STRENGTHENING THE PACIFIC BLUE SHIPPING PARTNERSHIP

High-level baseline assessment of fuel consumption and CO2 emissions from ships in Pacific Island Countries

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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 Baseline Assessment research paper was led by the World Bank, with the expert support of University Maritime Advisory Services (UMAS) and Equitable Maritime Consulting (EMC).

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 UMAS team was led Tristan Smith. Ronald Halim from EMC analytically supported the UMAS team.

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Executive Summary

Overview

To achieve the decarbonization targets of the Pacific Blue Shipping Partnership (PBSP), accurate and reliable data needs to be collected to set a baseline and enable transition planning. The PBSP made first steps towards such a baseline by developing an initial shipping inventory. This initial shipping inventory outlined baseline estimates for fuel consumption and greenhouse gas (GHG) emissions. However, there were still significant limitations to the inventory, such as limited data availability, particularly for domestic sea transport predominately served by small artisanal crafts, which made it challenging to develop any effective transition plan based upon it.

This report provides a revised approach to overcome these limitations and therefore estimate baseline fuel consumption and GHG emissions more accurately and reliably than initially done. The following sections outline this revised approach, explains the scope of the database, and presents key findings of this baseline assessment, broken down by domestic shipping and international shipping between the six Pacific Islands Countries (PICs) studied.

Approach

The initial shipping inventory developed by the PBSP was very valuable in providing initial insights into the profile of shipping fleets and the scale of GHG emissions. However, it also identified some significant limitations of the estimates which were based on automatic identification system (AIS) data. For instance, AIS data does not cover ships with sizes less than 300 gross tonnage as well as cargo ships below 500 gross tonnage that serve domestic voyages. Moreover, the dataset only covers four ship types—bulk carriers, containerships, oil tankers, and general cargo ships—which may not necessarily represent the wider variety of ship types that are used across the Pacific region.

Therefore, this high-level baseline assessment attempts to build on the previous work to address the limitations identified. As its base data, this assessment uses primary data sources and national documents for domestic and international vessels to develop an inventory database for the following six PICs: Fiji, Kiribati, the Republic of the Marshall Islands, Solomon Islands, Tonga, and Tuvalu. The database records the characteristics of each individual ship that is relevant for estimating the ship's fuel consumption and GHG emissions during the year 2019.[1] The dataset covers domestic and international ship registries for six PICs and is broken down into domestic and international ships, 25 ship types, and three engine types.

Where information was missing or incomplete, regression models were used to estimate fuel consumption and GHG emissions. This methodology was consistent with that applied in the internationally recognized Fourth International Maritime Organization (IMO) GHG Study (2020).[2] Details on the methodology and models used can be found in the complementary World Bank research paper "High-Level Baseline Assessment (working title)".

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[1] It must be noted that the accuracy of 2019 data varies from country to country depending on recent surveys and exercises to identify the domestic fleet firsthand. Tonga's data also needs to be read with caution as it is based on information prior to the 2022 volcanic eruption.

[2] International Maritime Organization. 2020. Fourth IMO Greenhouse Gas Study.

It must be noted that data gaps still exist within the database. For example, due to limited trade data availability for countries in the Pacific region, the database still only contains data for intra-island shipping between Fiji and the other five PICs.

Key findings

Domestic shipping

In 2019, domestic shipping in the six PICs—i.e., journeys departing and arriving within the same country—emitted 580,493 tons of carbon dioxide (CO_2) emissions. Most of these emissions were generated by Fiji, followed by the Solomon Islands, which is in line with prior expectations given the size of the shipping fleet in both nations, see Figure 1 and Figure 2.

Likewise, at the country level, CO_2 emissions among PICs strongly correlate with the population and gross domestic product (GDP) figures of the countries. Fiji and Solomon Islands have the highest GDP and population amongst the countries within this high-level baseline assessment, they also emit the highest CO_2 emissions and account for the majority of domestic shipping emissions among the six PICs.

Figure 1: Overview of ship number and type among six PICs

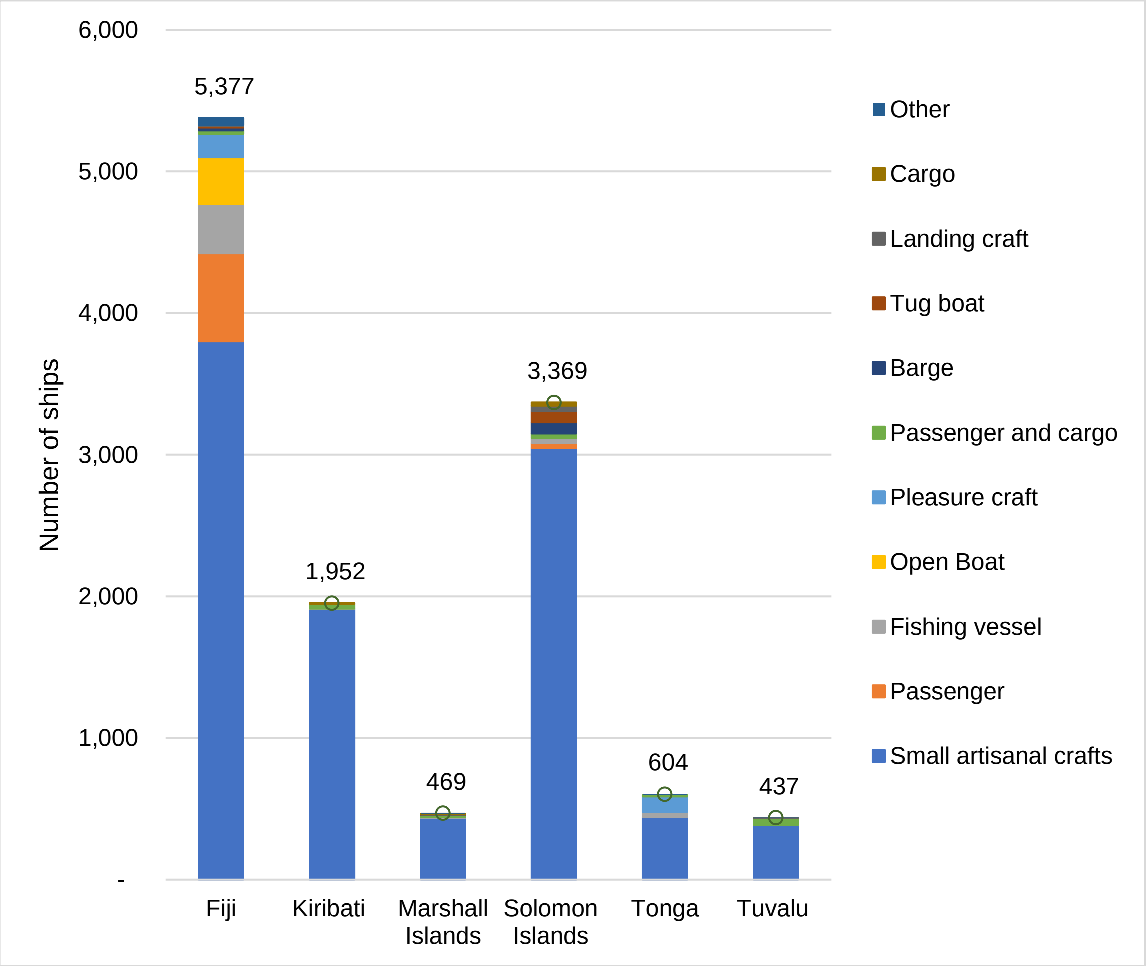
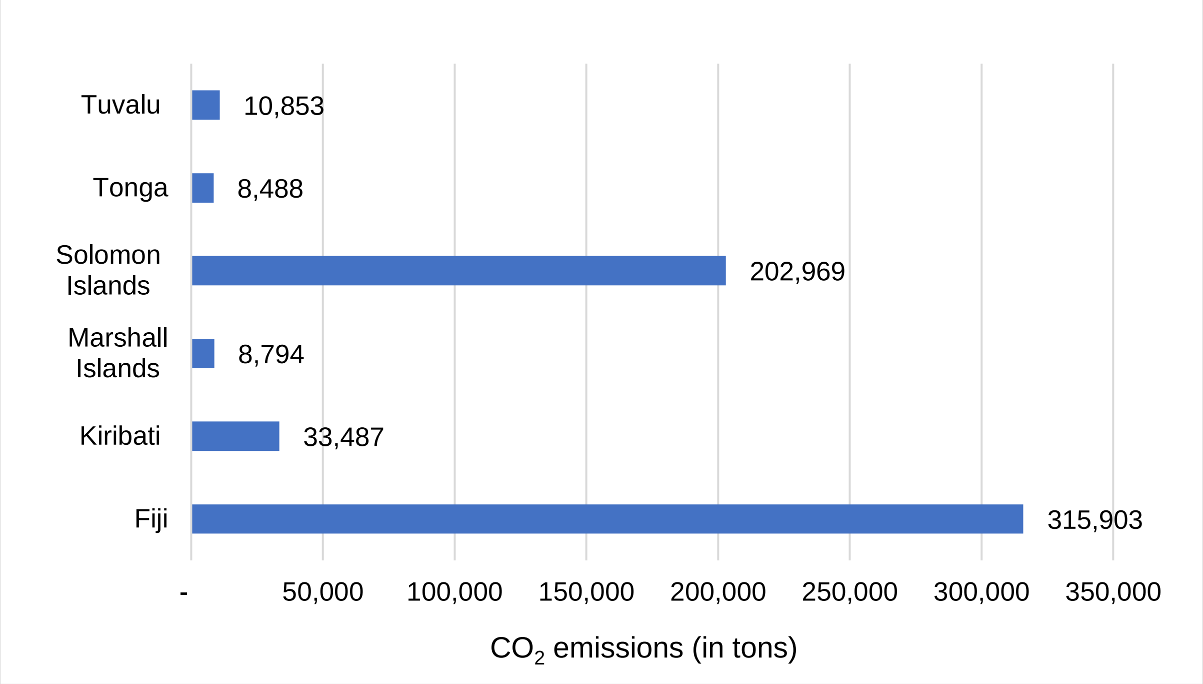


Figure 2: CO₂ emissions from domestic shipping among six PICs



Across the six PICs, journeys departing and arriving within the same country from small artisanal crafts, passenger ships and tugboats account for over 50 percent of domestic shipping CO_2 emissions. The highest share of CO_2 emissions is generated by small artisanal crafts (21 percent) and passenger ships (21 percent), followed by tugboats (11 percent), and fishing vessels (10 percent), see Figure 3. This pattern also holds true when GHG emissions are examined at the country level where small artisanal crafts, passenger ships, and fishing vessels represent major contributors to CO_2 emissions and consume most fuel across the countries (Figure 4).

Figure 3: Share of CO₂ emissions from domestic shipping by ship types

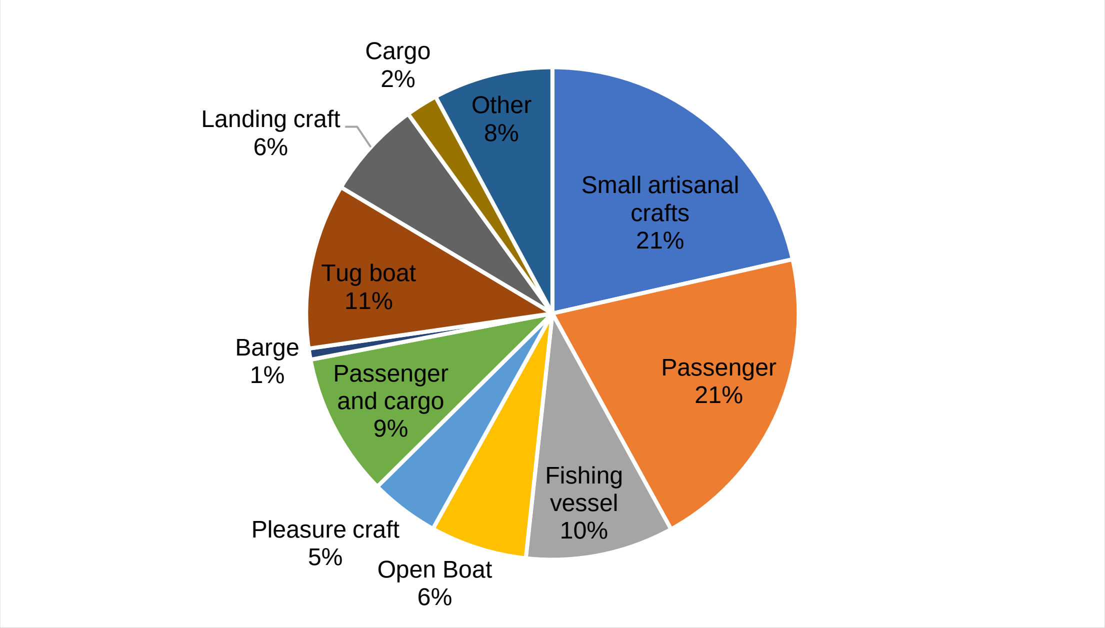
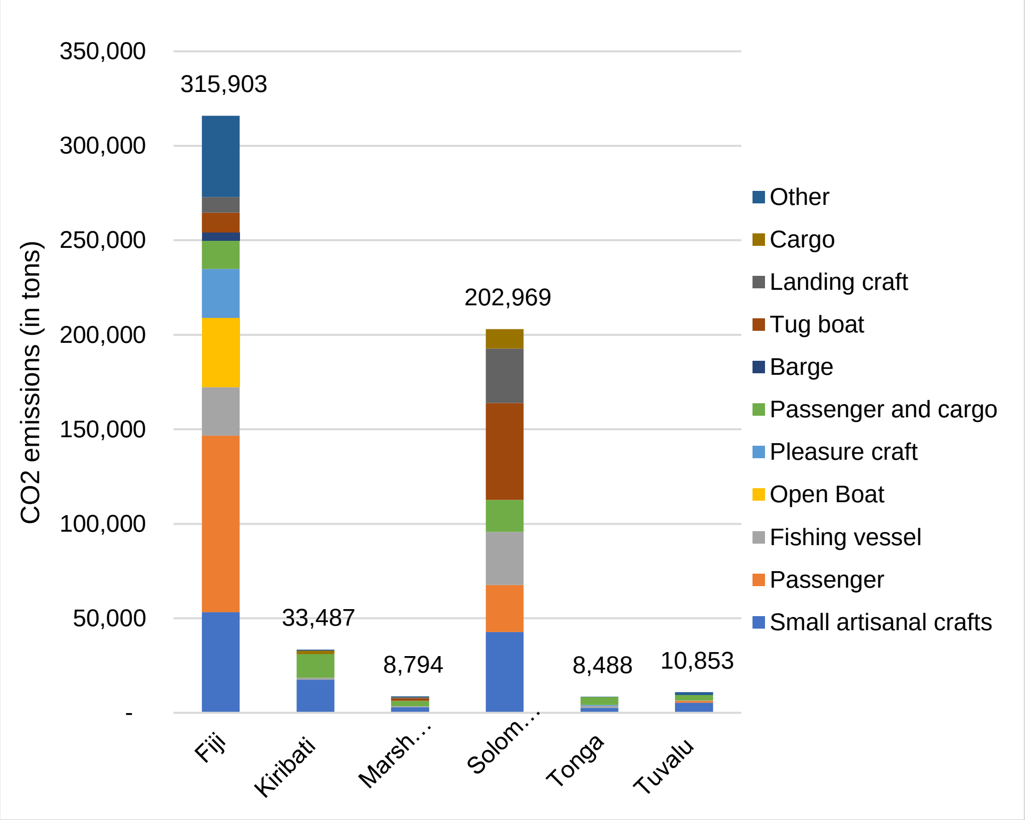
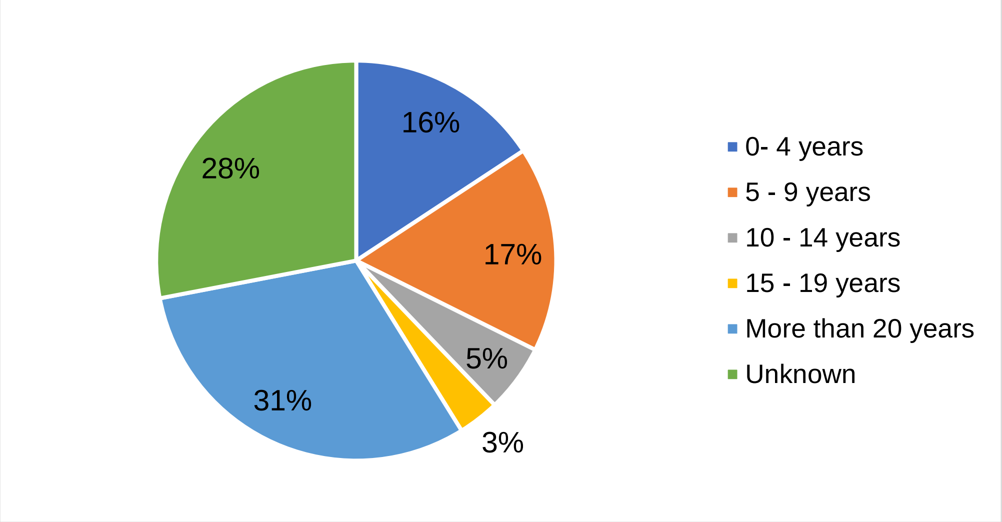


Figure 4: Annual domestic shipping CO_2 emissions from PICs by ship type



The database also reveals that ships which are 20 years or older are major contributors of GHG emissions (31 percent), followed by ships between five to nine years (17 percent), and between zero to four years (16 percent), see Figure 5. Note that a high fraction of the GHG emissions (28 percent) is emitted by ships without age data, which makes a fully robust assessment of the emission profile based on ship's age difficult. Nevertheless, the emissions profile from available data reconfirms the general understanding that old ships typically have lower fuel efficiency than younger ships.

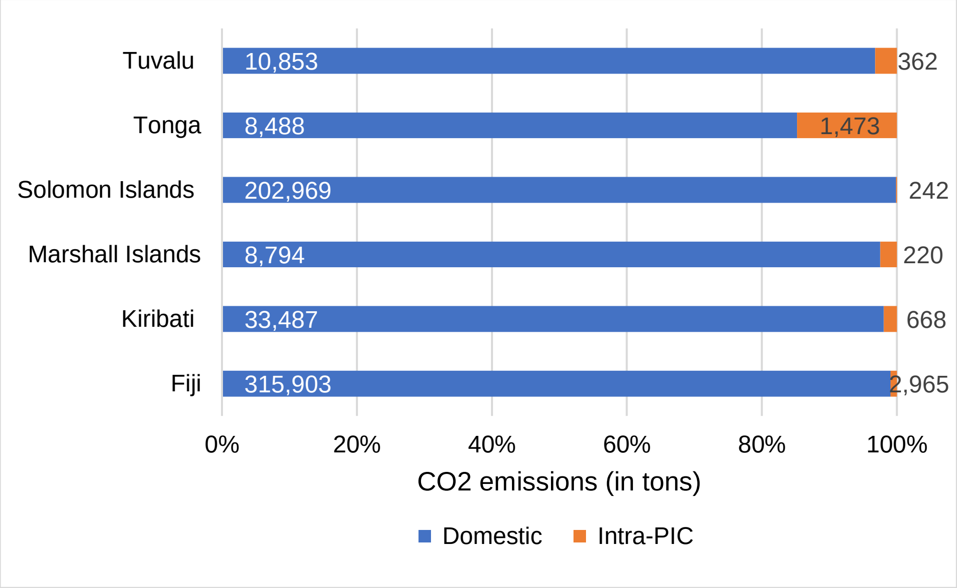
Figure 5: Shares of CO_2 emissions based on ship age



Intra-island shipping

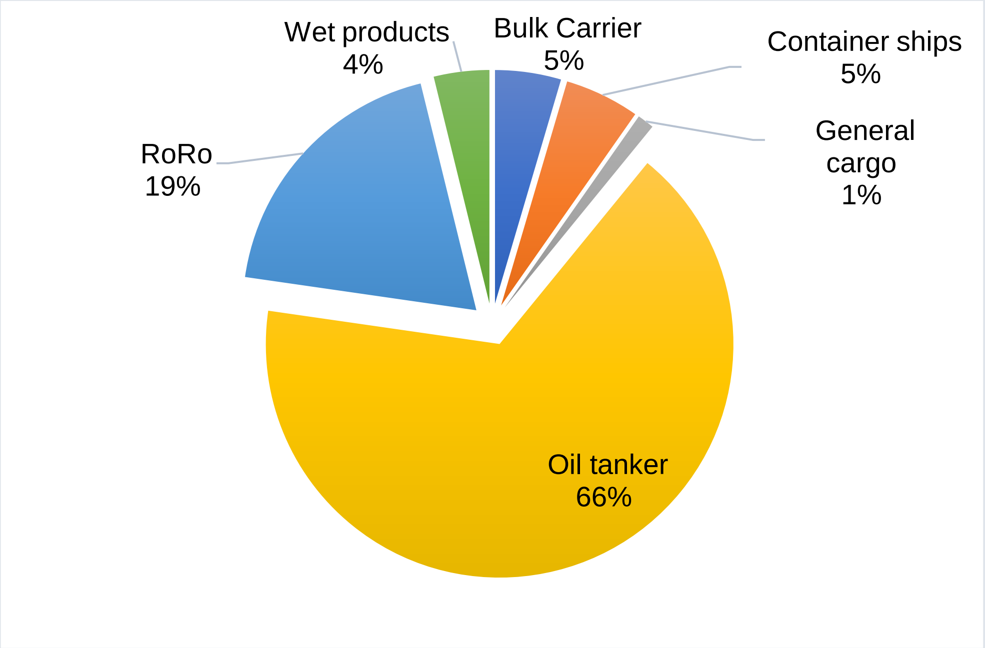
Estimations on CO_2 emissions generated on international voyages were calculated based on bilateral trade data obtained from the UN COMTRADE database. However, these estimates should be treated with caution as—due to limited trade data availability—the intra-PIC shipping dataset only comprises CO_2 emissions generated on routes between Fiji and the other five PICs included in this high-level baseline assessment. This means that data on GHG emissions generated between the other five PICs (excluding Fiji) was not included. This data shows that in 2019, ships operating internationally between the six PICs emitted 2,966 tons of CO_2. This is only a fraction of the PICs' domestic shipping emissions. Figure 6 shows that with the exception of Tonga, intra-PIC emissions account for (often much) less than five percent of their shipping emissions.

Figure 6: Comparison of CO_2 emissions from domestic and intra-PIC shipping



CO_2 emissions from intra-PIC shipping are dominated by oil tankers which account for up to 66 percent of total GHG emissions. Roll-on and roll-off ships represent the second highest emission contributor with 19 percent of the total emissions, see Figure 7. These GHG emissions shares reflect the trade characteristics and types of commodities most commonly shipped between the Pacific countries with oil or fuel products being at the top of the list.

Figure 7: Shares of CO_2 emissions from intra-PIC shipping by ship types



It is likely that even if the dataset included data for shipping between all six PICs, the share of intra-PIC shipping emissions would still be smaller than that for domestic shipping CO_2 emissions. Firstly, domestic shipping in the PIC which includes both cargo and passenger transport has generally higher activity than intra-PIC shipping. Secondly, ships serving intra-PIC routes are typically cargo ships with significantly higher economies of scale, which in turn, offers higher fuel efficiency per cargo transported between the PICs.

Recommendations

To ensure that any transition plan or any other future strategic work undertaken by the PBSP are accurate and well-informed, it is recommended that the accuracy and reliability of the revised shipping inventory from which the fuel consumption and GHG emissions are derived is to be strengthened further. This can be achieved by:

- **Regularly monitoring and registering international and domestic ships:** This would enable reliable and up-to-date ship registers to be easily accessible, thereby allowing for an even more accurate estimation of GHG emissions from both international and domestic shipping.
- **Establishing a commodity flow database for estimating national freight transport volumes and costs:** This would enable a more accurate estimation of intra-island shipping and hence allow for better-informed strategic forecasts and planning for shipping infrastructure. Specifically, within the context of GHG estimation and mitigation, complete origin and destination data, ideally for different modes and commodities and their transport costs will be invaluable to analyze the impact of climate policy measures such as taxes and subsidies on GHG emissions and PBSP member countries' economies.
- **Establishing a transport demand model to predict future expansion of vessel stocks, activities, and fuel consumption:** Such a model would not only aid estimation of future GHG emissions from ships based on the economic development of a country, but it would also be useful to plan infrastructure development for PICs.
- **Setting up a monitoring, reporting, and verification framework to enable the systematic and efficient collection of missing data:** Considering the importance of

monitoring the progress of GHG abatement, a functioning and strong mechanism would be beneficial to carry out monitoring, reporting and verification tasks on a regular basis such as annually or at least bi-annually.

1 Context

The development of sustainable, low-carbon shipping is a key priority for the Pacific region. The sector has been central to the region's culture, economy and society for thousands of years due to the long distances that need to be crossed both at the intra- and inter-country levels. As a result, a coalition of Pacific Island Countries (PICs) has established the Pacific Blue Shipping Partnership (PBSP). This coalition, co-chaired by Fiji and the Republic of the Marshall Islands (RMI), aims to accelerate the transition to zero carbon domestic shipping by 2050 in the Pacific region through the identification of a common technological transition and finance to implement its objectives.

To date, the PBSP has conducted a preliminary study that attempts to provide a comprehensive inventory of each member country's shipping sector, including information on fuel consumption and greenhouse gas (GHG) emission profiles. The inventory was compiled using Automatic Identification System (AIS) data which typically captures ship identity, position, type, speed, and movements in the region.[3] It has been valuable in providing initial insights into the profile of shipping fleets and the scale of GHG emissions. However, the initial assessment has identified some severe limitations of the AIS-based estimation. For instance, the AIS data does not cover ships with sizes less than 300 gross tonnage (GT) as well as cargo ships below 500 GT that serve domestic voyages. Moreover, the dataset also only covers four ship types - bulk carriers, containerships, oil tankers and general cargo ships - which may not represent the wider variety of ship types that are widely used in PICs.

Therefore, this study attempts to build on the previous PBSP study and address the limitations identified by building a database of ship fleets from six PICs.[4] The database compiles information on all the ships from the six PICs based on records from experts and national documents, including government registers of vessels. A bottom-up methodology was then applied to this data, whereby fuel consumption and the GHG emissions of each individual ship were used to create the comprehensive baseline assessment.

This report provides information on the database and methodologies used along with the key findings from the assessment for the six PICs. It also identifies a number of analytical gaps and provides recommendations on how to address these gaps in the future. The report is structured as follows: Section 2 provides an overview of the structure and components of the database. Section 3 presents the methodology used to estimate fuel consumption and GHG emissions of domestic ships. Section 4 presents the methodology to estimate emissions from international shipping between PIC. Section 5 provides an overview of the estimation results in terms of carbon dioxide (CO_2) emissions and fuel consumption across the PICs and ship types. Section 6 highlights the data and analytical gaps identified and provide recommendations for future work.

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[3] PBSP (2019). *Technical Working Paper 1: Country Profiles and Fleet data*. Pacific Blue Shipping Partnership – Technical Working Group.

[4] Fiji, Tonga, Kiribati, Tuvalu, RMI and Solomon Islands.

2 Database description and structure

The database records the characteristics of each individual ship that is relevant for estimating the ship’s fuel consumption and GHG emissions during the year 2019. The dataset covers domestic and international ship registries for six PICs and is broken down into domestic and international ships, 25 ship types, and three engine types.

2.1 Data sources

The individual ship records were obtained from various sources such as government registers and documentation of earlier reports with the help of experts and partners from six PICs. The following table provides a reference to the original Microsoft excel documents from which the dataset has been built upon.

Table 1: Original data sources of ship register data for each PIC

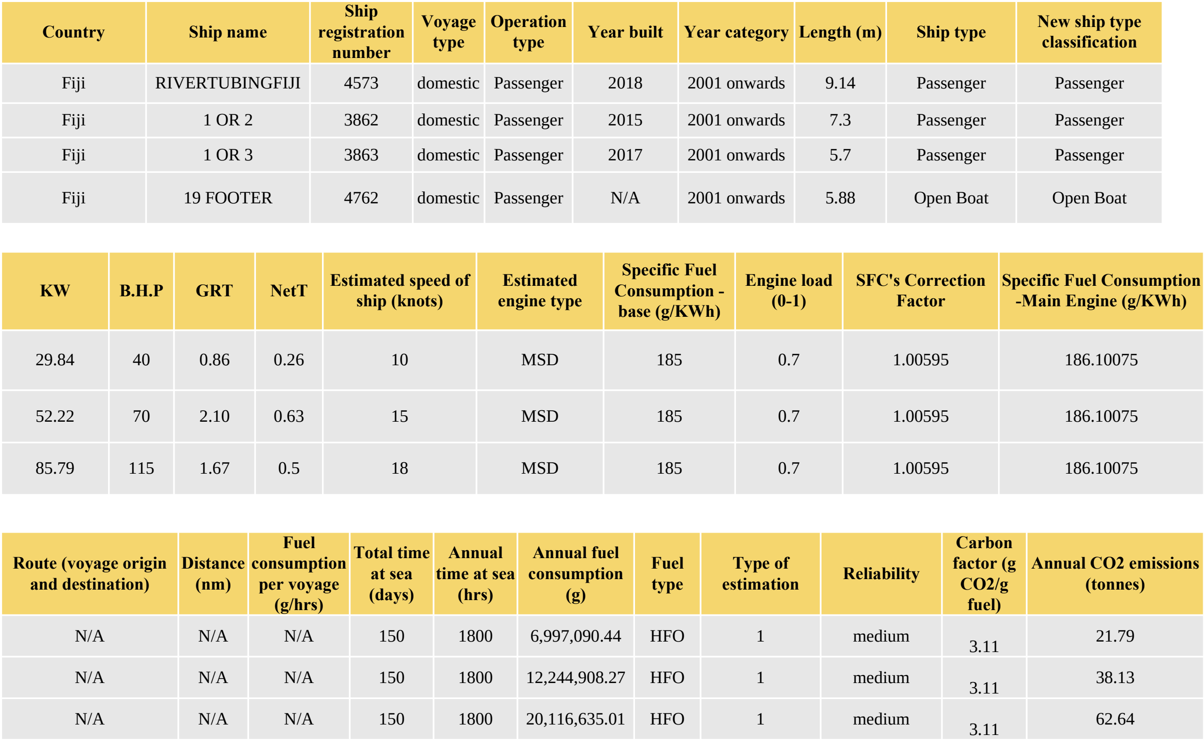
Country	Source of data (Name of excel spreadsheet)
Fiji	Fiji 2019 Ship Registry; Fiji Govt and related SOE vessels; Aggregated GHG emissions and fuel consumption in 2016-2017 Fiji GSS Vessels fuel consumption
Kiribati	Kiribati vessels (2019); Aggregated fuel consumption in Kiribati Marine transport fuel data (2019 MISE data)
Tuvalu	Tuvalu small boats 2018; Tuvalu vessel information;
Tonga	DRAFT Tongan National Action Plan for Shipping
Solomon Island	Solomon Islands MASTER - SHIPS REGISTRY 2019 08 19
Republic of Marshall Island	RMI Shipping Baseline Data Report PRIF'; Ship Registration Number: 'RMI Domestic Ship list updated 2020;

2.2 Implementation of the database

The database and the inventory have been developed in a Microsoft Excel spreadsheet to facilitate enhanced transparency, future refinement and expansion of the dataset. The main inventory sheet provides information on all individual vessel data, including their design features and estimates for fuel consumption and CO_2 emissions. Figure 8 provides an overview of the database structure of the inventory sheet. The spreadsheet also includes the following components, implemented on different sheets:

- Summary of emissions broken down by countries and ship types
- Summary of fuel consumption broken by countries and ship types
- Key parameters – a collection of key assumptions that are utilized to estimate fuel consumption and emissions for individual vessel
- Regression model for estimating the number of small artisanal craft, fuel consumption, and emissions
- Estimation of emission for each PIC’s international shipping.
- Regression model A: for estimating missing ship’s engine power data
- Regression model B: for estimating missing ship’s length data
- Regression model C: for estimating missing ship’s engine power for passenger ship type

Figure 8: Example of individual vessel data implemented on an Excel spreadsheet



Country	Ship name	Ship registration number	Voyage type	Operation type	Year built	Year category	Length (m)	Ship type	New ship type classification
Fiji	RIVERTUBINGFIJI	4573	domestic	Passenger	2018	2001 onwards	9.14	Passenger	Passenger
Fiji	1 OR 2	3862	domestic	Passenger	2015	2001 onwards	7.3	Passenger	Passenger
Fiji	1 OR 3	3863	domestic	Passenger	2017	2001 onwards	5.7	Passenger	Passenger
Fiji	19 FOOTER	4762	domestic	Passenger	N/A	2001 onwards	5.88	Open Boat	Open Boat

KW	B.H.P	GRT	NetT	Estimated speed of ship (knots)	Estimated engine type	Specific Fuel Consumption - base (g/KWh)	Engine load (0-1)	SFC's Correction Factor	Specific Fuel Consumption -Main Engine (g/KWh)
29.84	40	0.86	0.26	10	MSD	185	0.7	1.00595	186.10075
52.22	70	2.10	0.63	15	MSD	185	0.7	1.00595	186.10075
85.79	115	1.67	0.5	18	MSD	185	0.7	1.00595	186.10075

Route (voyage origin and destination)	Distance (nm)	Fuel consumption per voyage (g/hrs)	Total time at sea (days)	Annual time at sea (hrs)	Annual fuel consumption (g)	Fuel type	Type of estimation	Reliability	Carbon factor (g CO2/g fuel)	Annual CO2 emissions (tonnes)
N/A	N/A	N/A	150	1800	6,997,090.44	HFO	1	medium	3.11	21.79
N/A	N/A	N/A	150	1800	12,244,908.27	HFO	1	medium	3.11	38.13
N/A	N/A	N/A	150	1800	20,116,635.01	HFO	1	medium	3.11	62.64

3 Methodology to Estimate Fuel Consumption and GHG Emissions from Domestic Fleets

In general, there are several methods to estimate fuel consumption and GHG emissions which can be utilized based on the level of disaggregation desired and data availability. The review of available data indicates that data from government registers mostly provide information about individual vessels that operate domestically within the respective PICs. Therefore, a bottom-up method that leverages this detailed vessel data has been developed to estimate GHG emissions at a disaggregate ship level. A dedicated effort has been devoted to estimating fuel consumption and CO_2 emissions from small artisanal crafts which constitute a large fraction of the types of ships in the PIC regions. Specifically, the following steps have been taken to establish the baseline inventory of emissions:

1. Collecting and cleaning up all available ship data for six PICs
2. Developing a uniform categorization for individual ship
3. Estimating missing data for each vessel register
4. Estimating missing data for small artisanal crafts
5. Estimating fuel consumption for each individual vessel
6. Estimating CO_2 emissions based on ship's fuel consumption.

The following section elaborates on each of the steps taken above.

3.1 Collecting and cleaning up available ship data for six PICs

Datasets that record individual ships in operation during 2019 across the six PICs were collected and reviewed. Most of the ship datasets cover only ships that are engaged in domestic voyages within a PIC. A notable exception is Kiribati's ship registry which records ships that engage in international voyages. However, the data for ships' engine specifications is incomplete, making it impossible to estimate the fuel consumption for the ships within Kiribati's ship registry.

3.2 Developing a General Classification for Individual Ship

There is a wide variation in the terms used to define the types of ships reported in the government registers. For instance, the registers from six PICs record more than 79 distinct ship categories, many of which refer to the same ship types. Hence, a general categorization of ship types was developed to allow a simpler classification and to facilitate the estimation of missing data for each individual ship type. This new classification results in 26 distinct ship types that are assigned to each individual ship based on their original type or observed operation type (

Table 2).

Table 2: New ship type classification and the possible engine type

No	Ship type	Engine type	Possible alternative type
1	Cargo	SSD	MSD
2	Passenger	MSD	
3	Passenger and Cargo	MSD	SSD
4	Fishing vessel	HSD	MSD
5	Barge	MSD	
6	Dredging	SSD	MSD
7	Support vessel	HSD	
8	Pleasure craft	HSD	
9	Tug boat	MSD	SSD
10	Research vessel	HSD	
11	Oil Tanker	SSD	
12	Landing craft	HSD	
13	Non Commercial	MSD	
14	Drua	N/A	
15	Other	MSD	
16	Reefer	MSD	
17	Sailing boat	N/A	
18	Landing craft	HSD	
19	Medical boat	MSD	
20	Yacht	HSD	
21	Pollution response boat	HSD	
22	Open boat	HSD	
23	Work Boat	HSD	
24	RoRo	SSD	
25	Search and Rescue/Patrol	HSD	
26	Small artisanal crafts	HSD	

3.3 Estimating missing data for each vessel register

For each individual ship identified in the dataset, data regarding time spent at sea, engine type, engine power, and fuel type are typically missing or incomplete. In order to estimate the ship's engine type and power, the general design features of the vessel (ship type, size, speed, length, and weight) were used as determining variables. Further information regarding this can be seen in

Table 2. Furthermore, information regarding what type of estimation was done in relation to the specific missing data of the vessel was outlined on the Microsoft Excel sheet with each category describing the kind of missing data imputed and the model used to impute the missing data (Table 3). Based on the data available and assumptions made, three regression models were built – regression model A, B, C - to estimate various components of the missing data such as engine power and length of ship:

- Model A: establishes relationship between ship's engine power and length based on observations data obtained from Fiji and Solomon Island's register
- Model B: establishes relationship between ship's length and GT based on observations data obtained from Fiji and Solomon Island's register
- Model C: establishes relationship between ship's engine power and length and GT based on passenger ship data obtained from Fiji

Table 3: Type of estimation done to fill up the gap of missing vessel data

Type of estimation	Description
1	Estimation undertaken **for time spent at sea, engine type, fuel consumption, and emissions**
2	Estimation undertaken for all the variables estimated in Type 1 and ship's **engine power** (based on a regression Model-A)
3	Estimation undertaken for all the variables estimated in Type 1 and ship's **length and engine power** (based on a regression Model-B)
4	Estimation undertaken for all the variables estimated in type 1 and ship's **engine power** (based on a regression Model-C) **for passenger transport in Fiji and Solomon Islands**
5	Estimation undertaken for **number of small artisanal crafts** with outer boats based on regression model for small crafts
6	Estimation undertaken for international shipping between PICs based on trade volume for each ship type

Next, fuel consumption and emissions were estimated based on the engine power, fuel type, and time spent at sea of each individual ship. To develop the estimation, it was assumed that most of the domestic ships in the PICs are equipped with oil engines with the following categorizations taken from the Fourth IMO GHG Study:

- Slow-Speed Diesel (SSD): All two-stroke engines with speed lower than or equal 300 revolutions per minute (RPM).
- Medium-Speed Diesel (MSD): All engines with speed ranging from 300-900 RPM.
- High-Speed Diesel (HSD): All engines with speed above 900 RPM

Due to the absence of data on type of fuel used by the ships, it was assumed that Heavy Fuel Oil (HFO) or Marine Diesel Oil (MDO) were used as the default fuel types for ships. The estimation method for Type five (small artisanal crafts) and six (international shipping) will be described in section 3.4 and 4 respectively.

3.4 Estimating missing data for small artisanal vessels

The data for small artisanal vessels is among the most difficult to obtain due to limited surveys or data collection attempts. Recognizing this challenge, an observation on the number of small artisanal vessels that are available through earlier studies was undertaken, particularly for RMI, Tonga, Fiji, and Kiribati. These studies carried out a survey on the number of small crafts which use outboard motors across different islands in the PICs.

Subsequently, a simple regression model is built to estimate the number of small vessels in Solomon Island and Tuvalu based on socioeconomic and geographic variables such as gross domestic product (GDP), number of populations, coast-to-land ratio, coastal area, number of inhabited islands that are observable in other PICs. After experimenting with different model structures and arrived at a simple model which indicates a strong correlation between the number of population and the total number of small artisanal vessels in the PICs (**Regression model for small crafts tab**). Hence, the relationship to estimate the number of similar vessels for Solomon Island and Tuvalu was used (Table 4). Based on the number of vessels, fuel consumption and emissions were estimated using the methodology and assumptions described in the following section.

Table 4: Estimation of number of small artisanal vessels based on observation on other PICs

Country	Total number of small artisanal vessels	Fuel consumption p.a. (liters)	CO_2 emissions (tons)	Upper bound	Lower bound	Source
Kiribati	1,911.00	6,327,422.67	17,545.50	21,054.60	15,790.95	AR-CCM-11[5]
RMI	436.00	1,277,000.00	3,038.00	3,645.60	2,734.20	PRIF study[6] (2017)
Tonga	443.00	1,559,272.00	2,663.44	3,196.13	2,397.10	draft Tongan NAP (2022)
Fiji	3,800.00	19,208,942.70	53,265.05	79,897.57	47,938.54	Gillet, R (2020)[7]
Solomon Island	2,259.00	15,412,649.02	42,738.19	64,107.29	38,464.37	estimation
Tuvalu	383.25	1,937,322.97	5,372.06	8,058.09	4,834.85	estimation

To account for the wide uncertainties around the estimate, the lower and upper bound estimates for fuel consumption and emissions was computed, assuming a lower bound and upper bound at 10 percent and 20 percent of the baseline values for Kiribati, RMI and Tonga. Furthermore, a 50 percent upper bound range for PICs with higher degree of uncertainty such as Solomon Islands, Fiji, and Tuvalu was assumed. The higher upper bound range is assumed to reflect an increased likelihood of a higher number of ships from the baseline values. Figure 9 presents the visualization of the estimated emissions and their plausible range.

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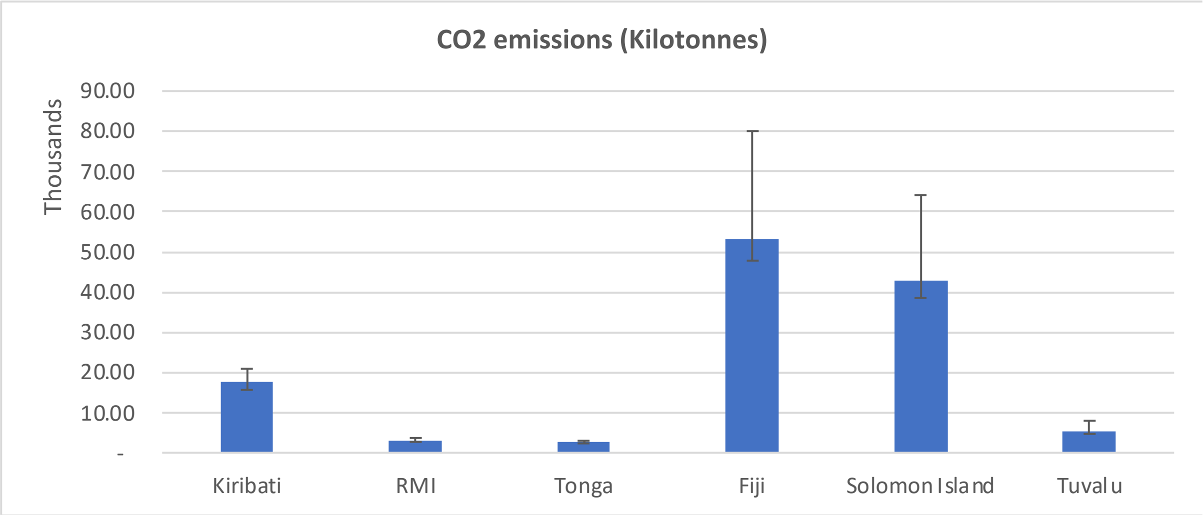
[5] Annual report to the Western and Central Pacific Fisheries Commission-11

[6] PRIF (2017). Establishing baseline data to support sustainable maritime transport services. Pacific Region Infrastructure Facility Coordination Office

[7] https://www.spc.int/DigitalLibrary/Doc/FAME/InfoBull/FishNews/162/FishNews162_23_Gillett.pdf

Figure 9: Estimated CO_2 emissions from small crafts with their plausible range



3.5 Estimating fuel consumption for each individual vessel

The methodology applied in this study to estimate fuel consumption is based on the same methodology applied in the Fourth IMO GHG Study 2020. In that, annual fuel consumption is calculated based on vessel's hourly fuel consumption and ship activity in terms of total time spent at sea which is defined by the following equation:

$$AFC_i = FC_i\ x\ TS_i + FCP_{i\,+} x\ TP_i\ + FCI_i\ x\ TI_i \qquad (1)$$

Where:

AFC_i = Annual fuel consumption of vessel-*i* (kg of fuel /year)

FC_i = hourly fuel consumption of vessel-*i* at sea(kg of fuel/ hour)

TS_i = time spent at sea (hour/year)

FCP_i = daily fuel consumption of vessel-*i* in port (tonne of fuel/ day)

TP_i = time spent at port (day/year)

FCI_i = daily fuel consumption of vessel-*i* during idle (tonne of fuel/ day)

TI_i = time spent by vessel -*i* being idle (day)

Note that data regarding ships' voyages such as origin and destination port, distance travelled, or travel time is unavailable for most of the six PIC ship registers. Therefore, the time spent for different operations (i.e., at sea, in port, during idle) needs to be estimated using available information such as distance travelled between main ports of a PIC and average speed of the ship and frequency of ship voyages. When such information is not available, a specific assumption for different ship operations and type were applied. These are presented in Table 5. Fuel consumption at the port is estimated based on the ship's engine power using a simple regression model. Ships with higher power output will have higher fuel consumption in port and vice versa. The fuel consumption of the vessel during idle time is assumed to be 25 percent of daily fuel consumption in port.

Table 5: Time spent for different operation types for each ship type

No	Ship type	% Time at sea	% Idle time	% Time at port	Time spent at sea
1	Cargo	0.7	0.2	0.1	210
2	Passenger	0.6	0.3	0.1	180
3	Passenger and Cargo	0.6	0.3	0.1	180
4	Fishing vessel	0.5	0.5	0	150
5	Barge	0.7	0.2	0.1	210
6	Dredging	0.4	0.5	0.1	120
7	Support vessel	0.7	0.2	0.1	210
8	Pleasure craft	0.5	0.4	0.1	150
9	Tug boat	0.5	0.4	0.1	150
10	Research vessel	0.6	0.3	0.1	180
11	Oil Tanker	0.7	0.2	0.1	210
12	Landing craft	0.7	0.2	0.1	210
13	Non Commercial	0.5	0.4	0.1	150
14	Drua	0.5	0.4	0.1	150
15	Other	0.5	0.4	0.1	150
16	Reefer	0.8	0.2	0	240
17	Sailing boat	0.5	0.4	0.1	150
19	Medical boat	0.5	0.4	0.1	150
20	Yacht	0.3	0.6	0.1	90
21	Pollution response boat	0.3	0.6	0.1	90
22	Open boat	0.5	0.3	0.2	150
23	Work Boat	0.7	0.2	0.1	210
24	RoRo	0.7	0.2	0.1	210
25	Search and Rescue/Patrol	0.5	0.4	0.1	150
26	Small artisanal crafts	0.35	0.4	0.25	105

In order to estimate the vessel’s hourly consumption, the following equation were used:

$$FC_i = SFC_i \text{ x } W_i \qquad (2)$$

Where:

SFC_i = hourly specific fuel consumption of an engine (g/KWh)

W_i = power demand of each hourly observation (KW), defined as engine maximum power output multiplied by hourly engine loading ($load_i$)

The specific fuel consumption is computed using the concept of baseline SFCs (SFC_{base}) which determines the baseline fuel consumption of a specific engine based on the vessels age, type, and fuel type. Table 6 provides the value of SFC_{base} for different engine and fuel types used in this study. The SFC_{base} value and engine load is used to calculate the SFC of main engine ($SFC_{ME,i}$) and auxiliary engine, and auxiliary boiler based on the following equation:

$$SFC_{ME,i} = SFC_{base} \text{ x } (0.455 \text{ x } load_i^2 - 0.71 \text{ x } load_i + 1.28) \qquad (3)$$

Where:

$SFC_{ME,I}$ = Specific fuel consumption of main engine of a given vessel-*i* (g/KWh)

SFC_{base} = Baseline specific fuel consumption (g/KWh)

$load_i$ = hourly main engine loading (0 – 100 percent)

The second component on the right-hand side of the equation represents correction factor to the *SFCbase* which takes into account the load of the engine in calculating the specific fuel consumption of a given vessel. In this study, the majority of engine load data is unavailable and hence needs to be estimated whenever other secondary data is available and allows for such estimation. An assumption that sets the default value for the engine load, where most ship's engine is run with 60 percent engine load was applied.

Table 6: SFC base for different engine and fuel types

Engine Type	Fuel Type	Before 1983 (g/KWH)	1984-2000 (g/KWH)	2001+ (g/KWH)
SSD	**HFO**	205	185	175
SSD	MDO	190	175	165
SSD	MeOH**	N/A	N/A	350
MSD	**HFO**	215	195	185
MSD	MDO	200	185	175
MSD	MeOH**	N/A	N/A	370
HSD	**HFO**	225	205	195
HSD	MDO	210	190	185

3.6 Estimating CO_2 Emissions Based on Ship's Fuel Consumption

Given the annual fuel consumption estimated using equation (1), the annual emission (AEM_i) of a given vessel based on the annual fuel consumption and emission factor of the fuel type was computed using the following equation:

$$AEM_i = AFC_i \times E_f \qquad (4)$$

Where:

AFC_i = Annual fuel consumption of vessel-*i*

E_f = Emission factor of a given fuel type. Table 7 provides the emission factor for each fuel type considered in this study.

Table 7: Fuel types and its emission factors

Fuel Type	Emission Factor (gCO_2/g fuel)
HFO	3.114
MDO	3.206
LNG	2.750
Methanol	1.375
LSHFO 1%	3.114

4 Methodology to Estimate Emissions from Inter-PICs International Shipping

Detailed data regarding international ship activities between PICs is scarce and they still need to be collected from relevant sources such as shipping companies and port authorities. To overcome this data gap, the estimation for GHG emissions is performed based on bilateral trade activities between the PICs with 2019 data obtained from the UN COMTRADE database. Due to limited trade data availability for countries in the Pacific region, Fiji's export and import data to the rest of the PIC to estimate intra-PIC emissions is mainly used. Unfortunately import and export data between five other PICs is not available. This dataset is obtained from the Observatory of Economic Complexity.[8]

A value-to-weight model was deployed which translates trade activities in value terms (US$) into transport volume terms (tonnages). A similar model has been built and applied in the literature such as in (Halim et al., 2028[9]; Martínez et al., 2015[10]; Ong & Sou, 2015[11]). A Poisson regression model was used to estimate the rate of conversion of value units (US dollars) into weight units of cargo (tons) by mode, calibrated using datasets from Eurostat and Economic Commission for Latin America and the Caribbean (ECLAC) data on value/weight.

.

$$w^{y}_{odk} = T^{y}_{odk}\, e^{rs^{y}_{odk}} \tag{5}$$

$$rs^{y}_{odk} = a + b_1\, e^{gdp\%^{y}_{o}} + b_2\, e^{gdp\%^{y}_{d}} + b_3\, e^{gdp_c\%^{y}_{o}} + \; b_4\, e^{gdp_c\%^{y}_{d}}$$

$$+b_5 \ln\left(\frac{gdp_{c}{}^{y}_{o}}{gdp_{c}{}^{y}_{d}}\right) + b_6\, contig_{od} + \; b_7\, lang_{od} + b_8\, rta_{od} + lgs_k e^{-logsum(cost_{od})} \tag{6}$$

In Equations (5) and (6),

$w^{y}_{odk}\mathrm{w}^{\mathrm{y}}_{\mathrm{odk}}$ = weight of commodity *k* that is traded between origin *o* and destination *d* for year *y* (in tons),

T^{y}_{odk} = value of trade for commodity *k* between origin *o* and destination *d* for year *y* (in US$),

$rs^{y}_{odk}\mathrm{rs}^{\mathrm{y}}_{\mathrm{odk}}$ = value-to-weight conversion factor for commodity *k*, between origin *o* and destination *d* for year *y* (in tons/US$),

$gdp\%^{y}_{o}\mathrm{gdp\%}^{\mathrm{y}}_{\mathrm{o}}$ = GDP percentile of origin in year *y*,

$gdp\%^{y}_{d}\mathrm{gdp\%}^{\mathrm{y}}_{\mathrm{d}}\mathrm{gdp\%}^{\mathrm{y}}_{\mathrm{d}}$ = GDP percentile of destination in year *y*,

$gdp_c\%^{y}_{o}\mathrm{gdp\_c\%}^{\mathrm{y}}_{\mathrm{o}}$ = GDP per capita percentile of origin in year *y*,

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[8] https://oec.world

[9] Halim, Ronald A., et al. (2018). Decarbonization Pathways for International Maritime Transport: A Model-Based Policy Impact Assessment. *Sustainability, 10*(7), 2243.

[10] Martínez, L Miguel, et al. (2015). International Freight and Related Carbon Dioxide Emissions by 2050: New Modeling Tool. *Transportation Research Record: Journal of the Transportation Research Board*(2477), 58-67.

[11] Ong, Ghim Ping, & Sou, Weng Sut. (2015). Modeling Commodity Value–Weight Trends Between the United States and Its Trading Partners. *Transportation Research Record: Journal of the Transportation Research Board, 2477*, 93-105. doi: 10.3141/2477-11

$gdp_c\%_d^y\mathrm{gdp\_c\%}_{\mathrm{d}}^{\mathrm{y}}$ = GDP per capita percentile of destination in year *y*,

$\ln\left(\frac{gdp_{c_o}^y}{gdp_{c_d}^y}\right)$ = natural logarithm of the ratio between GDP per capita of origin and GDP per capita of destination in year *y*,

$contig_{od}\mathrm{contig}_{\mathrm{od}}$ = land contiguity between origin *o* and destination *d*, *contig* = (0, 1),

$lang_{od}$ = shared language between origin *o* and destination *d*, *lang* = (0, 1),

rta_{od} = trade agreement between origin *o* and destination *d*, *rta* = (0,1),

$\mathrm{logsum}(\mathrm{cost}_{\mathrm{od}})logsum(cost_{od})$ = *logsum* variable of transport costs using different modes between origin *o* and destination *d*,d

lgs_k = *logsum* coefficient/panel term for commodity *k*.

Based on the volume of each commodity transported, and shipping distance from and to main ports of the relevant PICs, transport activities across various ship types in ton-kilometer were estimated. Finally, CO_2 emission for each ship type is calculated by multiplying the carbon intensity of each ship type (ton CO_2/tkm) with transport activity of each ship. Note that the estimate does not take into account emissions at ports or when ships are idle. The calculation of CO_2 emissions is carried out using equation below:

$$E_{qf} = A_q.S_{qf}.F_f \tag{7}$$

$$TCO_2 = \sum_{q=1}^{Q}\sum_{f=1}^{F} E_{qf} \tag{8}$$

- TCO_2 = total CO_2 emissions from international shipping,
- E_{qf} = total CO_2 emissions from ship type *q* using fuel type *f* (in tons CO_2),
- A_q = total annual activity for ship *q* (in ton kilometers),
- S_{qf} = share of ship type *q* which uses fuel type *f* (in %),
- F_f = emission factor of fuel type *f* (in tons CO_{2eq}/MJ or CO_{2eq}/ton fuel).

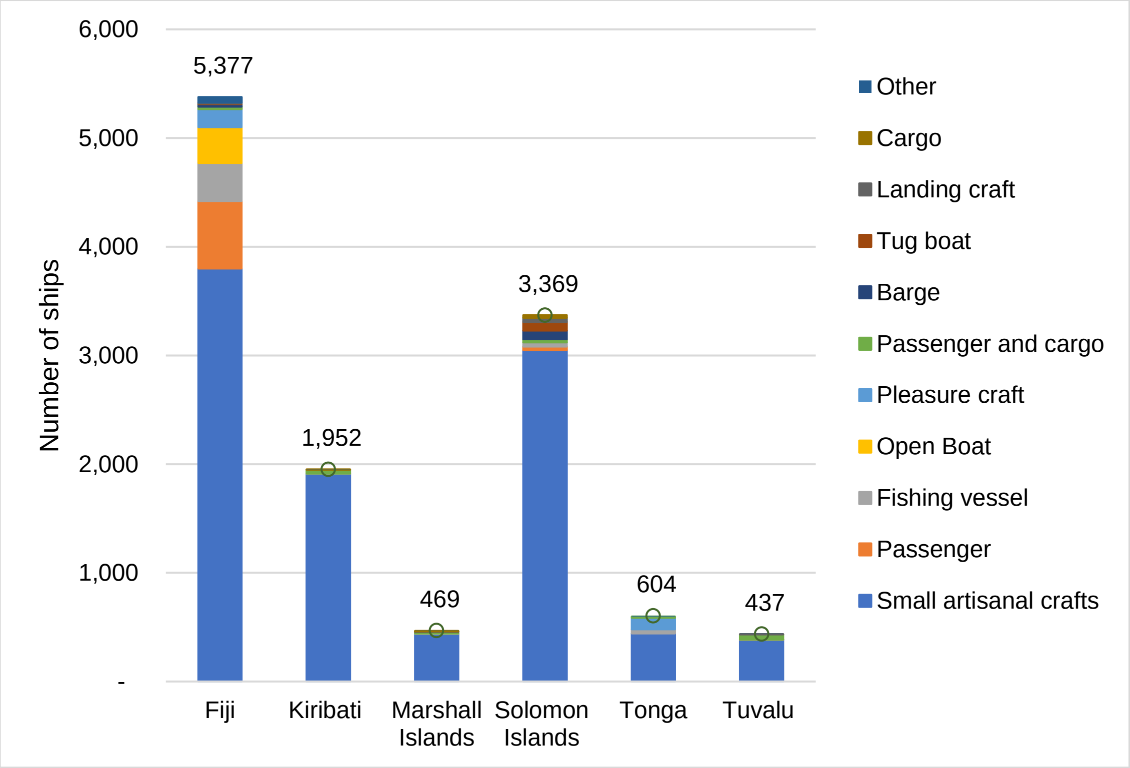
5 Results

5.1 Domestic shipping fleet

Based on the compiled data, each PIC has specific characteristics in regard to ship numbers.

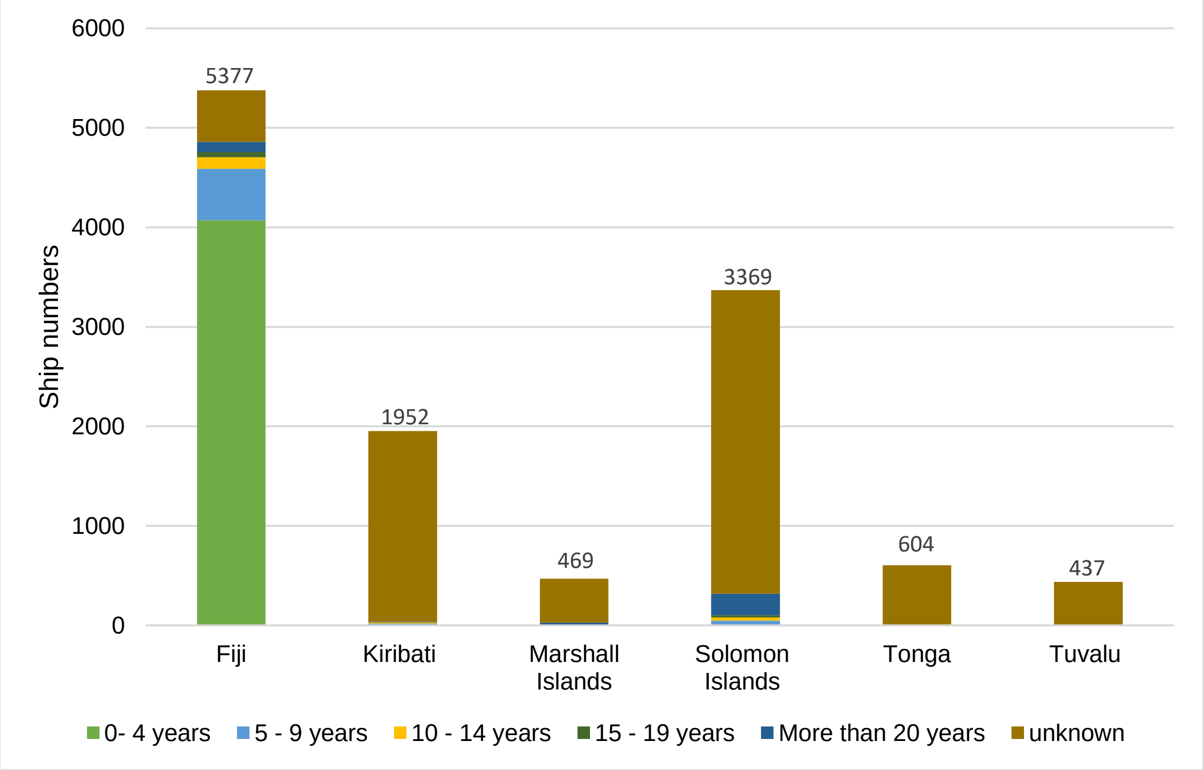
One common characteristic that can be seen across data from the six PICs is that there is a high number of small artisanal crafts and small boats which represents the majority of ship types (Figure 10). This is followed by passenger ship, and passenger and cargo ship which represent the second and third highest number of ships. It can be seen that some PICs such as Fiji and Solomon Islands have higher diversity of ship types that are reported in the database. This is mainly due to the higher coverage of ship register data which are available for these countries compared to the other PICs. Of the six PICs studied, Fiji has the highest number of ships operating domestically, followed by the Solomon Islands, Kiribati, Tonga, Marshall Islands and Tuvalu, see Figure 10.

Figure 10: Overview of ship number and type among six PICs



Looking at the age distribution of ships, Fiji has a relatively high number of young ships that are less than four years old (Figure 11). Solomon Islands on the contrary has the highest number of ships that are 20 years or older. Note that there are many ships for which age data is not available. A big fraction of these ships for which age data is not available belongs to small boats and small artisanal craft ship types. Hence this implies that a survey is needed to have a more accurate insight on ships' age composition in the PICs.

Figure 11: Overview of ships number and age among six PICs



5.2 CO_2 emissions from domestic shipping

Based on the inventory of each individual vessel across the six PICs for the year 2019 following the methodology outlined in the sections above, an Excel spreadsheet was compiled that can be used to estimate total fuel consumption and emissions across six PIC countries for the year 2019. Using Excel's pivot table functionality, these estimates can be aggregated depending on aggregation criterion such as ship types, countries, ship operations, and geographical boundaries (domestic or international shipping).

The bottom-up estimation of CO_2 emissions across the six PICs outlined in this report, found that 580,493 tons of CO_2 were emitted from domestic shipping in 2019. From the analysis, it was identified that the highest share of CO_2 emissions can be attributed to small artisanal crafts (21 percent), followed by passenger ships (21 percent), tugboats (11 precent), fishing vessels (10 percent) (Figure 12). On a country level, a similar pattern is also observable where small artisanal crafts, passenger ships, and small boats represent major contributors of the CO_2 emissions and consume most fuel across the countries (see Figure 13 and Figure 14). This is due to small artisanal crafts and small boats typically using outboard motors which are relatively less fuel-efficient and mainly consume a more carbon-intensive fuel such as diesel fuel.

Figure 12: Shares of CO_2 emissions from domestic shipping by ship types

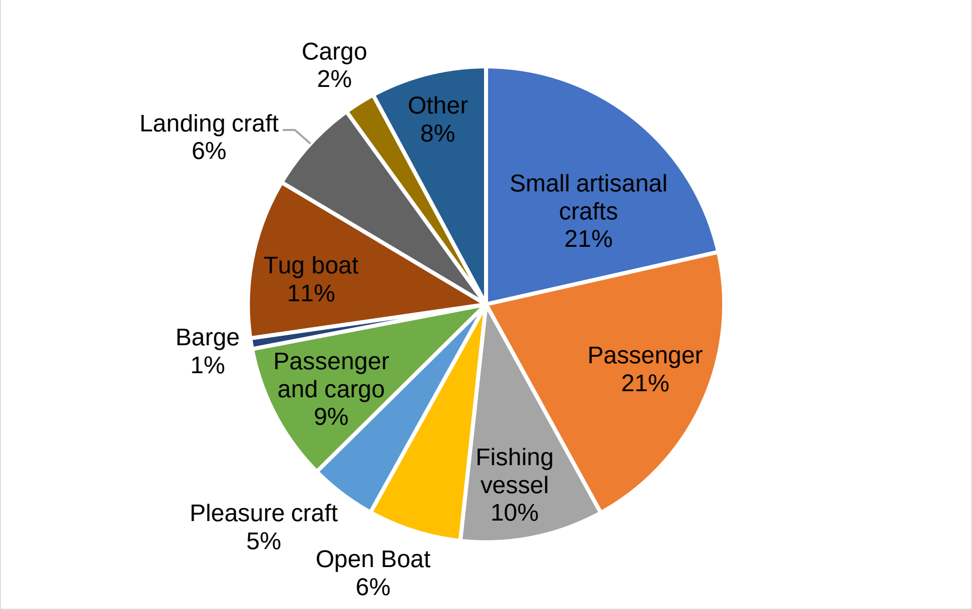


Figure 13: CO_2 emissions among PICs by ship types

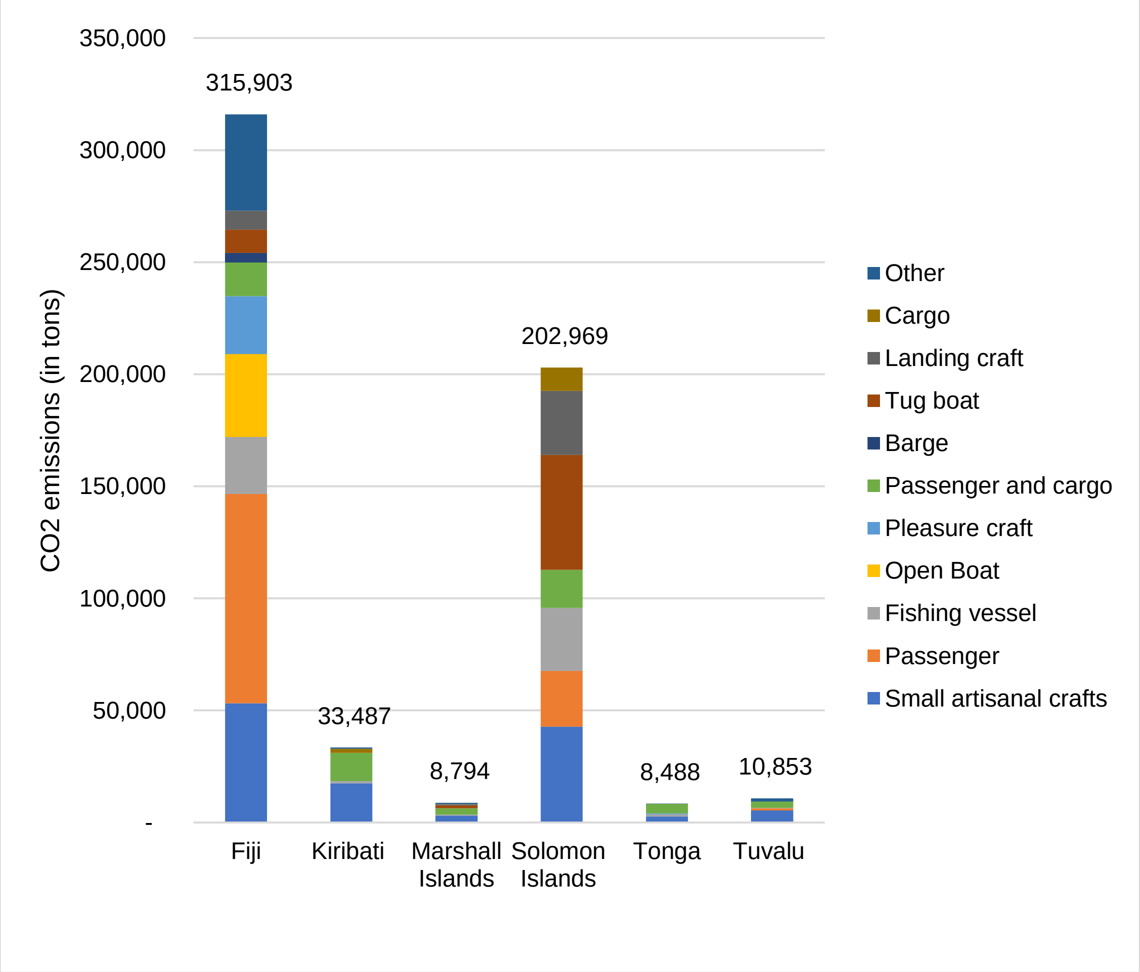
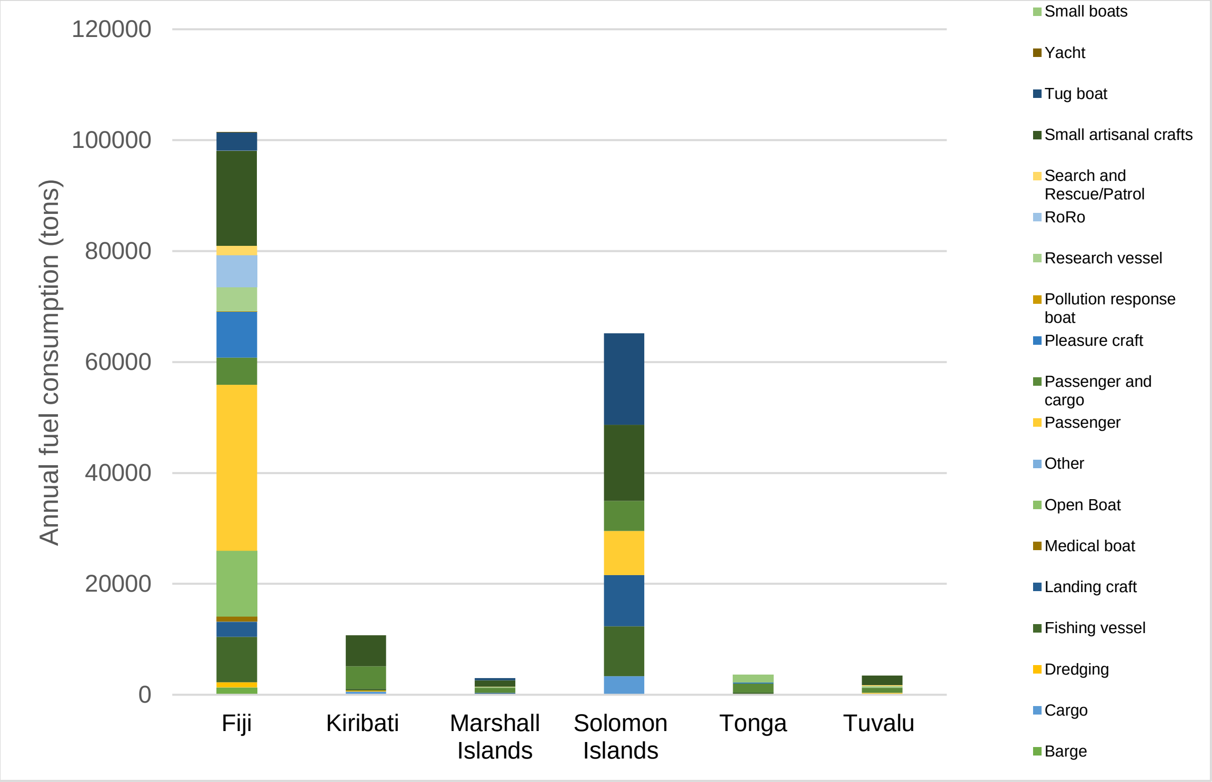


Figure 14: Overview of fuel consumption from 26 ship types across six PICs



On a country level, CO_2 emissions among PICs reflect a high proportionality with the population and GDP figures of the countries. Fiji and Solomon Islands as countries with the highest GDP and population emit highest CO_2 emissions (Figure 15) and represent the majority of the shares of domestic shipping emissions among the six PICs (Figure 16). This pattern on CO_2 emissions can also be explained by a higher number of ships among PICs with higher GDP and population.

Figure 15: CO_2 emissions from domestic shipping among six PICs

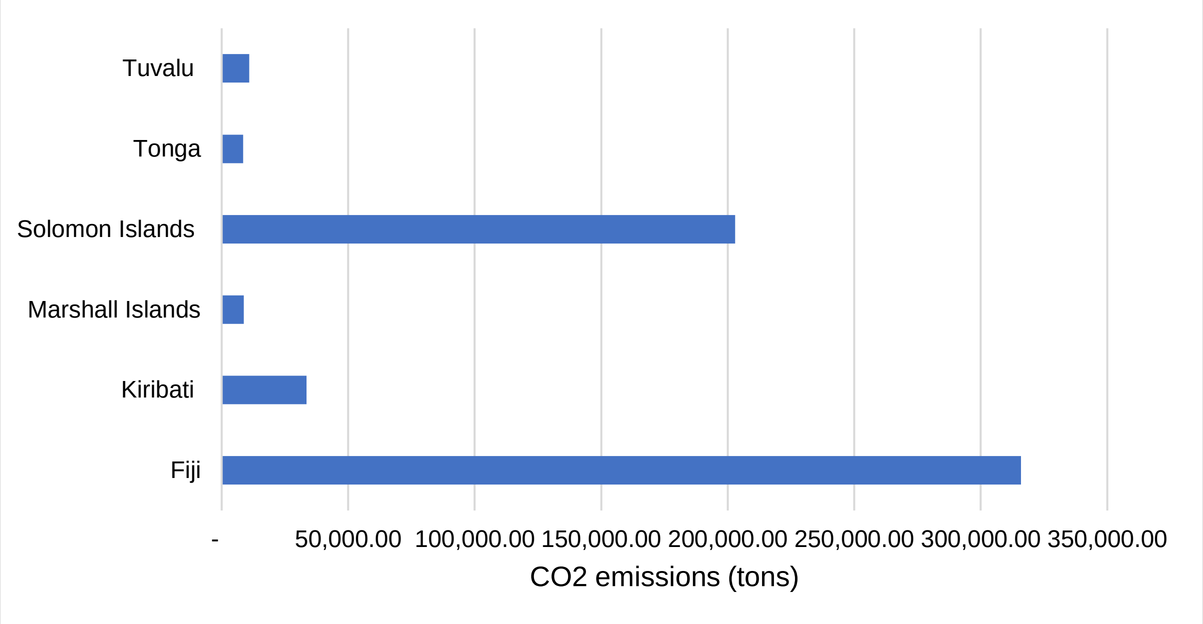
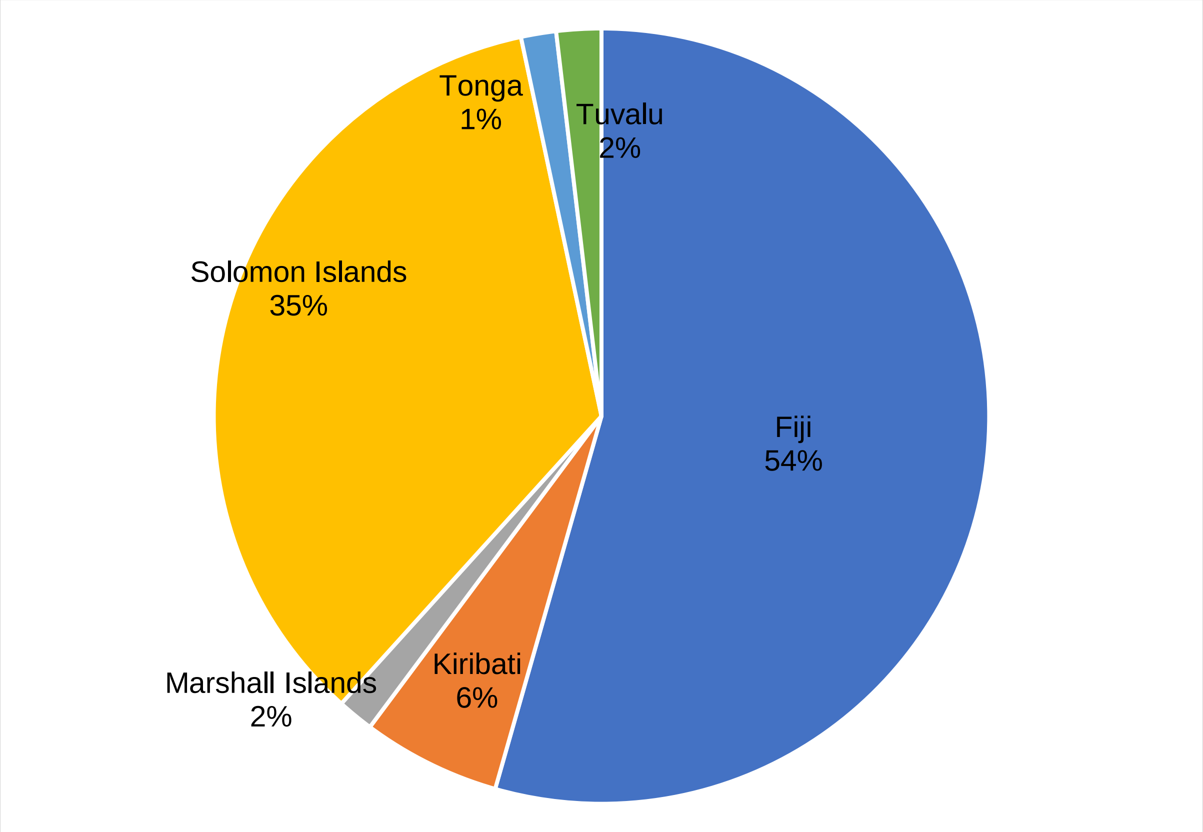


Figure 16: Share of CO_2 emissions from domestic shipping across six PICs



Another feature of the database is the inclusion of vessels age data which allows an analysis based on ships' age category (Figure 17). Including this information has identified that ships that are 20 years or older are major contributors of emissions (31 percent), followed by ships between 5-9 years (17 percent), and between 0-4 years (16 percent). Note that, a high fraction of the emission (28 percent) are emitted by ships without age data, which makes a robust assessment of emission profile based on ship's age difficult. Nevertheless, emission profile from available data indicates that old ships typically have lower fuel efficiency than younger ships. The total emissions that can be attributed to younger ships are relatively low compared to the high number of ships (4,081) which represents the highest number of ships across ship age's categories. In contrast, there are only 353 old ships which contribute to 16 percent of the total emissions.

Figure 17: Shares of CO_2 emissions based on ship age

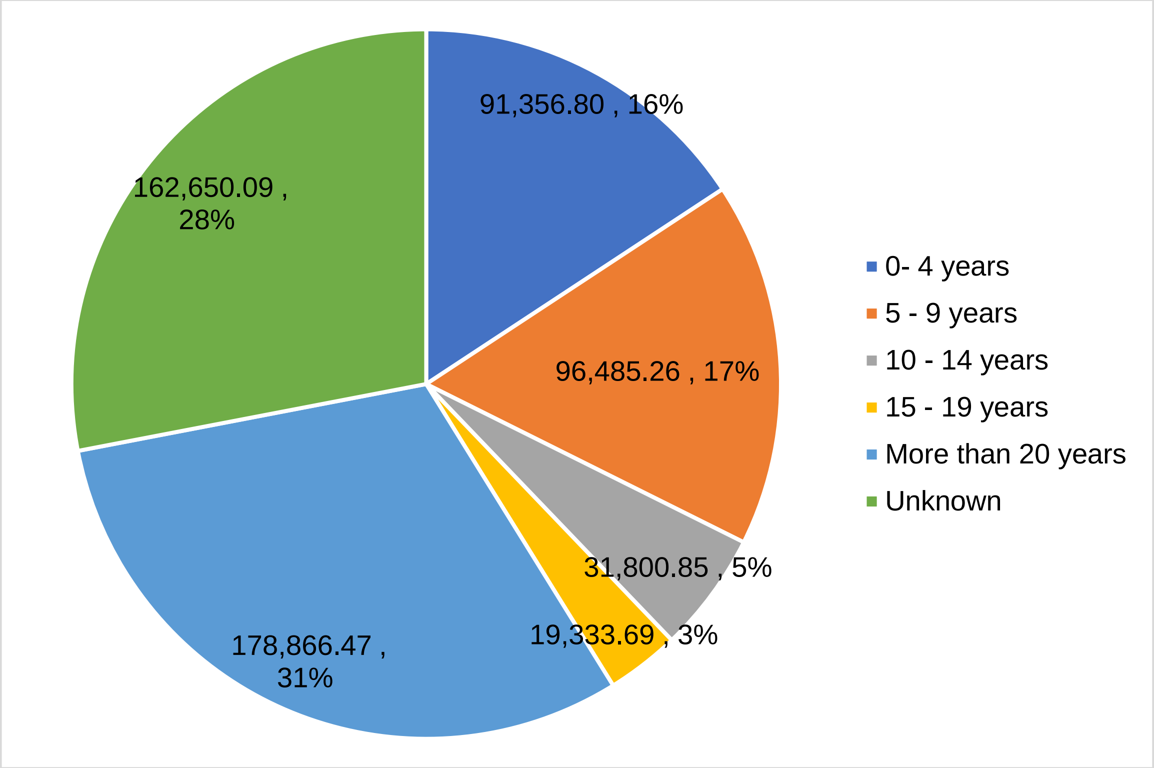
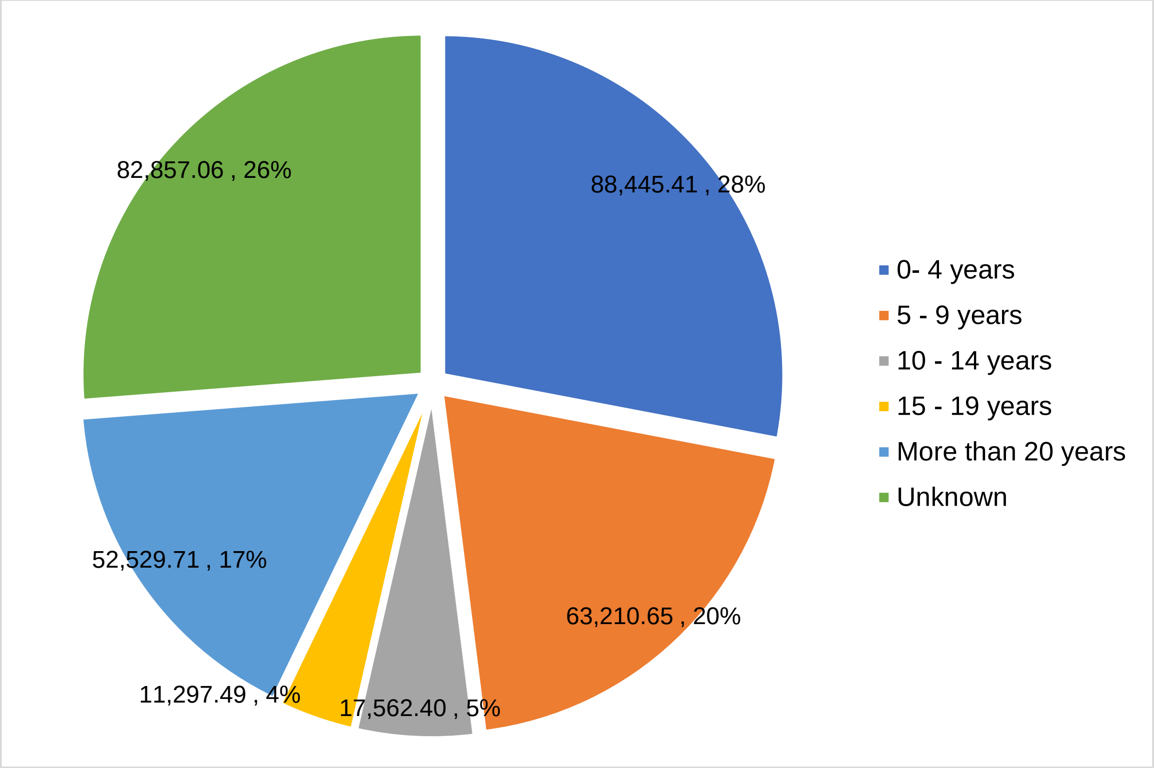


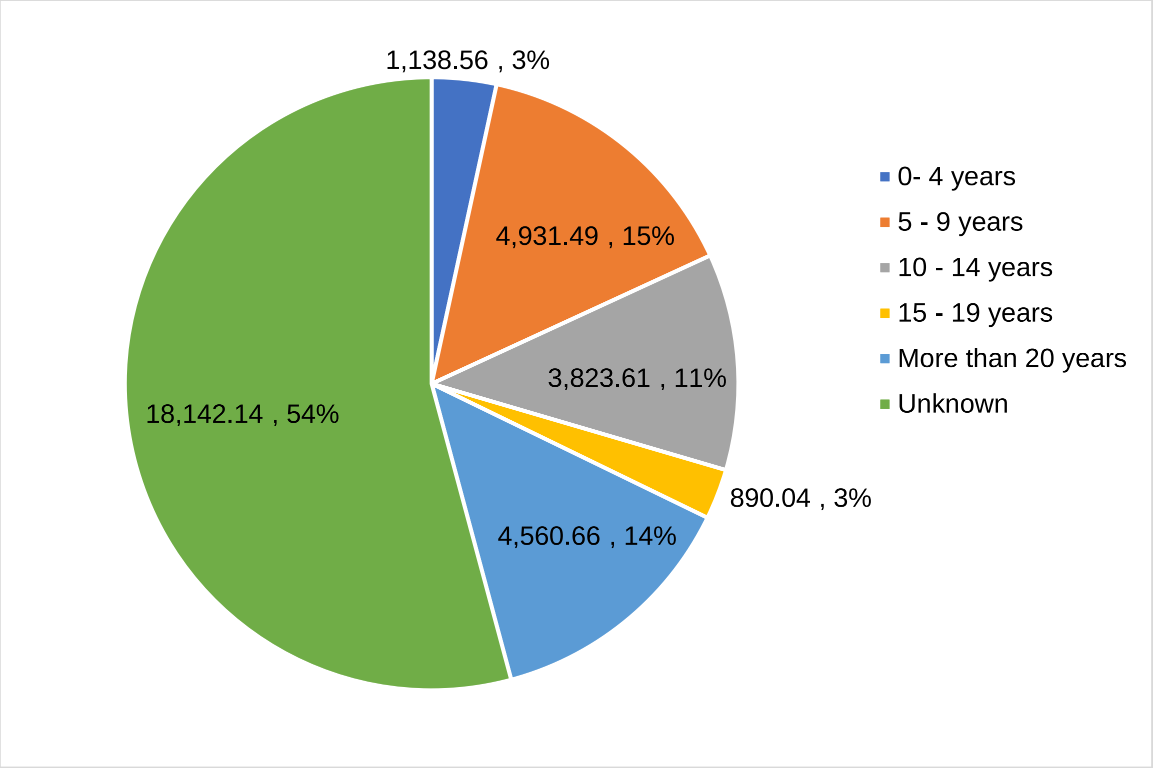
Figure 18 to Figure 22 provide a visual illustration on the shares of CO_2 emissions produced by ships based on ship age for each PIC, except for Tonga since data was unavailable. In Fiji, the majority of emissions – 28 percent - are from ships of 0-4 years age. Nevertheless, the fraction of ships whose age is not known is also high -26 percent. This high emissions from younger ships are primarily due to the high number of ships in the 0-4 age category (4071) which represents 75 percent of the total ship number.

Figure 18: Shares of CO_2 emissions based on ships' age in Fiji



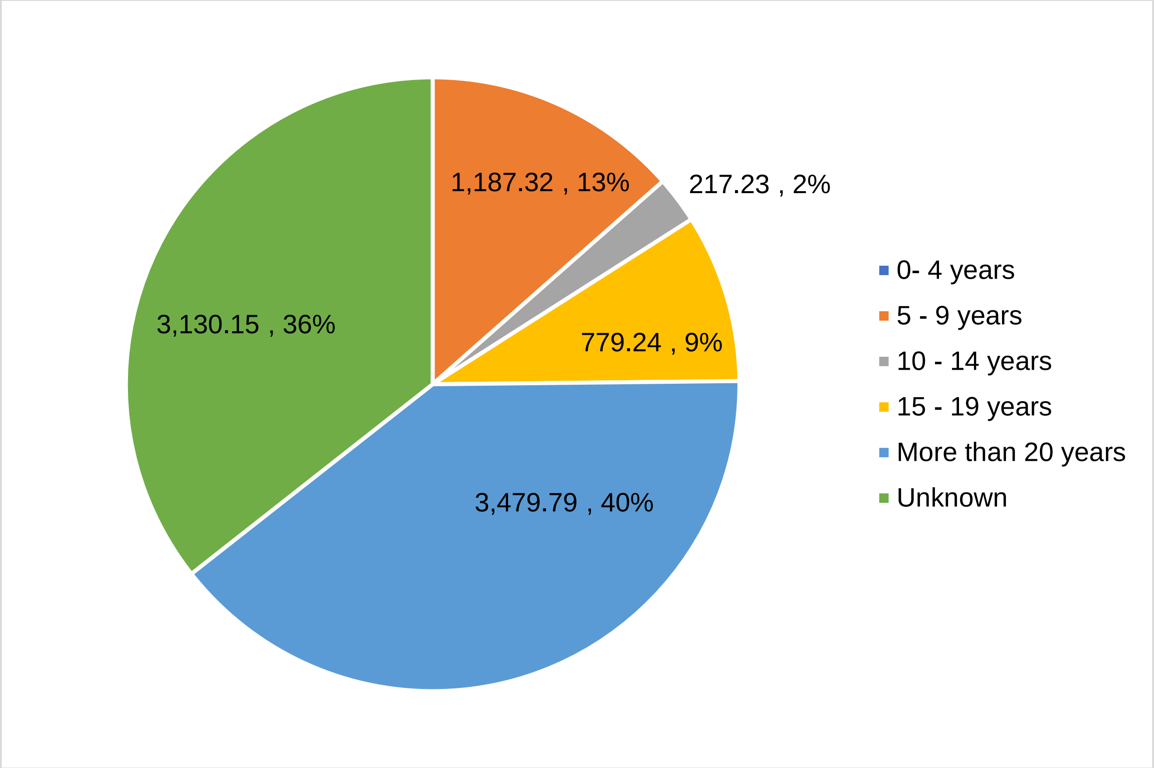
In Kiribati, a large share of emissions is contributed by ships whose age data is not available (54 percent). Ships between 5-9 years age and those that are 20 years or older contribute to the second and third highest total emissions. However, ships within the category of 5-9 years also represent the highest ship number in Kiribati.

Figure 19: Shares of CO_2 emissions based on ships' age in Kiribati



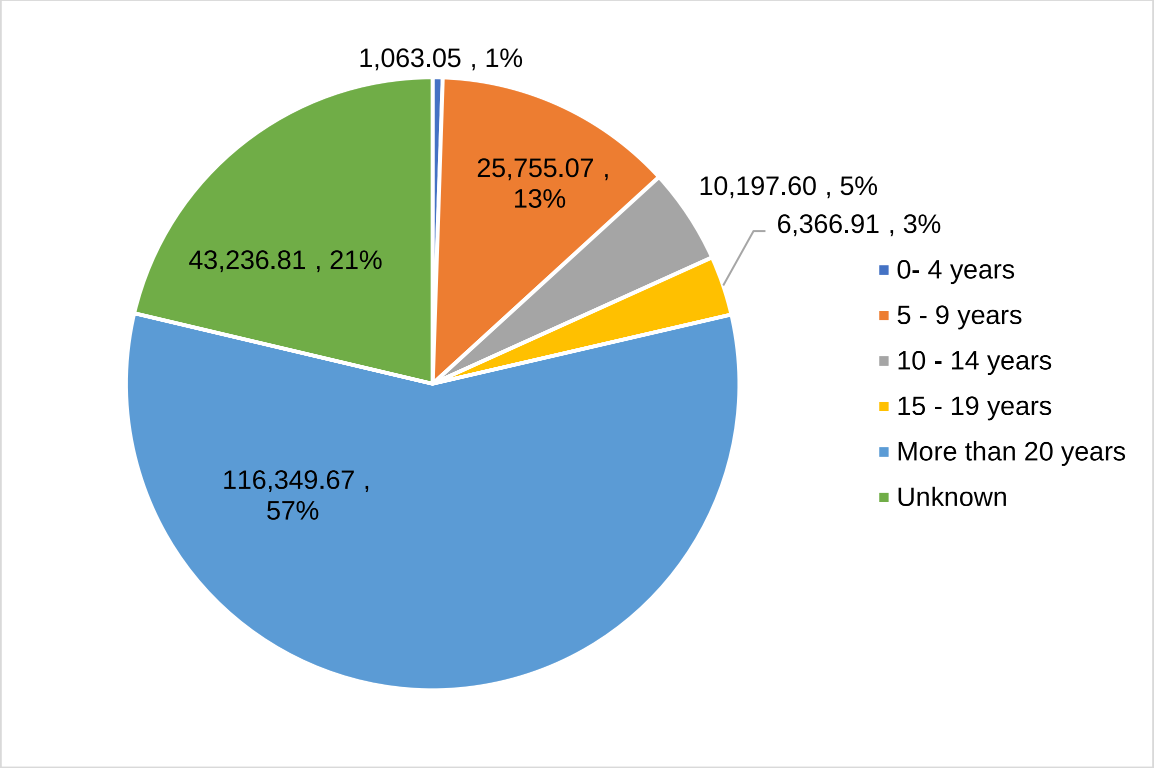
In RMI, older ships in the ≥ 20 years age group are major contributors (40 percent) to the emissions from domestic shipping. This is because this ship category also represents the highest number of ships in the country, followed by ships between 5-9 years age.

Figure 20: Shares of CO_2 emissions based on ships' age in Marshall Islands



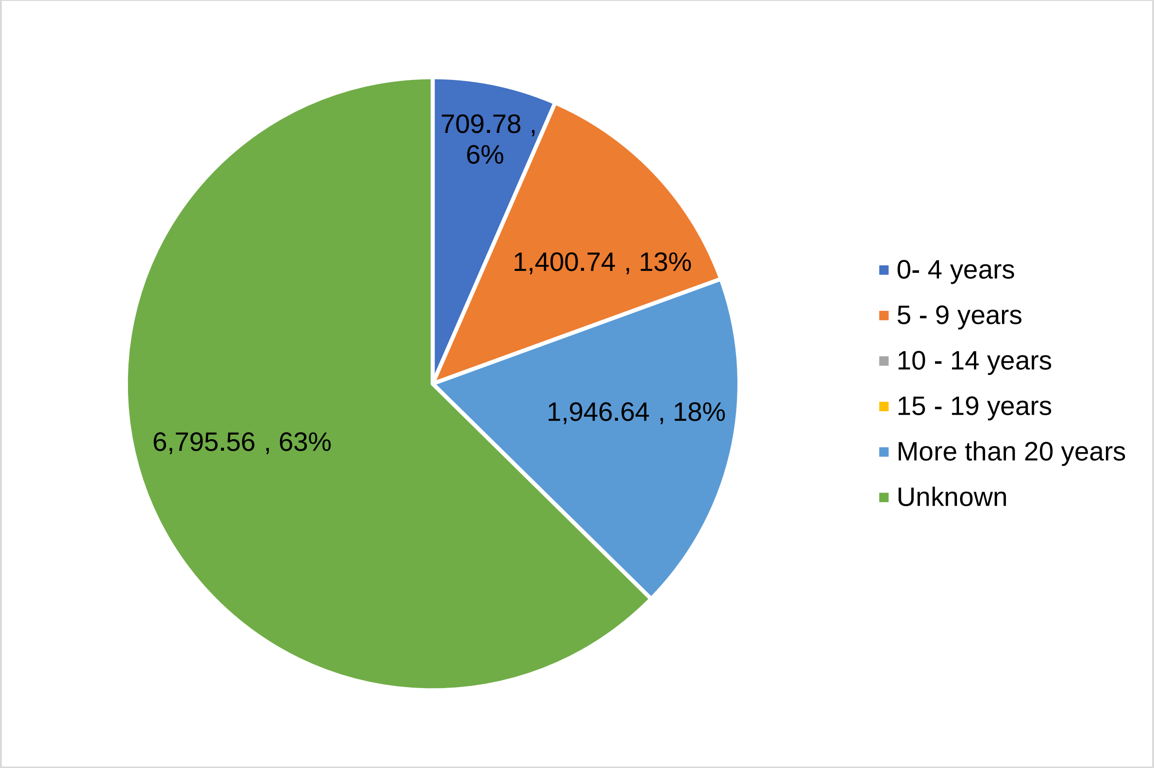
In Solomon Islands, old ships that are 20 years or older represent the largest share -57 percent- of CO_2 emissions from the sector. This age category also has the highest number of ships compared to other age categories. Unfortunately, there is a relatively high number of ships whose age is unknown which has made a robust emission estimation based on age group difficult.

Figure 21: Shares of CO_2 emissions based on ships' age in Solomon Islands



In Tuvalu, most of the emissions produced by the shipping sector, are produced by small artisanal ships whose age is unknown (63 percent). However, ships that are 20 years or older are the second highest emitters of CO_2, contributing 18 percent of the total shares.

Figure 22: Shares of CO_2 emissions based on ships' age in Tuvalu

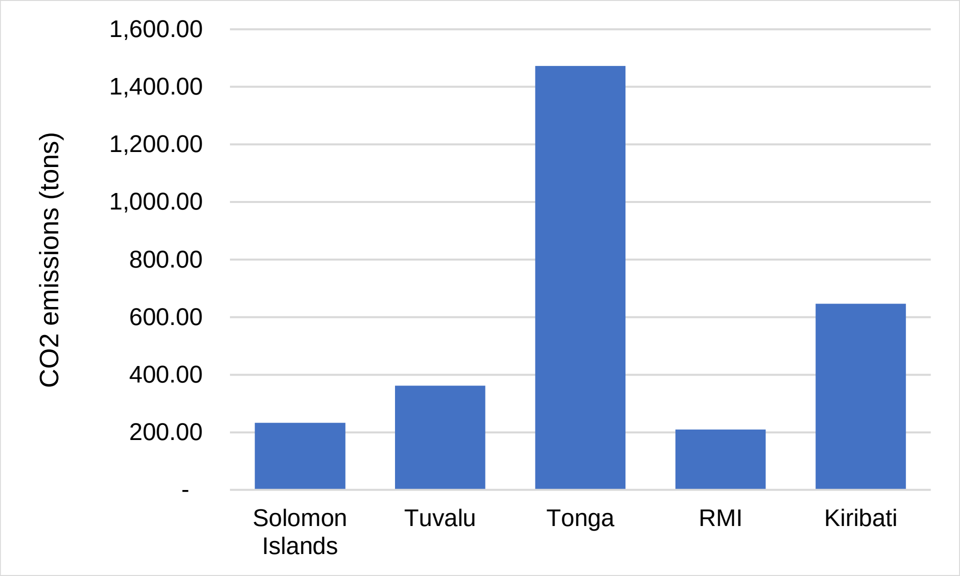


5.3 CO_2 emissions from intra-PIC shipping

As regards to intra-PICs shipping, this study only assesses emissions between Fiji and five other PICs: Kiribati, Marshall Islands, Solomon Islands, Tonga, and Tuvalu. As explained in Section 4, this is due to data for shipping between Fiji and five other PICs being available. Hence the main source of data used to estimate intra-PIC emissions are Fiji's export and import data to the rest of five PICs.

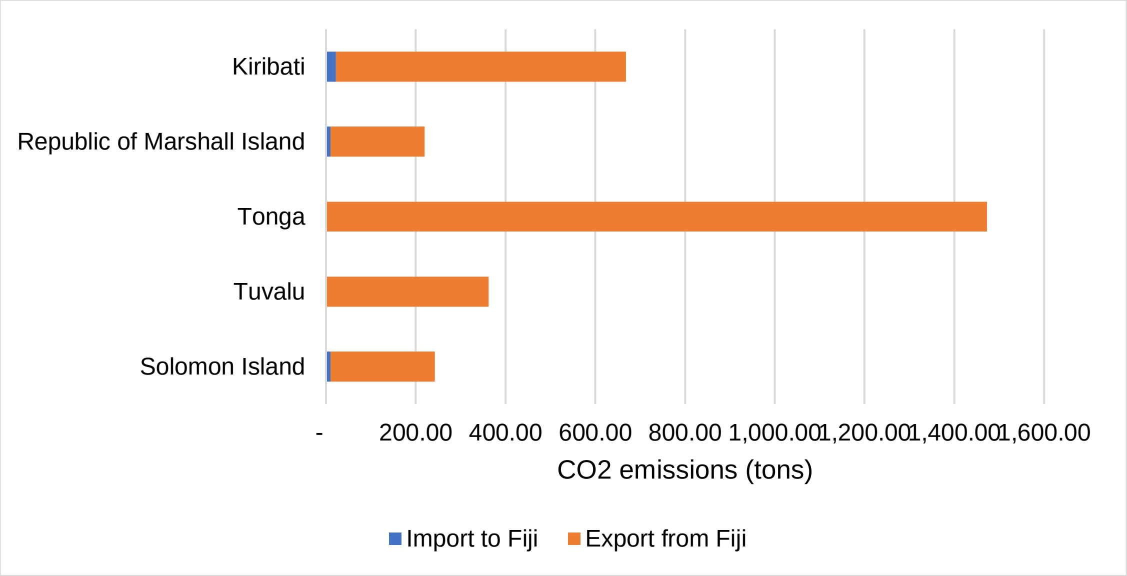
In 2019, CO_2 emissions associated with Fiji's export to the five other PICs are estimated to be around 2,922 tons, with export to Kiribati and Tonga as the top two routes with the highest emissions (Figure 23). These high emissions are proportional to import and export activities of these two countries which trade a relatively high volume of fuel oil.

Figure 23: CO$_2$ emissions from intra-PIC shipping



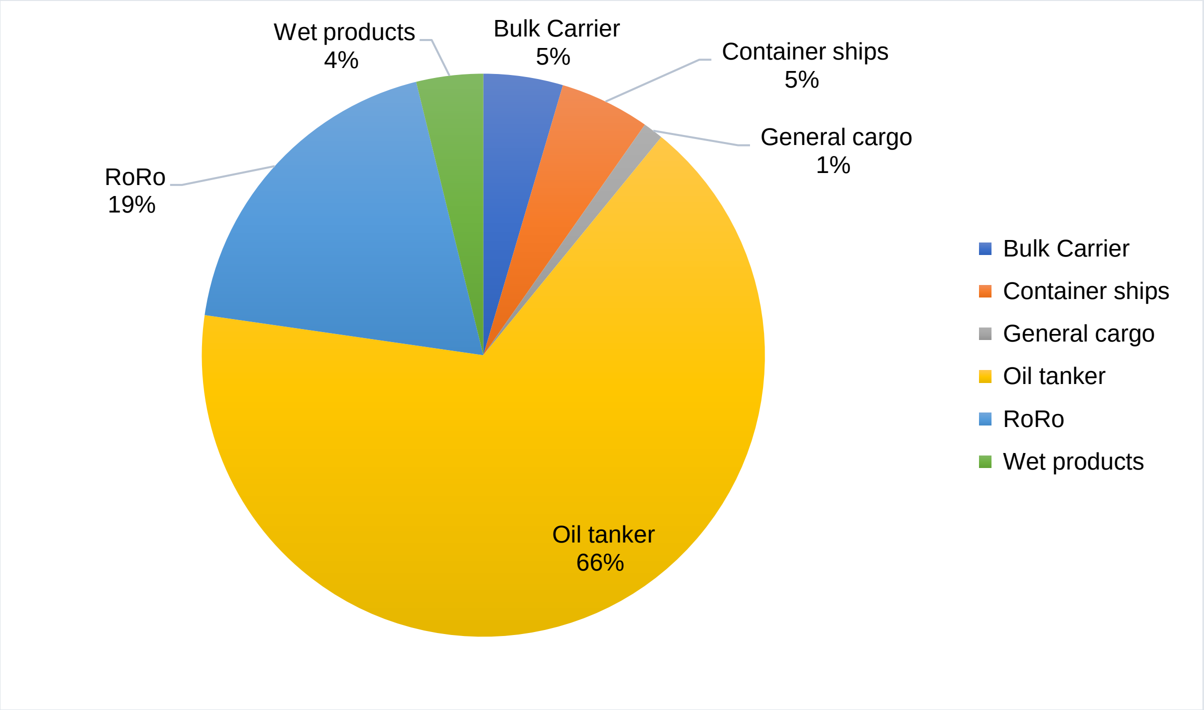
In terms of type of activity, most of the emissions come from exports from Fiji to the rest of PICs as opposed to imports to Fiji (Figure 24). Export of fuel oil to Tonga comprises the highest carbon emissions for intra PIC shipping at around 1,472 tons.

Figure 24: CO$_2$ emissions based on Fiji's trade activity with the other PICs



Based on ship types, intra-PIC shipping CO$_2$ emissions are dominated by oil tankers with a share up to 66 percent of the total emissions (Figure 25). Roll-on and roll-off ships represent the second highest emission contributor with 19 percent of the total emissions. These emission shares reflect the trade characteristics and types of commodities shipped between the Pacific countries with oil or fuel product being the top of the list.

Figure 25: Shares of CO_2 emissions from intra-PIC shipping by ship types



Furthermore, CO_2 emissions for six major ship types of each trade route was estimated based on the available data. In this way, it is possible to analyze the contribution of each ship type to the emissions associated with trade between Fiji and the rest of PICs. For the Fiji – Solomon Islands trade, Roll-on/Roll-off and wet products ships represent the majority of the CO_2 emissions (Figure 26). In the Fiji – Tuvalu trade Oil tanker and Roll-on/ Roll-off ships are the main ship types which carry goods exported from Fiji (Figure 27). In the Fiji – Tonga trade, the available data is limited to export data from Fiji to Tonga, and the main source of emissions is from Oil Tankers (Figure 28). Similar to this pattern, CO_2 emissions between Fiji – RMI are also dominated by oil tankers Figure 29). Lastly, for the Fiji – Kiribati trade, oil tanker and Roll-on/Roll-off ships are the two most polluting ships (Figure 30). This pattern is proportionate to the volume of commodities exported from Fiji to Kiribati observed in the trade data.

Figure 26: CO_2 Emissions for Fiji – Solomon Islands trade broken down by ship types

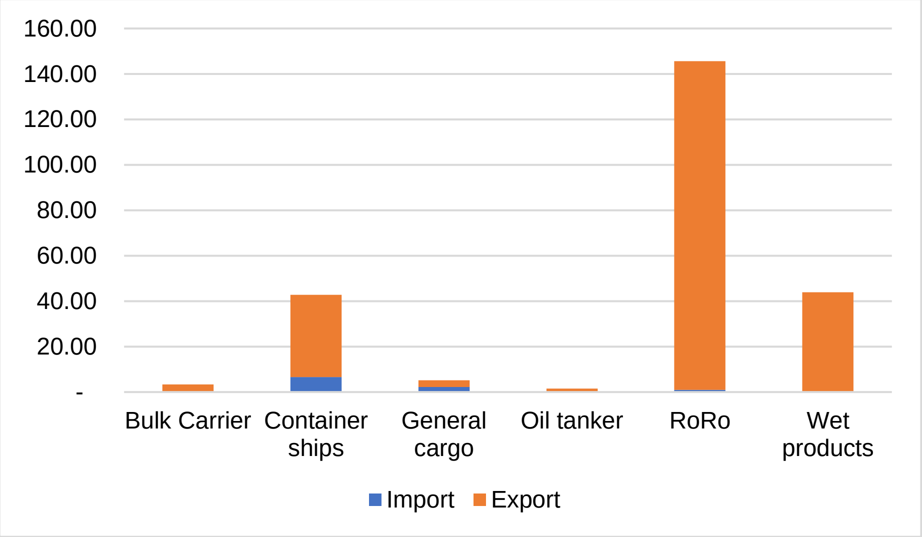


Figure 27: CO_2 Emissions for Fiji – Tuvalu trade broken down by ship types

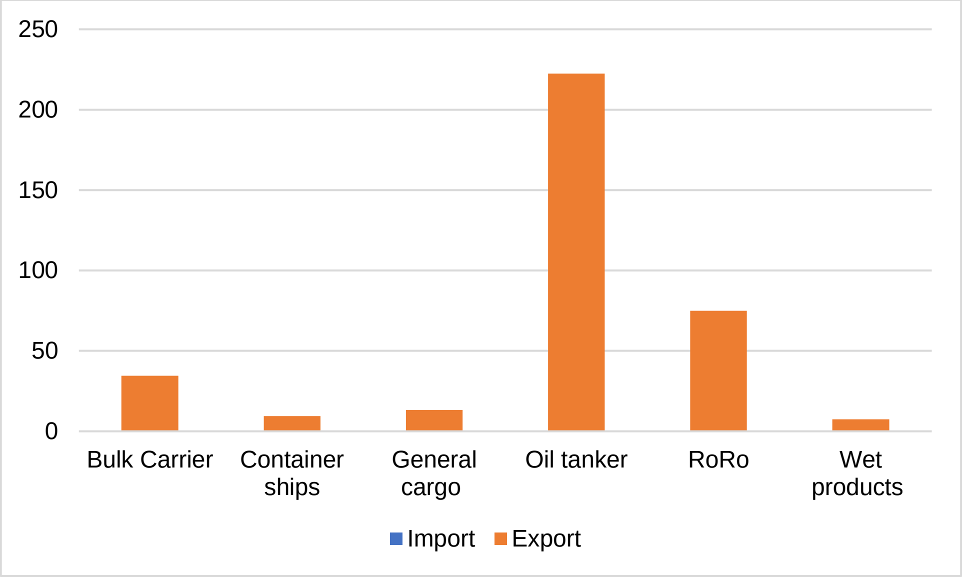


Figure 28: CO_2 Emissions for Fiji – Tonga trade broken down by ship types

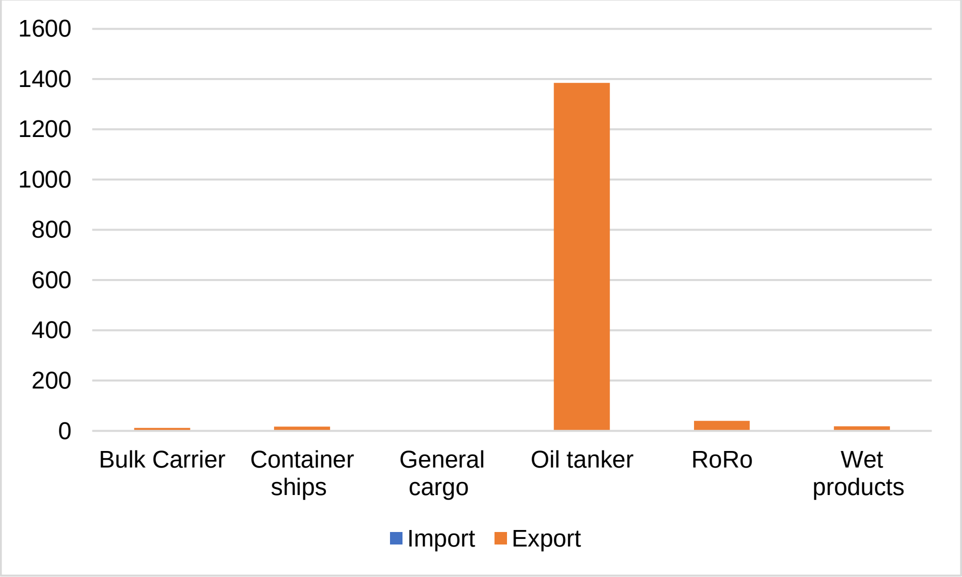


Figure 29: CO_2 Emissions for Fiji – RMI trade broken down by ship types

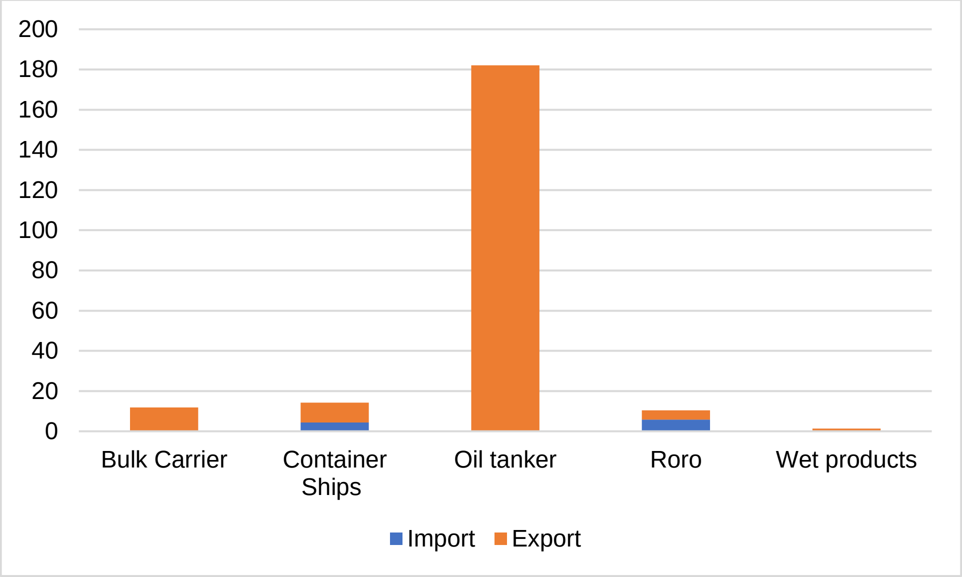
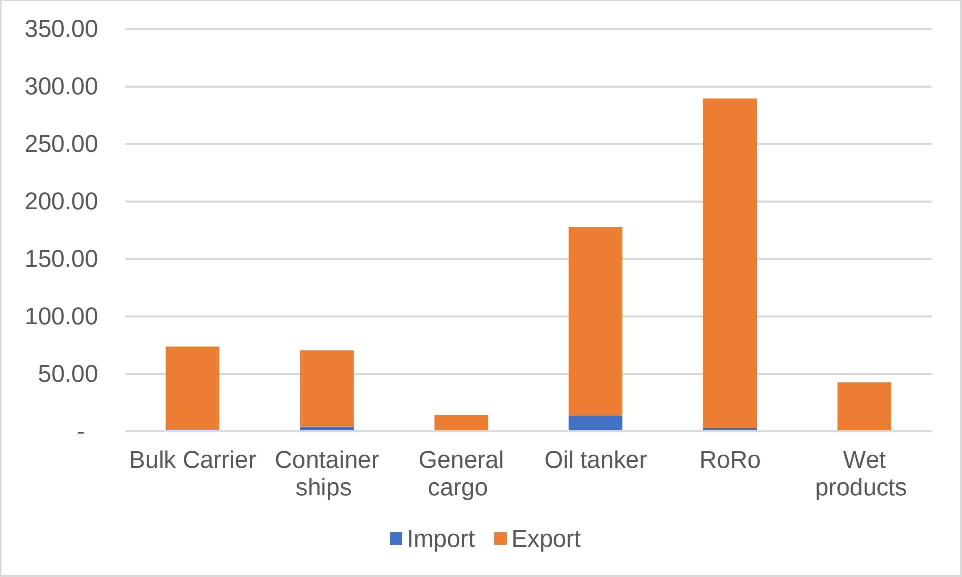


Figure 30: CO_2 Emissions for Fiji – Kiribati trade broken down by ship types



When CO_2 emissions from domestic and intra PICs shipping are compared, Figure 31 shows that domestic shipping emitted considerably more emissions than intra-PIC shipping. However, this finding should be treated with caution as the intra-PIC shipping dataset only comprises GHG emissions generated on routes between Fiji and the other five PICs included in this study, meaning that data for the trade between the five PICs is not included. As Fiji is the transshipment hub of the South Pacific[12], one could assume that the trade between Fiji and the other five PICs makes up most of the emissions between the six PICs. Therefore, it is likely that even if the dataset included data for shipping between all six PICs, the share of intra-PIC shipping emissions would still be smaller than that for domestic shipping emissions. This can be caused by several factors. Firstly, domestic shipping in the PIC which includes both cargo and passenger transport has generally higher activity than intra-PIC shipping. Secondly, ships serving intra-PIC routes are typically cargo ships with significantly higher

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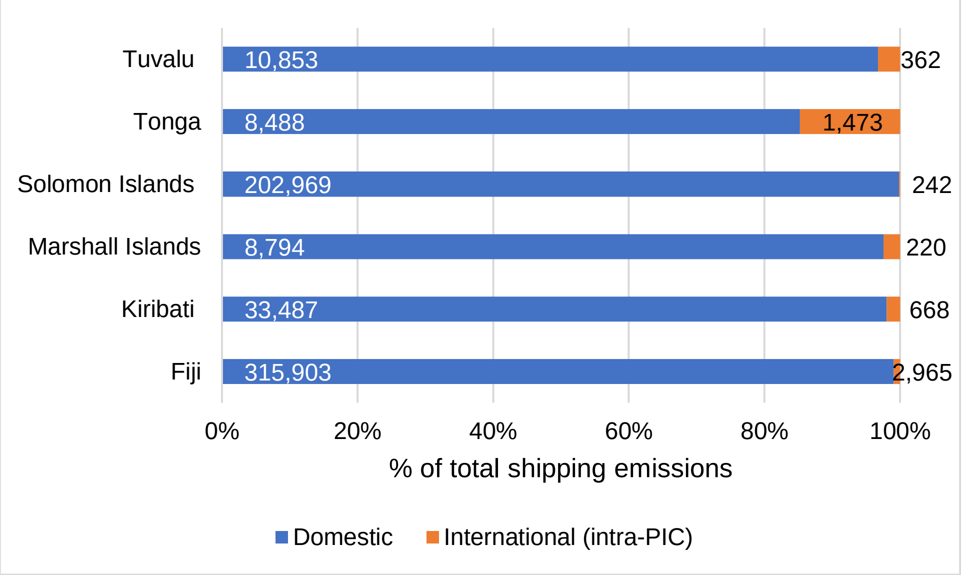
[12] Arslanalp, Serkan, Robin Koepke and Jasper Verschuur. 2021. “Tracking trade from space: an application to Pacific Island Countries.” IMF Working Paper WP/21/225, International Monetary Fund.

economies of scale, which in turn, offers higher fuel efficiency per cargo transported between the PICs. Another contributing factor is that emissions accounted in the intra PIC shipping do not include passenger ships and fishing vessels which operate internationally in the Pacific region.

Figure 31: Comparison of CO_2 emissions from domestic and intra-PIC shipping



6 Concluding remarks

6.1 Data and analytical gaps

Throughout the project lifecycle data gaps have been identified. Amendments to the primary datasets would be valuable to improve the accuracy of the estimated fuel consumption and GHG emissions from the respective PICs. These data gaps are present both in the broader ship category level and in a more specific individual vessel data. At a broader ship category level, such as domestic and international ships, a data issue where government ship registers from Kiribati and Solomon Island was identified, in that these do not seem to only record domestic vessels but also vessels that serve international shipping routes. This is possibly caused by change of ship ownership which also alters ship’s route operation in the recent year.

At ship category level, very limited data is available for small artisanal crafts with outboard engine. In order to estimate the missing number of these ships among PICs, we relied on observations made by various earlier studies on small crafts that are particularly used for main activities of the population of the countries such as fishing and transport. Nevertheless, this data may not fully capture all the small crafts which are not registered by the government as well as the intensity of their activities. This is a gap that is important to be addressed since based on current estimate, emissions from small artisanal crafts contributes the largest share - i.e., 21percent across the PICs.

On the other hand, the following detailed data at individual vessel level is valuable to refine the estimates for fuel consumptions and emissions:

- Engine type and power,
- Fuel type,
- Vessel average speed,
- Route trajectory,
- Time spent at sea per route or per year,
- Volume of cargo loaded,
- Average engine power utilized.

The collection of the abovementioned data could enable the following analysis to estimate missing data with higher robustness:

- Estimation on engine power utilized based on the observation of volume of cargo carried and speed of the vessels.
- Estimation of fuel consumption and CO_2 emissions of specific ship operation types such as inter-atolls trips, inter-island trips, domestic fishing trips.

6.2 Recommendation for future work

To ensure that any transition plan or any other future strategic work undertaken by the PBSP are accurate and well-informed, it is recommended that the accuracy and reliability of the revised shipping inventory from which the fuel consumption and GHG emissions are derived is to be strengthened further. This can be achieved by:

- **Regularly monitoring and registering international and domestic ships:** This would enable reliable and up-to-date ship registers to be easily accessible, thereby allowing for an even more accurate estimation of GHG emissions from both international and domestic shipping.

- **Establishing a commodity flow database for estimating national freight transport volumes and costs:** This would enable a more accurate estimation of intra-island shipping and hence allow for better-informed strategic forecasts and planning for shipping infrastructure. Specifically, within the context of GHG estimation and mitigation, complete origin and destination data, ideally for different modes and commodities and their transport costs will be invaluable to analyze the impact of climate policy measures such as taxes and subsidies on GHG emissions and PBSP member countries' economies.
- **Establishing a transport demand model to predict future expansion of vessel stocks, activities, and fuel consumption:** Such a model would not only aid estimation of future GHG emissions from ships based on the economic development of a country, but it would also be useful to plan infrastructure development for PICs.
- **Setting up a monitoring, reporting, and verification framework to enable the systematic and efficient collection of missing data:** Considering the importance of monitoring the progress of GHG abatement, a functioning and strong mechanism would be beneficial to carry out monitoring, reporting and verification tasks on a regular basis such as annually or at least bi-annually.