medical boats, open boats, pleasure craft, pollution response boats, search and rescue / patrol (i.e., Navy), small artisanal craft, small boats, tugboats, work boats, yachts.	>10m length	Both government and non-government sectors	-

#	Term	Start	Phase-in years	End	Phase-out years	Proposed abatement measure	Applicable vessels	Applicable vessel size	Applicable sector	Linked abatement measures
6	Short	2023	5	2035	5	Biofuel (Blended) – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	10% of all medium-large vessels except search and rescue / patrol (i.e., Navy)	>10m length	Both government and non-government sectors	Biofuel (Blended) abatement measures timed together and must be phased out by 2050
7	Short	2023	5	2035	5	Biofuel (Blended) – All vessels <10m length (assumed 2-stroke)	10% of all small vessels except search and rescue / patrol (i.e., Navy)	<10m length	Both government and non-government sectors	Biofuel (Blended) abatement measures timed together and must be phased out by 2050
8	Short	2023	5	2040	5	Motor Switching – 2-stroke to 4-stroke – All vessels <10m length (assumed 2 stroke)	**50% of all small vessels except search and rescue / patrol (i.e., Navy)**[42]	<10m length	Both government and non-government sectors	4-stroke motors using conventional fuel must be phased out by 2050
9	Long	2025	25	-	-	Electrification – Government sector vessels (excl. vessels <10m length – assumed 2-stroke)	47.5% of all medium-large government vessels except search and rescue / patrol (i.e., Navy)	>10m length	Government sector vessels only	Measures #9, #10, #12, #14, #15 linked to capture 100% of all large vessels by 2050
10	Long	2030	20	-	-	Electrification – Private/Commercial sector vessels (excl. vessels <10m length – assumed 2-stroke)	47.5% of all medium-large private/commercial vessels except search and rescue / patrol (i.e., Navy)	>10m length	Non-government sector vessels only	Measures #9, #10, #12, #14, #15 linked to capture 100% of all large vessels by 2050
11	Long	2030	20	-	-	Electrification – All vessels <10m length (assumed 2 and 4-stroke)	50% of all small vessels except search and rescue / patrol (i.e., Navy)	<10m length	Both government and non-government sectors	Measures #11 & #13 linked to capture 100% of all small vessels by 2050
12	Long	2030	20	-	-	Green e-fuels – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	47.5% of all medium-large vessels except search and rescue / patrol (i.e., Navy)	>10m length	Both government and non-government sectors	Measures #9, #10, #12, #14, #15 linked to capture 100% of all large vessels by 2050

[42] This assumption on motor switching is a general regional assumption whereby individual countries may have their own policy on the level of motor switching. In the case of Tonga, discussions at the PBSP Technical Forum (29th July 2022) indicated a higher CAPEX for motor switching than assumed in this modelling. The transition plan outlined in this report has attempted to balance short-term gains in emissions reductions with redundancy in investment due to the need to replace 4-stroke with electric motors / green e-fuels to ultimately achieve zero emissions by 2050. Hence this is why the modelling only assumes 50% motor switching.

#	Term	Start	Phase-in years	End	Phase-out years	Proposed abatement measure	Applicable vessels	Applicable vessel size	Applicable sector	Linked abatement measures
13	Long	2030	20	-	-	Green e-fuels – All vessels <10m length (assumed 2 and 4-stroke)	50% of all small vessels except search and rescue / patrol (i.e., Navy)	<10m length	Both government and non-government sectors	Measures #11 & #13 linked to capture 100% of all small vessels by 2050
14	Long	2030	10	-	-	Biofuel (B100) / Green e-fuels – Navy (Search and Rescue / Patrol)	All search and rescue / patrol (i.e., Navy)	All vessel lengths	Government sector vessels only	Measures #9, #10, #12, #14, #15 linked to capture 100% of all large vessels by 2050
15	Long	2030	5	-	-	Biofuel (B100) – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	5% of all medium-large vessels except search and rescue / patrol (i.e., Navy)	>10m length	Both government and non-government sectors	Measures #9, #10, #12, #15 linked to capture 100% of all large vessels (except Navy)

Color Legend

Applicable vessel size	Applicable sector
All vessel lengths	Both government and non-government sectors
<10m length	Government sector vessels only
>10m length	Non-government sector vessels only

5.1.5 Model functionality

The Microsoft Excel model calculates the reduction in emissions at a vessel level using filtered subsets of the baseline inventory. The reduction in emissions is phased in and out linearly over the respective years, with the total emissions reduction of each abatement measure summed together for each year. This includes the abatement measures that are in the process of being phased in or out proportioned accordingly. To avoid double-counting emissions reductions of abatement measures that can be applied together (and to avoid producing emissions reductions of more than 100% at 2050), each subsequent abatement measure uses the previous total emissions as the new initial emissions. While this assumes that the previous abatement measure is adopted, the model attempts to factor this in by adopting conservative estimates where possible.

Figure 24 illustrates the model process for both the calculation of GHG emissions and the Cost Estimate.

Figure 24: Model calculation process

In addition to importing the Baseline Inventory to the Microsoft Excel model, Figure 25 illustrates the key model inputs required to calculate the GHG emissions for each abatement measure. Refer Appendix D – Model Screenshots for further detail.

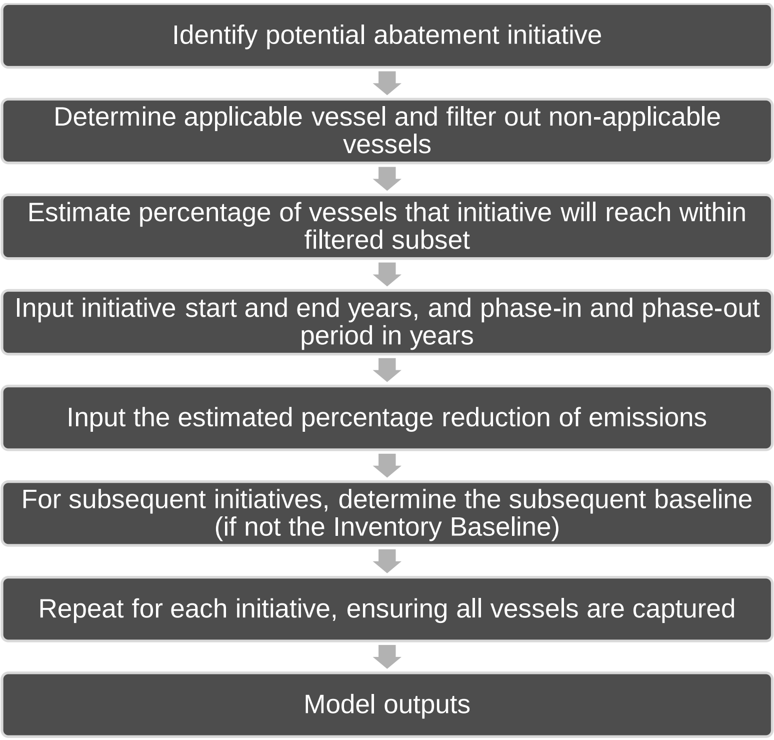


Figure 25: Overview of model inputs

Table 9 summarizes the abatement measures and the subsequent baseline dependencies.

Table 9: Abatement measure and corresponding subsequent baseline

#	Abatement Measure	Subsequent baseline
1	Improved Maintenance Programs – All sectors and vessel types	Inventory baseline
2	Demand-Supply Management, Data Systems, Supporting Infrastructure – All sectors and vessel types (excl. Navy)	#1
3	WASP Retrofit – Most vessels (excl. some specialist craft)	#2
4A	Engine Derating – All sectors and vessel types (excl. vessels <10m length – assumed 2 stroke)	#3
4B	Propulsion Improving Devices (PIDs) – All sectors and vessel types (excl. vessels <10m length – assumed 2 stroke)	#4A
4C	Biofuel (Blended) – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	#4B
4D	Biofuel (B100) – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	#4B
4E-1	Electrification – Government sector vessels (excl. vessels <10m length – assumed 2-stroke)	#4B
4E-2	Electrification – Private/Commercial sector vessels (excl. vessels <10m length – assumed 2-stroke)	#4B
4F	Green e-fuels – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	#4B
5A	Biofuel (Blended) – All vessels <10m length (assumed 2-stroke)	#3
5B	Motor Switching – 2-stroke to 4-stroke – All vessels <10m length (assumed 2 stroke)	#3
5C	Electrification – All vessels <10m length (assumed 2 and 4-stroke)	#3
5D	Green e-fuels – All vessels <10m length (assumed 2 and 4-stroke)	#3
6	Biofuel (B100) / Green e-fuels – Navy (Search and Rescue / Patrol)	#1

5.2 Regional overview

Regional summaries of the model outputs for each abatement measure for the short- and long-term are presented below. Key outputs for each abatement measure, are the number of applicable vessels, initial fuel demand (under BAU, in t), fuel demand with abatement measure (in t), charging energy demand (in kWh), and CO_2e emissions reduced (in tCO_2e). A summary of the short-term regional outputs is shown in Table 10 and a summary of the long-term regional outputs is shown in Table 11.

5.2.1 Short-term (present – 2030)

Table 10: Short-term regional overview (present – 2030)

Abatement Measure	No. of applicable vessels	Initial fuel demand (under BAU, in t)	Fuel demand with abatement measure (in t)	Charging energy demand (in kWh)	CO_2e Emissions Reduced (in tCO_2e)
Improved Maintenance Programs – All sectors and vessel types	12,208	186,416	158,453	0	87,069
Demand-Supply Management, Data Systems, Supporting Infrastructure – All sectors and vessel types (excl. Navy)	12,202	156,734	125,387	0	97,609
WASP Retrofit – Most vessels (excl. some specialist craft)	11,824	105,086	73,560	0	98,169
Engine Derating – All sectors and vessel types (excl. vessels <10m length – assumed 2 stroke)	435	33,533	31,856	0	5,218
Propulsion Improving Devices (PIDs) – All sectors and vessel types (excl. vessels <10m length – assumed 2 stroke)	259	24,506	23,281	0	3,812
Biofuel (Blended) – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	67	4,701	4,701	0	2,928
Biofuel (B100) – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	2031 – 2050 Strategy				
Electrification – Government sector vessels (excl. vessels <10m length – assumed 2-stroke)					
Electrification – Private/Commercial sector vessels (excl. vessels <10m length – assumed 2-stroke)					
Green e-fuels – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)					
Biofuel (Blended) – All vessels <10m length (assumed 2-stroke)	1,153	4,358	4,358	0	2,714
Motor Switching – 2-stroke to 4-stroke – All vessels <10m length (assumed 2 stroke)	5,767	21,791	17,432	0	13,570
Electrification – All vessels <10m length (assumed 2 and 4-stroke)	2031 – 2050 Strategy				
Green e-fuels – All vessels <10m length (assumed 2 and 4-stroke)					
Biofuel (B100) / Green e-fuels – Navy (Search and Rescue / Patrol)					

5.2.2 Long-term (2031 – 2050)

Table 11: Long-term regional overview

Abatement Measure	No. of applicable vessels	Initial fuel demand (under BAU, in t)	Fuel demand with abatement measure (in t)	Charging energy demand (in kWh)	CO_2e Emissions Reduced (in tCO_2e)
Improved Maintenance Programs – All sectors and vessel types	12,208	186,416	158,453	0	87,069
Demand-Supply Management, Data Systems, Supporting Infrastructure – All sectors and vessel types (excl. Navy)	12,202	156,734	125,387	0	97,609
WASP Retrofit – Most vessels (excl. some specialist craft)	11,824	105,086	73,560	0	98,169
Engine Derating – All sectors and vessel types (excl. vessels <10m length – assumed 2 stroke)	435	33,533	31,856	0	5,218
Propulsion Improving Devices (PIDs) – All sectors and vessel types (excl. vessels <10m length – assumed 2 stroke)	259	24,506	23,281	0	3,812
Biofuel (Blended) – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	2023 - 2030 Strategy				
Biofuel (B100) – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	33	2,351	2,351	0	7,320
Electrification – Government sector vessels (excl. vessels <10m length – assumed 2-stroke)	15	3,007	0	32,083,094	9,363
Electrification – Private/Commercial sector vessels (excl. vessels <10m length – assumed 2-stroke)	303	19,325	0	222,628,106	60,177
Green e-fuels – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)	318	22,332	22,332	0	69,540
Biofuel (Blended) – All vessels <10m length (assumed 2-stroke)	2023 - 2030 Strategy				
Motor Switching – 2-stroke to 4-stroke – All vessels <10m length (assumed 2 stroke)					
Electrification – All vessels <10m length (assumed 2 and 4-stroke)	5,767	21,791	0	200,525,506	67,855
Green e-fuels – All vessels <10m length (assumed 2 and 4-stroke)	5,767	21,791	21,791	0	67,855
Biofuel (B100) / Green e-fuels – Navy (Search and Rescue / Patrol)	6	1,721	1,721	0	5,360

5.2.2.1 Summary of Regional Inventory

The following charts present an aggregated summary of emissions across the regional domestic fleet. Inventory data for Fiji, Kiribati, the Republic of Marshall Islands, Solomon Islands, Tonga, and Tuvalu has been made available. The following sections provide individual country breakdowns.

Key observations

- Total vessel count: 12,208 (including 2-stroke outboards), Total GHG Emissions Baseline: 580 $ktCO_2e$
- Almost half of all emissions are from small vessels <10 meters, many of which are likely to be 2-stroke engines (exact data on 2-stroke is unavailable in inventory).
- Approximately 10% of emissions are from vessels around 40 years old or older, suggesting a need for immediate replacement, and almost 20% of vessels were built between 1984 and 2000.

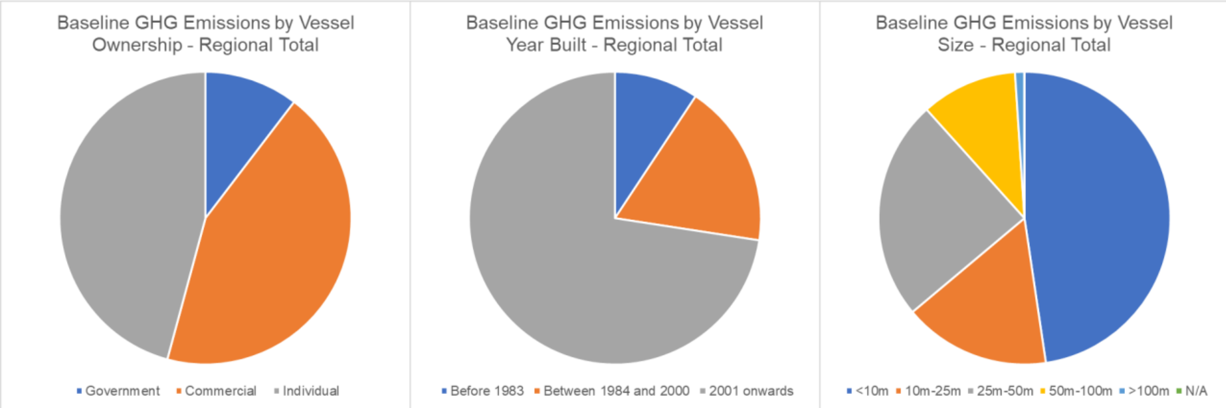


Figure 26: Distribution of GHG emissions by vessel ownership, age, and size

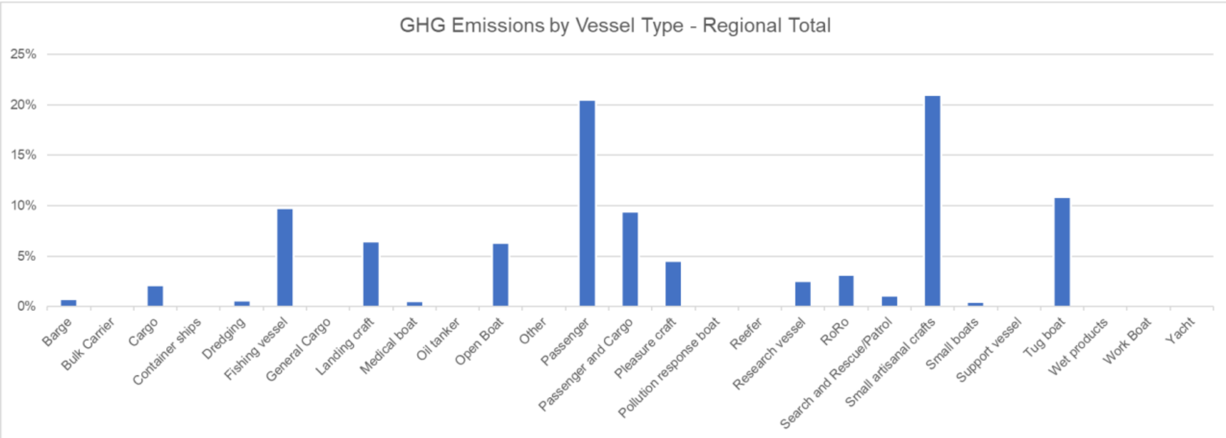


Figure 27: Distribution of GHG emissions by vessel type

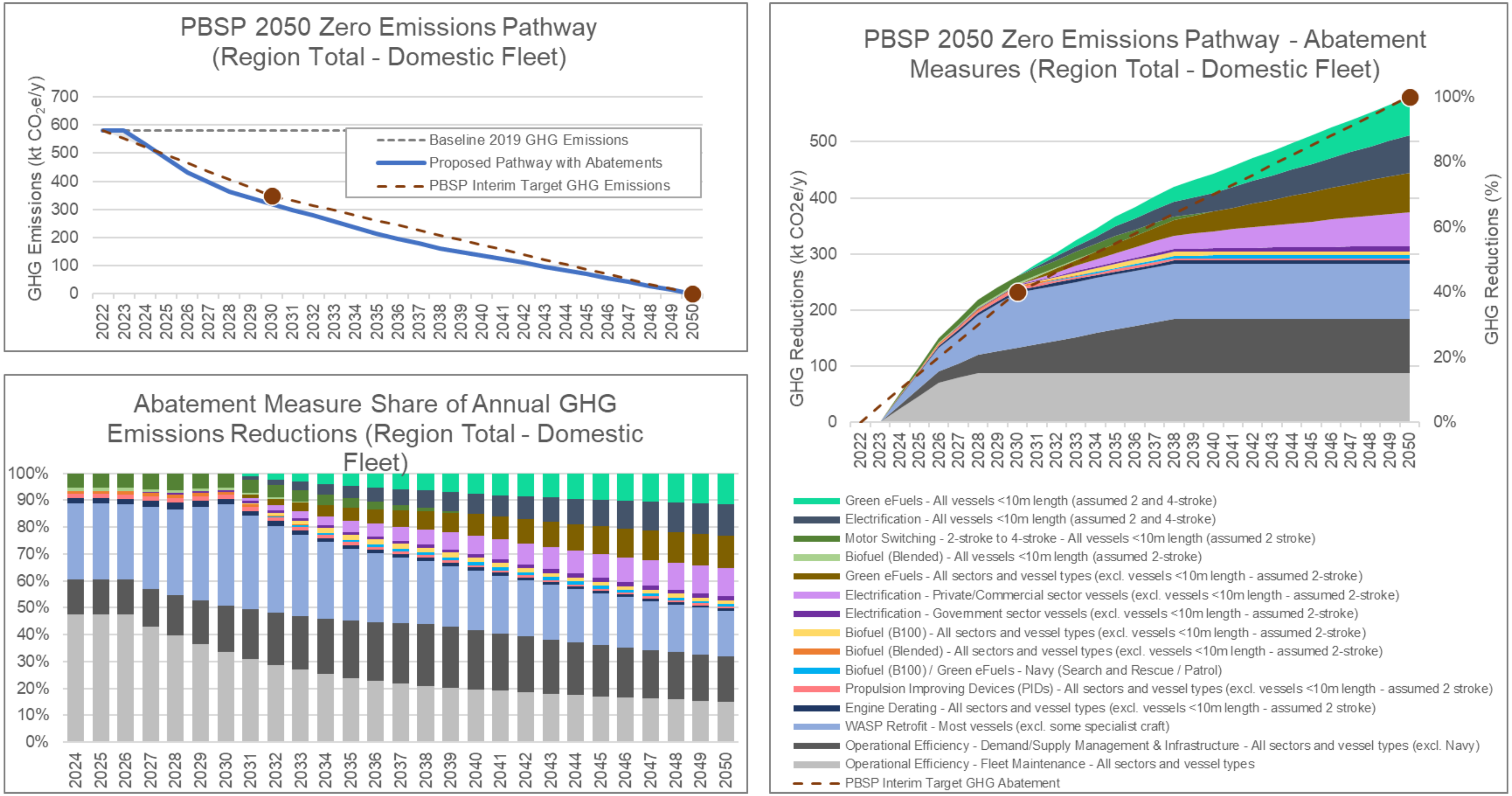


Figure 28: Proposed Zero Emissions Pathway (2023-2050)

5.2.2.2 Fiji – Summary Baseline GHG Emissions Analysis & Proposed Zero Emissions Pathway

Key observations

- Total vessel count: 5,377 (including 2-stroke outboards), Total GHG Emissions Baseline: 316 ktCO_2e
- Approximately two thirds of emissions are from small vessels <10 meters, many of which are likely to be 2-stroke engines (exact data on 2-stroke unavailable in inventory).
- Passenger vessels contribute almost a third of emissions.
- Approximately 20% of the emissions are from the government fleet representing opportunity for effective short-term targeting of abatement measures.

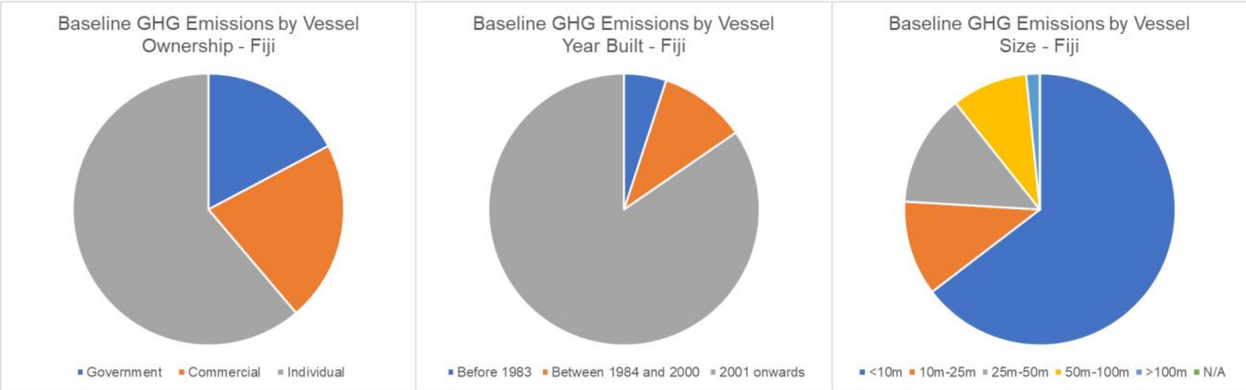


Figure 29: Distribution of GHG emissions by vessel ownership, age, and size

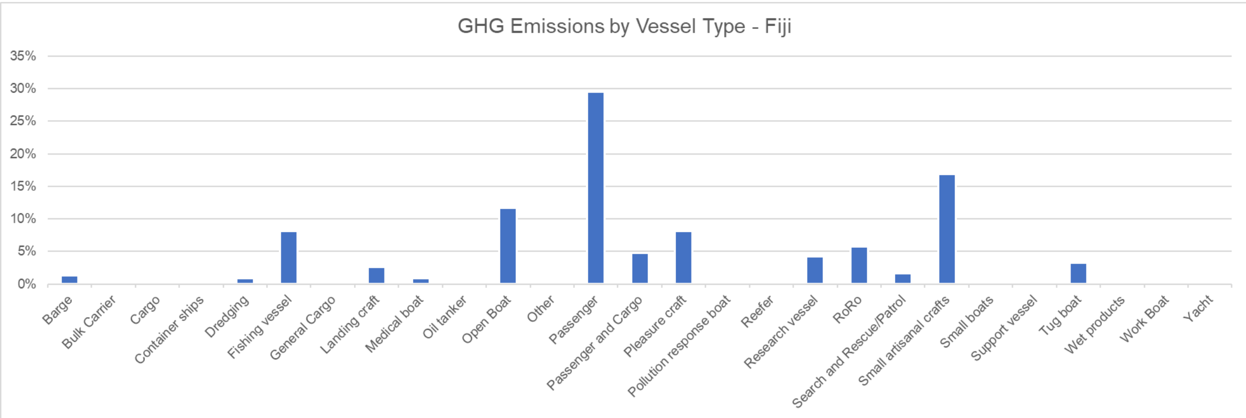
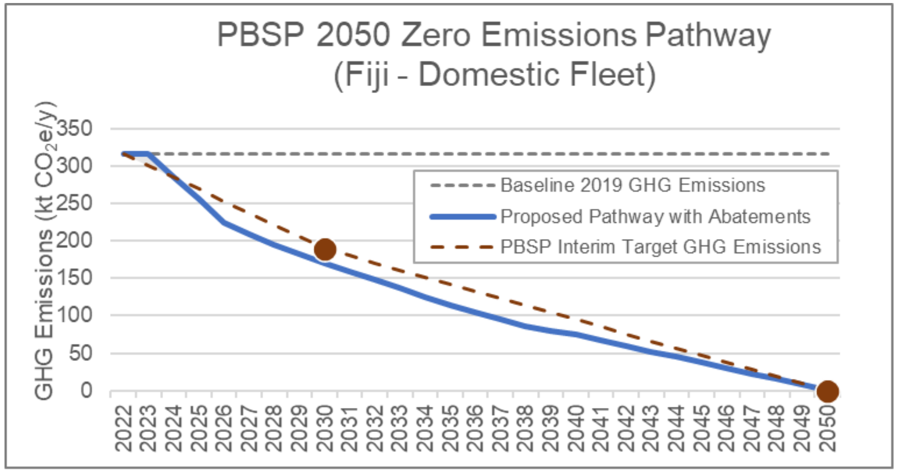
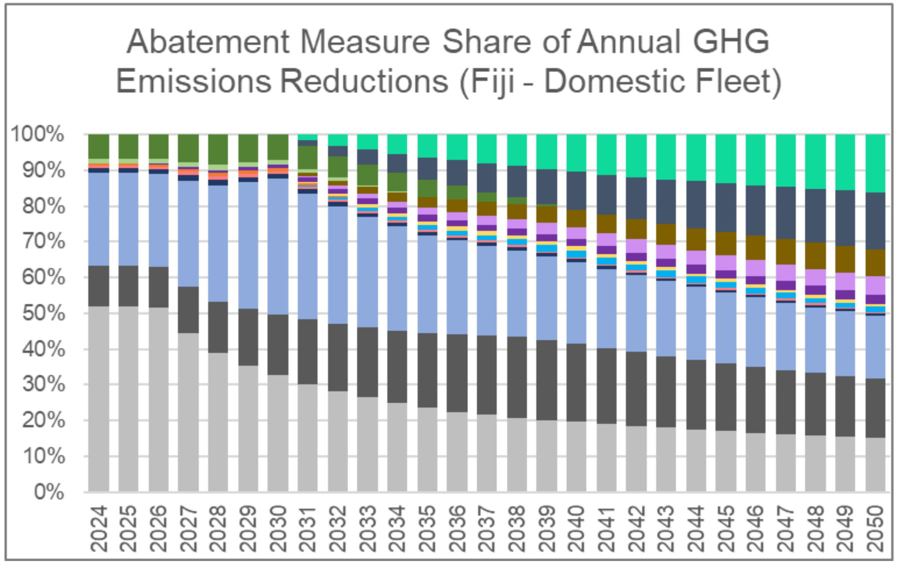


Figure 30: Distribution of GHG emissions by vessel type





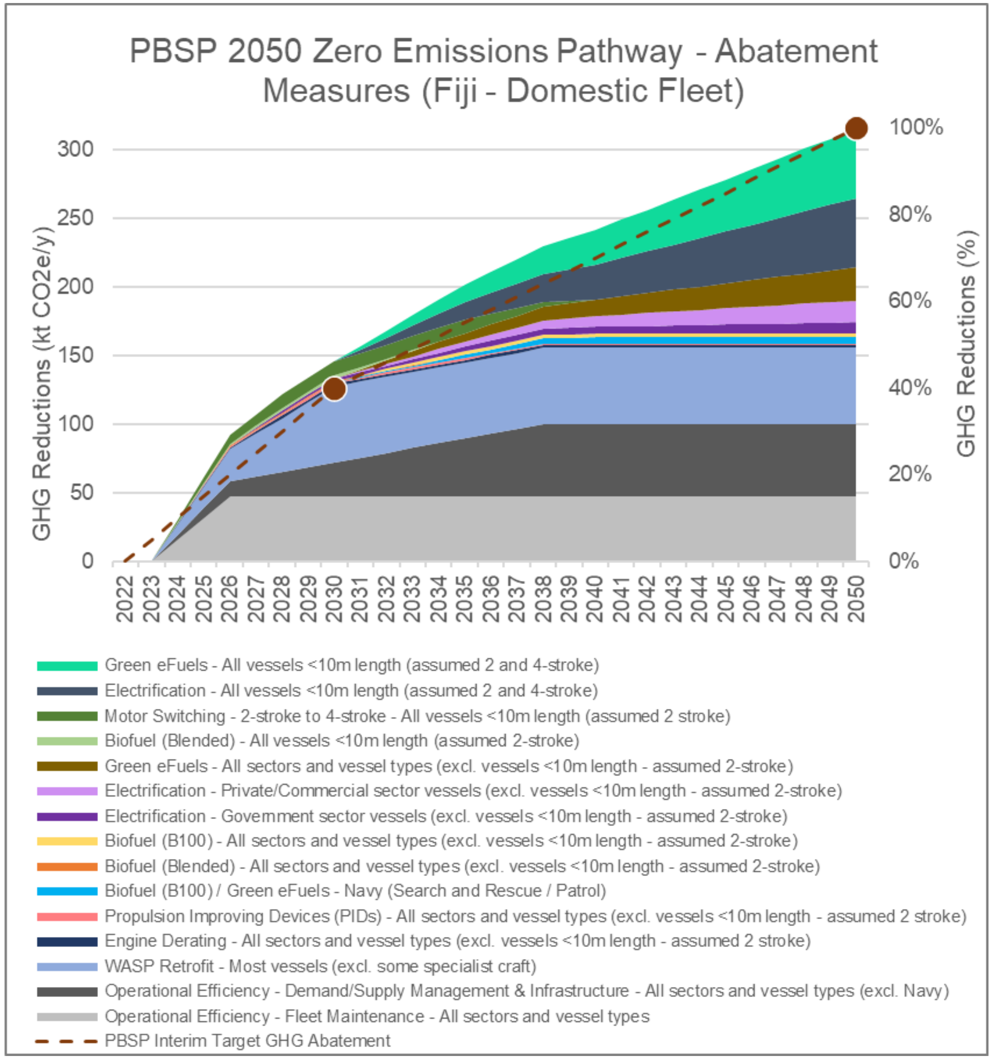


Figure 31: Proposed Zero Emissions Pathway (2023-2050)

5.2.2.3 Kiribati – Summary Baseline GHG Emissions Analysis & Proposed Zero Emissions Pathway

Key observations

- Total vessel count: 1,952 (including 2-stroke outboards), Total GHG Emissions Baseline: 33 $ktCO_2e$
- Over half the emissions are from small vessels, many of which are likely to be 2-stroke engines (exact data on 2-stroke unavailable in inventory).
- Over a third of the GHG emissions are from "passenger and cargo" vessels, presenting significant savings opportunity with passenger and cargo separation and operational measures.

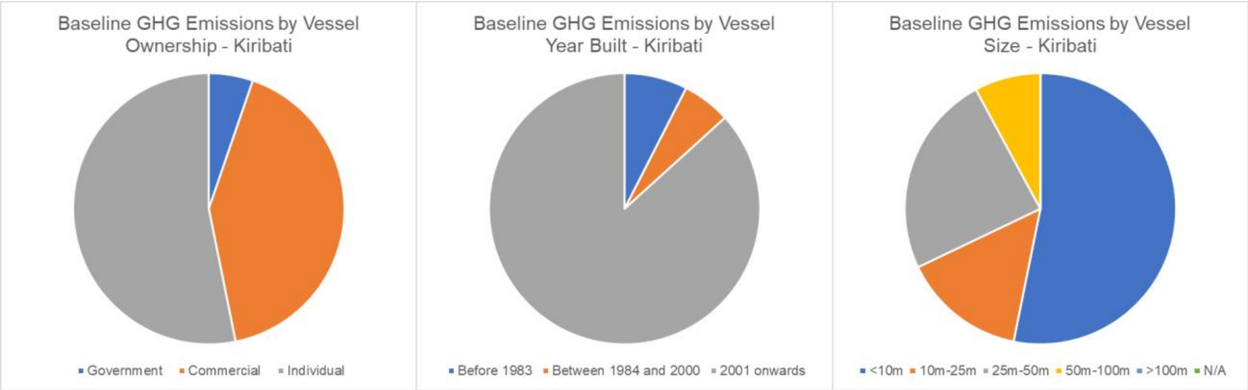


Figure 32: Distribution of GHG emissions by vessel ownership, age, and size

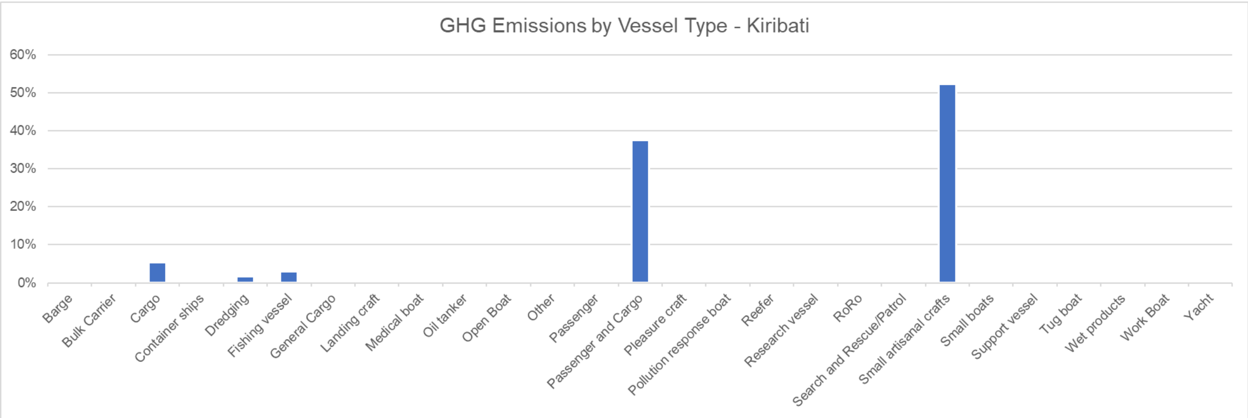


Figure 33: Distribution of GHG emissions by vessel type

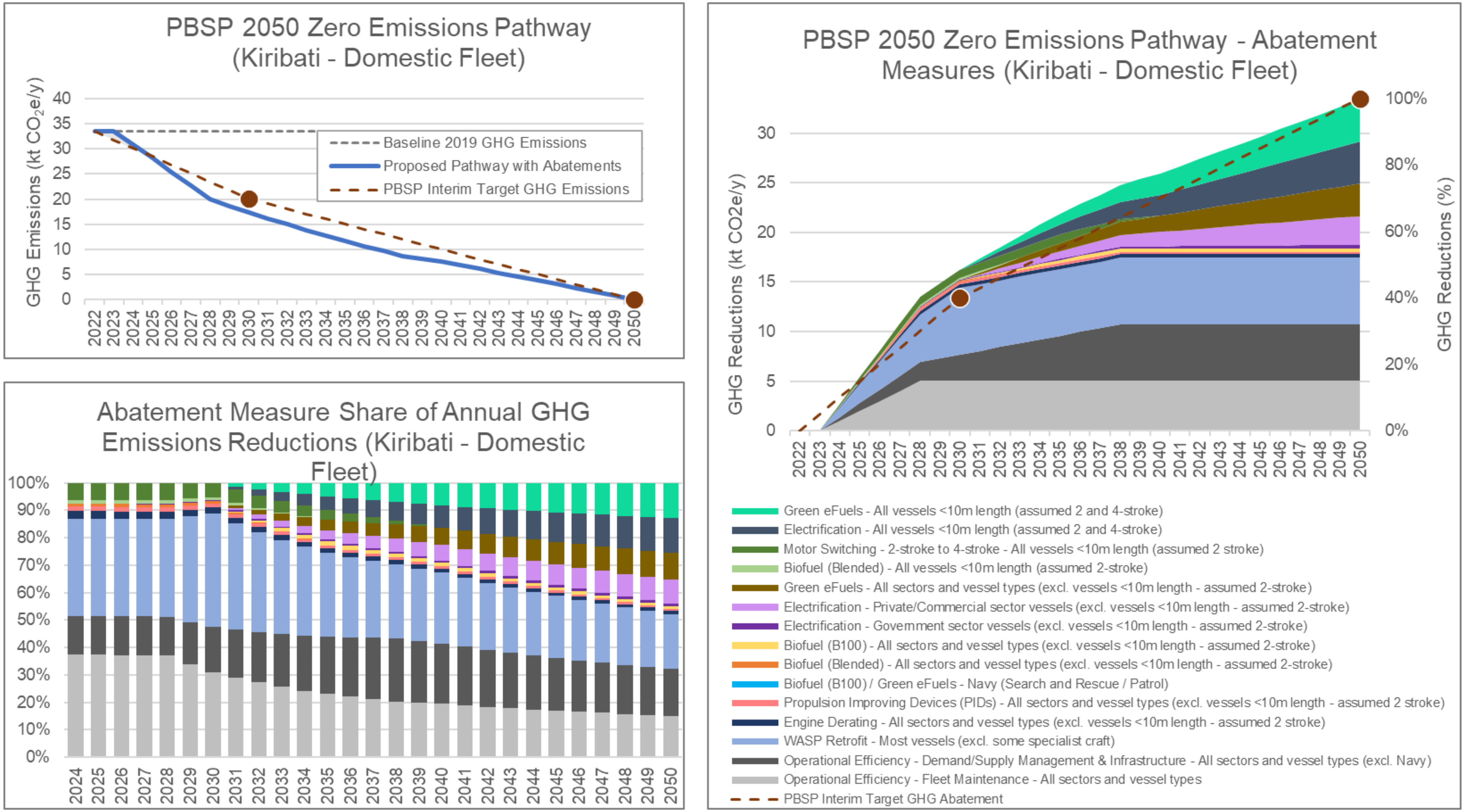


Figure 34: Proposed Zero Emissions Pathway (2023-2050)

5.2.2.4 Republic of Marshall Islands – Summary Baseline GHG Emissions Analysis & Proposed Zero Emissions Pathway

Key observations

- Total vessel count: 469 (including 2-stroke outboards, Total GHG Emissions Baseline: 8 ktCO_2e
- Classification of government fleet appears incomplete in inventory baseline.
- Almost three quarters of emissions are from vessels around 40 years old or older, suggesting a need for immediate replacement.
- A third of emissions from small vessels many of which are likely to be 2-stroke engines (exact data on 2-stroke unavailable in inventory).
- Approximately a third of the GHG emissions are from "passenger and cargo" vessels, presenting significant savings opportunity with passenger and cargo separation and operational measures.

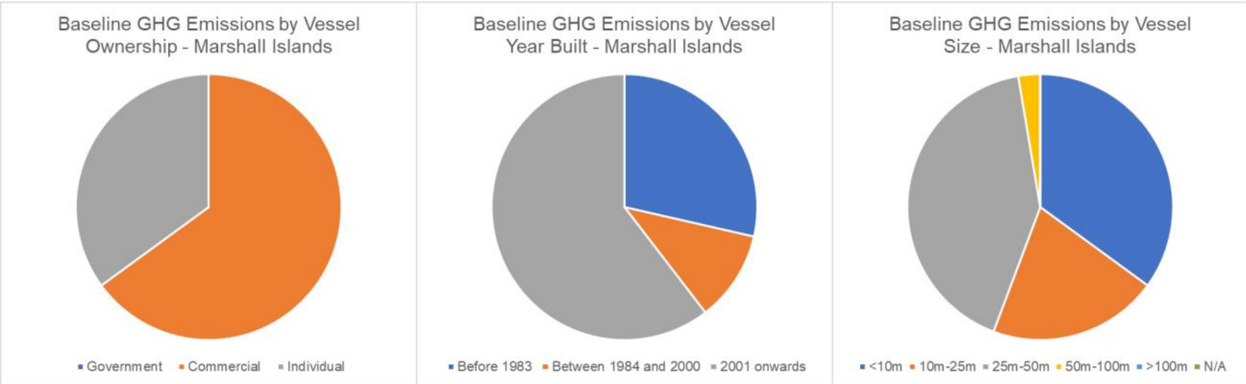


Figure 35: Distribution of GHG emissions by vessel ownership, age, and size

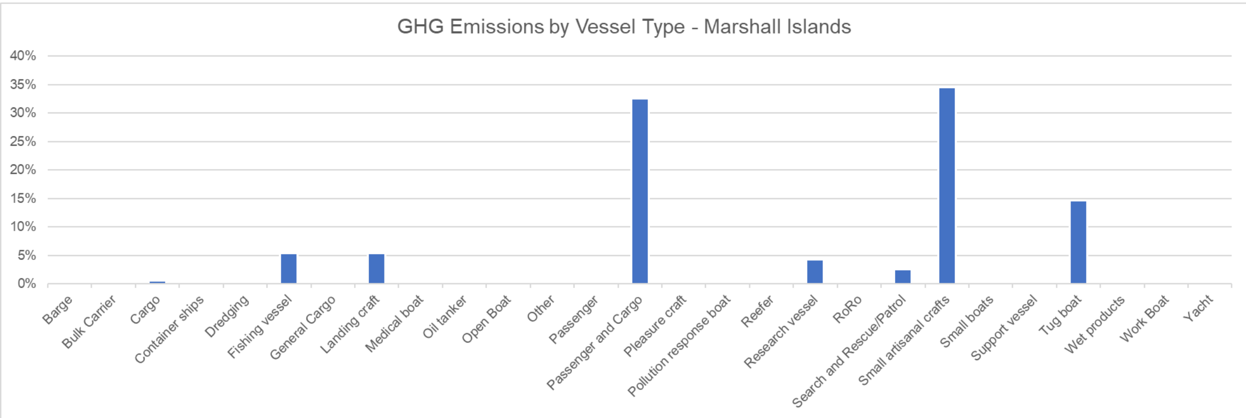


Figure 36: Distribution of GHG emissions by vessel type

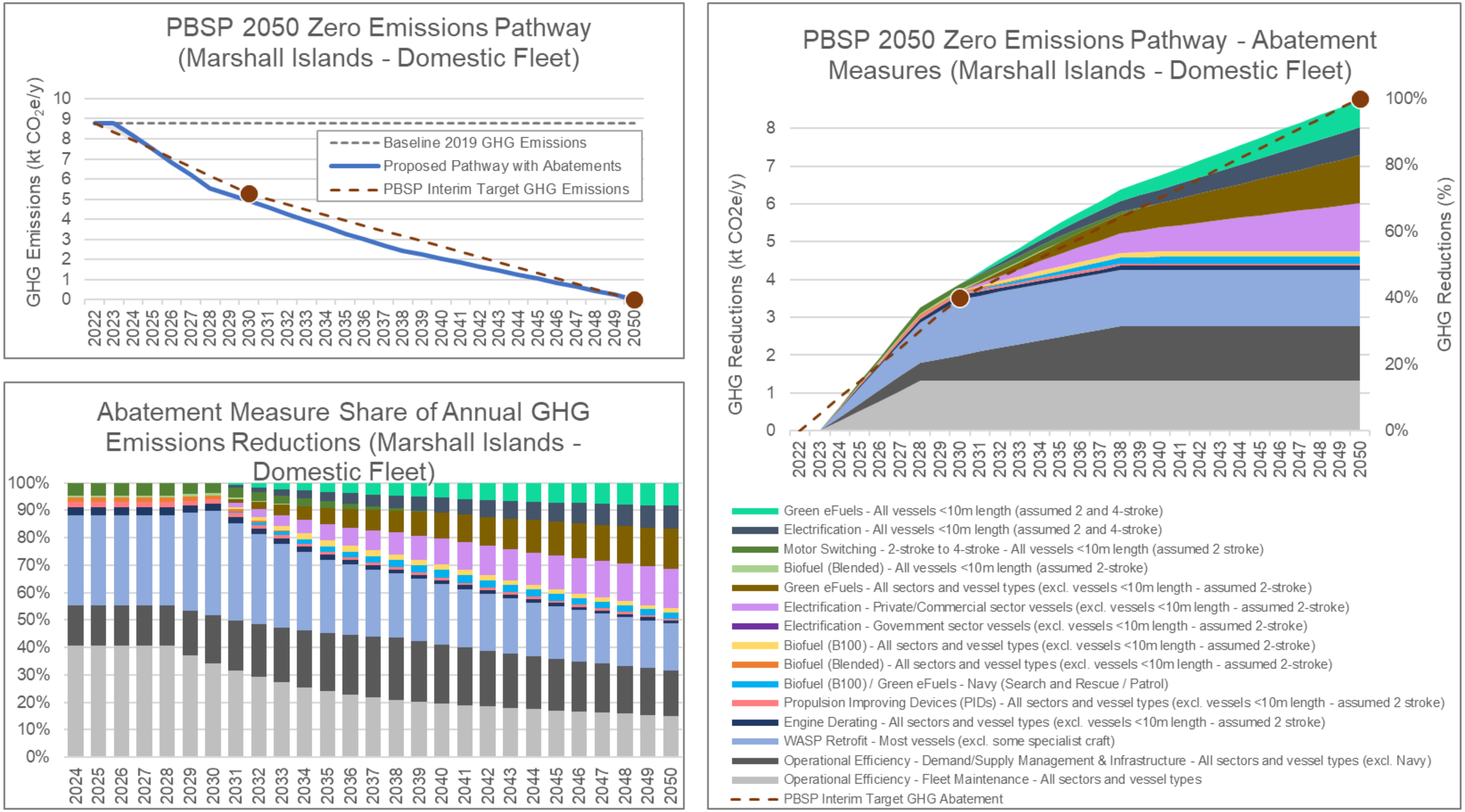


Figure 37: Proposed Zero Emissions Pathway (2023-2050)

5.2.2.5 Solomon Islands – Summary Baseline GHG Emissions Analysis & Proposed Zero Emissions Pathway

Key observations

- Total vessel count: 3,369 (including 2-stroke outboards), Total GHG Emissions Baseline: 203 $ktCO_2e$
- Classification of government fleet appears incomplete in inventory baseline.
- Approximately half the emissions are from vessels over 20 years old, suggesting a need for replacement soon.

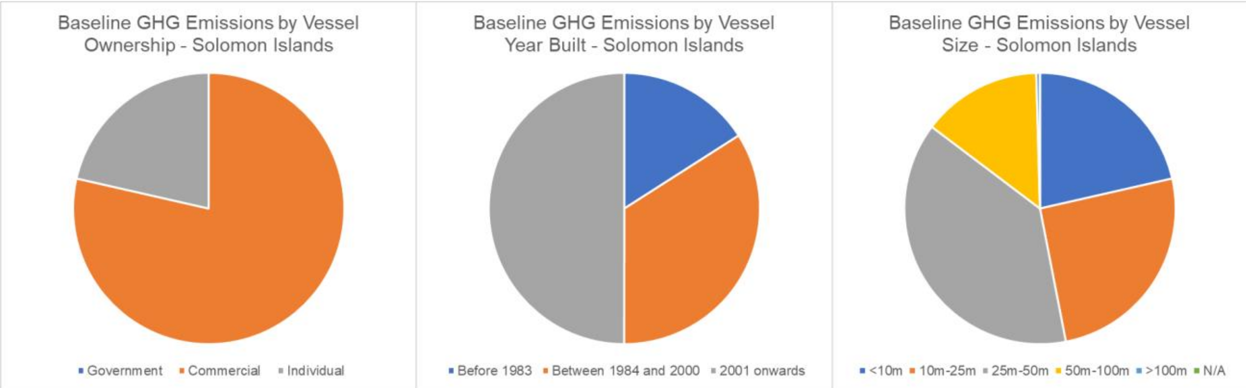


Figure 38: Distribution of GHG emissions by vessel ownership, age, and size

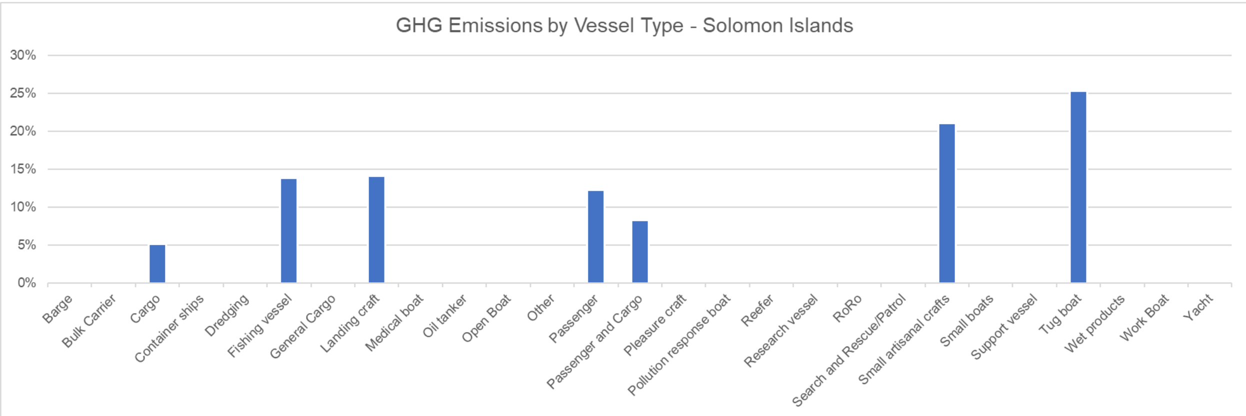
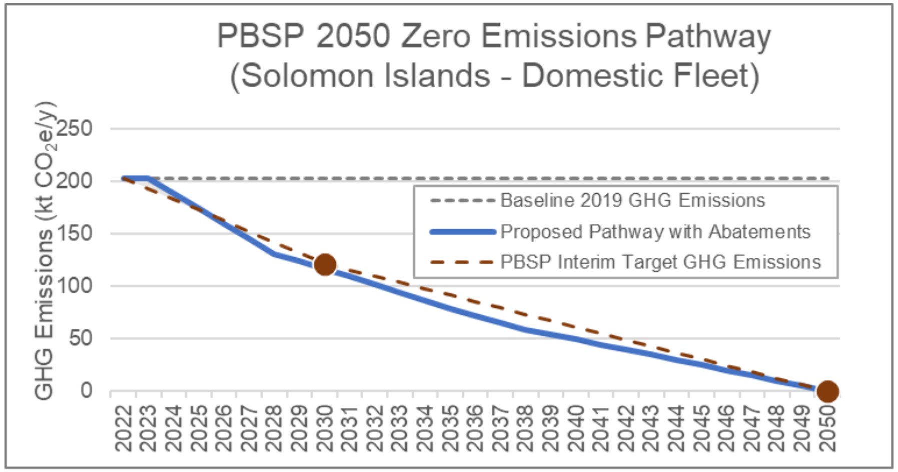
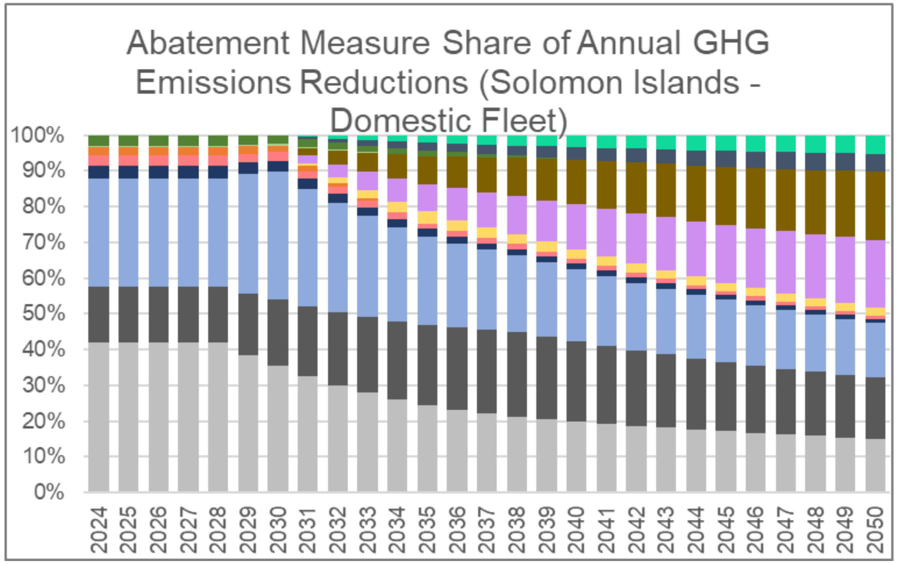


Figure 39: Distribution of GHG emissions by vessel type





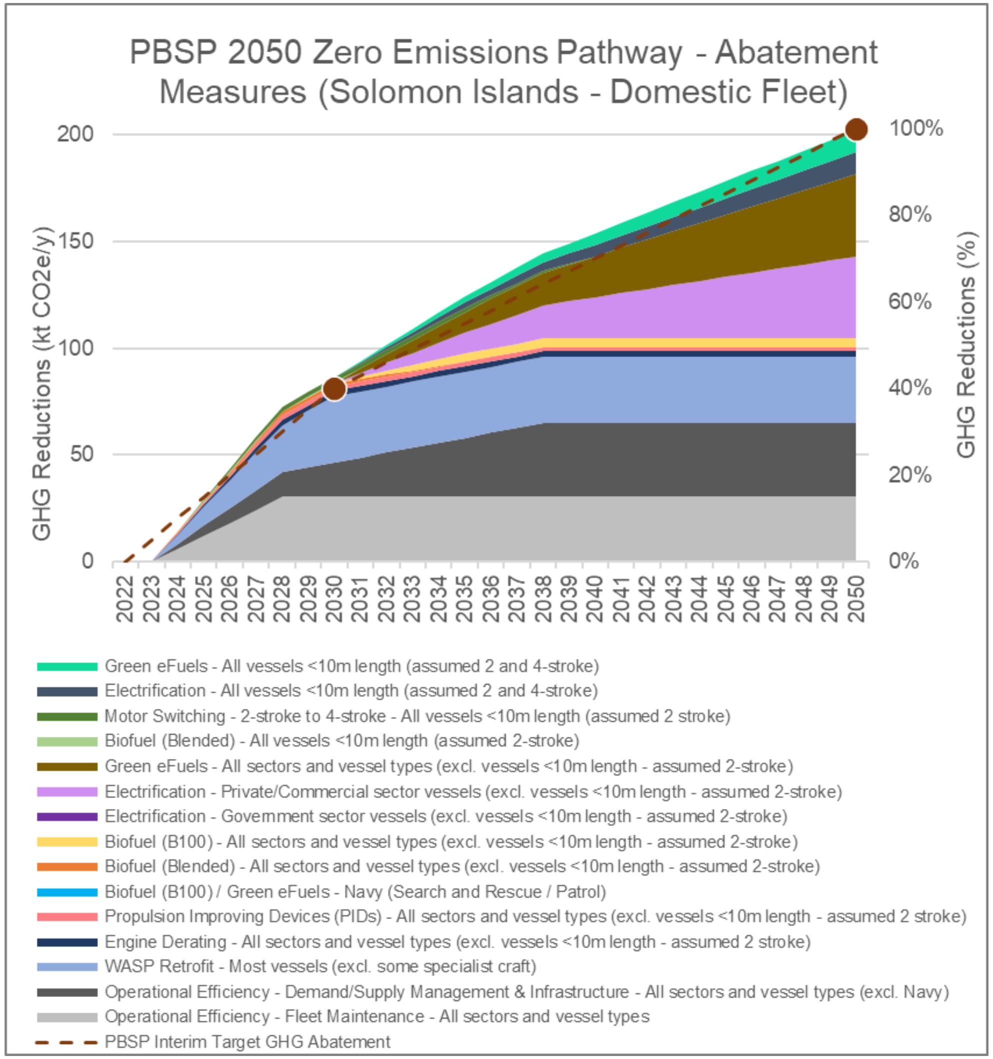


Figure 40: Proposed Zero Emissions Pathway (2023-2050)

5.2.2.6 Tonga – Summary Baseline GHG Emissions Analysis & Proposed Zero Emissions Pathway

Key observations

- Total vessel count: 604 (including 2-stroke outboards), Total GHG Emissions Baseline: 8 $ktCO_2e$
- Classification of vessel age and size is incomplete in inventory baseline.
- A third of GHG emissions are from small vessels <10 meters in baseline inventory.
- Approximately half the GHG emissions are from "passenger and cargo" vessels, presenting significant savings opportunity with passenger and cargo separation and operational measures.

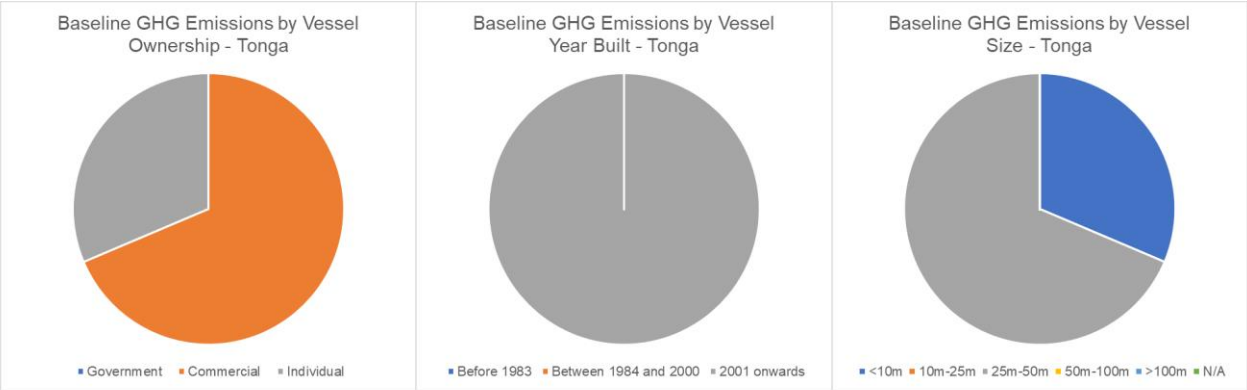


Figure 41: Distribution of GHG emissions by vessel ownership, age, and size

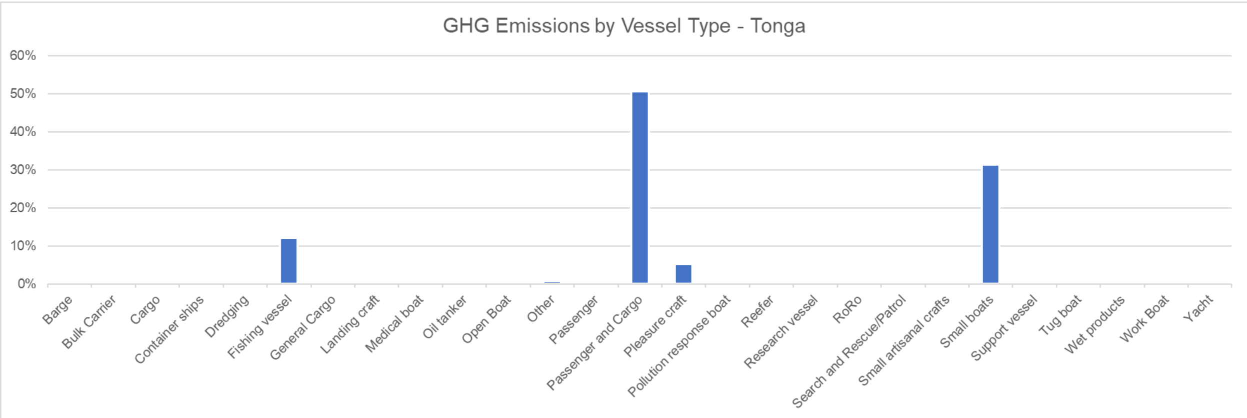


Figure 42: Distribution of GHG emissions by vessel type

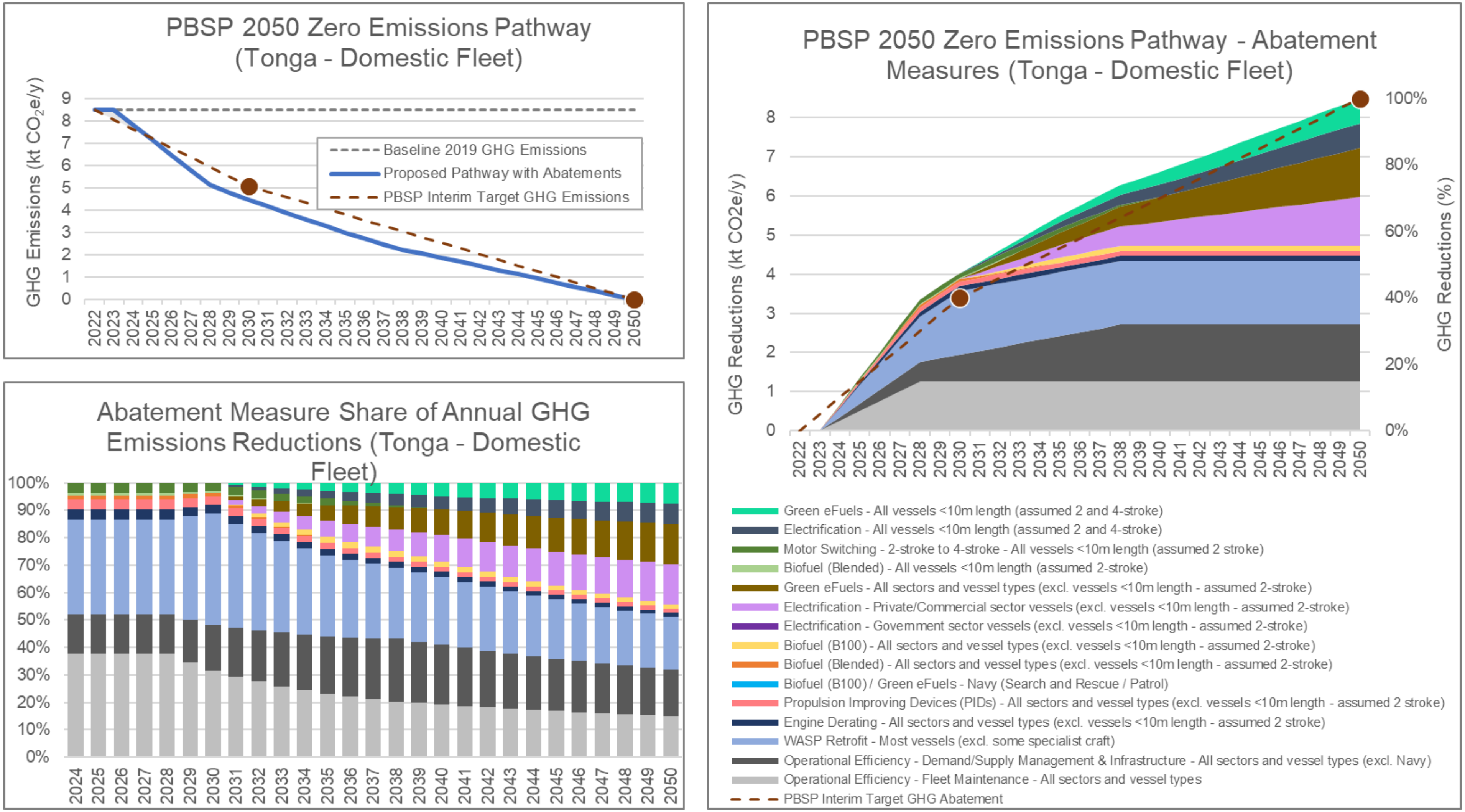


Figure 43: Proposed Zero Emissions Pathway (2023-2050)

5.2.2.7 Tuvalu – Summary Baseline GHG Emissions Analysis & Proposed Zero Emissions Pathway

Key observations

- Total vessel count: 437 (including 2-stroke outboards), Total GHG Emissions Baseline: 11 $ktCO_2e$
- Half GHG emissions are from small vessels <10 meters in baseline inventory.
- Approximately half the GHG emissions are from "Small artisanal crafts", presenting significant savings opportunity with immediate and near-term measures that address small outboard motor vessels.

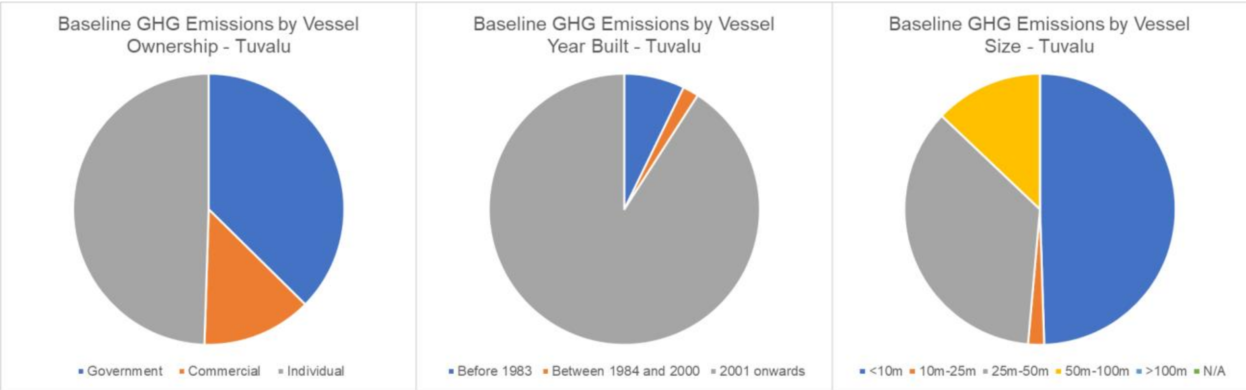


Figure 44: Distribution of GHG emissions by vessel ownership, age, and size

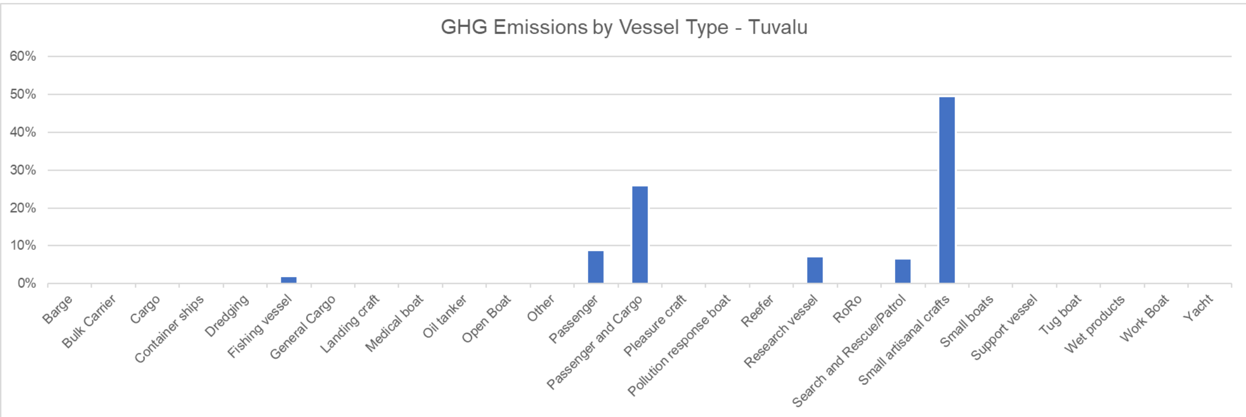


Figure 45: Distribution of GHG emissions by vessel type

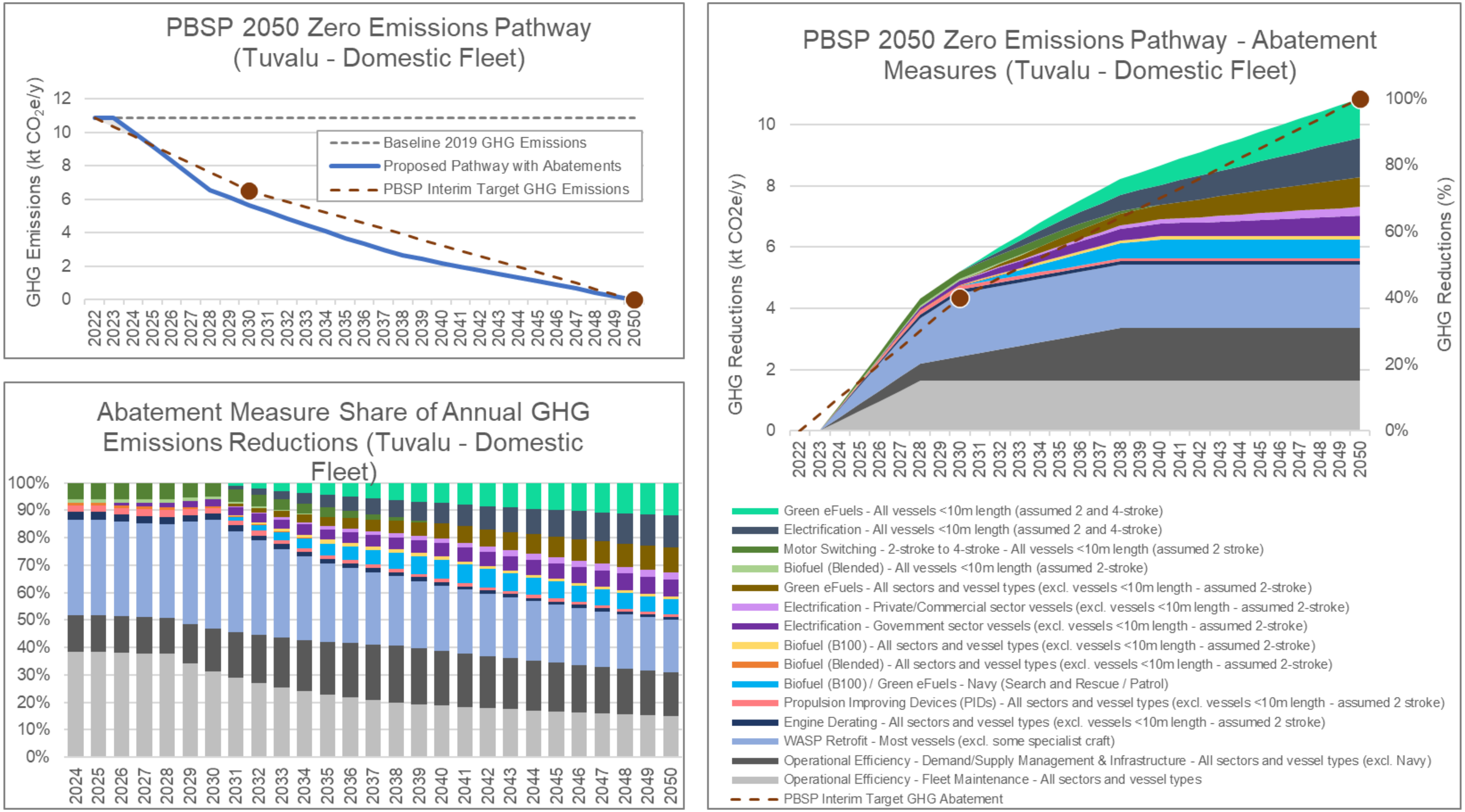


Figure 46: Proposed Zero Emissions Pathway (2023-2050)

5.2.3 Decarbonization pathway analysis – Key messages

From the assessment of potential abatement measures and the modelling of a decarbonization pathway, there are a number of key findings (messages).

1. The proposed Technical Transition Pathway includes the same abatement measures and timings across all PBSP nations, but specific countries with their fleet and their ability to harness wind may have different emissions savings for each abatement measure. The individual country's policy and roll-out of supporting mechanisms will determine how effective and how well adopted each abatement measure will be. Ongoing collaboration across the PBSP will also assist to achieve economies of scale and develop inter-country trade and knowledge-sharing opportunities surrounding each abatement measure.
2. Short-term and ongoing abatement measures (improved maintenance programs; demand-supply management, data systems, supporting infrastructure; wind-assisted ship propulsion (WASP) retrofit; engine derating; propulsion improving devices (PIDs), biofuel (blended); and motor switching) which are successfully implemented have the potential to get to 40% GHG emissions reductions by 2030, and will allow for sufficient time for long-term abatement measures involving electrification and green e-fuels to mature.
3. Long-term abatement measures to zero emissions by 2050 need to be reviewed and confirmed following an assessment of successes of short-term and ongoing abatement measures over the next 2-3 years, and a review of the mix of solutions best suited and available to PBSP nations in 2031-2050. These long-term abatement measures are likely to include a mix of electrification and green e-fuels. The proportion of fleet electrification compared to green eFuels will depend on the outcome of local pilot programs, technology development and maturity, and development of supporting infrastructure.
4. The proposed technical transition pathway includes the same abatement measures and timings across all PBSP nations, but specific countries with their fleet and their ability to harness wind may have different emissions savings for each abatement measure. For example, the GHG abatement potential of WASP in countries closer to the equator with lower wind resource (e.g., Kiribati), may be less attractive than in countries with a higher wind resource (e.g., Fiji). The individual country's policy and roll-out of supporting mechanisms will determine how effective and how well adopted each measure will be. Ongoing collaboration across the PBSP will also assist to achieve economies of scale and develop inter-country trade and knowledge-sharing opportunities surrounding each abatement measure.
5. Success of the decarbonization strategy relies not just on the initial Capital Expenditure (CAPEX) investment, but also providing support for ongoing Operating Expenditure (OPEX). This may include cash or discount incentives to operators to service their ship engine as part of an improved fleet maintenance program.
6. The technical transition pathway should not be considered in isolation of other sectors, particularly given the competing needs for land for agriculture and renewable energy generation. The ultimate goal is to achieve self-sustaining value chains and minimize the reliance on imports from outside the Pacific Island Countries.
7. Since operational measures primarily can get to 40% by 2030 it is possible that the fossil fuel import dependence is also reduced by more than 40% by 2030, however, as fuel expenses reduce due to improved efficiencies, there is a risk of operators to consume more fuel based on the savings achieved (i.e., the so-called "rebound effect"[43]). Total Baseline Regional fuel use is estimated at around 190k tonnes per year and a 40% GHG reduction implies significant savings to the economies of the PBSP nations in terms of imports subject to any rebound effect.
8. It is essential to have local proof of concept of all measures (including electric outboards, batteries, and green e-fuels) to better understanding operational needs, performance, and assurances of local demonstration for funding.

[43] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816020/potential-role-targets-economic-instruments.pdf

9. It is important to ensure that abatement measures are phased in and out in coordination with other abatement measures to reduce redundancy and waste of funds. In particular:
    a. identifying which existing vessels to upgrade/convert versus scrapping vessels and replacing with purpose-built new builds (electric or green eFuel).
    b. investment in motor switching from 2-stroke to 4-stroke outboards, given that the replacement 4-stroke motors will need to be transitioned to electric or green eFuels in the long-term to achieve zero emissions.
    c. investment in abatement measures that are compatible and complimentary to each other, for example, improved maintenance programs, demand-supply management, data systems, supporting infrastructure, and the operation of WASP freight/passenger vessels.
10. The role of blended biofuels is temporary and estimated to involve a regional amount of 1,500t of coconut oil as a 20% blend in total of 7,500t of blended fuel. This relatively small quantity of required coconut oil could be low enough to be produced locally (i.e., redirecting a 5-10% share of existing coconut oil exports) noting that Pacific Island countries (PICs) such as PNG, Vanuatu and the Solomon Island could be the primary suppliers with other PICs having to import (inter-PIC trade). After blended biofuel is phased out, conservatively the remaining coconut used to blend could be used in a minor way as 100% biofuel so as not create a need for additional imports at higher costs or massively invest in growing and processing by the PICs for biofuel use versus more lucrative value-added uses.
11. For those future measures that involve green eFuels and require large-scale industry facilities and high investments for production, it would be advisable for PBSP to monitor developments in the Pacific-Rim area (i.e., plans in Australia/New Zealand, PNG, Asia and North America) with regard to the likelihood and opportunity of PICs obtaining early, guaranteed supply at affordable prices of these types of future green eFuels. One-way could be to link a local trial (proof of concept) of a technology to an existing pilot supply from overseas to also test future supply-chains and local infrastructure needs.
12. Based on Fiji cost levels, the current cost of electric energy is more expensive than fossil fuels, and therefore would need incentivization to support this transition (refer Section 6.10 of GHD's Blended Finance Roadmap).
13. The regional and country fleets are predominantly made up to smaller vessels (less than 10m length) which are likely to be artisanal craft with 2-stroke outboards and privately owned by individuals. This has significant implications for the funding mechanisms more likely to be successful compared to funding mechanisms for the government sector (refer Sections 6.5 and 6.10 of GHD's Blended Finance Roadmap).
14. Level of financial savings will vary between countries due to the relative size of fleet and composition and level of fuel and electricity prices (compared to Fiji prices as used in this analysis). For instance, the cost of fuel of the Republic of the Marshall Islands is significantly greater than that in Fiji, which would suggest that WASP would have a greater pay-back return for its investment, than on a Fiji vessel.
15. Since the operational measures are critically dependent on slipways and ship lifts in the region, and a 3–5-year maintenance cycle is recommended to ensure operational savings are maintained, initial investment in these facilities and systems must be prioritized.
16. A high-level assessment the slipway capacity across PBSP countries has indicated a shortfall of about 6-10 slipways across the PBSP. Additional slipways as well as detailed understanding of capability and condition of existing slipway assets is required to determine the extent of additional investment required.

6 Associated infrastructure needs

6.1 Vessel associated infrastructure requirements

The vessel fleets form the primary level of assets, however, there is also a secondary level consisting of vessel-associated infrastructure requirements. This secondary level is discussed in this section. There is also a third level (finance, research, policy) which is covered in the Blended Finance Roadmap.

A number of the proposed abatement measures require vessels to be modified. This includes the regular servicing of vessels to improve operating efficiency, as well as the retrofitting or the installation of alternative vessel propulsion (WASP, bio-fueled or electric) systems. This section focusses on the infrastructure needed to apply the proposed abatement measures to the vessel fleet.

These tasks would be most efficiently and safely achieved at a dedicated vessel slipway or ship lift and associated vessel maintenance facility. The size and capacity of the required facility will depend on the vessels to be serviced and/or modified.

Some of the abatement measures also require upstream infrastructure to support their deployment. This includes the supply of alternative fuels (e.g., biofuels and electricity). An understanding of the associated infrastructure requirements requires detailed analysis of the production capacity, distribution and re-fueling or charging infrastructure to provide sufficient capacity to support the long-term deployment of these measures. These studies are beyond the scope of GHD's engagement.

6.2 Existing inventory

A desk-based review indicates there are 20 slipways in the partner countries. A summary of the slipways in Fiji, Kiribati, Republic of the Marshall Islands, Solomon Islands, Tonga and Tuvalu are shown on Figure 47.

Table 12 summarizes the available data on the existing inventory of slipways in the partner countries.

Figure 47: Summary of existing slipway assets in PBSP countries

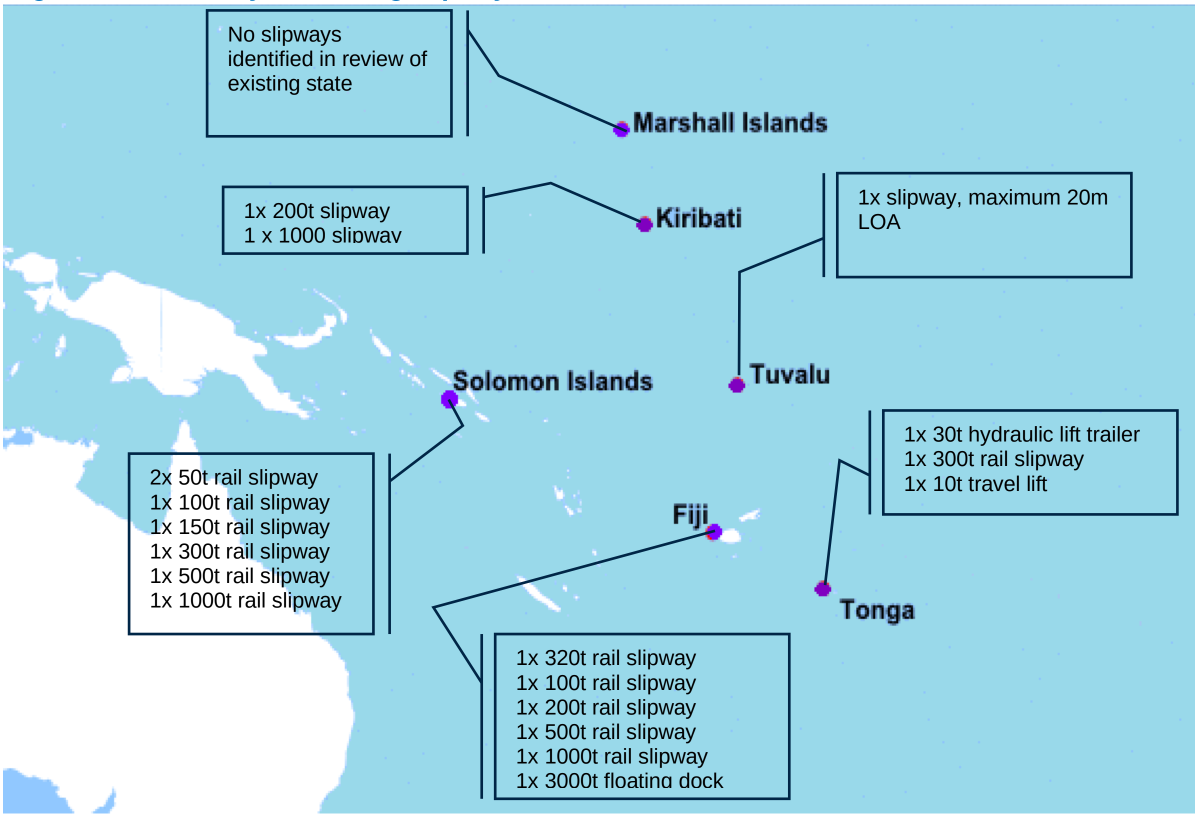


Table 12: Summary of existing slipways in PBSP member countries

Name	Capacity (DWT)	Cradle length (m)	Vessel Beam (m)	Vessel draft (m)	Condition	Owner/operator	Status
Fiji							
South Sea slipway, Suva	320	32.5	9.5	3.8	No data available	Solander (Pacific) limited	Operational
Fiji Ships & Heavy Industries Ltd (FSHIL), Suva	100	21	5.5	No data available	"Reported constraints due to condition with plan to rehabilitate"	Fiji Ports Corporation Ltd	Operational
FSHIL, Suva	200	23	7.0	No data available	"Reported constraints due to condition with plan upgrade to 500t capacity"	Fiji Ports Corporation Ltd	Operational
FSHIL, Suva	500	46	11.0	No data available	"Reported constraints due to condition with plan to rehabilitate"	Fiji Ports Corporation Ltd	Operational
FSHIL, Suva	1000	65	13.0	No data available	No data available	Fiji Ports Corporation Ltd	Operational
Industrial and Marine Engineering Ltd, Suva	3000	80	No data available	No data available	No data available	Industrial and Marine Engineering Ltd	Operational
Kiribati							
Betio Shipyard Limited, Tarawa (Non-Operational)	200	27	8	No data available	No data available	Betio Shipyard Limited	Operational
Betio Shipyard Limited, Tarawa (Non-Operational)	1000	50	12	No data available	No data available	Betio Shipyard Limited	Operational
Republic of Marshall Islands (RMI)							
No data available.							
Solomon Islands							
Sasape International Shipyard Tulagi	500	50	No data available	No data available	No data available	Silentworld Shipping and Logistics Ltd	No data available
Sasape International Shipyard Tulagi	100	25	No data available	No data available	No data available	Silentworld Shipping and Logistics Ltd	No data available
Liapari Ltd. Western Province	150	No data available	No data available	No data available	Aging infrastructure	No data available	No data available

Name	Capacity (DWT)	Cradle length (m)	Vessel Beam (m)	Vessel draft (m)	Condition	Owner/operator	Status
Liapari Ltd. Western Province	50	No data available	No data available	No data available	Aging infrastructure	No data available	No data available
Liapari Ltd. Western Province	50	No data available	No data available	No data available	Aging infrastructure	No data available	No data available
Taroniara, Ngella	300	No data available	No data available	No data available	No data available	Anglican Church of Melanesia	No data available
Markworth's Shipping facility at Ave	1000	80	20	5.5	Good: Recently upgraded	Avi Avi Marina Limited	No data available
Tonga							
Vava'u Boatyard, Neiafu	Of hydraulic lift trailer (30MT)	20	No data available	No data available	No data available	No data available	No data available
Slipway, Faua harbour Nuku'alofa, Tongatapu Island	300 (likely <100t)	30	10.0	2.5	'Disrepair': advanced erosion at tidal zone and corrosion of running gear (as of 2017)	Port Authority Tonga	Operational
Travel-Lift, Nuku'alofa, Tongatapu Island	Advertised (10t) Evaluated (5-6t)	Advertised (12m) Evaluated (8-10m)	Advertised (5m) Evaluated (4m)	Advertised (1.5m) Evaluated (1.0m)	'Subject to high risk of collapse into the sea under load'	Port Authority Tonga	Operational
Site of the existing Friendly Islands Shipping Agency ferry terminal.	2000	60-70	13-16	4-6	No data available	Friendly Islands Shipping Agency	Planned investment (as of 2017)
Tuvalu							
Fisheries infrastructure for Funafuti (incl. slipway repair)	No data available	Limited to vessels under 20m	No data available	No data available	No data available	No data available	No data available

Based on this inventory, GHD has undertaken a strategic level assessment of the total slipway provision across the six PBSP member countries to support the vessel maintenance and retrofit activities that are required to implement the decarbonization pathways.

A comparison of the vessel fleet with the physical constraints (i.e., capacity, cradle length and beam, where available) of the member country slipways indicates that:

– The physical constraints of the slipways in Fiji can accommodate all vessels in its fleet except for three vessels that are too long.
– The physical constraints of the slipways in Kiribati can accommodate all vessels in its fleet except for 10 vessels that are too long.
– GHD has found no data on slipway assets within the Republic of the Marshall Islands. Based on the data available, none of the slipways in the other partner countries can physically accommodate domestically operating Republic of the Marshall Islands fleet as captured in the UCL baseline data. These vessels would need to be serviced in neighboring countries.
– The physical constraints of the slipways in Solomon Islands can accommodate all vessels in its fleet.
– The physical constraints of the slipways in Tonga mean it cannot accommodate the two vessels in its fleet that require slipping.
– The physical constraints of the slipways in Tuvalu can accommodate all vessels in its fleet except for four vessels that are too long.

GHD has looked at the slipway utilization required to undertake the proposed vessel servicing. We have assumed:

– Slipways and maintenance infrastructure operate 52 weeks per year, apart from a total of 2 weeks of annual public holiday.
– Only vessels longer than 10m will require access to a slipway. All smaller vessels could be serviced at berth.
– All vessels that need to be slipped, will be slipped for maintenance at least once every 3 years.
– Abatement measure equipment will be fitted at the first slipway visit, within the first three years in parallel with routine maintenance. This will require:
  – 4 weeks of slipway time for vessels less than 25m length
  – 6 weeks of slipway time for vessels greater than 25m length
– Subsequent visits will be for regular maintenance and will require:
  – 3 weeks of slipway time for vessels less than 25m length
  – 5 weeks of slipway time for vessels greater than 25m length
– Vessel maintenance is actively managed to achieve an average 1 week of slipway time between vessels.
– A vessel would be accommodated in its home country (as identified on the Baseline Data) where possible. If this is not possible, it would be slipped at a suitable facility in another partner country.
– Slipways have the required capability and are in an appropriate state of repair.
– Where slipways are sufficiently long, up to two vessels can be slipped together.

Figure 48 shows the results of this assessment which indicates slipway utilization at a regional level of 147% for the initial three years when abatement measures are retrofitted, dropping to about 129% for routine maintenance visits.[44]

The slipway inventory identifies about 19 operating slipways. Based on these assumptions, this assessment amounts to a shortfall of about 6-10 slipways across the region. A detailed siting study

[44] Tonga is the outlier because the baseline data includes about 54 vessels longer than 25m slipped per year, but with only one in-country slipway that can accommodate them.

would be required to inform the cost provision for these slipways, which is beyond the scope of GHD's engagement.

A detailed assessment of infrastructure condition, capability and operating constraints was not included in GHD's scope of work. No data on operating times, resourcing, typical service times nor any details on the condition (other than as noted in Table 12) has been sighted as part of this work. These factors will all reduce the available slipway time. A detailed review of condition and operational constraints is required to identify any shortfall in slipway capacity which would adversely impact this assessment, and to propose appropriate infrastructure to provide the capacity necessary to achieve the technical transition pathway in the assumed timeframes.

Based on this assessment and the limited data presented in Table 12, it is reasonable to assume that additional investment will also be required to improve capability of existing slipways in PBSP countries. In the absence of a detailed review, there is no basis to quantify the extent of any intervention needed, nor the associated capex provision. Such capital provision would be in addition to the capital funding requirements identified in this report.

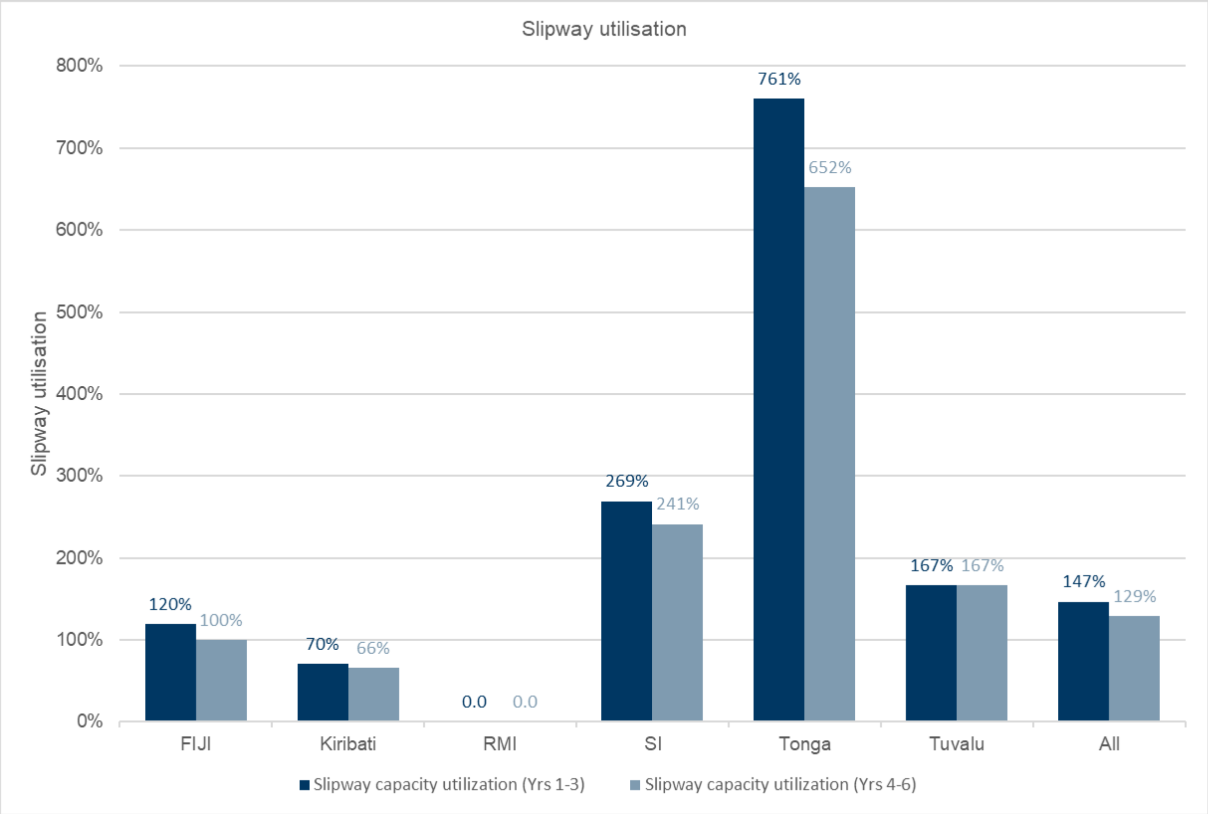


Figure 48: Slipway utilization

7 CAPEX and OPEX

Table 13 summarizes the CAPEX and OPEX associated with the abatement measures in the report broken down by each country. Please note that the timeframe for the allocation of the CAPEX and OPEX has been adjusted to align with 5+5-year financing plan (2023-2027 and 2028-2032) and beyond (2033-2050) as per the Blended Finance Roadmap.

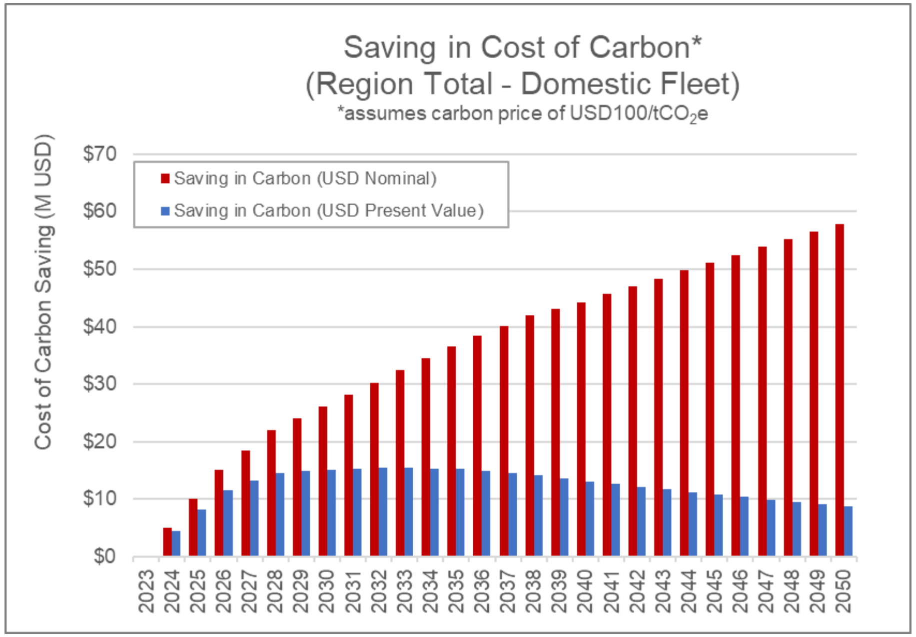
The CAPEX and OPEX data shown in Table 13 is the total for the relevant time period (e.g., the 5 years 2023-27). The total CAPEX for all abatement measures in 2023-27 is USD 214M delivering a net OPEX saving of USD 42M. The total CAPEX for all abatement measures in 2028-32 is USD 302M delivering a net OPEX saving of USD 75M. The total CAPEX for all abatement measures in 2033-50 is USD 884M with a net OPEX saving of USD 4M. It is noted that the major contributor to the long-term costs is the new purpose-built electric vessels and associated batteries.

Note the OPEX savings does not include the financial value of carbon abatement, i.e., there is no carbon price avoided due to reductions in emissions. However, for reference if a hypothetical global carbon price of USD100/tCO_2e is assumed, a potential saving of USD 1B (nominal value) may be achieved over the time period 2023 to 2050 (approximately USD 350M in 2022 present value).

Table 13: Regional Total CAPEX and OPEX for each abatement measure

Abatement Measure	Vessel Count	CAPEX / OPEX (USD$M)						Comment
		Immediate (2023-2027)		Near-term (2028-2032)		Long-term (2033-2050)		
		CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX	
Improved Maintenance Programs - All sectors and vessel types	12,208	-	-12.1	-	-10.6	-	-18.6	Based on a 3-year maintenance cycle. The ship lifts & port infrastructure is also included.
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	12,202	3.5	-9.7	3.3	-25.6	2.7	-89.4	High initial cost to establish information systems, software and data sharing implemented. Funding required to establish information systems, recruiting personnel, consistent cargo logging systems. Annual OPEX assumed to be 20% of initial system investment.
WASP Retrofit - Most vessels (excl. some specialist craft)	11,824	172.7	-13.3	122.2	-32.1	97.6	-62.1	Retrofitting existing vessels initially. When electrification and green e-fuels are introduced, the new vessels will require WASP installation again to ensure ongoing efficiency gains from WASP.
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	440	6.8	-1.7	1.4	-3.3	-	-5.8	Funding required for all large vessels where the operating speed is less than the engine design speed. New vessels joining the fleet are assumed to have equivalent efficiency gains due to more modern designs.
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	261	1.4	-1.2	1.4	-2.4	1.4	-4.1	Assume retrofit to all large vessels. New vessels assumed to be of more modern design and incorporate technologies equivalent to PID retrofits with associated efficiency gains.
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	76	-	0.6	-	1.0	-	0.1	Investment into local biofuel markets to ensure reliable supply chain to meet the nominated demand and reduce reliance on international markets (noting biofuels applied to a small proportion of total fleet only).
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	38	-	-	0.1	0.3	0.1	4.0	Investment into local biofuel markets to ensure reliable supply chain to meet the nominated demand and reduce reliance on international markets (noting biofuels applied to a small proportion of total fleet only).
Electrification - Government sector vessels (excl. vessels	15	5.5	0.3	11.0	2.2	19.2	11.6	Planning for pilot testing to begin in 2023, in preparation for wider-scale rollout from 2025 if successful. Old vessels are less likely to suit retrofitting of electric motor only, therefore costs represent new

Abatement Measure	Vessel Count	CAPEX / OPEX (USD$M)						Comment
		Immediate (2023-2027)		Near-term (2028-2032)		Long-term (2033-2050)		
		CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX	
<10m length - assumed 2-stroke)								purpose-built vessels. Costs include batteries and port charging facilities.
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	347	-	-	66.1	1.8	321.1	58.6	Planning for pilot testing to begin in 2023, in preparation for wider-scale rollout from 2030 if successful. Old vessels are less likely to suit retrofitting of electric motor only, therefore costs represent new purpose-built vessels. Costs include batteries and port charging facilities.
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	362	-	-	65.1	1.6	316.6	50.0	Planning for pilot testing to begin in 2025, in preparation for wider-scale rollout from 2030 if successful. Long-term rollout will be balanced with fleet electrification and minor contribution of biofuel (B100).
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	1,144	-	0.4	-	0.7	-	0.1	Investment into local biofuel markets to ensure reliable supply chain to meet the nominated demand and reduce reliance on international markets (noting biofuels applied to a small proportion of total fleet only).
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	5,720	24.3	-5.3	5.1	-10.2	-	-7.2	Assumed 50% of all 2-stroke switch to 4-stroke motors over a 5-year phase in period. These new motors to be fully replaced by electric / green eFuel motors by 2050.
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	5,720	-	-	20.1	1.0	97.5	32.4	Smaller motors readily available for retrofit, therefore pilot projects will test charging capability based on real use. Costs include batteries and port charging facilities. All small vessels to meet 2050 zero emissions target through either electrification or green e-fuels.
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	5,720	-	-	4.3	0.7	21.0	23.7	Planning for pilot testing to begin in 2025, in preparation for wider-scale rollout from 2030 if successful. All small vessels to meet 2050 zero emissions target through either electrification or green e-fuels.
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	6	-	-	2.4	0.1	6.8	3.1	Investment into local biofuel markets to ensure reliable supply chain to meet the nominated demand and reduce reliance on international markets (noting biofuels applied to a small proportion of total fleet only). Alternatively, green e-fuels option for navy will depend on technology maturity and future applicability to PICs, and the success of the pilot projects.
Total		**214.3**	**-42.1**	**302.4**	**-74.7**	**884.0**	**-3.7**	



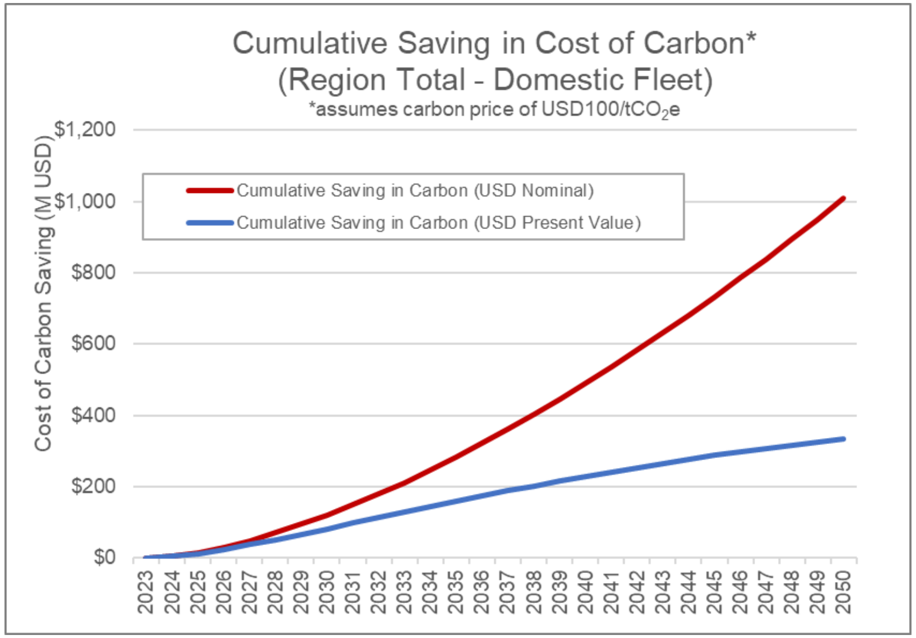


Figure 49: Saving in cost of carbon each year (left) and cumulative total (right)

8 Conclusions and recommended next steps

8.1 Conclusions relating to technical risks and challenges

The main short term technical transition risks and challenges to implementing the decarbonization pathways include:

1. The requirement for safeguarding the baseline emissions level in terms of any future replacement of vessels, i.e., any gifted or second-hand vessels procured must have emissions reductions technologies already installed. A further example is to halt the gifting or purchase of 2-strokes through policy settings.
2. Electrification and green e-fuels (including hydrogen, ammonia, etc.) are not specifically identified and supported in NDCs. Some NDCs such as for the Solomon Islands, Tonga and Tuvalu provide only targets without any abatement measures– this may need review by governments concerned as a starting point.
3. Detailed review of capability and condition of existing slipway assets, together with siting and feasibility studies for new slipways to determine the extent of potential investment (CAPEX) in dedicated port infrastructure.
4. Freight route efficiency improvements will require further integration with landside logistics and infrastructure such as warehousing, information systems, and electronic data visibility.
5. Effective implementation and monitoring of transition will require improved data-gathering systems at the country level, including performance of the transition plans.
6. As part of the supply/demand optimization, a requirement for potential investment (CAPEX) to allow possible separation of cargo and passengers at the port which unlocks barriers to efficiency.
7. WASP benefits are location specific as they are dependent on local wind conditions, which means that WASP solutions will need to be hybrid technologies in their approach, based on trialing / proof of concepts in each PBSP country.
8. Biofuel has risks associated with competition with local food supply as well as continued dependence on import where there are shortfalls in local production. It will be critical that conflict with food production on arable land is well managed. There is requirement for potential investment (CAPEX) to scale up biofuel production.
9. Global supply chain limitations for availability of specific technologies (i.e., 4-stroke motors to replace existing 2-stroke stock).
10. Additional policy settings will be required to achieve rapid update of new technology (refer to Sections 6 and 9 of GHDs Blended Finance Roadmap).

8.2 Recommended next steps

The proposed next steps for the technical aspects of the decarbonization pathway include:

1. Improve the baseline data with respect to vessel ownership (particularly government-owned vessels), length, and kW. Completeness of data relating to engine type, specific fuel consumption, annual time at sea, and fuel type will also improve inventory baseline and associated cost modelling. In addition, fuel consumption data for small vessels (<10m length) while in port and idling should be reviewed.
2. Review of relevant pilot studies. E.g., WASP, ammonia fuel/hydrogen/electric craft/ charging and storage and identify the next steps to allow for expansion and commercialization.

3. Conduct additional pilot studies (as required for local proof of concept) E.g., WASP, ammonia fuel/hydrogen/electric craft/ charging and storage and identify the next steps to allow for expansion and commercialization.
4. Socialization of abatement measures with policy makers to ensure integration of abatement measures into national policy documents.
5. Provide complete fleet data for vessel age and type, ownership, motor type and fuel type. It is noted that for some countries, this information was not available or incomplete. In addition to this, almost all vessels (even small craft) have been assigned Heavy Fuel Oil (HFO) as the primary fuel type in the baseline inventory.
6. Refinement of the Multi-Criteria Analysis (MCA) process to ensure aspects such as land use conflict (solar vs. food security) and availability of biofuels and green e-fuels to be imported or produced on the islands is considered.
7. Identify specific training needs and delivery requirements for short term abatement measures including improved fleet maintenance, WASP retrofit, engine derating and PIDs and biofuel production.
8. Refining abatement measures to be country specific taking into account their respective Nationally Determined Contributions (NDCs) and other policy initiatives.
9. Refine technical options based on likely wind conditions for WASP, land availability to install solar, port area required for infrastructure and supply lines for equipment, materials and fuels to the islands.
10. Detailed review of capability and condition of existing slipway assets, together with siting and feasibility studies for new slipways to determine the extent of potential investment (CAPEX) in dedicated port infrastructure.
11. The identification of short term and long-term financing options (e.g., subsidies, grants, loans etc.) to suit the corresponding abatement measure (covered in Section 6 of GHD's Blended Finance Roadmap)

Appendix A: Abatement Sheets

<table>
<tr><td>Project Data Sheet</td><td colspan="13">Improved Maintenance Programs - All sectors and vessel types</td></tr>
<tr><td>Detailed Description</td><td colspan="13">This project involves Improved Maintenance Programs for All vessels (incl. 2-stroke outboards) to provide improved vessel efficiency.
Applies to all vessels based on the minimum maintenance needs of all vessels for optimum efficiency.
Conservatively assumes 15% average fuel consumption & emissions savings. However, studies into the effect of biofouling on ship efficiency by GloFouling Partnerships in collaboration with the UNDP and the IMO suggests a decrease of efficiency of up to 55% in extreme cases.
Measure includes improved fleet maintenance and engine servicing and filter replacement, more regular hull inspection, cleaning programs and service regimes</td></tr>
<tr><td rowspan="2">Summary</td><td rowspan="2"></td><td colspan="2">Applicable Vessels</td><td colspan="2">Fuel Saved (T)</td><td colspan="2">Emissions Reduced (TCO_2e)</td><td colspan="2">Project Life</td><td colspan="2">Inflation Rate (%)</td><td colspan="2">NPV Discount Rate (%)</td></tr>
<tr><td colspan="2">12,208</td><td colspan="2">28,000</td><td colspan="2">87,100</td><td colspan="2">2023 - 2050</td><td colspan="2">-</td><td colspan="2">7.0%</td></tr>
<tr><td>Operational Benefits</td><td colspan="13">Reduced GHG emissions
Reduced running costs from fuel savings
Longer life / reduced maintenance on motors
Health benefits due to reduced SOX, NOX and particulate emissions</td></tr>
<tr><td rowspan="5">Financial Assumptions</td><td rowspan="2">Term</td><td colspan="4">CAPEX (USD$M)</td><td colspan="8">OPEX (USD$M)</td></tr>
<tr><td>Onshore Costs</td><td>Upgrade or Retrofit</td><td>Battery & Replace</td><td>Total CAPEX</td><td>Shipyard Cost (Increm.)</td><td>Labor Cost (Increm.)</td><td>Repair & Maint. Cost (Increm.)</td><td>Initial Fuel</td><td>Proposed Fuel</td><td>Charging Cost</td><td>Energy Cost (Increm.)</td><td>Total OPEX</td></tr>
<tr><td>2023-2027</td><td>-</td><td>-</td><td>-</td><td>-</td><td>8.2</td><td>-</td><td>20</td><td>270</td><td>230</td><td>-</td><td>-41</td><td>-12.0</td></tr>
<tr><td>2028-2032</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>14</td><td>-</td><td>36</td><td>400</td></tr>
<tr><td>2031-2050</td><td>-</td><td>-</td><td>-</td><td>-</td><td>25</td><td>-</td><td>62</td><td>710</td><td>600</td><td>-</td><td>-110</td><td>-19</td></tr>
<tr><td>Implementation Plan</td><td colspan="13">Review requirement for investment (CAPEX) and OPEX in additional port infrastructure / local slipways / ship-lifts
Establish and support training programs in vessel and engine maintenance</td></tr>
<tr><td>Risk Management</td><td colspan="13">Minimize impact from additional time vessel is out of service via incentive program
Ensure adequate access to local slipways / yards with lifters
Ensure training programs provide skilled and experience maintenance personnel</td></tr>
<tr><td></td><td>C1</td><td>C2</td><td>C3</td><td>C4</td><td>C5</td><td>C6</td><td>C7</td><td>C8</td><td>C9</td><td>C10</td><td></td><td colspan="2"></td></tr>
</table>

Multi Criteria Analysis	Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
	5	2	5	4	3	3	4	4	3	3	3.65	Yes (ongoing)
	10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)
Detailed Description	This project involves Demand-Supply Management, Data Systems and Supporting Infrastructure. Efficiencies achieved through optimized routing, vessel specialization, passenger/cargo separation and improved information systems. Currently assumed up to 20% average fuel consumption & emissions savings, however successful implementation can have the most effective improvement on maritime fleet efficiency of all abatement measures and will ease the transition to zero emissions significantly. Separation of cargo and passengers can provide opportunities for vessel and route specialization, reduce port congestion and improve safety.

Summary

	Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
	12,202	31,300	97,600	2023 - 2050	-	7.0%

Operational Benefits	
	Reduced GHG emissions Reduced cost due to fuel savings Longer life / reduced maintenance on motors from vessel/engine specific voyages Health benefits due to reduced SOX, NOX and particulate emissions

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	3.5	-	-	**3.5**	-	2.1	-	59	48	-	-12	**-9.7**
2028-2032	3.3	-	-	**3.3**	-	5.6	-	160	120	-	-31	**-26**
2031-2050	2.7	-	-	**2.7**	-	20	-	550	440	-	-110	**-89**

Implementation Plan	
	Review of existing port and marina infrastructure and business models to identify factors limiting commercial growth, e.g. availability of warehousing and cold-storage, lease arrangements, connectivity with other services etc. Establish and support training programs in logistics, data management and scheduling.

Risk Management	
	Need to ensure that supporting systems and networks are in place including data collection and sharing systems, regional port facilities, warehousing/ cold storage, training.

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		

Multi Criteria Analysis	Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
	5	3	4	1	5	5	5	2	5	3	3.65	Yes (ongoing)
	10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	WASP Retrofit - Most vessels (excl. some specialist craft)
Detailed Description	This project involves the conversion to WASP primarily via retrofit, supplemented by installation on new build. Assumed to be applicable to all vessels excluding some specialist craft such as dredging, pleasure craft, pollution response boats, search and rescue/ patrol, tugboats and yachts. This is primarily based on functionality requirements. Model assumes a 20%-30% reduction in GHG emissions depending on wind resource of the country. Further efficiency can be achieved, however voyage times and weather conditions will need to be factored. Includes all forms of WASP, including soft sails, rigid and wing sails, towing kite, Flettner rotors etc (noting that some technologies perform better than others).

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
11,824	31,500	98,200	2023 - 2050	-	7.0%

Operational Benefits

Reduced GHG emissions
Cost savings via reduced fuel consumption
Longer life / reduced maintenance on motors
Health benefits due to reduced SOX, NOX and particulate emissions
Reduced fuel discharge to water and improved water quality

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	170	-	170	-	-	12	86	60	-	-26	-13
2028-2032	-	120	-	120	-	-	30	210	150	-	-62	-32
2031-2050	-	98	-	98	-	-	58	400	280	-	-120	-62

Implementation Plan

Review requirement for investment (CAPEX) and OPEX in dedicated port and marina developments / local shipyards / slipways / ship-lifts.
Obtain quotations from sail retrofitters.
Establish and support training programs in sailing.

Risk Management

Need to ensure port side infrastructure is available for retrofitting sails to existing vessels.
Need to ensure skilled labor for retrofitting vessels and owners/operators trained in sailing.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
4	4	4	3	4	4	5	3	5	4	4.00	Yes (ongoing)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)
Detailed Description	This project involves Motor Derating to optimize engine to suit typical operating speed. Conservatively assumes 5% average fuel consumption & emissions savings.

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
440	1,680	5,220	2023 - 2050	-	7.0%

Operational Benefits

Reduced GHG emissions
Cost savings via reduced fuel consumption
Longer life / reduced maintenance on motors
Health benefits due to reduced SOX, NOX and particulate emissions

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	6.8	-	**6.8**	-	-	-	35	33	-	-1.7	**-1.7**
2028-2032	-	1.4	-	**1.4**	-	-	-	67	64	-	-3.3	**-3.3**
2031-2050	-	-	-	**-**	-	-	-	120	110	-	-5.8	**-5.8**

Implementation Plan

Review requirement for investment (CAPEX) and OPEX in local shipyards / slipways / ship-lifts.
Establish and support training programs engine maintenance and derating.

Risk Management

Need to ensure port side infrastructure is available for increased engine maintenance and tuning.
Need to ensure skilled labor for engine maintenance and derating.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies		
3	2	5	4	4	4	5	4	3	3	3.60	Yes (short-term)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)
Detailed Description	This project involves the Retrofit of Propulsion Improving Devices (PIDs) to existing vessels with significant life remaining. Conservatively assumes 5% average fuel consumption & emissions savings.

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
261	1,230	3,810	2023 - 2050	-	7.0%

Operational Benefits

Reduced GHG emissions.
Reduced running costs from fuel savings.
Longer life / reduced maintenance on motors.
Health benefits due to reduced SOX, NOX and particulate emissions.

Financial Assumptions

Term	CAPEX (USD$M) Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	OPEX (USD$M) Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	1.4	-	**1.4**	-	-	-	25	24	-	-1.2	**-1.2**
2028-2032	-	1.4	-	**1.4**	-	-	-	47	45	-	-2.4	**-2.4**
2031-2050	-	1.4	-	**1.4**	-	-	-	83	79	-	-4.1	**-4.1**

Implementation Plan

Review requirement for investment (CAPEX) and OPEX in additional port and marina developments / local shipyards / slipways / ship lifts
Establish and support training programs in vessel and engine maintenance

Risk Management

Minimize impact from additional time vessel is out of service via incentive program
Ensure adequate access to local slipways / yards with lifters
Ensure training programs provide skilled and experience maintenance personnel

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
2	2	5	4	3	4	5	3	3	3	3.40	Yes short-term)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)
Detailed Description	This project involves the use of biofuels (blended) as a replacement 'drop-in' fuel for existing engine. Blended biofuels (phased/temporary) are applicable to all vessel types including 2-stroke transition fuel for future electrification of 2 strokes. Existing engines may only require minor upgrades to operate on blended biofuels. Biofuel feedstock includes copra, sugarcane, bagasse etc. Blended biofuels assumed to reduce GHG by 20% in the model (assuming a 20% biofuel blend).

Summary		Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
		76	0	2,930	2023 - 2035	-	7.0%

Operational Benefits	Reduced GHG emissions.

Financial Assumptions		CAPEX (USD$M)				OPEX (USD$M)							
	Term	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
	2023-2027	-	-	-	**-**	-	-	-	5.0	5.6	-	0.61	**0.61**
	2028-2032	-	-	-	**-**	-	-	-	8.5	10	-	1.0	**1.0**
	2031-2050	-	-	-	**-**	-	-	-	0.91	1.0	-	0.11	**0.11**

Implementation Plan	Review the status of sugar mill biofuel plants and suitability for supplying biofuel in quantities required. Review availability of energy crops (especially copra) that do not compete with food production. Establish and support training programs in biofuel production. Develop and deliver education and awareness program around biofuels and impacts on food production.
Risk Management	Ensuring that previous biofuel production projects challenges are overcome or minimized is critical for future success. Need to manage social and economic impacts from biofuels on food production.

Multi Criteria Analysis	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
	Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
	5	3	5	4	4	3	2	4	3	2	3.60	Yes (short-term)
	10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)
Detailed Description	This project involves the use of Biofuels as a Replacement 'drop-in' fuel for existing engine. 100% biofuels (ongoing) will require significant input to ensure a sustainable supply chain. Therefore at this stage the model has assumed only 5% of vessels (excluding 2-stroke outboards) to be applicable for this abatement measure. 100% biofuels may be applicable to Navy vessels to maintain existing operational functionality, e.g. speed, range etc. It is expected that some vessels will remain on 100% biofuel and not transition to electric or green e-fuels. Biofuel feedstock includes copra, sugarcane, bagasse etc. 100% Biofuels assumed to reduce GHG emissions by 100% (assuming sustainably-sourced).

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
38	0	7,320	2030 - 2050	-	7.0%

Operational Benefits	Reduced GHG emissions.

Financial Assumptions

Term	CAPEX (USD$M) Onshore Costs	CAPEX Upgrade or Retrofit	CAPEX Battery & Replace	Total CAPEX	OPEX (USD$M) Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	-	-	**-**	-	-	-	-	-	-	-	**-**
2028-2032	-	0.058	-	**0.058**	-	-	0.0011	0.51	0.76	-	0.25	**0.26**
2031-2050	-	0.07	-	**0.07**	-	-	0.017	8	12	-	3.9	**4.0**

Implementation Plan	Review the status of sugar mill biofuel plants and suitability for supplying biofuel in quantities required. Review availability of energy crops (especially copra) that do not compete with food production. Establish and support training programs in biofuel production. Develop and deliver education and awareness program around biofuels and impacts on food production.
Risk Management	Ensuring that previous biofuel production projects challenges are overcome or minimized is critical for future success. Need to manage social and economic impacts from biofuels on food production.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
1	5	3	3	3	3	1	3	2	1	2.60	Yes (to be further evaluated)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)
Detailed Description	This project involves the new build of battery electric vessels. Approximately half of Government vessels will ultimately transition to electric from 100% biofuel, with approximately half of Government and Commercial vessels transitioning to green e-fuels or 100% biofuel due to lack of renewable energy infrastructure. Electrified vessels and vessels operating on green e-fuels will retain potential for WASP to further reduce battery charging and fuel demand. Source of energy may include onboard solar photovoltaics and onshore generation. Onshore energy to meet charging demand are likely to include a mix of solar photovoltaic, wind, hydro, wave, geothermal, and generation from 100% biofuel. GHG abatement of 100% (assuming renewable energy.

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
15	3,010	9,360	2025 - 2050	-	7.0%

Operational Benefits

Reduced GHG emissions.
Longer life / reduced maintenance on motors.
Health benefits due to reduced SOX, NOX and particulate emissions.
Reduced fuel discharge to water and improved water quality.

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	0.036	5.5	0.036	**5.5**	-	-0.0089	-0.014	0.18	-	0.54	0.36	**0.34**
2028-2032	0.071	11	0.071	**11**	-	-0.058	-0.09	1.1	-	3.5	2.3	**2.2**
2031-2050	0.12	19	0.12	**19**	-	-0.31	-0.49	6.0	-	18	12	**12**

Implementation Plan

Detailed analysis of generation, transmission and charging infrastructure to assist in long term planning of transition.
Identification of most appropriate vessel types for PIC.
Commence discussion with potential vessel suppliers.

Risk Management

This is a long-term abatement measure that relies upon the renewable energy of generation, transmission and charging infrastructure
Need to manage the competition with other renewable energy demands such as land transport.
Need to manage battery disposal at end-of-life.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
4	5	2	1	2	4	5	2	3	2	2.90	Yes (to be further evaluated)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)
Detailed Description	This project involves the new build of battery electric vessels. Approximately half of Commercial vessels will ultimately transition to electric from 100% biofuel, with approximately half of Commercial vessels transitioning to green e-fuels or 100% biofuel due to lack of renewable energy infrastructure. Electrified vessels and vessels operating on green e-fuels will retain potential for WASP to further reduce battery charging and fuel demand. Source of energy may include onboard solar photovoltaics and onshore generation. Onshore energy to meet charging demand are likely to include a mix of solar photovoltaic, wind, hydro, wave, geothermal, and generation from 100% biofuel. GHG abatement of 100% (assuming renewable energy.

Summary	Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
	347	19,300	60,200	2030 - 2050	-	7.0%

Operational Benefits
Reduced GHG emissions. Longer life / reduced maintenance on motors. Health benefits due to reduced SOX, NOX and particulate emissions. Reduced fuel discharge to water and improved water quality.

Financial Assumptions

	CAPEX (USD$M)				OPEX (USD$M)							
Term	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	-	-	-	-	-	-	-	-	-	-	-
2028-2032	0.73	65	0.73	66	-	-0.12	-0.18	1.1	-	3.2	2.1	1.8
2031-2050	3.6	310	3.6	320	-	-3.8	-5.6	33	-	100	68	59

Implementation Plan
Detailed analysis of generation, transmission and charging infrastructure to assist in long term planning of transition. Identification of most appropriate vessel types for PIC. Commence discussion with potential vessel suppliers.

Risk Management
This is a long-term abatement measure that relies upon the renewable energy of generation, transmission and charging infrastructure Need to manage the competition with other renewable energy demands such as land transport. Need to manage battery disposal at end-of-life.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
4	5	2	1	2	4	5	2	3	2	2.90	Yes (to be further evaluated)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)
Detailed Description	This project involves the replacement of fossil fuels with green e-fuels (liquid hydrogen, ammonia, methanol, etc.) in new build designs. The long-term assumption of green e-fuels is currently modelled as being applicable to half the vessels that are not utilizing 100% biofuels (i.e. approximately half of all large vessels and 2-stroke outboards by 2050). It is noted that as some 2-stroke motors transition to 4-stroke, the new 4-strokes will also have a similar fuel share as the larger vessels as they too will be able to operate on 100% biofuel. GHG abatement of 100% (assuming produced using renewable energy)

Summary	Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
	362	0	69,500	2030 - 2050	-	7.0%

Operational Benefits	
	Reduced GHG emissions. Longer life / reduced maintenance on motors. Health benefits due to reduced SOX, NOX and particulate emissions. Reduced fuel discharge to water and improved water quality.

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	-	-	**-**	-	-	-	-	-	-	-	**-**
2028-2032	-	65	-	**65**	-	-	1.0	1.2	1.8	-	0.60	**1.6**
2031-2050	-	320	-	**320**	-	-	31	38	58	-	19	**50**

Implementation Plan	Detailed analysis of eFuels supply chain and local infrastructure (access to green e-fuel bunkers / tanks / drums) required to assist in long term planning of transition. Identification of most appropriate vessel types for PIC. Commence discussion with potential vessel suppliers.
Risk Management	This is a long-term abatement measure that relies upon the eFuel supply chain and local infrastructure. It is unlikely that a local e Fuel production industry would develop in the PICs and the challenges of reliance upon an international fuel supply chain would remain.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
4	5	2	3	3	3	1	2	3	2	2.90	Yes (to be further evaluated)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)
Detailed Description	This project involves the use of Biofuels (Blended) as a Replacement 'drop-in' fuel for existing engine. Blended biofuels (phased/temporary) are applicable to all vessel types including 2-stroke transition fuel for future electrification of 2 strokes. Existing engines may only require minor upgrades to operate on blended biofuels. Biofuel feedstock includes copra, sugarcane, bagasse etc. Blended biofuels assumed to reduce GHG by 20% in the model (assuming a 20% biofuel blend).

Summary	Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
	1,144	0	2,710	2023 - 2035	-	7.0%

Operational Benefits
Reduced GHG emissions. Longer life / reduced maintenance on motors. Health benefits due to reduced SOX, NOX and particulate emissions. Reduced fuel discharge to water and improved water quality.

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	-	-	-	-	-	-	5.3	5.8	-	0.42	0.42
2028-2032	-	-	-	-	-	-	-	9.1	9.8	-	0.72	0.72
2031-2050	-	-	-	-	-	-	-	0.97	1.00	-	0.077	0.077

Implementation Plan
Review the status of sugar mill biofuel plants and suitability for supplying biofuel in quantities required. Review availability of energy crops (especially copra) that do not compete with food production. Establish and support training programs in biofuel production. Develop and deliver education and awareness program around biofuels and impacts on food production.

Risk Management
Ensuring that previous biofuel production projects challenges are overcome or minimized is critical for future success. Need to manage social and economic impacts from biofuels on food production.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
5	3	5	4	4	3	2	4	3	2	3.60	Yes (short-term)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)
Detailed Description	This project involves the replacement of 2-stroke outboard motors with a 4-stroke equivalent. Assumed 20% GHG emissions reduction due to reduced fuel wastage and cleaner fuel burning technology. Applicable to most 2-stroke outboard motors. Exceptions may include some very small vessels (e.g. <5 meters length) and port trolling motors. Abatement measure can potentially begin phasing in immediately.

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
5,720	4,360	13,600	2023 - 2040	-	7.0%

Operational Benefits

Reduced GHG emissions.
Health benefits due to reduced SOX, NOX and particulate emissions.
Reduced fuel discharge to water and improved water quality.

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	24	-	**24**	-	-	-	27	21	-	-5.3	**-5.3**
2028-2032	-	5.1	-	**5.1**	-	-	-	51	41	-	-10	**-10**
2031-2050	-	-	-	**-**	-	-	-	36	29	-	-7.2	**-7.2**

Implementation Plan

Government policy and financing arrangements need to be implemented to support rapid uptake of technology.

Risk Management

Measure can begin immediately providing there are adequate incentives and funding mechanism to support the transition.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
5	3	5	3	4	4	5	4	4	5	4.25	Yes (short-term)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Electrification - All vessels <10m length (assumed 2 and 4-stroke)
Detailed Description	This project involves new build battery electric vessels. Assumed all 2-stroke motors (outboards) will eventually transition to electric (or green e-fuels) from blended biofuels due to inability of these motors (outboards) to easily run on 100% biofuel or transition to 4-stroke to allow 100% biofuel. Electrified vessels and vessels operating on green e-fuels will retain potential for WASP to further reduce battery charging and fuel demand. Source of energy may include onboard solar photovoltaics and onshore generation. Onshore energy to meet charging demand are likely to include a mix of solar photovoltaic, wind, hydro, wave, geothermal, and generation from 100% biofuel. GHG abatement of 100% (assuming renewable energy).

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
5,720	21,800	67,900	2030 - 2050	-	7.0%

Operational Benefits

Reduced GHG emissions.
Longer life / reduced maintenance on motors.
Health benefits due to reduced SOX, NOX and particulate emissions.
Reduced fuel discharge to water and improved water quality.

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	-	-	**-**	-	-	-	-	-	-	-	**-**
2028-2032	6.0	2.0	12	**20**	-	-	-0.014	1.4	-	2.4	1.0	**1.0**
2031-2050	29	10	58	**98**	-	-	-0.45	43	-	76	33	**32**

Implementation Plan

Detailed analysis of generation, transmission and charging infrastructure to assist in long term planning of transition.
Identification of most appropriate vessel types for PIC.
Commence discussion with potential vessel suppliers.

Risk Management

This is a long-term abatement measure that relies upon the renewable energy of generation, transmission and charging infrastructure.
Need to manage the competition with other renewable energy demands such as land transport.
Need to manage battery disposal at end-of-life.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
4	5	2	1	2	4	5	2	3	2	2.90	Yes (to be further evaluated)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)
Detailed Description	This project involves the replacement of fossil fuels with green e-fuels (liquid hydrogen, ammonia, methanol, etc.) in new build designs. The long-term assumption of green e-fuels is currently modelled as being applicable to half the vessels that are not utilizing 100% biofuels (i.e., approximately half of all large vessels and 2-stroke outboards by 2050, with a small proportion using 100% biofuels). It is noted that as some 2-stroke motors transition to 4-stroke, the new 4-strokes will also have a similar fuel share as the larger vessels as they too will be able to operate on 100% biofuel. GHG abatement of 100% (assuming produced using renewable energy)

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
5,720	0	67,900	2030 - 2050	-	7.0%

Operational Benefits	Reduced GHG emissions. Health benefits due to reduced SOX, NOX and particulate emissions. Reduced fuel discharge to water and improved water quality.

Financial Assumptions

Term	CAPEX (USD$M)				OPEX (USD$M)							
	Onshore Costs	Upgrade or Retrofit	Battery & Replace	Total CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	Total OPEX
2023-2027	-	-	-	**-**	-	-	-	-	-	-	-	**-**
2028-2032	-	4.3	-	**4.3**	-	-	0.064	1.4	2.0	-	0.68	**0.75**
2031-2050	-	21	-	**21**	-	-	2.0	43	65	-	22	**24**

Implementation Plan	Detailed analysis of eFuels supply chain and local infrastructure (access to green e-fuel bunkers / tanks / drums) required to assist in long term planning of transition. Identification of most appropriate vessel types for PIC. Commence discussion with potential vessel suppliers.
Risk Management	This is a long-term abatement measure that relies upon the eFuels supply chain and local infrastructure. It is unlikely that a local eFuel production industry would develop in the PICs and the challenges of reliance upon an international fuel supply chain would remain.

Multi Criteria Analysis

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
Vessel Fleet Coverage Level	CO_2e Emissions Abatement Capability	Technical Readiness	Min. CAPEX Needs	OPEX Net Benefits Level	PIC Enviro Whole-of-Life Benefits Level	PIC Fuel Overseas Supply Reduction	PIC Min. Gov., Mgt. & Training Level	PIC Socio - Econ. Benefits Level	Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
4	5	2	3	3	3	1	2	3	2	2.90	Yes (to be further evaluated)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Project Data Sheet	Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)
Detailed Description	This project involves the replacement of fossil fuels with 100% biofuels or green e-fuels (liquid hydrogen, ammonia, methanol, etc.) for existing Navy vessels and in new build designs. This is applicable to Navy vessels to maintain existing operational functionality, e.g. speed, range etc. It is expected that some vessels will remain on 100% biofuel and not transition to electric or green e-fuels. Biofuel feedstock includes copra, sugarcane, bagasse etc. 100% Biofuels assumed to reduce GHG emissions by 100% (assuming sustainably-sourced). Green e Fuels GHG abatement of 100% (assuming produced using renewable energy).

Summary

Applicable Vessels	Fuel Saved (T)	Emissions Reduced (TCO_2e)	Project Life	Inflation Rate (%)	NPV Discount Rate (%)
6	0	5,360	2023 onwards	-	7.0%

Operational Benefits

Reduced GHG emissions.
Health benefits due to reduced SOX, NOX and particulate emissions (for green e-fuels).

Financial Assumptions

Term	CAPEX (USD$M) Onshore Costs	CAPEX (USD$M) Upgrade or Retrofit	CAPEX (USD$M) Battery & Replace	CAPEX (USD$M) Total CAPEX	OPEX (USD$M) Shipyard Cost (Increm.)	OPEX (USD$M) Labor Cost (Increm.)	OPEX (USD$M) Repair & Maint. Cost (Increm.)	OPEX (USD$M) Initial Fuel	OPEX (USD$M) Proposed Fuel	OPEX (USD$M) Charging Cost	OPEX (USD$M) Energy Cost (Increm.)	OPEX (USD$M) Total OPEX
2023-2027	-	-	-	**-**	-	-	-	-	-	-	-	**-**
2028-2032	-	2.4	-	**2.4**	-	-	0.04	0.18	0.26	-	0.09	**0.12**
2031-2050	-	7	-	**7**	-	-	0.9	4	7	-	2.2	**3.1**

Implementation Plan

Detailed analysis of 100% biofuel and eFuels supply chain and local infrastructure (production, access to biofuel/ green e-fuel bunkers / tanks / drums) required to assist in long term planning of transition.
Identification of most appropriate vessel types for PIC.
Commence discussion with potential vessel suppliers.

Risk Management

This is a long-term abatement measure that relies upon the biofuel and eFuels supply chain and local infrastructure.
It is unlikely that a local e Fuel production industry would develop in the PICs and the challenges of reliance upon an international fuel supply chain would remain.

Multi Criteria Analysis

C1 Vessel Fleet Coverage Level	C2 CO_2e Emissions Abatement Capability	C3 Technical Readiness	C4 Min. CAPEX Needs	C5 OPEX Net Benefits Level	C6 PIC Enviro Whole-of-Life Benefits Level	C7 PIC Fuel Overseas Supply Reduction	C8 PIC Min. Gov., Mgt. & Training Level	C9 PIC Socio - Econ. Benefits Level	C10 Availability of Local Energy & Ease of Supplies	OVERALL MCA Weighted Score	Proposed Inclusion as Option for PBSP
4	5	2	3	3	3	1	2	3	2	2.90	Yes (to be further evaluated)
10%	15%	20%	10%	5%	5%	5%	5%	10%	15%	100%	

Appendix B: Cost Estimates

Regional Total (2023-2027)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	12,208	-	-	-	-	-	-	-	8.2	-	20.4	272.1	231.3	-	-40.8	-12.1
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	12,202	-	-	-	3.5	-	-	3.5	-	2.1	-	59.4	47.5	-	-11.9	-9.7
WASP Retrofit - Most vessels (excl. some specialist craft)	11,824	1,563.6	-	-	-	172.7	-	172.7	-	-	12.4	85.6	59.9	-	-25.7	-13.3
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	440	-	-	277.0	-	6.8	-	6.8	-	-	-	35.0	33.2	-	-1.7	-1.7
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	261	-	-	58.3	-	1.4	-	1.4	-	-	-	24.8	23.5	-	-1.2	-1.2
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	76	-	-	-	-	-	-	-	-	-	-	5.0	5.6	-	0.6	0.6
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	15	4.9	6.3	-	0.04	5.5	0.04	5.5	-	-0.01	-0.01	0.2	-	0.5	0.4	0.3
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	347	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	362	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	1,144	-	-	-	-	-	-	-	-	-	-	5.3	5.8	-	0.4	0.4
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	5,720	-	-	12.7	-	24.3	-	24.3	-	-	-	26.7	21.4	-	-5.3	-5.3
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	5,720	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	5,720	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**1,568.6**	**6.3**	**348.0**	**3.6**	**210.7**	**0.0**	**214.3**	**8.2**	**2.1**	**32.8**	**514.0**	**428.2**	**0.5**	**-85.3**	**-42.1**

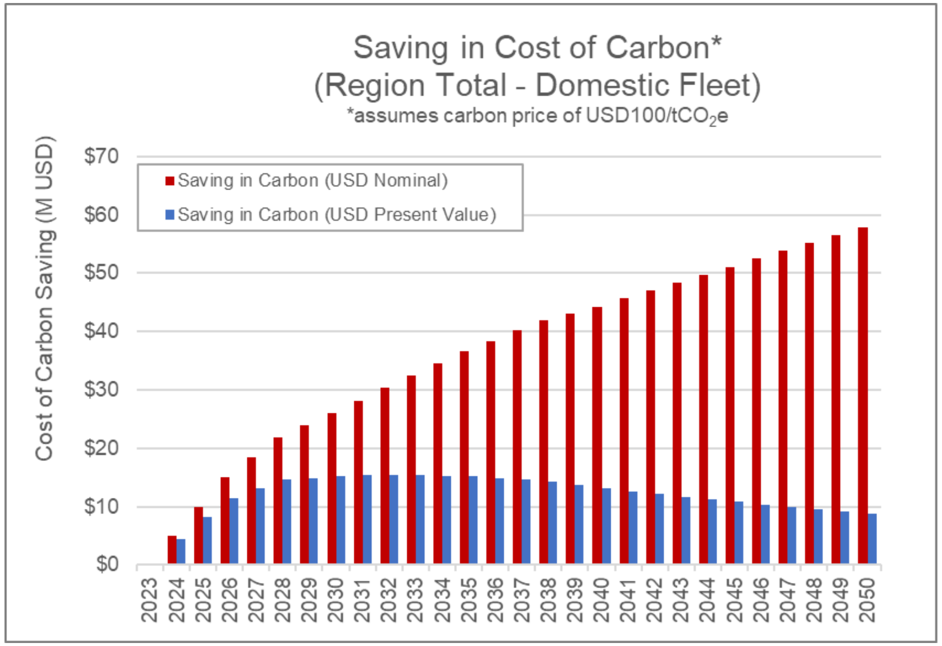
Regional Total (2028-2032)

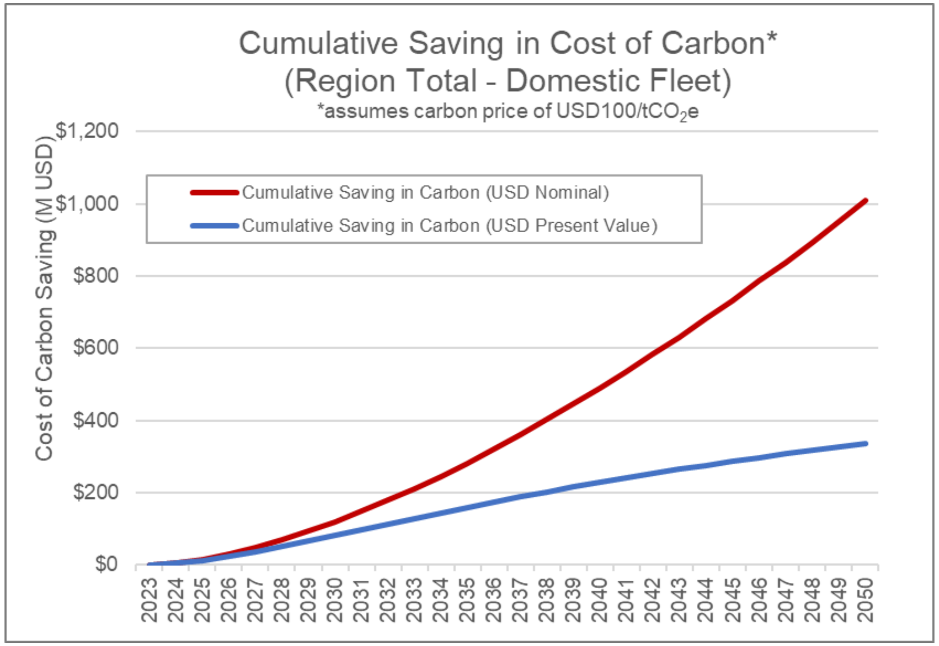
		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	Vessel Count	Like-for-Like Vessel Replace	New Purpose-Built Vessel	Like-for-Like Engine Replace	Onshore Cost	Upgrade or Retrofit Cost	Initial Battery Cost & Replace	TOTAL CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	12,208	-	-	-	-	-	-	-	14.5	-	35.6	404.6	343.9	-	-60.7	-10.6
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	12,202	-	-	-	3.3	-	-	3.3	-	5.6	-	155.9	124.7	-	-31.2	-25.6
WASP Retrofit - Most vessels (excl. some specialist craft)	11,824	1,106.1	-	-	-	122.2	-	122.2	-	-	30.1	207.2	145.0	-	-62.2	-32.1
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	440	-	-	58.3	-	1.4	-	1.4	-	-	-	66.9	63.5	-	-3.3	-3.3
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	261	-	-	58.3	-	1.4	-	1.4	-	-	-	47.3	45.0	-	-2.4	-2.4
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	76	-	-	-	-	-	-	-	-	-	-	8.5	9.5	-	1.0	1.0
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	38	9.6	9.7	-	-	0.1	-	0.1	-	-	0.001	0.5	0.8	-	0.3	0.3
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	15	9.8	12.5	-	0.1	10.8	0.1	11.0	-	-0.1	-0.1	1.1	-	3.5	2.3	2.2
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	347	97.7	125.0	-	0.7	64.6	0.7	66.1	-	-0.1	-0.2	1.1	-	3.2	2.1	1.8
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	362	102.1	122.5	-	-	65.1	-	65.1	-	-	1.0	1.2	1.8	-	0.6	1.6
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	1,144	-	-	-	-	-	-	-	-	-	-	9.1	9.8	-	0.7	0.7
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	5,720	-	-	2.7	-	5.1	-	5.1	-	-	-	51.0	40.8	-	-10.2	-10.2
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	5,720	3.0	3.3	-	6.0	2.0	12.0	20.1	-	-	-0.01	1.4	-	2.4	1.0	1.0
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	5,720	3.0	4.5	-	-	4.3	-	4.3	-	-	0.1	1.4	2.0	-	0.7	0.7
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	6	2.1	2.5	-	-	2.4	-	2.4	-	-	0.0	0.2	0.3	-	0.1	0.1
Total		**1,333.4**	**280.0**	**119.3**	**10.1**	**279.5**	**12.8**	**302.4**	**14.5**	**5.4**	**66.4**	**957.4**	**787.2**	**9.1**	**-161.0**	**-74.7**

Regional Total (2033-2050)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	12,208	-	-	-	-	-	-	-	25.4	-	62.2	707.8	601.6	-	-106.2	-18.6
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	12,202	-	-	-	2.7	-	-	2.7	-	19.6	-	545.0	436.0	-	-109.0	-89.4
WASP Retrofit - Most vessels (excl. some specialist craft)	11,824	884.0	-	-	-	97.6	-	97.6	-	-	58.1	400.7	280.5	-	-120.2	-62.1
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	440	-	-	-	-	-	-	-	-	-	-	116.9	111.1	-	-5.8	-5.8
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	261	-	-	58.3	-	1.4	-	1.4	-	-	-	82.8	78.7	-	-4.1	-4.1
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	76	-	-	-	-	-	-	-	-	-	-	0.9	1.0	-	0.1	0.1
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	38	12.2	12.3	-	-	0.1	-	0.1	-	-	0.02	7.9	11.8	-	3.9	4.0
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	15	17.1	21.8	-	0.1	18.9	0.1	19.2	-	-0.3	-0.5	6.0	-	18.5	12.4	11.6
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	347	474.7	607.6	-	3.6	314.0	3.6	321.1	-	-3.8	-5.6	33.5	-	101.5	68.1	58.6
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	362	496.0	595.2	-	-	316.6	-	316.6	-	-	30.8	38.4	57.7	-	19.2	50.0
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	1,144	-	-	-	-	-	-	-	-	-	-	1.0	1.0	-	0.1	0.1
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	5,720	-	-	-	-	-	-	-	-	-	-	36.0	28.8	-	-7.2	-7.2
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	5,720	14.6	16.0	-	29.2	9.8	58.5	97.5	-	-	-0.5	43.4	-	76.3	32.9	32.4
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	5,720	14.6	21.9	-	-	21.0	-	21.0	-	-	2.0	43.4	65.1	-	21.7	23.7
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	6	6.1	7.3	-	-	6.8	-	6.8	-	-	0.9	4.4	6.6	-	2.2	3.1
Total		**1,919.2**	**1,282.1**	**58.3**	**35.6**	**786.3**	**62.2**	**884.0**	**25.4**	**15.4**	**147.5**	**2,068.1**	**1,679.9**	**196.3**	**-191.9**	**-3.7**

Regional Total (Cost of Carbon Saving)





Fiji (2023-2027)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	5,377	-	-	-	-	-	-	-	1.96	-	5.42	178.61	151.82	-	-26.79	-19.41
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	5,373	-	-	-	1.41	-	-	1.41	-	0.85	-	32.99	26.39	-	-6.60	-5.75
WASP Retrofit - Most vessels (excl. some specialist craft)	5,191	246.66	-	-	-	33.88	-	33.88	-	-	3.55	49.51	34.66	-	-14.85	-11.31
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	113	-	-	41.88	-	1.07	-	1.07	-	-	-	13.11	12.45	-	-0.66	-0.66
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	29	-	-	8.82	-	0.23	-	0.23	-	-	-	8.39	7.97	-	-0.42	-0.42
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	17	-	-	-	-	-	-	-	-	-	-	1.73	1.94	-	0.21	0.21
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	12	3.80	4.87	-	0.03	4.08	0.03	4.14	-	-0.01	-0.01	0.16	-	0.48	0.32	0.30
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	521	-	-	-	-	-	-	-	-	-	-	3.98	4.29	-	0.31	0.31
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	2,603	-	-	5.77	-	10.85	-	10.85	-	-	-	19.90	15.92	-	-3.98	-3.98
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	2,603	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	2,603	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**250.46**	**4.87**	**56.46**	**1.44**	**50.10**	**0.03**	**51.57**	**1.96**	**0.84**	**8.96**	**308.37**	**255.45**	**0.48**	**-52.45**	**-40.70**

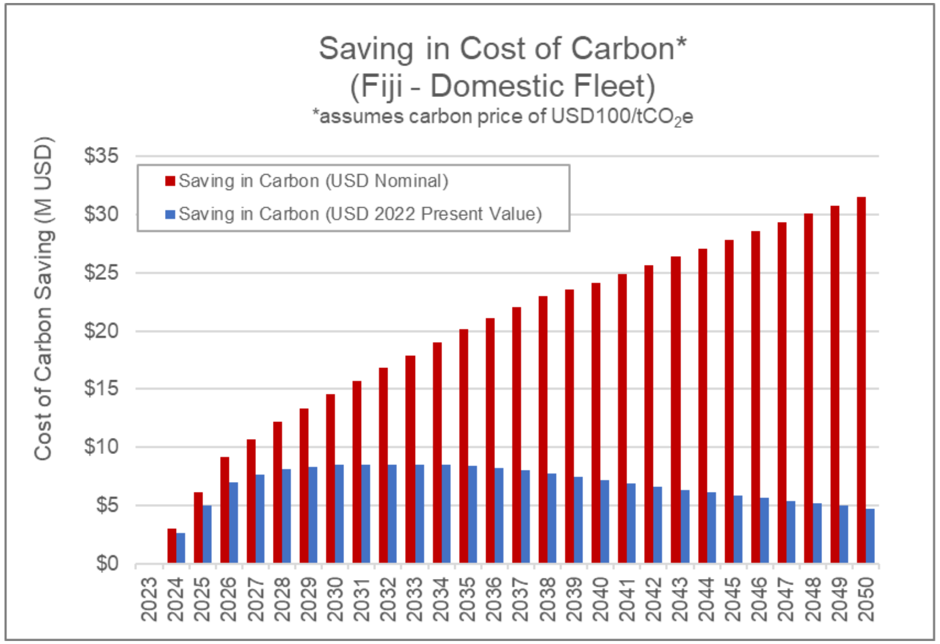
Fiji (2028-2032)

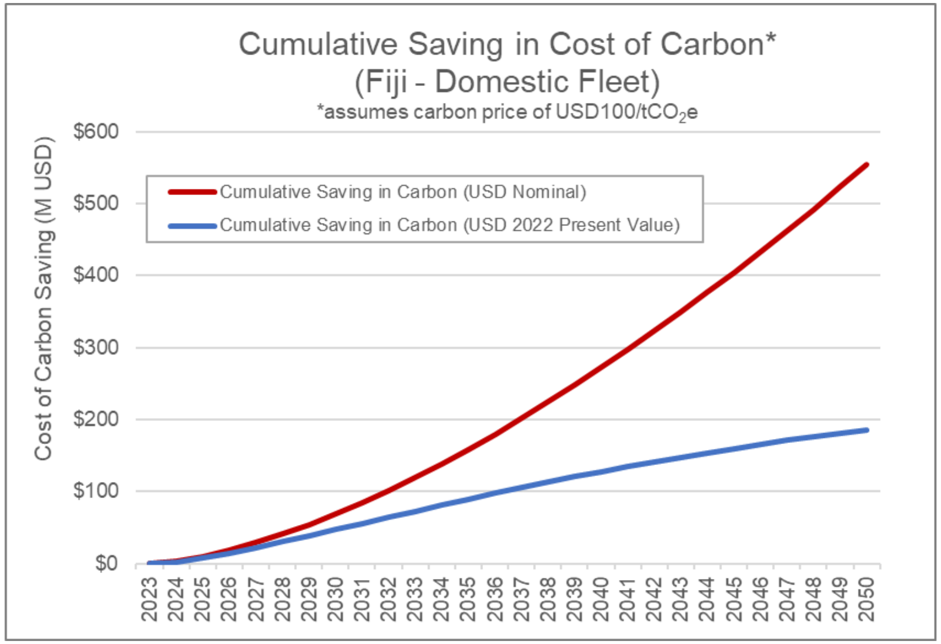
		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	5,377	-	-	-	-	-	-	-	2.47	-	6.86	225.91	192.03	-	-33.89	-24.56
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	5,373	-	-	-	1.30	-	-	1.30	-	2.23	-	86.58	69.27	-	-17.32	-15.08
WASP Retrofit - Most vessels (excl. some specialist craft)	5,191	174.49	-	-	-	23.96	-	23.96	-	-	8.59	119.85	83.89	-	-35.95	-27.37
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	113	-	-	8.82	-	0.23	-	0.23	-	-	-	25.06	23.81	-	-1.25	-1.25
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	29	-	-	8.82	-	0.23	-	0.23	-	-	-	16.04	15.24	-	-0.80	-0.80
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	17	-	-	-	-	-	-	-	-	-	-	2.95	3.32	-	0.36	0.36
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	8	1.20	1.21	-	-	0.01	-	0.01	-	-	0.00	0.18	0.26	-	0.09	0.09
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	12	7.53	9.64	-	0.06	8.08	0.06	8.20	-	-0.04	-0.07	1.02	-	3.10	2.08	1.97
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	67	9.88	12.65	-	0.14	6.95	0.14	7.24	-	-0.01	-0.02	0.28	-	0.88	0.60	0.57
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	80	13.27	15.93	-	-	9.93	-	9.93	-	-	0.15	0.42	0.63	-	0.21	0.36
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	521	-	-	-	-	-	-	-	-	-	-	6.80	7.33	-	0.53	0.53
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	2,603	-	-	1.21	-	2.28	-	2.28	-	-	-	38.04	30.43	-	-7.61	-7.61
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	2,603	1.37	1.50	-	2.74	0.90	5.48	9.12	-	-	-0.01	1.02	-	1.34	0.32	0.31
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	2,603	1.37	2.05	-	-	1.93	-	1.93	-	-	0.03	1.02	1.52	-	0.51	0.54
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	4	1.58	1.89	-	-	1.69	-	1.69	-	-	0.03	0.15	0.22	-	0.07	0.10
Total		**210.69**	**44.87**	**18.85**	**4.24**	**56.20**	**5.68**	**66.11**	**2.47**	**2.18**	**15.55**	**525.29**	**427.94**	**5.31**	**-92.05**	**-71.84**

Fiji (2033-2050)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	Vessel Count	Like-for-Like Vessel Replace	New Purpose-Built Vessel	Like-for-Like Engine Replace	Onshore Cost	Upgrade or Retrofit Cost	Initial Battery Cost & Replace	TOTAL CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	5,377	-	-	-	-	-	-	-	4.33	-	11.99	395.16	335.89	-	-59.27	-42.95
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	5,373	-	-	-	1.08	-	-	1.08	-	7.81	-	302.72	242.18	-	-60.54	-52.74
WASP Retrofit - Most vessels (excl. some specialist craft)	5,191	139.45	-	-	-	19.15	-	19.15	-	-	16.61	231.78	162.25	-	-69.53	-52.93
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	113	-	-	-	-	-	-	-	-	-	-	43.83	41.64	-	-2.19	-2.19
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	29	-	-	8.82	-	0.23	-	0.23	-	-	-	28.05	26.65	-	-1.40	-1.40
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	17	-	-	-	-	-	-	-	-	-	-	0.32	0.35	-	0.04	0.04
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	8	1.52	1.54	-	-	0.01	-	0.01	-	-	0.004	2.73	4.10	-	1.37	1.37
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	12	13.17	16.86	-	0.10	14.14	0.10	14.34	-	-0.22	-0.36	5.37	-	16.39	11.01	10.42
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	67	48.03	61.48	-	0.69	33.78	0.69	35.16	-	-0.31	-0.56	8.92	-	27.92	19.00	18.12
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	80	64.49	77.39	-	-	48.24	-	48.24	-	-	4.69	13.36	20.04	-	6.68	11.37
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	521	-	-	-	-	-	-	-	-	-	-	0.73	0.78	-	0.06	0.06
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	2,603	-	-	-	-	-	-	-	-	-	-	26.81	21.45	-	-5.36	-5.36
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	2,603	6.65	7.28	-	13.31	4.38	26.62	44.31	-	-	-0.20	32.34	-	42.57	10.22	10.02
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	2,603	6.65	9.98	-	-	9.39	-	9.39	-	-	0.91	32.34	48.52	-	16.17	17.09
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	4	4.55	5.46	-	-	4.89	-	4.89	-	-	0.63	3.74	5.61	-	1.87	2.50
Total		**284.53**	**179.99**	**8.82**	**15.18**	**134.20**	**27.41**	**176.78**	**4.33**	**7.27**	**33.71**	**1,128.22**	**909.46**	**86.87**	**-131.89**	**-86.58**

Fiji (Cost of Carbon Saving)





Kiribati (2023-2027)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	1,952	-	-	-	-	-	-	-	0.34	-	1.07	12.32	10.47	-	-1.85	-0.43
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	1,952	-	-	-	0.50	-	-	0.50	-	0.30	-	3.49	2.79	-	-0.70	-0.39
WASP Retrofit - Most vessels (excl. some specialist craft)	1,951	49.90	-	-	-	11.72	-	11.72	-	-	1.33	5.89	4.12	-	-1.77	-0.43
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	36	-	-	13.23	-	0.35	-	0.35	-	-	-	2.44	2.32	-	-0.12	-0.12
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	12	-	-	2.79	-	0.07	-	0.07	-	-	-	1.49	1.42	-	-0.07	-0.07
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	4	-	-	-	-	-	-	-	-	-	-	0.23	0.26	-	0.03	0.03
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	1	0.28	0.36	-	0.002	0.42	0.002	0.43	-	-0.001	-0.001	0.01	-	0.02	0.01	0.01
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	192	-	-	-	-	-	-	-	-	-	-	0.33	0.36	-	0.03	0.03
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	958	-	-	2.12	-	3.96	-	3.96	-	-	-	1.67	1.33	-	-0.33	-0.33
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	958	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	958	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**50.18**	**0.36**	**18.14**	**0.51**	**16.53**	**0.00**	**17.04**	**0.34**	**0.303**	**2.40**	**27.87**	**23.07**	**0.02**	**-4.77**	**-1.72**

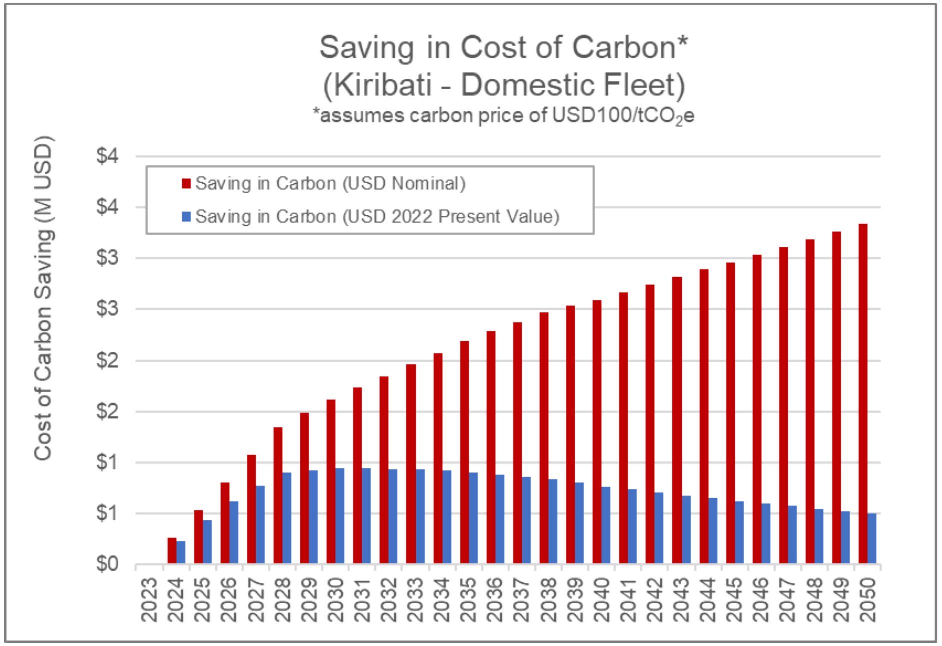
Kiribati (2028-2032)

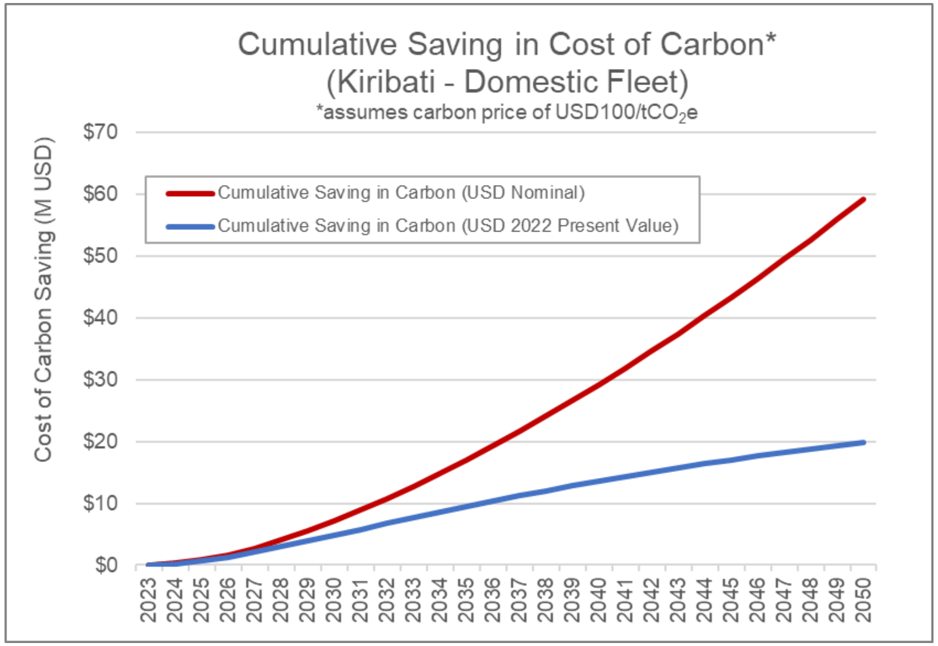
Abatement Measure	Vessel Count	BASELINE (USD$M) Like-for-Like Vessel Replace	BASELINE (USD$M) New Purpose-Built Vessel	BASELINE (USD$M) Like-for-Like Engine Replace	CAPEX (USD$M) Onshore Cost	CAPEX (USD$M) Upgrade or Retrofit Cost	CAPEX (USD$M) Initial Battery Cost & Replace	CAPEX (USD$M) TOTAL CAPEX	OPEX (USD$M) Shipyard Cost (Increm.)	OPEX (USD$M) Labor Cost (Increm.)	OPEX (USD$M) Repair & Maint. Cost (Increm.)	OPEX (USD$M) Initial Fuel	OPEX (USD$M) Proposed Fuel	OPEX (USD$M) Charging Cost	OPEX (USD$M) Energy Cost (Increm.)	OPEX (USD$M) TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	1,952	-	-	-	-	-	-	-	0.66	-	2.05	23.54	20.01	-	-3.53	-0.83
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	1,952	-	-	-	0.46	-	-	0.46	-	0.80	-	9.16	7.33	-	-1.83	-1.03
WASP Retrofit - Most vessels (excl. some specialist craft)	1,951	35.30	-	-	-	8.29	-	8.29	-	-	3.23	14.26	9.98	-	-4.28	-1.05
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	36	-	-	2.79	-	0.07	-	0.07	-	-	-	4.66	4.43	-	-0.23	-0.23
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	12	-	-	2.79	-	0.07	-	0.07	-	-	-	2.85	2.71	-	-0.14	-0.14
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	4	-	-	-	-	-	-	-	-	-	-	0.40	0.45	-	0.05	0.05
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	2	0.23	0.24	-	-	0.002	-	0.002	-	-	0.0001	0.02	0.04	-	0.01	0.01
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	1	0.56	0.71	-	0.004	0.84	0.004	0.85	-	-0.01	-0.01	0.04	-	0.13	0.09	0.07
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	17	2.15	2.76	-	0.03	2.37	0.03	2.44	-	-0.004	-0.01	0.05	-	0.16	0.11	0.09
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	18	2.40	2.89	-	-	2.58	-	2.58	-	-	0.04	0.06	0.08	-	0.03	0.07
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	192	-	-	-	-	-	-	-	-	-	-	0.57	0.61	-	0.04	0.04
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	958	-	-	0.45	-	0.83	-	0.83	-	-	-	3.19	2.55	-	-0.64	-0.64
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	958	0.50	0.55	-	1.01	0.33	2.02	3.35	-	-	-0.002	0.09	-	0.27	0.18	0.18
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	958	0.50	0.76	-	-	0.71	-	0.71	-	-	0.01	0.09	0.13	-	0.04	0.05
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**41.66**	**7.90**	**6.02**	**1.51**	**16.10**	**2.05**	**19.66**	**0.66**	**0.79**	**5.31**	**58.97**	**48.31**	**0.55**	**-10.10**	**-3.35**

Kiribati (2033-2050)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	1,952	-	-	-	-	-	-	-	1.15	-	3.58	41.18	35.00	-	-6.18	-1.45
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	1,952	-	-	-	0.39	-	-	0.39	-	2.79	-	32.02	25.62	-	-6.40	-3.62
WASP Retrofit - Most vessels (excl. some specialist craft)	1,951	28.21	-	-	-	6.62	-	6.62	-	-	6.24	27.57	19.30	-	-8.27	-2.03
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	36	-	-	-	-	-	-	-	-	-	-	8.15	7.75	-	-0.41	-0.41
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	12	-	-	2.79	-	0.07	-	0.07	-	-	-	4.99	4.74	-	-0.25	-0.25
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	4	-	-	-	-	-	-	-	-	-	-	0.04	0.05	-	0.01	0.01
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	2	0.30	0.30	-	-	0.003	-	0.003	-	-	0.001	0.37	0.55	-	0.18	0.18
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	1	0.97	1.24	-	0.01	1.47	0.01	1.48	-	-0.03	-0.04	0.23	-	0.70	0.47	0.39
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	17	10.47	13.40	-	0.17	11.54	0.17	11.88	-	-0.13	-0.20	1.61	-	4.96	3.36	3.02
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	18	11.68	14.02	-	-	12.53	-	12.53	-	-	1.22	1.80	2.70	-	0.90	2.12
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	192	-	-	-	-	-	-	-	-	-	-	0.06	0.07	-	0.005	0.005
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	958	-	-	-	-	-	-	-	-	-	-	2.25	1.80	-	-0.45	-0.45
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	958	2.45	2.68	-	4.90	1.60	9.79	16.29	-	-	-0.07	2.71	-	8.50	5.79	5.72
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	958	2.45	3.67	-	-	3.43	-	3.43	-	-	0.33	2.71	4.06	-	1.35	1.69
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**56.53**	**35.31**	**2.79**	**5.46**	**37.27**	**9.97**	**52.70**	**1.15**	**2.63**	**11.06**	**125.69**	**101.63**	**14.16**	**-9.90**	**4.93**

Kiribati (Cost of Carbon Saving)





Republic of the Marshall Islands (2023-2027)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	469	-	-	-	-	-	-	-	0.25	-	0.61	3.15	2.68	-	-0.47	0.39
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	468	-	-	-	0.16	-	-	0.16	-	0.10	-	0.87	0.69	-	-0.17	-0.08
WASP Retrofit - Most vessels (excl. some specialist craft)	466	36.31	-	-	-	6.38	-	6.38	-	-	0.52	1.29	0.90	-	-0.39	0.13
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	27	-	-	10.79	-	0.25	-	0.25	-	-	-	0.68	0.65	-	-0.03	-0.03
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	9	-	-	2.27	-	0.05	-	0.05	-	-	-	0.38	0.36	-	-0.02	-0.02
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	3	-	-	-	-	-	-	-	-	-	-	0.09	0.10	-	0.01	0.01
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	44	-	-	-	-	-	-	-	-	-	-	0.06	0.06	-	0.005	0.005
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	220	-	-	0.49	-	1.17	-	1.17	-	-	-	0.29	0.23	-	-0.06	-0.06
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**36.31**	**-**	**13.55**	**0.16**	**7.84**	**-**	**8.01**	**0.25**	**0.097**	**1.13**	**6.81**	**5.68**	**-**	**-1.13**	**0.35**

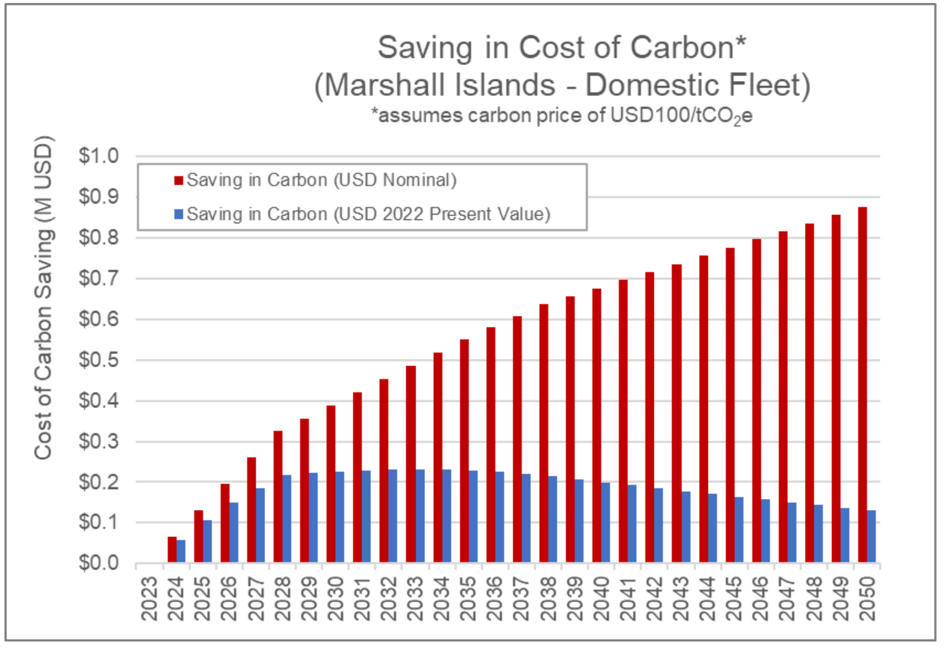
Republic of the Marshall Islands (2028-2032)

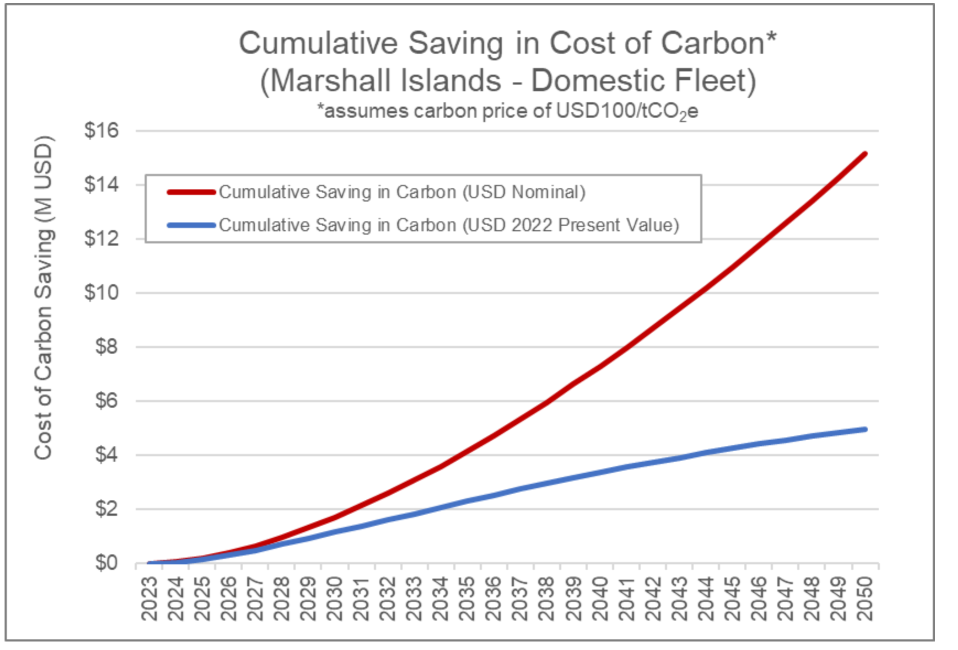
		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	469	-	-	-	-	-	-	-	0.49	-	1.17	6.02	5.11	-	-0.90	0.75
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	468	-	-	-	0.15	-	-	0.15	-	0.26	-	2.28	1.82	-	-0.46	-0.20
WASP Retrofit - Most vessels (excl. some specialist craft)	466	25.69	-	-	-	4.51	-	4.51	-	-	1.25	3.11	2.18	-	-0.93	0.31
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	27	-	-	2.27	-	0.05	-	0.05	-	-	-	1.31	1.24	-	-0.07	-0.07
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	9	-	-	2.27	-	0.05	-	0.05	-	-	-	0.73	0.70	-	-0.04	-0.04
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	3	-	-	-	-	-	-	-	-	-	-	0.15	0.17	-	0.02	0.02
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	1	0.21	0.21	-	-	0.002	-	0.002	-	-	0.00004	0.01	0.01	-	0.005	0.005
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	14	2.15	2.75	-	0.03	2.18	0.03	2.24	-	-0.004	-0.01	0.02	-	0.06	0.04	0.03
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	14	2.15	2.58	-	-	2.04	-	2.04	-	-	0.03	0.02	0.03	-	0.01	0.04
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	44	-	-	-	-	-	-	-	-	-	-	0.10	0.11	-	0.01	0.01
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	220	-	-	0.10	-	0.25	-	0.25	-	-	-	0.55	0.44	-	-0.11	-0.11
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	220	0.12	0.13	-	0.23	0.10	0.46	0.79	-	-	-0.001	0.01	-	0.02	0.01	0.01
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	220	0.12	0.17	-	-	0.21	-	0.21	-	-	0.00	0.01	0.02	-	0.01	0.01
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	1	0.01	0.01	-	-	0.01	-	0.01	-	-	0.00	0.01	0.01	-	0.004	0.004
Total		**30.42**	**5.84**	**4.65**	**0.41**	**9.40**	**0.49**	**10.30**	**0.49**	**0.25**	**2.44**	**14.34**	**11.85**	**0.09**	**-2.40**	**0.78**

Republic of the Marshall Islands (2033-2050)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	469	-	-	-	-	-	-	-	0.85	-	2.05	10.53	8.95	-	-1.58	1.32
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	468	-	-	-	0.12	-	-	0.12	-	0.89	-	7.97	6.37	-	-1.59	-0.70
WASP Retrofit - Most vessels (excl. some specialist craft)	466	20.53	-	-	-	3.61	-	3.61	-	-	2.41	6.02	4.21	-	-1.81	0.61
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	27	-	-	-	-	-	-	-	-	-	-	2.29	2.17	-	-0.11	-0.11
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	9	-	-	2.27	-	0.05	-	0.05	-	-	-	1.28	1.22	-	-0.06	-0.06
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	3	-	-	-	-	-	-	-	-	-	-	0.02	0.02	-	0.002	0.002
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	1	0.26	0.26	-	-	0.002	-	0.002	-	-	0.001	0.14	0.21	-	0.07	0.07
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	14	10.43	13.35	-	0.14	10.60	0.14	10.88	-	-0.12	-0.18	0.69	-	1.95	1.25	0.95
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	14	10.43	12.52	-	-	9.93	-	9.93	-	-	0.97	0.69	1.04	-	0.35	1.31
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	44	-	-	-	-	-	-	-	-	-	-	0.01	0.01	-	0.001	0.001
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	220	-	-	-	-	-	-	-	-	-	-	0.39	0.31	-	-0.08	-0.08
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	220	0.56	0.61	-	1.12	0.47	2.24	3.84	-	-	-0.02	0.47	-	0.78	0.32	0.29
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	220	0.56	0.84	-	-	1.01	-	1.01	-	-	0.10	0.47	0.70	-	0.23	0.33
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	1	0.02	0.02	-	-	0.02	-	0.02	-	-	0.00	0.18	0.27	-	0.09	0.09
Total		**42.79**	**27.61**	**2.27**	**1.39**	**25.69**	**2.39**	**29.46**	**0.85**	**0.78**	**5.32**	**31.15**	**25.50**	**2.73**	**-2.92**	**4.03**

Republic of the Marshall Islands (Cost of Carbon Saving)





Solomon Islands (2023-2027)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	3,369	-	-	-	-	-	-	-	2.83	-	6.55	71.20	60.52	-	-10.68	-1.30
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	3,369	-	-	-	1.00	-	-	1.00	-	0.60	-	20.17	16.14	-	-4.03	-3.43
WASP Retrofit - Most vessels (excl. some specialist craft)	3,289	991.79	-	-	-	74.07	-	74.07	-	-	4.40	25.78	18.05	-	-7.73	-3.34
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	160	-	-	126.07	-	3.14	-	3.14	-	-	-	17.16	16.30	-	-0.86	-0.86
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	108	-	-	26.54	-	0.66	-	0.66	-	-	-	13.03	12.38	-	-0.65	-0.65
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	32	-	-	-	-	-	-	-	-	-	-	2.77	3.11	-	0.34	0.34
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	151	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	151	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	305	-	-	-	-	-	-	-	-	-	-	0.82	0.88	-	0.06	0.06
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	1,526	-	-	3.38	-	6.31	-	6.31	-	-	-	4.09	3.27	-	-0.82	-0.82
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	1,526	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	1,526	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**991.79**	**-**	**155.98**	**1.00**	**84.19**	**-**	**85.19**	**2.83**	**0.60**	**10.95**	**155.02**	**130.65**	**-**	**-24.37**	**-9.99**

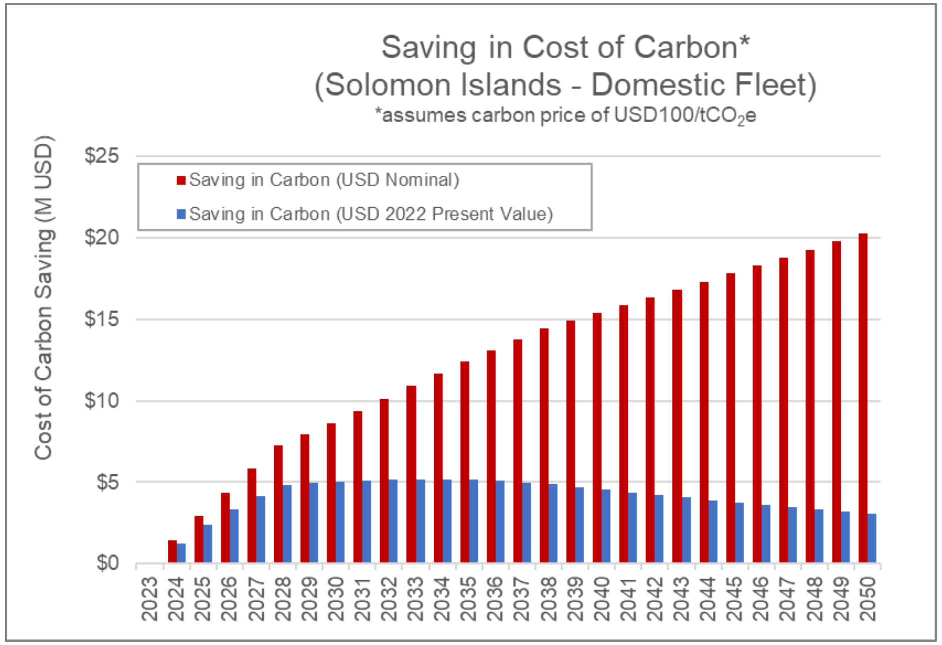
Solomon Islands (2028-2032)

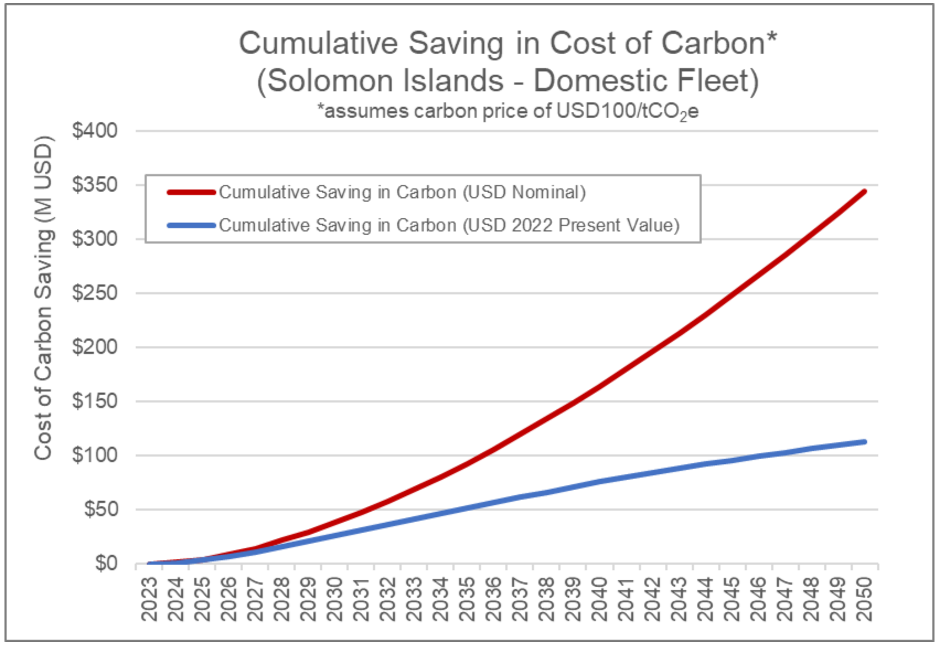
Abatement Measure	Vessel Count	BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
		Like-for-Like Vessel Replace	New Purpose-Built Vessel	Like-for-Like Engine Replace	Onshore Cost	Upgrade or Retrofit Cost	Initial Battery Cost & Replace	TOTAL CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	3,369	-	-	-	-	-	-	-	5.41	-	12.52	136.09	115.68	-	-20.41	-2.48
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	3,369	-	-	-	0.92	-	-	0.92	-	1.59	-	52.94	42.35	-	-10.59	-9.00
WASP Retrofit - Most vessels (excl. some specialist craft)	3,289	701.61	-	-	-	52.40	-	52.40	-	-	10.65	62.40	43.68	-	-18.72	-8.07
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	160	-	-	26.54	-	0.66	-	0.66	-	-	-	32.80	31.16	-	-1.64	-1.64
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	108	-	-	26.54	-	0.66	-	0.66	-	-	-	24.91	23.67	-	-1.25	-1.25
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	32	-	-	-	-	-	-	-	-	-	-	4.74	5.31	-	0.57	0.57
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	16	5.13	5.18	-	-	0.02	-	0.02	-	-	0.0005	0.28	0.42	-	0.14	0.14
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	151	57.12	73.12	-	0.32	26.62	0.32	27.25	-	-0.05	-0.07	0.67	-	1.99	1.32	1.21
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	151	57.12	68.55	-	-	24.96	-	24.96	-	-	0.37	0.67	1.01	-	0.34	0.71
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	305	-	-	-	-	-	-	-	-	-	-	1.40	1.50	-	0.11	0.11
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	1,526	-	-	0.71	-	1.33	-	1.33	-	-	-	7.81	6.25	-	-1.56	-1.56
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	1,526	0.80	0.88	-	1.61	0.52	3.21	5.34	-	-	-0.004	0.21	-	0.64	0.43	0.43
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	1,526	0.80	1.20	-	-	1.12	-	1.12	-	-	0.02	0.21	0.31	-	0.10	0.12
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**822.59**	**148.93**	**53.78**	**2.85**	**108.30**	**3.53**	**114.67**	**5.41**	**1.54**	**23.48**	**325.14**	**271.36**	**2.64**	**-51.15**	**-20.72**

Solomon Islands (2033-2050)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	Vessel Count	Like-for-Like Vessel Replace	New Purpose-Built Vessel	Like-for-Like Engine Replace	Onshore Cost	Upgrade or Retrofit Cost	Initial Battery Cost & Replace	TOTAL CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	3,369	-	-	-	-	-	-	-	9.47	-	21.90	238.05	202.34	-	-35.71	-4.34
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	3,369	-	-	-	0.77	-	-	0.77	-	5.54	-	185.11	148.09	-	-37.02	-31.48
WASP Retrofit - Most vessels (excl. some specialist craft)	3,289	560.73	-	-	-	41.88	-	41.88	-	-	20.59	120.69	84.48	-	-36.21	-15.61
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	160	-	-	-	-	-	-	-	-	-	-	57.38	54.51	-	-2.87	-2.87
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	108	-	-	26.54	-	0.66	-	0.66	-	-	-	43.58	41.40	-	-2.18	-2.18
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	32	-	-	-	-	-	-	-	-	-	-	0.51	0.57	-	0.06	0.06
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	16	6.50	6.57	-	-	0.03	-	0.03	-	-	0.01	4.38	6.58	-	2.19	2.20
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	151	277.60	355.32	-	1.54	129.36	1.54	132.44	-	-1.44	-2.25	21.42	-	63.50	42.08	38.40
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	151	277.60	333.12	-	-	121.28	-	121.28	-	-	11.79	21.42	32.13	-	10.71	22.50
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	305	-	-	-	-	-	-	-	-	-	-	0.15	0.16	-	0.01	0.01
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	1,526	-	-	-	-	-	-	-	-	-	-	5.50	4.40	-	-1.10	-1.10
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	1,526	3.90	4.27	-	7.80	2.55	15.61	25.96	-	-	-0.12	6.64	-	20.46	13.81	13.70
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	1,526	3.90	5.85	-	-	5.46	-	5.46	-	-	0.53	6.64	9.96	-	3.32	3.85
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**1,130.22**	**705.13**	**26.54**	**10.11**	**301.22**	**17.15**	**328.47**	**9.47**	**4.11**	**52.45**	**711.47**	**584.62**	**83.96**	**-42.89**	**23.14**

Solomon Islands (Cost of Carbon Saving)





Tonga (2023-2027)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	Vessel Count	Like-for-Like Vessel Replace	New Purpose-Built Vessel	Like-for-Like Engine Replace	Onshore Cost	Upgrade or Retrofit Cost	Initial Battery Cost & Replace	TOTAL CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	604	-	-	-	-	-	-	-	2.16	-	5.06	2.94	2.50	-	-0.44	6.78
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	604	-	-	-	0.31	-	-	0.31	-	0.19	-	0.83	0.67	-	-0.17	0.02
WASP Retrofit - Most vessels (excl. some specialist craft)	491	110.54	-	-	-	22.91	-	22.91	-	-	1.34	1.35	0.94	-	-0.40	0.93
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	53	-	-	41.94	-	1.01	-	1.01	-	-	-	0.84	0.80	-	-0.04	-0.04
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	53	-	-	8.83	-	0.21	-	0.21	-	-	-	0.80	0.76	-	-0.04	-0.04
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	16	-	-	-	-	-	-	-	-	-	-	0.09	0.10	-	0.01	0.01
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	44	-	-	-	-	-	-	-	-	-	-	0.05	0.05	-	0.004	0.004
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	222	-	-	0.49	-	1.18	-	1.18	-	-	-	0.25	0.20	-	-0.05	-0.05
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	222	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	222	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**110.54**	**-**	**51.26**	**0.31**	**25.31**	**-**	**25.62**	**2.16**	**0.19**	**6.40**	**7.15**	**6.02**	**-**	**-1.13**	**7.62**

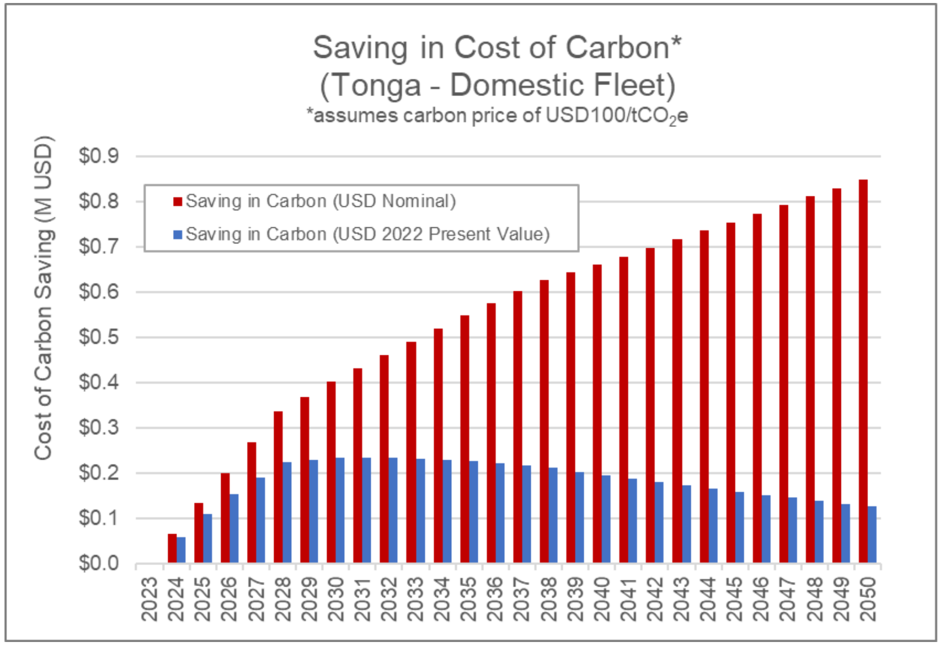
Tonga (2028-2032)

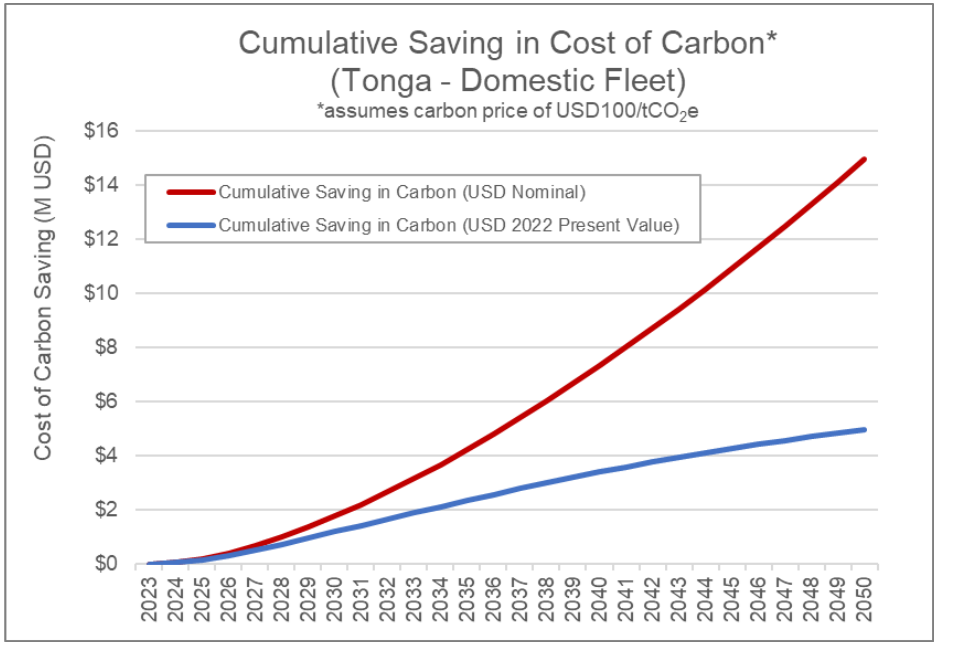
Abatement Measure	Vessel Count	BASELINE (USD$M) Like-for-Like Vessel Replace	BASELINE (USD$M) New Purpose-Built Vessel	BASELINE (USD$M) Like-for-Like Engine Replace	CAPEX (USD$M) Onshore Cost	CAPEX (USD$M) Upgrade or Retrofit Cost	CAPEX (USD$M) Initial Battery Cost & Replace	CAPEX (USD$M) TOTAL CAPEX	OPEX (USD$M) Shipyard Cost (Increm.)	OPEX (USD$M) Labor Cost (Increm.)	OPEX (USD$M) Repair & Maint. Cost (Increm.)	OPEX (USD$M) Initial Fuel	OPEX (USD$M) Proposed Fuel	OPEX (USD$M) Charging Cost	OPEX (USD$M) Energy Cost (Increm.)	OPEX (USD$M) TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	604	-	-	-	-	-	-	-	4.12	-	9.67	5.62	4.78	-	-0.84	12.95
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	604	-	-	-	0.29	-	-	0.29	-	0.49	-	2.19	1.75	-	-0.44	0.05
WASP Retrofit - Most vessels (excl. some specialist craft)	491	78.20	-	-	-	16.21	-	16.21	-	-	3.24	3.27	2.29	-	-0.98	2.26
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	53	-	-	8.83	-	0.21	-	0.21	-	-	-	1.60	1.52	-	-0.08	-0.08
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	53	-	-	8.83	-	0.21	-	0.21	-	-	-	1.52	1.45	-	-0.08	-0.08
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	16	-	-	-	-	-	-	-	-	-	-	0.15	0.17	-	0.02	0.02
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	8	2.12	2.14	-	-	0.02	-	0.02	-	-	0.0003	0.01	0.01	-	0.004	0.005
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	76	20.12	25.75	-	0.16	20.60	0.16	20.92	-	-0.05	-0.06	0.02	-	0.08	0.06	-0.04
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	76	20.12	24.14	-	-	19.31	-	19.31	-	-	0.29	0.02	0.03	-	0.01	0.30
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	44	-	-	-	-	-	-	-	-	-	-	0.09	0.09	-	0.01	0.01
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	222	-	-	0.10	-	0.25	-	0.25	-	-	-	0.48	0.38	-	-0.10	-0.10
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	222	0.12	0.13	-	0.23	0.10	0.47	0.80	-	-	-0.00	0.01	-	0.04	0.03	0.03
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	222	0.12	0.17	-	-	0.21	-	0.21	-	-	0.00	0.01	0.02	-	0.01	0.01
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**120.78**	**52.33**	**17.76**	**0.68**	**57.12**	**0.63**	**58.42**	**4.12**	**0.45**	**13.14**	**14.99**	**12.49**	**0.13**	**-2.37**	**15.34**

Tonga (2033-2050)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	Vessel Count	Like-for-Like Vessel Replace	New Purpose-Built Vessel	Like-for-Like Engine Replace	Onshore Cost	Upgrade or Retrofit Cost	Initial Battery Cost & Replace	TOTAL CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	604	-	-	-	-	-	-	-	7.22	-	16.92	9.83	8.36	-	-1.47	22.66
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	604	-	-	-	0.24	-	-	0.24	-	1.72	-	7.65	6.12	-	-1.53	0.19
WASP Retrofit - Most vessels (excl. some specialist craft)	491	62.50	-	-	-	12.95	-	12.95	-	-	6.27	6.32	4.42	-	-1.90	4.37
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	53	-	-	-	-	-	-	-	-	-	-	2.80	2.66	-	-0.14	-0.14
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	53	-	-	8.83	-	0.21	-	0.21	-	-	-	2.67	2.53	-	-0.13	-0.13
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	16	-	-	-	-	-	-	-	-	-	-	0.02	0.02	-	0.002	0.002
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	8	2.68	2.71	-	-	0.02	-	0.02	-	-	0.004	0.14	0.20	-	0.07	0.07
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	76	97.76	125.14	-	0.78	100.11	0.78	101.67	-	-1.44	-1.90	0.66	-	2.67	2.01	-1.33
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	76	97.76	117.32	-	-	93.85	-	93.85	-	-	9.12	0.66	0.99	-	0.33	9.46
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	44	-	-	-	-	-	-	-	-	-	-	0.01	0.01	-	0.001	0.001
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	222	-	-	-	-	-	-	-	-	-	-	0.34	0.27	-	-0.07	-0.07
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	222	0.57	0.62	-	1.13	0.48	2.27	3.87	-	-	-0.02	0.41	-	1.43	1.02	1.00
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	222	0.57	0.85	-	-	1.02	-	1.02	-	-	0.10	0.41	0.61	-	0.20	0.30
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**261.84**	**246.64**	**8.83**	**2.15**	**208.64**	**3.05**	**213.84**	**7.22**	**0.28**	**30.49**	**31.90**	**26.20**	**4.10**	**-1.60**	**36.38**

Tonga (Cost of Carbon Saving)





Tuvalu (2023-2027)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	437	-	-	-	-	-	-	-	0.70	-	1.72	3.90	3.32	-	-0.59	1.84
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	436	-	-	-	0.15	-	-	0.15	-	0.09	-	1.04	0.83	-	-0.21	-0.12
WASP Retrofit - Most vessels (excl. some specialist craft)	436	128.43	-	-	-	23.75	-	23.75	-	-	1.28	1.78	1.25	-	-0.53	0.75
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	51	-	-	43.06	-	0.98	-	0.98	-	-	-	0.74	0.70	-	-0.04	-0.04
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	50	-	-	9.06	-	0.21	-	0.21	-	-	-	0.67	0.64	-	-0.03	-0.03
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	5	-	-	-	-	-	-	-	-	-	-	0.07	0.08	-	0.01	0.01
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	2	0.84	1.08	-	0.00	0.96	0.00	0.97	-	-0.00	-0.00	0.01	-	0.04	0.03	0.02
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	39	-	-	-	-	-	-	-	-	-	-	0.10	0.11	-	0.01	0.01
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	193	-	-	0.42	-	0.79	-	0.79	-	-	-	0.50	0.40	-	-0.10	-0.10
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	193	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	193	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**129.27**	**1.08**	**52.55**	**0.15**	**26.69**	**0.00**	**26.85**	**0.70**	**0.09**	**3.00**	**8.82**	**7.32**	**0.04**	**-1.45**	**2.34**

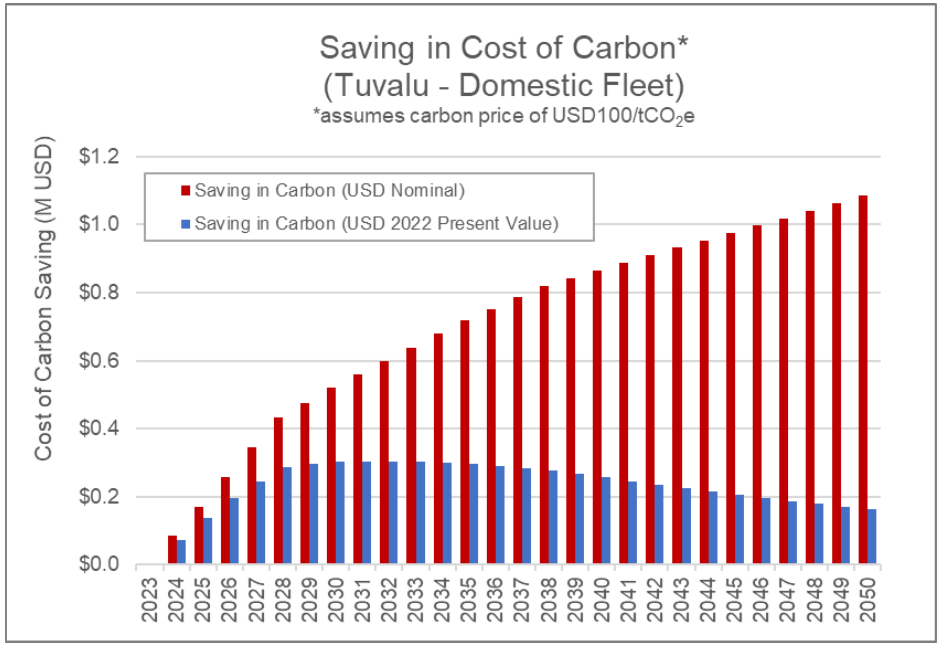
Tuvalu (2028-2032)

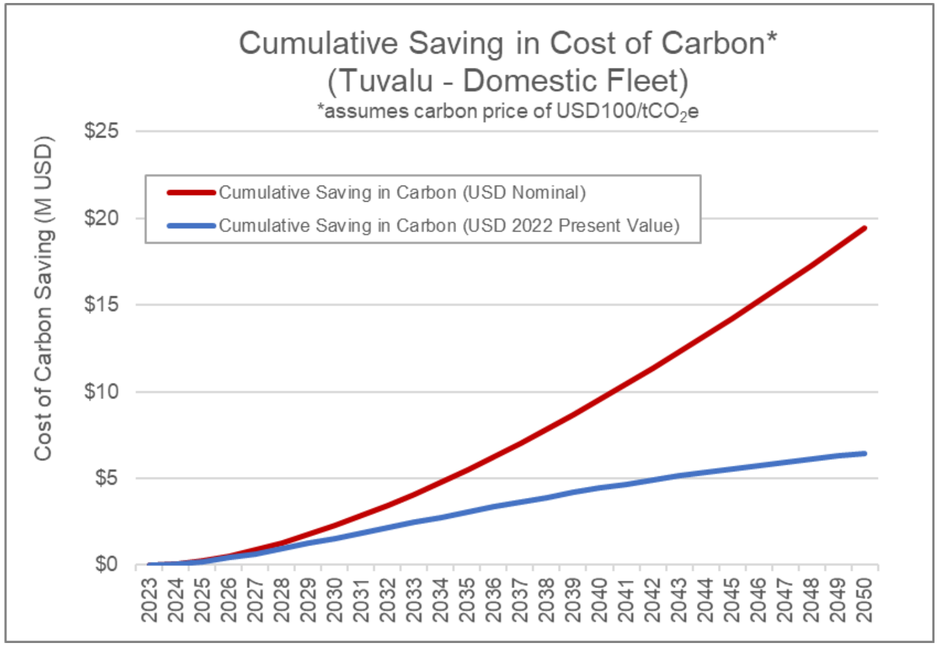
		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	**Vessel Count**	**Like-for-Like Vessel Replace**	**New Purpose-Built Vessel**	**Like-for-Like Engine Replace**	**Onshore Cost**	**Upgrade or Retrofit Cost**	**Initial Battery Cost & Replace**	**TOTAL CAPEX**	**Shipyard Cost (Increm.)**	**Labor Cost (Increm.)**	**Repair & Maint. Cost (Increm.)**	**Initial Fuel**	**Proposed Fuel**	**Charging Cost**	**Energy Cost (Increm.)**	**TOTAL OPEX**
Improved Maintenance Programs - All sectors and vessel types	437	-	-	-	-	-	-	-	1.34	-	3.29	7.46	6.34	-	-1.12	3.51
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	436	-	-	-	0.14	-	-	0.14	-	0.24	-	2.73	2.18	-	-0.55	-0.31
WASP Retrofit - Most vessels (excl. some specialist craft)	436	90.85	-	-	-	16.80	-	16.80	-	-	3.11	4.32	3.02	-	-1.29	1.81
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	51	-	-	9.06	-	0.21	-	0.21	-	-	-	1.42	1.35	-	-0.07	-0.07
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	50	-	-	9.06	-	0.21	-	0.21	-	-	-	1.28	1.22	-	-0.06	-0.06
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	5	-	-	-	-	-	-	-	-	-	-	0.11	0.13	-	0.02	0.02
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	3	0.72	0.72	-	-	0.01	-	0.01	-	-	0.0001	0.01	0.01	-	0.003	0.003
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	2	1.67	2.14	-	0.01	1.91	0.01	1.93	-	-0.01	-0.02	0.08	-	0.26	0.18	0.15
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	22	6.25	8.00	-	0.05	5.89	0.05	5.98	-	-0.01	-0.02	0.005	-	0.02	0.01	-0.02
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	24	7.00	8.40	-	-	6.32	-	6.32	-	-	0.09	0.02	0.02	-	0.01	0.10
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	39	-	-	-	-	-	-	-	-	-	-	0.17	0.19	-	0.01	0.01
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	193	-	-	0.09	-	0.17	-	0.17	-	-	-	0.96	0.77	-	-0.19	-0.19
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	193	0.10	0.11	-	0.20	0.07	0.40	0.67	-	-	-0.0005	0.03	-	0.08	0.05	0.05
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	193	0.10	0.15	-	-	0.14	-	0.14	-	-	0.00	0.03	0.04	-	0.01	0.01
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	1	0.53	0.63	-	-	0.67	-	0.67	-	-	0.01	0.02	0.03	-	0.01	0.02
Total		**107.21**	**20.15**	**18.22**	**0.39**	**32.37**	**0.46**	**33.23**	**1.34**	**0.21**	**6.46**	**18.63**	**15.29**	**0.36**	**-2.98**	**5.04**

Tuvalu (2033-2050)

		BASELINE (USD$M)			CAPEX (USD$M)				OPEX (USD$M)							
Abatement Measure	Vessel Count	Like-for-Like Vessel Replace	New Purpose-Built Vessel	Like-for-Like Engine Replace	Onshore Cost	Upgrade or Retrofit Cost	Initial Battery Cost & Replace	TOTAL CAPEX	Shipyard Cost (Increm.)	Labor Cost (Increm.)	Repair & Maint. Cost (Increm.)	Initial Fuel	Proposed Fuel	Charging Cost	Energy Cost (Increm.)	TOTAL OPEX
Improved Maintenance Programs - All sectors and vessel types	437	-	-	-	-	-	-	-	2.35	-	5.75	13.04	11.09	-	-1.96	6.14
Demand-Supply Management, Data Systems, Supporting Infrastructure - All sectors and vessel types (excl. Navy)	436	-	-	-	0.11	-	-	0.11	-	0.82	-	9.54	7.64	-	-1.91	-1.09
WASP Retrofit - Most vessels (excl. some specialist craft)	436	72.61	-	-	-	13.43	-	13.43	-	-	6.01	8.35	5.84	-	-2.50	3.50
Engine Derating - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	51	-	-	-	-	-	-	-	-	-	-	2.48	2.36	-	-0.12	-0.12
Propulsion Improving Devices (PIDs) - All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)	50	-	-	9.06	-	0.21	-	0.21	-	-	-	2.24	2.13	-	-0.11	-0.11
Biofuel (Blended) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	5	-	-	-	-	-	-	-	-	-	-	0.01	0.01	-	0.002	0.002
Biofuel (B100) - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	3	0.91	0.92	-	-	0.01	-	0.01	-	-	0.001	0.11	0.16	-	0.05	0.05
Electrification - Government sector vessels (excl. vessels <10m length - assumed 2-stroke)	2	2.92	3.74	-	0.02	3.34	0.02	3.37	-	-0.05	-0.08	0.44	-	1.40	0.96	0.82
Electrification - Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)	22	30.36	38.86	-	0.23	28.60	0.23	29.06	-	-0.41	-0.54	0.15	-	0.52	0.37	-0.59
Green e-fuels - All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)	24	34.01	40.81	-	-	30.73	-	30.73	-	-	2.99	0.52	0.77	-	0.26	3.25
Biofuel (Blended) - All vessels <10m length (assumed 2-stroke)	39	-	-	-	-	-	-	-	-	-	-	0.02	0.02	-	0.001	0.001
Motor Switching - 2-stroke to 4-stroke - All vessels <10m length (assumed 2 stroke)	193	-	-	-	-	-	-	-	-	-	-	0.68	0.54	-	-0.14	-0.14
Electrification - All vessels <10m length (assumed 2 and 4-stroke)	193	0.49	0.54	-	0.98	0.32	1.96	3.26	-	-	-0.01	0.82	-	2.55	1.73	1.72
Green e-fuels - All vessels <10m length (assumed 2 and 4-stroke)	193	0.49	0.73	-	-	0.69	-	0.69	-	-	0.07	0.82	1.23	-	0.41	0.48
Biofuel (B100) / Green e-fuels - Navy (Search and Rescue / Patrol)	1	1.52	1.82	-	-	1.92	-	1.92	-	-	0.25	0.50	0.76	-	0.25	0.50
Total		**143.30**	**87.42**	**9.06**	**1.34**	**79.24**	**2.20**	**82.78**	**2.35**	**0.36**	**14.42**	**39.72**	**32.54**	**4.47**	**-2.71**	**14.42**

Tuvalu (Cost of Carbon Saving)





Appendix C: Model Assumptions

Improved Maintenance Programs – All sectors and vessel types			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		All vessels	Applicable to entire maritime fleet of each nation.
Excluded Vessels		-	
% Vessels within Group		100%	
Vessel Count	**Fiji**	5,377	
	Kiribati	1,952	
	RMI	469	
	Solomon Islands	3,369	
	Tonga	604	
	Tuvalu	437	
Initiative Start		2023	Ongoing abatement measure that can potentially begin within 12 months and reach saturation across the fleet over 5 years. This abatement measure is expected to be ongoing based on the current baseline.
Phase-in Period (Years)		3	
Initiative End		Ongoing	
Phase-out Period (Years)		N/A	
Fuel CO_2e Emissions Factor Reduction		N/A	No change in fuel type used.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		15%	Efficiency gains are expected to come from a range of improved maintenance activities, included hull cleaning, propeller polishing, more frequent engine maintenance and servicing. Regular hull cleaning activities has shown to reduce fuel consumption and CO_2e emissions by up to 18%[45]. The Model conservatively assumes 15% across the fleet as a number of these maintenance operations may already be adopted for some vessels and operations.
Associated Abatement Measure		-	Fleet maintenance is considered independent of other abatement measures.

Demand/Supply Management & Infrastructure – All sectors and vessel types (excl. Navy)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		Almost all vessels	Applicable to all vessels except navy vessels that will continue to operate normally as demand arises. Note that navy vessels of Tonga (and possibly other nations) may be incomplete.
Excluded Vessels		Navy (Search & Rescue / Patrol)	
% Vessels within Group		100%	
Vessel Count	**Fiji**	5,373	
	Kiribati	1,952	
	RMI	468	
	Solomon Islands	3,369	
	Tonga	604	
	Tuvalu	436	
Initiative Start		2023	Ongoing abatement measure that can potentially begin within 12 months and achieve nominated potential reduction in 5 years. This abatement measure is expected to be ongoing based on the current baseline.
Phase-in Period (Years)		15	
Initiative End		Ongoing	
Phase-out Period (Years)		N/A	
Fuel CO_2e Emissions Factor Reduction		N/A	No change in fuel type used.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		20%	Efficiency gains are expected to come from a range of activities that rely on improved logistics and route planning, information systems, data capture and sharing, and port infrastructure (main hubs and regional). The emissions reduction may range between 10% and 27%[46] [47] [48] [49]. The Model conservatively assumes 20% across the fleet as a number of these activities may already be adopted for some vessels and operations.

[45] Elidolu, Gizem & Uyanık, Tayfun & Karabıyık, Pınar & Arslanoğlu, Yasin. (2020). *Hull cleaning effects on CO2 emissions estimation with machine learning methods*.
[46] Winnes, H., Styhre, L., Fridell E. (2015). *Reducing GHG emissions from ships in port areas*. Research in Transportation Business & Management, 17 (2015), pp. 73-82.
[47] Faber, J., Markowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I., Selstad, E., Kågeson, P., Lee, D., Buhaug, Ø. and Lindtsad, H. (2009). *Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport*. *CE Delft*, Delft (2009)
[48] Faber, J., Nelissen, D., Hon, G., Wang, H. and Tsimplis, M. (2012). *Regulated slow steaming in maritime transport. An assessment of options, costs and benefits*. *CE Delft*, Delft (2012)
[49] Bazari, Z. and Longva, T. (2011). Assessment of IMO mandated energy efficiency measures for international shipping. *IMO*, 10.

Associated Abatement Measure	-	This measure is considered independent of other abatement measures.

<table>
<tr><th colspan="4">WASP Retrofit – Most vessels (excl. some specialist craft)</th></tr>
<tr><th colspan="2">Parameter</th><th>Model Inputs</th><th>Assumption</th></tr>
<tr><td colspan="2">Applicable Vessels</td><td>Most vessels</td><td rowspan="9">Based on the concept of returning to traditional vessel design and reinvigorating traditional sailing knowledge, this abatement measure is generally applicable to all vessels except some specialist craft due to functional reasons. Retrofitting sails to smaller vessels (<10m length) is also feasible and recommended based on feedback from PBSP country representatives.</td></tr>
<tr><td colspan="2">Excluded Vessels</td><td>Dredging, Pleasure Craft, Pollution Response Boats, Search & Rescue / Patrol, Tugboats, Yachts</td></tr>
<tr><td colspan="2">% Vessels within Group</td><td>100%</td></tr>
<tr><td rowspan="6">Vessel Count</td><td>Fiji</td><td>5,191</td></tr>
<tr><td>Kiribati</td><td>1,951</td></tr>
<tr><td>RMI</td><td>466</td></tr>
<tr><td>Solomon Islands</td><td>3,289</td></tr>
<tr><td>Tonga</td><td>491</td></tr>
<tr><td>Tuvalu</td><td>436</td></tr>
<tr><td colspan="2">Initiative Start</td><td>2023</td><td rowspan="4">As this recognizes the value of traditional vessel design and sailing knowledge, this is an ongoing abatement measure that can potentially begin within 12 months and achieve nominated potential reduction in 7 years.</td></tr>
<tr><td colspan="2">Phase-in Period (Years)</td><td>7</td></tr>
<tr><td colspan="2">Initiative End</td><td>Ongoing</td></tr>
<tr><td colspan="2">Phase-out Period (Years)</td><td>N/A</td></tr>
<tr><td colspan="2">Fuel CO_2e Emissions Factor Reduction</td><td>N/A</td><td>No change in fuel type used but noting that this abatement measure can be combined with other fuel/motor-switching measures.</td></tr>
<tr><td colspan="2">Fuel Reduction due to Improved Efficiency or Technology Upgrade</td><td>30% (Fiji)
20% (Kiribati)
25% (RMI)
20% (Solomon Islands)
25% (Tonga)
20% (Tuvalu)</td><td>Based on research carried out in the South Pacific demonstrating up to 37% emissions reduction per voyage including within Kiribati[50]. This value is then scaled based on the available wind resource of each individual country, sourced from https://globalwindatlas.info/, based on mean power density (W/m²) of the upper range (approx. 100-330 W/m² for Fiji) and the lower range (approx. 60-70 W/m² for Kiribati). For large carriers, a single rigid sail can save up to 5% in greenhouse gas emissions[51].</td></tr>
<tr><td colspan="2">Associated Abatement Measure</td><td>-</td><td>This measure is considered independent of other abatement measures, but in practice can be combined with other measures.</td></tr>
</table>

<table>
<tr><th colspan="4">Engine Derating – All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)</th></tr>
<tr><th colspan="2">Parameter</th><th>Model Inputs</th><th>Assumption</th></tr>
<tr><td colspan="2">Applicable Vessels</td><td>Generally larger vessel</td><td rowspan="9">Applicable to all vessels greater than 10m, excluding vessels that require maximum available motor output for operational and functional reasons.</td></tr>
<tr><td colspan="2">Excluded Vessels</td><td>Vessels <10m, Barges, Dredging, Medical Boats, Open Boats, Pleasure Craft, Pollution Response Boats, Search & Rescue / Patrol, Small Artisanal Crafts, Small Boats, Tugboats, Work Boats, Yachts</td></tr>
<tr><td colspan="2">% Vessels within Group</td><td>100%</td></tr>
<tr><td rowspan="6">Vessel Count</td><td>Fiji</td><td>113</td></tr>
<tr><td>Kiribati</td><td>36</td></tr>
<tr><td>RMI</td><td>27</td></tr>
<tr><td>Solomon Islands</td><td>160</td></tr>
<tr><td>Tonga</td><td>53</td></tr>
<tr><td>Tuvalu</td><td>51</td></tr>
<tr><td colspan="2">Initiative Start</td><td>2023</td><td rowspan="4">Ongoing abatement measure that can potentially begin within 12 months and achieve nominated potential reduction in 5 years. This abatement measure is expected to be ongoing based on the current baseline.</td></tr>
<tr><td colspan="2">Phase-in Period (Years)</td><td>5</td></tr>
<tr><td colspan="2">Initiative End</td><td>Ongoing</td></tr>
<tr><td colspan="2">Phase-out Period (Years)</td><td>N/A</td></tr>
<tr><td colspan="2">Fuel CO_2e Emissions Factor Reduction</td><td>N/A</td><td>No change in fuel type used.</td></tr>
<tr><td colspan="2">Fuel Reduction due to Improved Efficiency or Technology Upgrade</td><td>5%</td><td>Efficiency gains based on the assumption that the current operational speed is generally lower than what the engine has been originally designed</td></tr>
</table>

[50] Lupoae, L.A., (2022). *Development of a Sustainable Impact Method for Pacific Inter-Island Maritime Transport*. Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Netherlands.
[51] Shipping Australia Limited (2022). *MOL to bring world first hard sail-equipped bulker to Australia*. Available at: https://www.shippingaustralia.com.au/mol-to-bring-world-first-hard-sail-equipped-bulker-to-australia/ (Accessed 26 August 2022)

		for. This may include modifications to the existing engine or optimizing the propeller size to suit the typical operational speed[52].
Associated Abatement Measure	-	This measure is considered independent of other abatement measures.

Propulsion Improving Devices (PIDs) – All sectors and vessel types (excl. vessels <10m length - assumed 2 stroke)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		Generally larger vessel	Applicable to all vessels greater than 10m, excluding some vessels for operational and functional reasons.
Excluded Vessels		Vessels <10m, Barges, Dredging, Medical Boats, Open Boats, Pleasure Craft, Pollution Response Boats, Search & Rescue / Patrol, Small Artisanal Crafts, Small Boats, Tugboats, Work Boats, Yachts	
% Vessels within Group		100%	
Vessel Count	**Fiji**	29	
	Kiribati	12	
	RMI	9	
	Solomon Islands	108	
	Tonga	53	
	Tuvalu	50	
Initiative Start		2023	Ongoing abatement measure that can potentially begin within 12 months and achieve nominated potential reduction in 5 years. This abatement measure is expected to be ongoing based on the current baseline.
Phase-in Period (Years)		5	
Initiative End		Ongoing	
Phase-out Period (Years)		N/A	
Fuel CO_2e Emissions Factor Reduction		N/A	No change in fuel type used.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		5%	Activities include installation of different ducts, pre-swirl fins, fin on hull, rudders, caps, contra-rotating propellers, or other modifications to reduce turbulence and improve efficiency[53] [54] [55]. A combination of can be made to a vessel with diminishing improvement. Some modifications may only be appropriate for slower-moving vessels with high block coefficient, such as Contracted and Loaded Tip (CLT) propellers[56].
Associated Abatement Measure		-	This measure is considered independent of other abatement measures.

Biofuel (Blended) – All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		All vessels >10m length	Applicable to a small (5%) of all vessels greater than 10m, excluding some vessels for operational and functional reasons such as navy (Search & Rescue / Patrol). These vessels are captured in other abatement measures. A 5% applicability is based on low biofuel production potential within the PBSP nations for reasons including, competition with agricultural land, and supporting socio-economic incentives and drivers. International biofuel is readily available and can be imported while local supply is established (if local production is preferred). No engine upgrades are assumed to be required to accommodate Biofuel (Blended).
Excluded Vessels		Vessels <10m, Navy	
% Vessels within Group		10%	
Vessel Count	**Fiji**	17	
	Kiribati	4	
	RMI	3	
	Solomon Islands	32	
	Tonga	16	
	Tuvalu	5	
Initiative Start		2023	Short-term abatement measure that can potentially begin within 12 months provided sufficient blended biofuel supply can be establish. As blended biofuel still has CO_2e emissions, this fuel must be phased out in favor of a zero-emissions fuel. Timing aligns with Biofuel (Blended) for small vessels.
Phase-in Period (Years)		5	
Initiative End		2035	
Phase-out Period (Years)		5	

[52] Global Maritime Energy Efficiency Partnerships (GloMEEP) (2022). Global Environment Facility (GEF) – United Nations Development Programme (UNDP) –IMO *Engine De-Rating*. Available at: https://glomeep.imo.org/technology/engine-de-rating/ (Accessed 06 July 2022).
[53] Global Maritime Energy Efficiency Partnerships (GloMEEP) (2022). Global Environment Facility (GEF) – United Nations Development Programme (UNDP) –IMO *Propulsion Improving Devices (PIDs)*. Available at: https://glomeep.imo.org/technology/propulsion-improving-devices-pids/ (Accessed 06 July 2022).
[54] Wärtsilä (2022). *Air Lubrication System cuts fuel consumption and emissions by up to 10%.* Available at: https://www.wartsila.com/marine/products/propulsors-and-gears/energy-saving-technology/air-lubrication-system (Accessed 13 July 2022).
[55] Hapag-Lloyd (2022). *Investing in sustainability: Hapag-Lloyd to make existing fleet more efficient*. Available at: https://www.hapag-lloyd.com/en/company/press/releases/2022/08/investing-in-sustainability--hapag-lloyd-to-make-existing-fleet-.html (Accessed 26 August 2022).
[56] Gennaro, G. (2012). *Improving the Propulsion Efficiency by means of Contracted and Loaded Tip (CLT) Propellers* [Presentation]. The Society of Naval Architects and Marine Engineers, Italy. Available at: http://www.sinm.it/sites/default/files/CLT_SNAME_Athens2012_Speech.pdf (Accessed 06 July 2022).

Fuel CO_2e Emissions Factor Reduction	20%	Assumes a 20% reduction in CO_2e emissions for B20 mix[57]. Refer Table 14 for details.
Fuel Reduction due to Improved Efficiency or Technology Upgrade	-	N/A
Associated Abatement Measure	Biofuel (B100)	Blended Biofuel must be phased-out eventually in favor of zero-emissions fuels such as Biofuel (B100), Green e-fuels, and/or Electrification.

Biofuel (B100) – All sectors and vessel types (excl. vessels <10m length - assumed 2-stroke)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		All vessels >10m length	Applicable to a small (5%) of all vessels greater than 10m, excluding some vessels for operational and functional reasons. These vessels are captured in other abatement measures. A 5% applicability is based on low biofuel production potential within the PBSP nations for reasons including, competition with agricultural land, and supporting socio-economic incentives and drivers. International biofuel is readily available and can be imported while local supply is established (if local production is preferred). Some engine upgrades are expected including additional filters, pumps, and heaters to accommodate fuel's higher viscosity.
Excluded Vessels		Vessels <10m, Navy (Search & Rescue / Patrol)	
% Vessels within Group		5%	
Vessel Count	**Fiji**	8	
	Kiribati	2	
	RMI	1	
	Solomon Islands	16	
	Tonga	8	
	Tuvalu	3	
Initiative Start		2030	Potentially long-term abatement measure that will begin to replace blended biofuels. Significant challenge is to establish robust local supply chain.
Phase-in Period (Years)		5	
Initiative End		Ongoing	
Phase-out Period (Years)		N/A	
Fuel CO_2e Emissions Factor Reduction		100%	Assumes a 100% reduction in CO_2e emissions for B100[58]. Refer Table 14 for details.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		-	N/A
Associated Abatement Measure		Biofuel (Blended), Electrification, Green e-fuel	Final fuel mix may include a combination of Biofuel (B100), Green e-fuels, and/or Electrification. Model currently assumes a low proportion (5%) of applicable vessels will operate on Biofuel (B100), and the remaining will be split evenly between Electrification and green e-fuels until these technologies are reviewed again.

Electrification – Government sector vessels (excl. vessels <10m length - assumed 2-stroke)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		All vessels >10m length	Electrification of Government and Private/Commercial vessels form half of the remaining larger vessels not powered by Biofuel (B100) in the Model. The remaining half is assumed to be Green e-fuels until these technologies are reviewed again. Electrification of fleet is expected to be based on replacing retired vessels with new purpose-built electric vessels, and not electric motor retrofits.
Excluded Vessels		Private/Commercial Vessels, Vessels <10m, Navy (Search & Rescue / Patrol)	
% Vessels within Group		47.5%	
Vessel Count	**Fiji**	12	
	Kiribati	1	
	RMI	-	
	Solomon Islands	-	
	Tonga	-	
	Tuvalu	2	
Initiative Start		2025	Long-term abatement measure that will begin phasing-in 5 years before Electrification of Private/Commercial vessels begin. This assumes that Government can lead the way in demonstrating real-world viability before broader commercialization. Significant challenge is establishing the supporting energy generation and battery charging infrastructure, particularly at the regional ports. Based on current prices for like-for-like engine capacities, batteries are also potentially cost-prohibitive. Price reductions are expected as this technology matures and is more widely adopted, however the Model does not account for future price reduction.
Phase-in Period (Years)		25	
Initiative End		Ongoing	
Phase-out Period (Years)		N/A	
Fuel CO_2e Emissions Factor Reduction		100%	Assumes a 100% reduction in CO_2e emissions. Refer Table 14 for details.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		-	N/A

[57] Australian Government Department of Industry, Science, Energy and Resources, 2020. *National Greenhouse Accounts Factors*, Canberra.
[58] Australian Government Department of Industry, Science, Energy and Resources, 2020. *National Greenhouse Accounts Factors*, Canberra: Australian Greenhouse Office.

<table>
<tr><td>Associated Abatement Measure</td><td>Biofuel (B100), Electrification – Private/Commercial, Green e-fuels</td><td>Final fuel mix may include a combination of Biofuel (B100), Green e-fuels, and/or Electrification. Model currently assumes a low proportion (5%) of applicable vessels will operate on Biofuel (B100), and the remaining will be split evenly between Electrification and Green e-fuels until these technologies are reviewed again.</td></tr>
</table>

<table>
<tr><th colspan="4">Electrification – Private/Commercial sector vessels (excl. vessels <10m length - assumed 2-stroke)</th></tr>
<tr><th colspan="2">Parameter</th><th>Model Inputs</th><th>Assumption</th></tr>
<tr><td colspan="2">Applicable Vessels</td><td>All vessels >10m length</td><td rowspan="9">Electrification of Government and Private/Commercial vessels form half of the remaining larger vessels not powered by Biofuel (B100) in the Model. The remaining half is assumed to be Green e-fuels until these technologies are reviewed again. Electrification of fleet is expected to be based on replacing retired vessels with new purpose-built electric vessels, and not electric motor retrofits.</td></tr>
<tr><td colspan="2">Excluded Vessels</td><td>Government Vessels, Vessels <10m, Navy (Search & Rescue / Patrol)</td></tr>
<tr><td colspan="2">% Vessels within Group</td><td>47.5%</td></tr>
<tr><td rowspan="6">Vessel Count</td><td>Fiji</td><td>67</td></tr>
<tr><td>Kiribati</td><td>17</td></tr>
<tr><td>RMI</td><td>14</td></tr>
<tr><td>Solomon Islands</td><td>151</td></tr>
<tr><td>Tonga</td><td>76</td></tr>
<tr><td>Tuvalu</td><td>22</td></tr>
<tr><td colspan="2">Initiative Start</td><td>2030</td><td rowspan="4">Long-term abatement measure that will begin phasing-in 5 years after Electrification of Government vessels begin. However some private operations may adopt this technology sooner. Significant challenge is establishing the supporting energy generation and battery charging infrastructure, particularly at the regional ports. Based on current prices for like-for-like engine capacities, batteries are also potentially cost-prohibitive. Price reductions are expected as this technology matures and is more widely adopted, however the Model does not account for future price reduction.</td></tr>
<tr><td colspan="2">Phase-in Period (Years)</td><td>20</td></tr>
<tr><td colspan="2">Initiative End</td><td>Ongoing</td></tr>
<tr><td colspan="2">Phase-out Period (Years)</td><td>N/A</td></tr>
<tr><td colspan="2">Fuel CO_2e Emissions Factor Reduction</td><td>100%</td><td>Assumes a 100% reduction in CO_2e emissions. Refer Table 14 for details.</td></tr>
<tr><td colspan="2">Fuel Reduction due to Improved Efficiency or Technology Upgrade</td><td>-</td><td>N/A</td></tr>
<tr><td colspan="2">Associated Abatement Measure</td><td>Biofuel (B100), Electrification – Government, Green e-fuels</td><td>Final fuel mix may include a combination of Biofuel (B100), Green e-fuels, and/or Electrification. Model currently assumes a low proportion (5%) of applicable vessels will operate on Biofuel (B100), and the remaining will be split evenly between Electrification and Green e-fuels until these technologies are reviewed again.</td></tr>
</table>

<table>
<tr><th colspan="4">Green e-fuels – All sectors and vessel types (excl. vessels <10m length – assumed 2-stroke)</th></tr>
<tr><th colspan="2">Parameter</th><th>Model Inputs</th><th>Assumption</th></tr>
<tr><td colspan="2">Applicable Vessels</td><td>All vessels >10m length</td><td rowspan="9">New Green e-fuel vessels form half of the remaining larger vessels not powered by Biofuel (B100) in the Model. The remaining half is assumed to be Electric vessels until these technologies are reviewed again. Depending on the specific Green e-fuel adopted (i.e., eMethanol, ammonia, hydrogen etc.), retrofit may be possible, however based on the timing the Model currently assumes that these are likely to be new purpose-built vessels replacing retired conventional vessels.</td></tr>
<tr><td colspan="2">Excluded Vessels</td><td>Government Vessels, Vessels <10m, Navy (Search & Rescue / Patrol)</td></tr>
<tr><td colspan="2">% Vessels within Group</td><td>47.5%</td></tr>
<tr><td rowspan="6">Vessel Count</td><td>Fiji</td><td>80</td></tr>
<tr><td>Kiribati</td><td>18</td></tr>
<tr><td>RMI</td><td>14</td></tr>
<tr><td>Solomon Islands</td><td>151</td></tr>
<tr><td>Tonga</td><td>76</td></tr>
<tr><td>Tuvalu</td><td>24</td></tr>
<tr><td colspan="2">Initiative Start</td><td>2030</td><td rowspan="4">Long-term abatement measure that will begin phasing-in at the same time as Electrification of Private/Commercial vessels. Significant challenge is establishing the supply chain for Green e-fuel and supporting infrastructure, particularly at the regional ports. Current Green e-fuel pricing is unclear and has therefore been assumed to be 1.5 times Biofuel (B100) prices. Price reductions are expected as this technology matures and is more widely adopted, however the Model does not account for future price reduction.</td></tr>
<tr><td colspan="2">Phase-in Period (Years)</td><td>20</td></tr>
<tr><td colspan="2">Initiative End</td><td>Ongoing</td></tr>
<tr><td colspan="2">Phase-out Period (Years)</td><td>N/A</td></tr>
<tr><td colspan="2">Fuel CO_2e Emissions Factor Reduction</td><td>100%</td><td>Assumes a 100% reduction in CO_2e emissions. Refer Table 14 for details.</td></tr>
<tr><td colspan="2">Fuel Reduction due to Improved Efficiency or Technology Upgrade</td><td>-</td><td>N/A</td></tr>
<tr><td colspan="2">Associated Abatement Measure</td><td>Biofuel (B100), Electrification</td><td>Final fuel mix may include a combination of Biofuel (B100), Green e-fuels, and/or Electrification. Model currently assumes a low proportion (5%) of</td></tr>
</table>

		applicable vessels will operate on Biofuel (B100), and the remaining will be split evenly between Electrification and Green e-fuels until these technologies are reviewed again.

Blended Biofuel – All vessels <10m length (assumed 2 stroke)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		All vessels <10m length	Applicable to half the vessels assumed to be operating on 2-stroke outboard motors. 50% applicability is based on low biofuel production potential within the PBSP nations for reasons including, competition with agricultural land, and supporting socio-economic incentives and drivers. International biofuel is readily available and can be imported while local supply is established (if local production is preferred). No engine upgrades are assumed to be required to accommodate Biofuel (B20).
Excluded Vessels		Vessels >10m length, Navy (Search & Rescue / Patrol)	
% Vessels within Group		10%	
Vessel Count	**Fiji**	521	
	Kiribati	192	
	RMI	44	
	Solomon Islands	305	
	Tonga	44	
	Tuvalu	39	
Initiative Start		2023	Short-term abatement measure that can potentially begin within 12 months provided sufficient blended biofuel supply can be establish. As blended biofuel still has CO_2e emissions, this fuel must be phased out in favor of a zero-emissions alternative. Timing aligns with Biofuel (Blended) for larger vessels.
Phase-in Period (Years)		5	
Initiative End		2035	
Phase-out Period (Years)		5	
Fuel CO_2e Emissions Factor Reduction		20%	Assumes a 20% reduction in CO_2e emissions for B20 mix[59]. Refer Table 14 for details.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		-	N/A
Associated Abatement Measure		Electrification, Green e-fuel	Blended Biofuel must be phased-out eventually in favor of zero-emissions fuels. For 2-stroke outboard motors, this may include Green e-fuels, and/or Electrification.

Motor Switching – 2-stroke to 4-stroke – All vessels <10m length (assumed 2 stroke)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		All vessels <10m length	Applicable to half the vessels assumed to be operating on 2-stroke outboard motors. 50% applicability is based on uptake of abatement measure, but is considered optimistic. Similar to all other measures the uptake of this measure will depend on the effectiveness of the measure roll-out, funding mechanisms, and how it is incentivized for the individual operators.
Excluded Vessels		Vessels >10m length, Navy (Search & Rescue / Patrol)	
% Vessels within Group		50%	
Vessel Count	**Fiji**	2,603	
	Kiribati	958	
	RMI	220	
	Solomon Islands	1,526	
	Tonga	222	
	Tuvalu	193	
Initiative Start		2023	Short-term abatement measure that can potentially begin within 12 months and reach peak coverage of 50% after 5 years. As motor-switching still has CO_2e emissions, this abatement measure must be phased out in favor of a zero-emissions alternative.
Phase-in Period (Years)		5	
Initiative End		2040	
Phase-out Period (Years)		5	
Fuel CO_2e Emissions Factor Reduction		-	Refer below.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		20%	Assumes a 20% reduction in CO_2e emissions due to a more efficient fuel combustion cycle, and savings in fuel additives. Due to the configuration of the combustion cycle, 2-stroke engines can release up to 30% of their fuel unburned to the water[60]. A conservative improvement of 20% is applied.
Associated Abatement Measure		Electrification, Green e-fuel	2-stroke and 4-stroke motors must be phased-out eventually in favor of zero-emissions fuels, this may include Green e-fuels, and/or Electrification.

[59] Australian Government Department of Industry, Science, Energy and Resources, 2020. *National Greenhouse Accounts Factors*, Canberra: Australian Greenhouse Office.

[60] Mosisch, T. D., Arthington, A. H., 1998, *The impacts of Power Boating and water skiing on Lakes and Reservoirs*, Lakes and Reservoirs Research and Management 1998 3 1-17.

Electrification – All vessels <10m length (assumed 2 and 4 stroke)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		All vessels <10m length	Currently assumes an even split between Electrification and adoption of Green e-fuels for small vessels (assumed to be 2-stroke). Electrification of fleet is expected to be based on replacing retired vessels with new purpose-built electric vessels, and not electric motor retrofits.
Excluded Vessels		Vessels >10m length, Navy (Search & Rescue / Patrol)	
% Vessels within Group		50%	
Vessel Count	**Fiji**	2,603	
	Kiribati	958	
	RMI	220	
	Solomon Islands	1,526	
	Tonga	222	
	Tuvalu	193	
Initiative Start		2030	Long-term abatement measure that will begin phasing-in over 20 years from 2030 to achieve 50% coverage of small vessels with 2-stroke motors. However, some operations may adopt this technology sooner, depending on charging facilities, and cost of battery and motor switching. Significant challenge for wide-scale adoption is establishing the supporting energy generation and battery charging infrastructure, particularly at the regional ports. Based on current prices for like-for-like engine capacities, batteries are also potentially cost-prohibitive. Price reductions are expected as this technology matures and is more widely adopted, however the Model does not account for future price reduction.
Phase-in Period (Years)		20	
Initiative End		Ongoing	
Phase-out Period (Years)		N/A	
Fuel CO_2e Emissions Factor Reduction		100%	Assumes a 100% reduction in CO_2e emissions. Refer Table 14 for details.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		-	N/A
Associated Abatement Measure		Green e-fuel	Final fuel mix for smaller vessels may include a combination of Green e-fuels and/or Electrification. Model currently assumes no Biofuel (B100) uptake for 2-stroke motors that have been converted to 4-stroke motors, therefore to achieve zero emissions for small vessels, proposed options are Electrification and adoption of Green e-fuels.

Green e-fuels – All vessels <10m length (assumed 2 and 4-stroke)			
Parameter		**Model Inputs**	**Assumption**
Applicable Vessels		All vessels <10m length	Currently assumes an even split between Electrification and adoption of Green e-fuels for small vessels (assumed to be 2-stroke). Green e-fuels is expected to be based on replacing retired vessels with new purpose-built compatible vessels, and not motor retrofits. This also aligns with the timing of the need for replacement for many vessels.
Excluded Vessels		Vessels >10m length, Navy (Search & Rescue / Patrol)	
% Vessels within Group		50%	
Vessel Count	**Fiji**	2,603	
	Kiribati	958	
	RMI	220	
	Solomon Islands	1,526	
	Tonga	222	
	Tuvalu	193	
Initiative Start		2030	Long-term abatement measure that will begin phasing-in over 20 years from 2030 to achieve 50% coverage of small vessels with 2-stroke motors. Significant challenge is establishing the supply chain for Green e-fuel and supporting infrastructure, particularly at the regional ports. Current Green e-fuel pricing is unclear and has therefore been assumed to be 1.5 times Biofuel (B100) prices. Price reductions are expected as this technology matures and is more widely adopted, however the Model does not account for future price reduction.
Phase-in Period (Years)		20	
Initiative End		Ongoing	
Phase-out Period (Years)		N/A	
Fuel CO_2e Emissions Factor Reduction		100%	Assumes a 100% reduction in CO_2e emissions. Refer Table 14 for details.
Fuel Reduction due to Improved Efficiency or Technology Upgrade		-	N/A
Associated Abatement Measure		Electrification	Final fuel mix for smaller vessels may include a combination of Green e-fuels and/or Electrification. Model currently assumes no Biofuel (B100) uptake for 2-stroke motors that have been converted to 4-stroke motors, therefore to achieve zero emissions for small vessels, proposed options are Electrification and adoption of Green e-fuels.

<table>
<tr><th colspan="4">Biofuel (B100) / Green e-fuel – Navy (Search and Rescue / Patrol)</th></tr>
<tr><th colspan="2">Parameter</th><th>Model Inputs</th><th>Assumption</th></tr>
<tr><td colspan="2">Applicable Vessels</td><td>All Navy vessels (Search & Rescue / Patrol)</td><td rowspan="9">Search & Rescue / Patrol (Navy) vessels are expected in the long-term to operate on either Biofuel (B100) or a Green e-fuel alternative. Currently, electrification is not considered appropriate based on range and speed requirements for standard operations of this vessel type. It is expected to be based on replacing retired vessels with new purpose-built compatible vessels, and not motor retrofits. This also aligns with the timing of the need for replacement for many vessels.</td></tr>
<tr><td colspan="2">Excluded Vessels</td><td>All other vessels.</td></tr>
<tr><td colspan="2">% Vessels within Group</td><td>100%</td></tr>
<tr><td rowspan="6">Vessel Count</td><td>Fiji</td><td>4</td></tr>
<tr><td>Kiribati</td><td>-</td></tr>
<tr><td>RMI</td><td>1</td></tr>
<tr><td>Solomon Islands</td><td>-</td></tr>
<tr><td>Tonga</td><td>-</td></tr>
<tr><td>Tuvalu</td><td>1</td></tr>
<tr><td colspan="2">Initiative Start</td><td>2030</td><td rowspan="4">Long-term abatement measure that will begin phasing-in over 10 years from 2030 to achieve full coverage of all navy vessels. Significant challenge is establishing the supply chain for either Biofuel or Green e-fuel and supporting infrastructure, particularly at the regional ports. Current Green e-fuel pricing is unclear and has therefore been assumed to be 1.5 times Biofuel (B100) prices. Price reductions are expected as this technology matures and is more widely adopted, however the Model does not account for future price reduction.</td></tr>
<tr><td colspan="2">Phase-in Period (Years)</td><td>10</td></tr>
<tr><td colspan="2">Initiative End</td><td>Ongoing</td></tr>
<tr><td colspan="2">Phase-out Period (Years)</td><td>N/A</td></tr>
<tr><td colspan="2">Fuel CO_2e Emissions Factor Reduction</td><td>100%</td><td>Assumes a 100% reduction in CO_2e emissions. Refer Table 14 for details.</td></tr>
<tr><td colspan="2">Fuel Reduction due to Improved Efficiency or Technology Upgrade</td><td>-</td><td>N/A</td></tr>
<tr><td colspan="2">Associated Abatement Measure</td><td>-</td><td>This measure is considered independent of other abatement measures, however the preference for Biofuel (B100) or Green e-fuel make depend on the preference for these fuels across other vessel types.</td></tr>
</table>

Table 14: Fuel emissions factors used in the model

Fuel Type	Energy Content Factor	Gas Type Emission Factor	Fuel Specific Density	Fuel Emissions Factor	Application to Model	Reference	Comment
	EC_i	EF_{ijoxec}					
	[GJ/kL]	[kgCO_2e/GJ]	[kg/kL]	[gCO_2e/ gFuel]			
Heavy Fuel Oil (HFO)	*Fuel Emission Factor nominated in UCL Inventory Baseline*			3.11	Inventory baseline fuel type for all vessels.	UCL Baseline Inventory.	Baseline Inventory currently assumes HFO Fuel Emission Factor for all vessels for all nations.
Marine Diesel Oil (MDO)	38.6	69.9	980	2.75	Not currently used in Model.	Australian Government Department of Industry, Science, Energy and Resources, 2020. *National Greenhouse Accounts Factors*, Canberra: Australian Greenhouse Office.	Not used in Baseline Inventory. Model assumes the critical information is the % reduction in CO_2e emissions, i.e., X% reduction from the Baseline fuel which is currently nominated as HFO.
Liquefied Natural Gas (LNG)	25.3	51.4	450	2.89	Not currently used in Model.		
Gasoline	34.2	67.4	750	3.07	Not currently used in Model.		
Biofuel B10	23.4	0	970	2.80	Not currently used in Model.		10%, 20% or 100% sustainably sourced biofuel mixed with Baseline fuel (i.e., HFO), assuming that biofuel portion has zero CO_2e emissions as per reference.
Biofuel B20	23.4	0	960	2.49	Abatement Measures: Biofuel (Blended)		
Biofuel B100	23.4	0	880	0.00	Abatement Measures: Biofuel (B100)		
Green e-fuel	varies	0	varies	0.00	Abatement Measures: Electrification	-	Assumed to be sustainably sourced fuel with zero CO_2e emissions.
Plastic Waste Fuel	varies	0	980	varies	Not currently used in Model.	-	Not currently used in the model. Assumed to have similar emissions factor as the equivalent biofuel blend.
Electric	N/A	0	N/A	0.00	Abatement Measures: Green e-fuels	-	Assumed to have zero CO_2e emissions.

Table 15: Summary of assumptions and factors used for Cost Estimate

Annual Growth Rate	~0%	Assumed typical for all PBSP nations
Discount Rate	7%	Assumed typical for all PBSP nations
FJD:USD	0.45	
AUD:USD	0.70	
Maintenance Cycle	3	Years
Carbon Cost	100	USD/tCO_2e

	[1]	[2]	[3]	[4]	[5]
Length Category	**CAPEX of Like-for-Like Vessel**	**Engine CAPEX as % of Vessel CAPEX**	**New Like-for-like Engine CAPEX**	**New Biofuel (B100) Engine CAPEX Factor (Uplift)**	**New Biofuel (B100) Engine CAPEX (Uplift)**
Comment		Cost of new life-for-like/conventional engine as a percentage of the like-for-like vessel cost.		Cost of Biofuel (B100) Engine uplift over a conventional engine.	
Calculation			*[1] X [2]*		*[3] X [4]*
<10m	$10,000	33.3%	$3,333	N/A	N/A
10m-25m	$50,000	33.3%	$16,667	10.0%	$1,667
25m-50m	$5,000,000	25.0%	$1,250,000	1.0%	$12,500
50m-100m	$20,000,000	20.0%	$4,000,000	1.0%	$40,000
>100m	$25,000,000	20.0%	$5,000,000	1.0%	$50,000
N/A	$50,000	33.3%	$16,667	10.0%	$1,667

	[6]	[7]	[8]	[9]	[10]
Length Category	**R&M % of Conventional Engine CAPEX**	**Biofuel (B100) R&M % of Engine CAPEX**	**Electric R&M % of Engine CAPEX**	**Green e-fuel R&M % of Engine CAPEX**	**WASP R&M % of Sail CAPEX**
Comment	Repair and maintenance for conventional engine as a percentage of the vessel.	Repair and maintenance uplift for Biofuel (B100) engine as a percentage of the vessel, and considers additional pumps, filters, and heaters etc.	Repair and maintenance saving for Electric motor as a percentage of the vessel.	Repair and maintenance uplift for Green e-fuel vessel as a percentage of the vessel. Specific R&M requirements currently unknown, but uplift is expected.	Repair and maintenance for WASP vessel add-ons as a percentage of the vessel, and considers sails, masts, ropes, pulleys etc.
Calculation					
<10m	5.0%	N/A	1.0%	1.0%	10.0%
10m-25m	2.0%	5.0%	1.0%	1.0%	5.0%
25m-50m	2.0%	1.0%	1.0%	1.0%	2.0%
50m-100m	2.0%	1.0%	1.0%	1.0%	1.0%
>100m	2.0%	1.0%	1.0%	1.0%	1.0%
N/A	2.0%	5.0%	1.0%	1.0%	5.0%

	[11]	[12]	[13]	[14]
Length Category	**Derating Engine CAPEX Factor**	**Derating Engine CAPEX**	**Propulsion Increasing Devices (PIDs) CAPEX Factor**	**Propulsion Increasing Devices (PIDs) CAPEX**
Comment	Cost to derate a conventional engine (uplift over regular engine servicing).		Cost to install PIDs to a conventional vessel.	
Calculation		*[11] X [3]*		*[13] X [1]*
<10m	10.0%	N/A	N/A	N/A
10m-25m	10.0%	$1,667	N/A	N/A
25m-50m	3.0%	$37,500	5.0%	$250,000
50m-100m	2.5%	$100,000	5.0%	$1,000,000
>100m	2.5%	$125,000	5.0%	$1,250,000
N/A	10.0%	$1,667	5.0%	$2,500

Table 16: Summary of assumptions and factors used for Cost Estimate (cont.)

	[15]	[16]	[17]
Length Category	**Initial Fuel Cost (USD/T)**	**Local Biofuel (Blended) Cost (USD/T)**	**Imported Biofuel (B100) & Green e-fuel Cost (USD/T)**
Comment	Outboard 2-stroke premix @ USD 2.0/Liter; Diesel for 10m-25m vessels @ USD 1.9/Liter; HFO for larger vessels @ USD 1.65/Liter.	20% Biofuel @ USD 0.7/Liter + USD 500/Tonne processing, plus 80% @ Initial Fuel Cost.	Biofuel (100) and Green e-fuels assumed to be imported and comparable in price. Price expected to be highly variable depending on source.
Calculation	USD per Liter multiplied by Fuel Specific Density (Fiji prices)	USD per Liter multiplied by Fuel Specific Density and apportioned based on B20 mix (Fiji prices)	Initial Fuel Cost X 1.5
<10m	$801	$864	$1,202
10m-25m	$752	$825	$1,129
25m-50m	$661	$752	$991
50m-100m	$661	$752	$991
>100m	$661	$752	$991
N/A	$752	$825	$1,129

	[18]	[19]	[20]
Length Category	**No. of Crew Saved with Electric**	**Battery Charge Range (Hrs)**	**Charging Cost ($/kWh)**
Comment	Electric motors expected to reduce operational crew cost. Expressed in terms of number of crew at a daily rate of FJD 21,000 per crew (average annual Mechanic salary for Fiji, www.salaryexplorer.com).	Battery hours to replace conventional engine, assuming charging facilities available on both ends of trip. Current battery price per kWh to be used with caution when forecasting long-term technology roll-out.	Assumed vessels <25m length have retail pricing applied, and larger vessels have wholesale prices applied based on access large-scale charging facilities at port (Fiji prices).
Calculation			
<10m	0	1	$0.1530
10m-25m	0	1	$0.1530
25m-50m	1	3	$0.1933
50m-100m	2	3	$0.1933
>100m	2	3	$0.1933
N/A	0	1	$0.1933

Appendix D: Model Screenshots

1

Operational Efficiency - Fleet Maintenance - All sectors and vessel types

Inventory baseline

Subsequent Baseline CO2 Abatement Inputs		
Initiative Type	Ops	
Initiative Start & Phase In Period (Yrs)	2023	3
Initiative End & Phase Out Period (Yrs)	2050	0
% vessel to apply to	100%	
Proposed Fuel Type	Heavy Fuel Oil (HFO)	
Initial Carbon Factor (g CO2/g fuel)	3.11	
Proposed Carbon Factor (g CO2/g fuel)	3.11	
Carbon Factor Reduction	0%	
Sail-Assist	0%	
Carbon Capture & Storage	0%	
Other % Reduction	15%	

CO2 Abatement of Total	
Total Initial Annual Emissions (tCO2)	220,854
Total Proposed Annual Emissions (tCO2)	187,726
Proposed Abatement (tCO2)	33,128
% Abatement of Total	**15%**

CO2 Abatement of Subset	
Subset Initial Annual Emissions (tCO2)	220,854
Subset Proposed Annual Emissions (tCO2)	187,726
Subset % of Total Emissions	100%
% Abatement of Subset	**15%**

Outputs for Cost Calculations

Length Category	Vessel Count	Combined Length (L)	Average Power (kW)	Charging Energy (kWh)	Stored Battery Energy (kWh)	Initial Fuel (T)	Proposed Fuel (T)
<10m	5,206	36,731	37	N/A	N/A	35,040	29,784
10m-25m	119	1,622	281	N/A	N/A	11,461	9,742
25m-50m	30	1,045	1,662	N/A	N/A	13,604	11,563
50m-100m	10	639	3,136	N/A	N/A	9,169	7,793
>100m	1	120	4,476	N/A	N/A	1,650	1,402
N/A	0	0	0	N/A	N/A	0	0
Total	**5,366**	**40,158**		**0**	**0**	**70,923**	**60,284**

	BASELINE				CAPEX			OPEX							NPV
	Like-for-Like Vessel Replacement	New Purpose-Built Vessel	Like-for-Like Engine Replacement	New Purpose-Built Engine	Onshore Cost / kWh (4 vessels/day)	Upgrade or Retrofit Cost / Vessel	Initial Battery Cost & Replacement / kWh	Incremental Shipyard Cost / m	Incremental Labour Cost / Vessel	Incremental Repair & Maintenance Cost / Vessel	Initial Fuel ($/T)	Proposed Fuel ($/T)	Charging cost ($/kWh)	Incremental Energy Cost ($)	
								$ -		$ 167	$ 801	$ 801			
								$ 197		$ 333	$ 752	$ 752			
								$ 292		$ 25,000	$ 661	$ 661			
								$ 292		$ 80,000	$ 661	$ 661			
								$ 292		$ 100,000	$ 661	$ 661			
								$ 197		$ 333	$ 752	$ 752			
	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 845,910	$ -	$ 2,557,333	$ 52,828,823	$ 44,904,499	$ -	-$ 7,924,323	
-$ 44,165,228	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,955,089	$ -	$ 5,910,576	$122,099,360	$103,784,456	$ -	-$ 18,314,904	$ 10,449,239
-$ 38,106,342	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,472,920	$ -	$ 7,476,068	$154,438,940	$131,273,099	$ -	-$ 23,165,841	$ 13,216,854
-$ 186,974,092	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4,325,586	$ -	$ 13,077,000	$270,141,754	$229,620,491	$ -	-$ 40,521,263	$ 23,118,677

Figure 50: Example inputs (shaded yellow) required for each abatement measure.

Ownership	On/Off	%CO2
Government	1	22%
Private	1	78%

Voyage Type	On/Off	%CO2
Domestic	1	100%
International	1	0%
N/A	1	0%

Year Category	On/Off	%CO2
Before 1983	1	7%
Between 1984 and 2000	1	13%
2001 onwards	1	80%

Vessel Length	On/Off	%CO2
<10m	1	49%
10m-25m	1	16%
25m-50m	1	19%
50m-100m	1	13%
>100m	1	2%
N/A	1	0%

Ship Type	On/Off	%CO2
Barge	1	2%
Bulk Carrier	1	0%
Cargo	1	0%
Container ships	1	0%
Dredging	1	1%
Fishing vessel	1	5%
General Cargo	1	0%
Landing craft	1	4%
Medical boat	1	1%
Oil tanker	1	0%
Open Boat	1	4%
Other	1	0%
Passenger	1	24%
Passenger and Cargo	1	6%
Pleasure craft	1	7%
Pollution response boat	1	0%
Reefer	1	0%
Research vessel	1	5%
RoRo	1	8%
Search and Rescue/Patrol	1	4%
Small artisanal crafts	1	24%
Small boats	1	0%
Support vessel	1	0%
Tug boat	1	5%
Wet products	1	0%
Work Boat	1	0%
Yacht	1	0%

Engine Type	On/Off	%CO2
SSD	1	9%
MSD	1	38%
HSD	1	53%
LNG-Otto	1	0%
LNG-Diesel	1	0%
LBGI	1	0%
Gas Turbine	1	0%
Steam Turbines	1	0%
Auxiliary Engines	1	0%
N/A	1	0%

Fuel Type	On/Off	%CO2
HFO	1	100%
MDO	1	0%
Petrol	1	0%
MeOH	1	0%
LNG	1	0%
LSHFO 1%	1	0%
Biofuel B10	1	0%
Biofuel B20	1	0%
Diesel and Petrol	1	0%
Electric	1	0%

Figure 51: Vessel filtering tables in model for each abatement measure with dynamic % CO2 contribution based on subsequent baseline.

Appendix E: Summary of Country NDCs and related documents

A number of the identified abatement measures for the PBSP are not discussed in any of the Country NDCs, NDC roadmaps, and related documents, and as a result are excluded from the tables below - these abatement measures being Engine Derating and Propulsion Improving Devices (PIDs). The reference source of the Country NDCs used for review is the UN Climate Change NDC Register as of July 2022[61].

Fiji

General	The 2030 reductions target in the Fiji NDC is 30% compared to 2013 levels. The NDC[62] sets a target to reduce domestic maritime shipping emissions by 40%. The NDC Implementation Roadmap[63] provides further information.
Fleet maintenance	Improved Maintenance for Sea Vessels is supported by the Fiji NDC with a medium-term action (2021-2025). It is estimated this will achieve savings of 5000 tCO_{2e}/year with total investment cost of $4-8 Million USD.
Demand/Supply Management and support	Not specifically addressed in NDC.
WASP Retrofit	Not specifically addressed in NDC, The NDC highlights the potential for renewable energy driven sea vessels including wind and solar, but does not specify if this is WASP or wind electricity generation.
Biofuels	The Fiji NDC has committed to incorporating 5% biodiesel into diesel for land transport, however, currently no commitment has been made regarding maritime vehicles. It has been assumed the biodiesel will be imported.
Motor Switching	Switching from inefficient 2-Stroke to more efficient direct injection 2-Stroke or 4-Stroke outboard motors for small private and commercial boats (10-150hp) is supported by the Fiji NDC. The total emissions reduction and investment requirement of this initiative have not been quantified due to lack of data. It is estimated that a 20% reduction in fuel use and emissions can be achieved by each motor switched.
Electrification	The NDC does not specifically address electrification of marine vessels, however, the electrification of vehicles (type not specifically stated) in general is listed as an additional action for further consideration in future transport policies and plans. In addition, the NDC sets a target for 100% renewable energy generation by 2030, which will be achieved predominately with a combination of biomass energy generation, waste to energy, hydropower, and photovoltaic power.
Green e-fuels	Not specifically addressed in NDC.

Kiribati

General	The Kiribati NDC[64] sets targets to unconditionally reduce 12.8% of BAU greenhouse gas emissions and conditionally reduce 49% of BAU greenhouse gas emissions by 2030, compared to 2014 levels.
Fleet maintenance	Not specifically addressed in NDC.
Demand/Supply Management and Support	Not specifically addressed in NDC.

[61] https://unfccc.int/NDCREG
[62] https://unfccc.int/sites/default/files/NDC/2022-06/Republic%20of%20Fiji%27s%20Updated%20NDC%2020201.pdf
[63] https://www.economy.gov.fj/images/CCIC/uploads/Mitigation/Brief__Fiji_NDC_Implementation_Roadmap_Policy.pdf
[64] https://unfccc.int/sites/default/files/NDC/2022-06/INDC_KIRIBATI.pdf

WASP Retrofit	The NDC commits to investing in a low carbon mini-container ship and a small low carbon cargo/passenger freighter both of which may use wind-hybrid propulsion.
Biofuels	The NDC acknowledges the potential to use imported biofuels for maritime transport, however, the emissions reduction due to maritime biofuel use is not quantified.
Motor Switching	The NDC Implementation Roadmap[65] commits to replacing 2,010 2-stroke outboards with either 4-stroke (1,560) or electric outboards (450) by 2030. The commitment includes a capacity building and training program. It is estimated this will result in a reduction of 3,700 tCO_2e per year with an estimated cost of $20.8M USD.
Electrification	As stated above the NDC Implementation Roadmap commits to replacing 450 older 2-stroke outboards with electrical outboards. It is acknowledged in the NDC roadmap that some of the 2030 targets will require renewable power generation which is not included in the NDC roadmap.
Green e-fuels	Not specifically addressed in NDC.

Republic of the Marshall Islands

General	RMI's NDC was updated in December 2020[66]. The following documents were available: • Update Communication on the Marshall Islands Paris Agreement NDC (30 December 2020). • Tile Til Eo 2050 Climate Strategy "Lighting the way" (September 2018)[67]. • RMI Electricity Road Map[68] The RMI has committed through its NDC (referenced in the above documents) to reduce emissions 45% from 2010 levels by 2030.
Fleet maintenance	Not specifically addressed in documents.
Demand/Supply Management and Support	Changes to operations and improved docking facilities are highlighted as an option for reducing domestic shipping emissions in the 2050 Climate Strategy.
WASP Retrofit	Changes to ship design is highlighted as an option for reducing domestic shipping emissions in the 2050 Climate Strategy. The type of changes are not specified but could include WASP.
Biofuels	Fuel switching, or mixing is highlighted as an option for reducing domestic shipping emissions in the 2050 Climate Strategy and biofuel is mentioned as an option. It is noted that supply of coconut to generate biofuels would be limiting.
Motor Switching	Not specifically addressed in documents in relation to domestic shipping.
Electrification	The documents do not specifically address electrification of marine vessels. The RMI has committed, in the RMI Electricity Road Map to reduce electricity sector emissions and the use of diesel for electricity generation by 50% by 2025. This would be achieved using wind and solar energy generation, and potentially switching to biodiesel.
Green e-fuels	Not specifically addressed in the documents in relation to domestic shipping.

[65] https://gggi.org/report/kiribati-ndc-implementation-roadmap-2021/
[66] https://unfccc.int/sites/default/files/NDC/2022-06/INDC_KIRIBATI.pdf
[67] https://policy.asiapacificenergy.org/node/3754/portal
[68] https://rmi-data.sprep.org/dataset/rmi-electricity-roadmap

Solomon Islands

General	The 2030 reductions target in the Solomon Islands NDC[69] is 30% compared to 2015 levels. In addition, the Solomon Islands committed to 45% reduction of emissions by 2030 on the condition that international financial and technical resources were available.
Fleet maintenance	Not specifically addressed in NDC.
Demand/Supply Management and Support	Not specifically addressed in NDC.
WASP Retrofit	Not specifically addressed in the NDC.
Biofuels	Not specifically addressed in the NDC.
Motor Switching	Not specifically addressed in the NDC.
Electrification	Electrification of maritime vessels is not specifically addressed in the NDC, however, there are a number of renewable energy options proposed for conditional and non-conditional emissions reductions options.
Green e-fuels	Not specifically addressed in NDC.

Tonga

General	The Tongan NDC[70] commits to a 13% reduction in energy related emissions by 2030, compared to 2006.
Fleet maintenance	Not specifically addressed in the NDC.
Demand/Supply Management and Support	Not specifically addressed in the NDC.
WASP Retrofit	Not specifically addressed in the NDC.
Biofuels	Not specifically addressed in the NDC.
Motor Switching	Not specifically addressed in the NDC.
Electrification	Not specifically addressed in the NDC in relation to domestic shipping, however, the NDC sets a target of 70% of electricity being generated from renewables by 2030, using a mix of solar, wind and battery storage.
Green e-fuels	Not specifically addressed in the NDC.

Tuvalu

General	The Tuvalu NDC[71] provides an indicative target of 60% reduction in emissions below 2010 levels by 2025.
Fleet maintenance	Not specifically addressed in NDC.
Demand/Supply Management and Support	Not specifically addressed in NDC.
WASP Retrofit	Not specifically addressed in NDC.
Biofuels	Not specifically addressed in NDC.
Motor Switching	Not specifically addressed in NDC.

[69] https://unfccc.int/sites/default/files/NDC/2022-06/NDC%20Report%202021%20Final%20Solomon%20Islands%20%281%29.pdf
[70] https://unfccc.int/sites/default/files/NDC/2022-06/Tonga%27s%20Second%20NDC.pdf
[71] https://unfccc.int/sites/default/files/NDC/2022-06/TUVALU%20INDC.pdf

Electrification	Electrification of maritime vessels is not specifically addressed in the NDC, however, the NDC commits Tuvalu to transitioning to 100% renewable energy generation by 2025, primarily by improved energy efficiency and installation of photovoltaic arrays.
Green e-fuels	Not specifically addressed in NDC.