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Fuel demand and emissions for maritime sector in Fiji: Current status and low-carbon strategies

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ABSTRACT

The Green Growth Framework for Fiji under its theme for sustainable maritime transportation, envisages deployment of renewable energy technologies, retrofitting of existing vessels and development of improved vessel designs as some of the measures needed to make shipping more energy efficient. In this study, the Long-range Energy Alternatives Planning System (LEAP) tool is used to develop various maritime transport scenarios (2016–2040) based on possible interventions. Domestic maritime transport used approximately 79 million litres of fuel in 2016 out of which 77% was marine diesel oil while the remaining was premix. The total emissions from maritime transport in 2016 was estimated to be 214 Gg of CO_2e. At 2% annual growth rate in maritime passenger and freight activity, the total annual fuel consumption will increase to 127 million litres by 2040 with corresponding GHG emissions of 342 Gg of CO_2e under the BAU scenario. This paper quantifies possible reductions in fossil fuel usage and associated emissions through energy efficiency and alternative fuels in the domestic sea transport sector in Fiji.

1. Introduction

The International Convention for the Prevention of Pollution from Ships (MARPOL) developed by International Maritime Organisation (IMO) has led countries to focus attention on emission reduction from shipping. In April 2018, IMO members adopted a strategy for reducing annual emissions from international shipping by at least 50% by 2050 compared to 2008 with efforts to reduce emissions to zero by the end of this century [1]. In the past, the International Council for Clean Transportation (ICCT), IMO and other organizations have studied the technologies and measures needed to reduce fuel usage on ships resulting in lower carbon emissions [2–5]. According to the Third GHG emissions study by IMO, shipping emissions of 961 million tonnes of CO_2e accounted for 2.5% of total global emissions in 2012 [5].

Fiji is an island nation with over 300 islands of which about a third are inhabited. Fiji's exclusive economic zone covers 1.3 million km^2 of South Pacific Ocean while its land area is about 1.4% of the EEZ area. Due to dispersed smaller islands, there is a need for inter-island maritime transport for passenger travel and freight transport. People on remote islands in Fiji need to be connected to the main islands for accessing most services including health and education. In addition, Fiji's growing tourism and fishing industries are heavily dependent on shipping services.

Fiji's transport sector is fully dependent on imported fossil fuels and accounts for about 60% of the total petroleum consumption [6]. Fiji is committed to reducing its fossil fuel consumption as noted in its Nationally Determined Contribution to GHG reductions [7]. There has been a concern that maritime transport does not feature explicitly in the NDC and hence financing for new sustainable sea transport projects will be difficult to get from international agencies [8]. Authors [8,9] further mention that sea transport is also not mentioned prominently in the national energy policy even though there is a reference to the Framework for Action on Transport Services 2011–2020 (FATS)'s existence in Fiji. Theme 5 in FATS prioritizes efficient use of green technology in ships and ports [10], while the draft national energy policy in Fiji mentions a review of improving fuel efficiency in maritime transport and recommends imposing mandatory inter-island maritime vessel standards [6].

Research on reducing maritime transport fuel consumption in Fiji started as early as 1980. Auxiliary soft sails fitted in inter-island motor ships recorded fuel savings of 23% on average during a research project carried out by the Fijian government and Asian Development Bank in 1983 [11]. Another vessel (Tai Kabara), built in 1984 by the local maritime school in Fiji operated purely using sail during its first 3 years of operation when it transported passenger and cargo from Southern Lau, Fiji [12]. Due to a reduction in prevailing fuel prices, sails were not

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used in that vessel after 3 years. No further research was undertaken in reducing fuel usage in maritime vessels because oil prices were affordable and climate change concerns were still in their infancy. Recently, because of enforcement of MARPOL and global climate change concerns, shipping industries are once again focused on reducing their fuel consumption and associated emissions.

A group of researchers in Fiji [13–15] are suggesting the use of soft sails or hybrid vessels for sustainable and low carbon sea transport in Fiji and the Pacific region. Nuttal et al. [15] suggest that the best option for sustainable sea transport in the Pacific is hybrid vessels which use both wind and solar or wind/solar/diesel for operation. Material Flow Management (MFM) framework was used by Searcy [16] for sustainable shipping investigations in lower southern Lau islands in Fiji using hybrid powered vessels. Flettner rotor technology has been found to reduce fuel consumption on shipping vessels operating in Southern Lau Group using simulations [17]. However, according to GLOMEEP [18], Flettner rotor is not a mature technology and has a high cost. Bola [14] mentions that one of the barriers in conducting maritime transport research in the region is the non-availability of fuel consumption data.

This study aims to enhance the qualitative work carried out in the Pacific region by various researchers through quantitative modelling. It attempts to estimate the current and future overall fuel usage in maritime transport and its related emissions in Fiji as a function of various interventions. The Maritime Safety Authority of Fiji (MSAF) provided data on registered vessels and number of passenger and cargo travel over the past 3 years (2015–2017) and a questionnaire based survey provided other necessary data for input into the Long-range Energy Alternatives Planning System (LEAP) tool. The base year of study is 2016 and low-carbon future scenarios are developed for the period 2016–2040.

The next section (section 2) of this paper overviews Fiji's maritime transport system. Section 3 presents the methodology and the tool used in this study followed by results presentation. Section 5 discusses policy implications of low carbon strategies in the Fiji maritime sector.

2. Fiji maritime transport activity

Considering the geography of Fiji Islands, sea transport is the most important means of transporting goods and people from small islands to main islands and vice versa. The tourism sector, the main income earner in Fiji, has tourists mostly transported in boats from airports to smaller island resorts in the Mamanuca group or Yasawa group or other smaller islands around Fiji.

FAO [19] categorizes Fiji's fisheries into coastal commercial, coastal subsistence, offshore locally-based, offshore foreign based,[1] freshwater and aquaculture. It further estimates that annual yields of coastal subsistence fishing and coastal commercial fishing are 17,400 and 9500 tonnes of fish respectively where subsistence fishing is mostly done in rural or remote areas (dispersed smaller islands) and commercial fishing is for supplying urban food markets and exports.

MSAF's registration of domestic shipping vessels shows 2153 registered vessels with passenger vessels having the largest share, followed by fishing vessels and tourist vessels, Fig. 1 [20]. Currently vessels are registered once and they undergo regular checks by MSAF to monitor that they meet all requirements. Big ships for domestic transport use marine diesel oil as fuel [20] while smaller outboard-powered vessels are fueled by premix fuel (gasoline fuel: 2 stroke oil = 50:1 ratio).

In 2016, the total number of passengers using maritime transport was 1.69 million. This is the total of inward and outward passenger

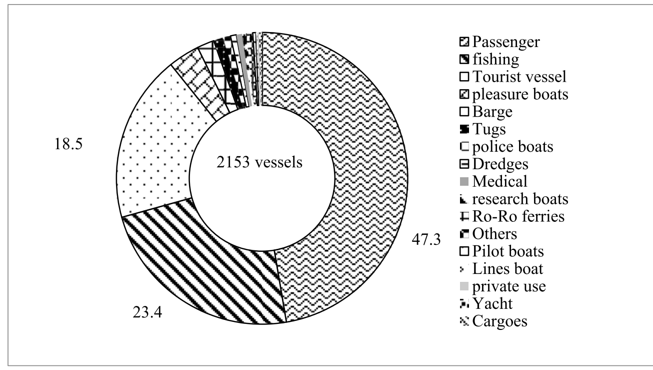

Fig. 1. Percentage share of types of vessel registered in Fiji in 2017. Data Source: [20].

count from 12 ports around Fiji Islands. It is seen that Denarau has the highest number of maritime passengers (this is mainly for tourist to be transported to and from Yasawa and Mamanuca group of islands to Port Denarau) followed by Natovi and Nabouwalu which mainly handle locals travelling between the two main islands, Fig. 2.

The total cargo transported in 2016 was 1.1 million tonnes with Port Denarau having the least share. Natovi, Nabouwalu, Suva and Savusavu are the major ports that transport cargo in shipping vessels, Fig. 3. The annual growth for passenger travel is 2.33% while for cargo transported is 0.5%, Fig. 4.

3. Materials and method

3.1. Data collection

MSAF provided data on registered vessels that also included data on passengers and cargo transported from March 2015 to June 2017. There is no official record of fuel consumed by maritime vessels in Fiji, so a questionnaire based survey (See Appendix) was developed to get data on fuel consumption and passenger activity. The questionnaire asked information on the number of passengers per trip, number of trips taken in a day or year, amount and type of fuel used per trip, model of vessel, size of generator onboard and other relevant information. Vessel owners/operators/engineers were approached at their offices or sometimes on their vessels if they were berthed at Suva harbour. Altogether 53 vessels were surveyed in 2017, (Fig. 5). All surveyed vessels were using diesel fuel except fishing boats with outboard motors (5 vessels) and 3 police vessels that used premix. The data collected from this survey was used to construct Table 1.

3.2. Assumptions and uncertainties for maritime transport model

Uncertainties in modelling arise because of several assumptions made in estimating the fuel consumption. One of the key assumption for modelling was that the data (number of vessels) provided by MSAF represented the actual number of domestic vessels currently operational in Fiji. This assumption is made on the basis that MSAF is the only agency that has official information on registered vessels. However, it is acknowledged, that there are a number of small boat operators not registered and hence unaccounted for. Another issue could be that some of the registered vessels might not be operational. The MSAF registered vessels were categorized based on their length; (i) vessels more than 15 *m* long and (ii) vessels less than 15 *m* long. Vessels more than 15 *m* long were assumed to operate on Marine Diesel Oil (MDO) while vessels less than 15 *m* long were assumed to operate mainly on premix fuel (gasoline to oil ratio = 50:1).

A questionnaire based survey was used to determine annual fuel consumption values while annual distance travelled were used to calculate fuel economy of vessels. The average fuel economy, average

[1] This is the catch in Fiji waters by vessels based outside the country [19]. FAO. FAOSTAT Country Profile: Fiji. http://www.fao.org/countryprofiles/index/en/?iso3=FJI [Accessed: 27/06/17]: Food and Agriculture Organisation of the United Nations; 2017.

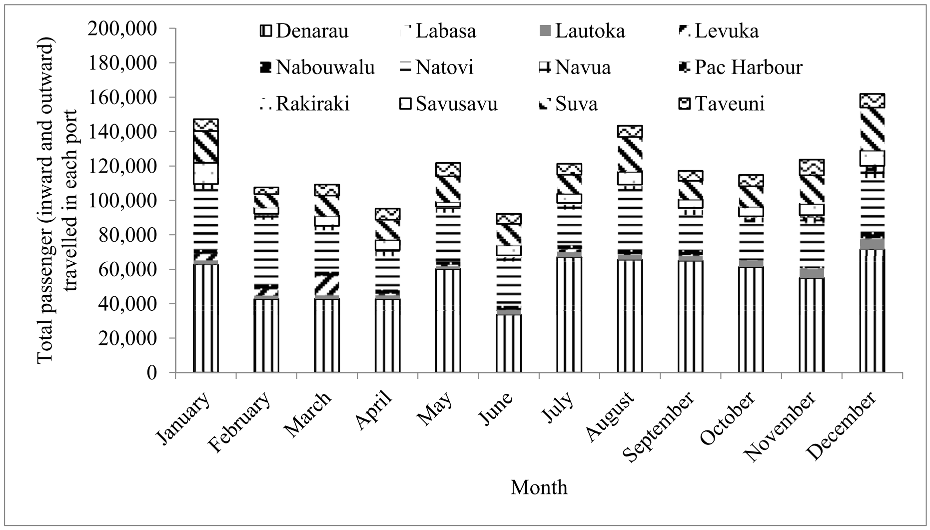

Fig. 2. Month total number of passenger travel in maritime transport in 2016. Data Source: [20].

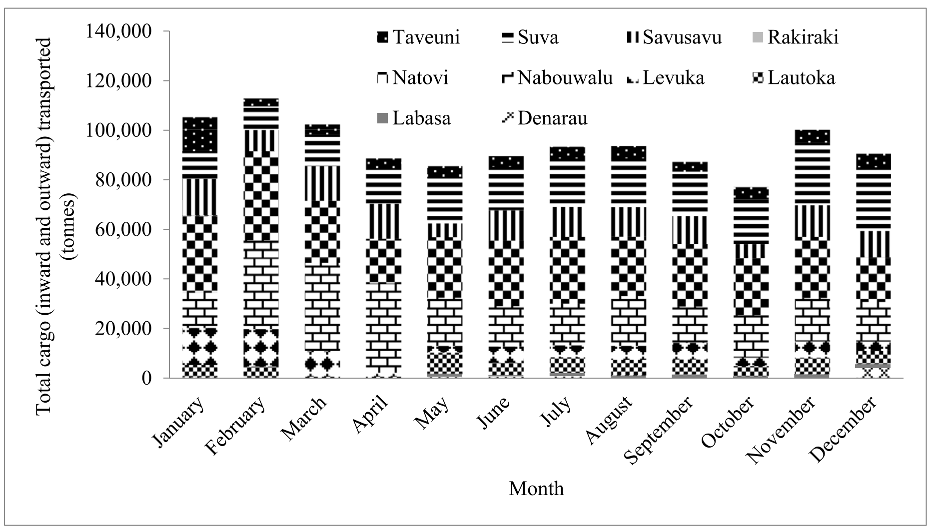

Fig. 3. Monthly total cargo transported to and from different ports in 2016. Data Source: [20].

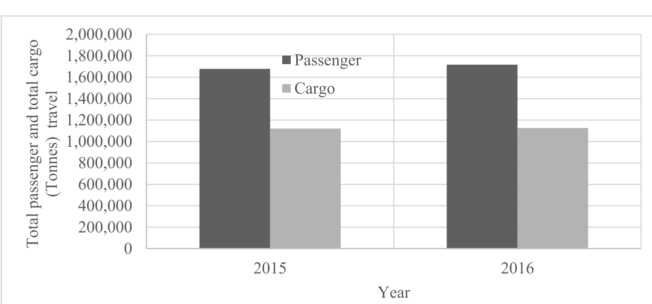

Fig. 4. Total passenger and total cargo transported in Fiji in 2015 and 2016. Data Source: [20].

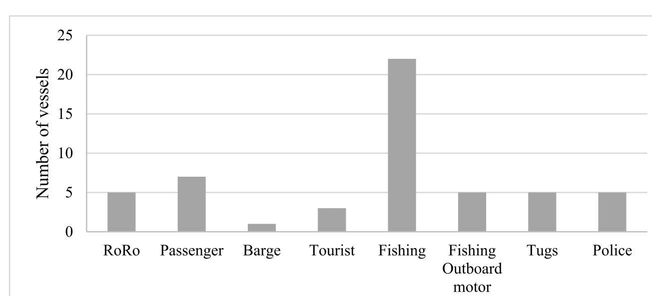

Fig. 5. Number of domestic vessel surveyed in Fiji in 2017.

number of passengers per trip and load (freight) transported per trip were used in our maritime transport model. However, there are uncertainties associated with this data as per some operators the annual fuel consumption varies depending on hours of operation. This uncertainty is difficult to quantify as the data provided by operators was just for one year. The difficulty in ascertaining maritime fuel usage is highlighted in the IPCC guidelines [21] which states that for water-borne navigation, uncertainty in activity data can be as high as ± 50%.

We have assumed an annual growth rate in maritime transport activity of 2%. This assumption is based on the 2.33% annual growth rate of passenger travel as shown in Fig. 6. In addition, it was assumed that the number of vessels would also increase at the rate of 2%. Due to the lack of data in domestic maritime transport activity (pkm) over the past years, it was not possible to relate domestic transport activity to GDP. However, it is worth mentioning at this point, that the average annual growth rate for GDP at constant basic price is 3.2% where Transport (land, maritime and air) and Storage sectors contribute 7.9% (on

Table 1
Parameters of sea transport used in LEAP tool. (These values are mainly average results from questionnaire survey and number of vessel from MSAF.)

Vessel type	Fuel used	Number of vessels registered	Avg. annual distance (km)	Load factor[a] (# of passengers per vessel)	Freight carried per trip	Fuel economy (km/litre) *Italics are assumed values*
Ro-Ro						
All vessels diesel	MDO	8	33,000	180	200	0.0581
Passenger						
More than 15 m	MDO	37	26,000	68	120	0.1777
less than 15 m	premix	980	13,000	15		*1.5100*
Fishing						
More than 15 m	MDO	113	13,000	12.5	36.85	0.0421
less than 15 m	premix	390	26,600	5	0.735	1.5100
Tourists						
More than 15 m	MDO	33	76,800	127	2.75	0.2416
less than 15 m	Premix	366	13,000	15		*1.5100*
Tugs						
More than 15 m	MDO	15	17,800	8		0.1603
less than 15 m	MDO	9	10,000	4		0.1000
Barge + cargos						
More than 15 m	MDO	32	7300		1000	0.1089
less than 15 m	MDO	12	4000		500	0.1000
Police						
More than 15 m	MDO	1	454	8	0.8	0.0334
less than 15 m	unleaded or premix	16	380	4.5	0.45	0.3641
Other sea vessels						
More than 15 m	MDO	9	400	8		0.1461
less than 15 m	Premix	108	400	4		0.9400

[a] For fishing vessels, load factor is taken as the number of crew member per vessel.

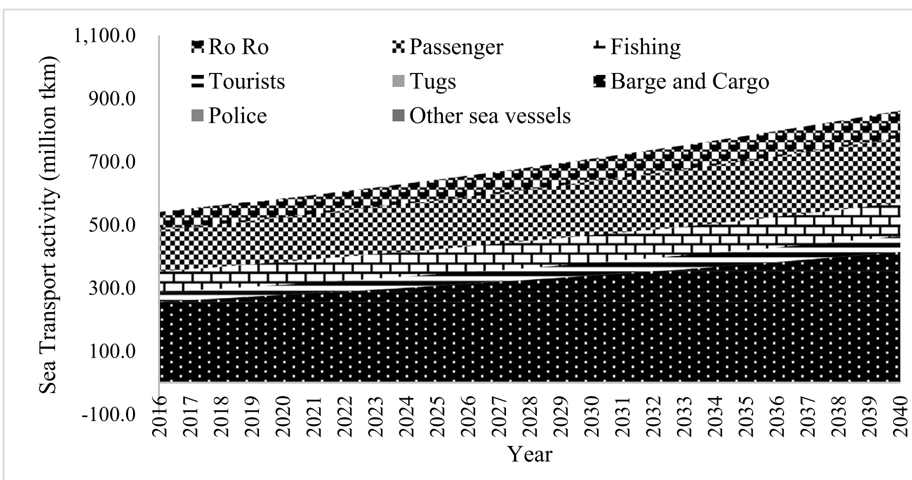

Fig. 6. Domestic maritime transport activity.

average) to the total GDP [22]. According to UNCTAD [23] the international seaborne trade to GDP elasticity was around 0.7 for the period 2008–2013. Assuming similar elasticity for Fiji a 3% GDP growth would translate to 2.1% growth in the maritime activity.

3.3. Maritime transport energy model framework

3.3.1. Transport model structure

The impact of different energy efficiency measures and alternative fuel on fossil fuel consumption in maritime transport is studied using the LEAP tool. This is an integrated software which uses user-defined structure and data input to calculate the energy demand and its related GHG emissions [24]. The base year for this study was 2016 and end year was 2040. Maritime transport activity in this study is measured in tkm and calculated using eq. (1).

$$A_t = \sum N_{ijt} \times DT_{ijt} \times LF_{ijt} \tag{1}$$

Where A_t is the vessel activity measured in tkm in a given year, t. i is the vessel type and j is the fuel type. N is the number of vessel in a given year t, DT is the average annual distance travelled by a vessel (km/vessel) and LF is the load factor measured in average load carried per vessel where each passenger is assumed to have 60 kg mass.

To convert transport activity to energy consumption, eq. (2) is used.

$$E_t = \sum A_{ijt} \times EI_{ij} \times EC_j \tag{2}$$

Where EC is the energy conversion factor for fuel type j in (GJ/l) and EI is Energy intensity which is product of fuel economy and load factor, eq. (3).

$$EI_{ij} = FE_{ij} \times LF_{ij} \tag{3}$$

Where fuel economy, FE, for i vessel type and j fuel type is the distance travelled in per litre of fuel (km/l).

3.3.2. Emission factors

The emission factors for fuels used in maritime transport were chosen from the IPCC 2006 report [21] for water transport with Tier 1 emission factors for sea transport. Tier 1 emission factors are based on the type of fuel used and not the engine type. This study used the CO_2 emission factors of 69,300 kg/TJ and 74,100 kg/TJ for gasoline and marine diesel oil fuel, respectively. Emission of non-CO_2 gases from combustion of any fuel is taken as 7 kg/TJ ± 50% for methane (CH_4) and 2 kg/TJ +140%–40% for nitrous oxide (N_2O). LEAP calculates total emissions (*EM*) as shown in eq. (4).

$$EM_{ijkt} = E_{ijt} \times EF_{ijk} \tag{4}$$

Where k is the type of emission based on the fuel's chemical composition, *EF* is the emission factor (kg/GJ).

3.3.3. Fuel economy of maritime vessels

Table 1 summarizes some of the results from the questionnaire based survey, which were used in modelling. Searcy [17], reports annual distance and annual fuel consumption as 4992 nautical miles and 60 metric tons respectively for shipping vessels in Southern Lau group of Fiji islands. Using fuel density as 0.94 kg/l, the fuel economy was estimated to be 0.14 km/l which is comparable to the average fuel economy of some vessels surveyed in this study as shown in Table 1. In addition, results from a preliminary survey for Republic of Marshal Islands (RMI) in 2017 for 4 marine vessels gave a fuel economy to in the range 5.71–16.52 kg/nautical mile [25]. These values are again comparable to those for Fijian vessels. Fishing vessels had the lowest fuel economy compared to other vessels (Table 1). This is mainly due to the use of refrigerators on large fishing vessels while small fishing boats use two stroke outboard motors, which are less efficient. The fuel economy of ships depends on the age of vessels, hull and propeller conditions, design of the ship, load carried and the average speed.

3.3.4. Model consistency check

To check if the modelling results were consistent with manual calculations, eq. (5) was used to calculate the volume of fuel from the fuel energy demand obtained from modelling and eq. (6) was used to manually calculate fuel consumption from average values obtained from the survey.

$$\text{Vol. of fuel (million litres)} = \frac{\text{fuel energy used (million GJ)} \times 1000\ \text{kg/metric ton}}{\text{Net energy content (GJ/metric ton)} \times \text{density (kg/litre)}} \tag{5}$$

$$\text{Vol. of fuel (million litres)} = \frac{\text{Annual distace (km)} \times \text{No. of vessels}}{\text{Fuel Economy (km/l)} \times 1000000} \tag{6}$$

There was very little deviation between manual calculation of fuel consumption and modelling results.

However, it is difficult to verify modelling results with the actual maritime transport fuel consumption as no official record of this consumption can be found in public domain. The only data on fuel consumption that can be found is from fuel import data, which does not distinguish between fuel consumed by maritime transport and land transport.

3.4. Low carbon measures considered in scenario analysis

Reducing fuel consumption in domestic shipping vessels is a challenging task. One has to consider the vessels passenger load and the cargo transported. If sail were to be installed this would mean more ship crewmembers than on a normal diesel operated vessel. In addition, even new vessels brought into the country are second hand vessels and the existing shipping vessels as reported by Nuttal [15] are at the end of their working life which would mean that these vessels have poor fuel economy. However, authors [2,26] show that there are a number of ways such as hull cleaning, hull coating, main engine retrofits, propeller upgrade, waste heat reduction and others that would reduce fuel consumption and related GHG emissions in vessels. Researchers [27–29] report similar strategies for reducing fuel consumption in fishing vessels. Speed reduction is the most effective way of reducing emission from ships followed by hull cleaning but the cost of speed reduction is high compared to hull cleaning and both their costs are higher compared to propeller polishing [2].

For sea transport, some low carbon measures applicable to Fiji have been studied. Authors [15,17] suggest Flettner rotors onboard of existing vessels but this requires heavy financial investments and the technology is not mature as informed by Ref. [18]. In addition, installation of Flettner rotors on board of shipping vessels requires lot of decking area availability, which may not be available in the case of some large vessels. Authors [2,3] have also presented other technological options available to reducing emissions from shipping vessels. Based on these, options available for fossil fuel consumption reduction in Fijian shipping vessels are discussed below with the proviso that the technology is proven or mature, applies to all vessels of any type and age and does not require large capital investments.

Hull coating is applying a high performance coating on vessels hull to reduce its resistance when sea bound. These coatings are not just simple paints but are complex coating used to reduce hydrodynamic drag and buildup of marine organisms on a vessels hull [30]. This is done at a dry dock. FATHOM [30] provides a wide range hull coatings available in the market, market barriers and many other information. Hull coating is one of the relatively cheap options of vessel owners and done after every 5 years that the ship has been in service. Hull coating costs around USD30,000–500,000 depending on vessel size with fuel consumption reduction estimated to be 1–4% [18].

Hull cleaning uses divers to clean a vessels hull underwater. Underwater cleaning is the most frequent form of hull cleaning. Hull cleaning costs around USD5000-50000 with main engine fuel consumption reduction between 1 and 5% [18]. *Propeller polishing* is applicable to all vessels irrespective of age and consists of periodically (maybe 2 times a year) polishing the propeller either dry dock or berthed and loading cargo. GLOMEEP [18] estimates its cost between USD4000-8000 with main engine fuel consumption reduction between 3 and 4%.

Speed management does not have any investment costs but it has other costs related to longer sailing time and need for more vessels to cater for passenger activity at the same level. This measure has the potential to reduce main engine fuel consumption by 10–50% as fuel consumption increases exponentially with linear increase in speed. GLOMEEP [18] reports that vessel operating at variable speed consumes more fuel than one at constant speed. Factors such as weather conditions, load on vessel and expected time of arrival of scheduled journey need to be studied and speed of the vessel planned properly.

Based on the above discussion, these measures were studied in maritime transport model for reduction in fuel consumption and emissions, Table 2. For the various measures, the activity level (tkm) for different vessels is assumed to increase at an average rate of 2%/annum.

4. Results

The total energy demand for fossil fuel in Fiji maritime sector increases from 2.9 PJ to 4.6 PJ from 2016 to 2040 in BAU scenario, Fig. 7. Marine diesel oil is the major fuel while 20% of the total fuel consumed is premix. A total of 60.6 million litres of diesel and 18.5 million litres of premix was consumed in 2016. Maritime fossil fuel consumption would increase to 97 and 30 million litres of diesel and premix respectively in 2040 with an annual activity growth rate of 2% under BAU scenario, Fig. 8.

The major consumer of diesel are fishing vessels, followed by tourist, passenger, barge and RoRo vessels as shown in Fig. 7. Fuel

Table 2
Measures studied for reduction in fuel consumption in maritime transport sector in Fiji.

Scenarios	Change in model	Reason
BAU	For each type of vessel, the activity tkm increases annually at an assumed rate of mere 2%, Fig. 6.	The assumed growth rate is explained in section 3.2. In addition, this scenario does not consider any improvement in fuel efficiency of vessels. International Maritime Organization (IMO) predicts that shipping activity (miles tonnes) would increase 2–4% annually from now (2011) to 2050 [2]. Sea transport activity is measured in tonnes kilometers (tkm). The number of passenger travelling per trip for each type of vessel was converted to tonnes using 1 passenger mass equal to 60 kg.
Biofuel used in ships (B5 standard)	This initiative is envisioned to start in 2020 with 5% of the passenger diesel vessels, 2 out of the 8 Ro-Ro vessels, 5% tourist vessels and 5% of fishing vessels using B5. This will continuously grow to 80% of the diesel vessels using B5 standard biodiesel. It is assumed vessels running on B5 fuel will have the same fuel economy as vessels running on diesel fuel.	Biofuel is assumed to be used in large vessels (more than 15 *m*) - passenger, tourist, fishing and Ro-Ro boats.
Hull coating and cleaning and propeller polishing.	These strategies would start from 2020 with 10% of the vessels adapting hull coating and cleaning regularly. This goes for 100% of vessels adapting this strategy of reducing fuel consumption by 2040.	SBE [31] states that using Surface-Treated Coating (STC) can reduce a ship operators fuels costs by up to 25%. Hence, if similar is used in Fijian domestic shipping vessels, then a conservative value of 15% improvement in fuel economy is used. This improvement is applied to Ro-Ro, passenger, fishing and tourist vessels that are more than 15 *m* long.
Speed reduction	This can be taken up immediately. However, vessel operators need to be convinced and motivated to use this strategy. This strategy is applied to Ro-Ro vessels, fishing vessels, barge and cargo vessels. Modelling assumes uptake of this strategy by operators from 2021. The transport activity changes as following: In 2021, 5%–50% in 2040. Same is also assumed for less than 15 *m* vessels for passenger, fishing and tourist vessels.	Using Lindstad [32] results of 19–28% reduction in emissions. Hence, for modelling purpose 10% improvement in fuel economy is used in the model. Speed reduction is not chosen for passenger, tourist, police, tugs and other sea vessels as speed reduction can adversely affect their normal businesses.
Sail boats and hybrid vessels	For passenger and fishing boats less than 15 *m*, some of new vessels registered are using sail so the activity level will change from 0.5% in 2020 to 3.8% in 2040 while for fishing vessels, purely sail vessels activity will increase from 1.2% in 2020 to 8.1% in 2040. For vessels longer than 15 *m*, some of new registered vessels are hybrid. Their activity will change as follows: RoRo: 10% in 2020 to 25% in 2040, Passenger: 2.5% in 2020 to 25% in 2040, Fishing: 1.6% in 2020 to 11% in 2040, Tourist: 2.8% in 2020 to 28.3% in 2040 and Other sea vessels: 10% in 2025 to 28.6% in 2040.	Some of the new boats (less than 15 *m*) registered for passenger and fishing vessels are purely operating using sail where 2 crewmembers are needed and can transport around 10 passengers. Hybrid vessels (new registered vessels), which are 15 *m* and longer are considered to have auxiliary sail, have solar power on board and are using energy efficient lights. These technologies are assumed to improve fuel efficiency by 20%. This 20% improvement infuel economy is based on the results from Maclister [11] which is discussed in section 1. Modelling does not consider hybrid vessels for Tugs, barge, and police operations.

efficiency measures and cleaner fuel introduction in maritime vessels achieve significant reduction in fuel consumption, Fig. 8. Biodiesel blend (B5) introduction in vessels decreases diesel consumption by almost 4% with volume reducing from 97 to 93 million litres, Figs. 9 and 10. Introduction of hybrid and sail can reduce diesel consumption from 97 to 94 million litres while premix consumption decreases from

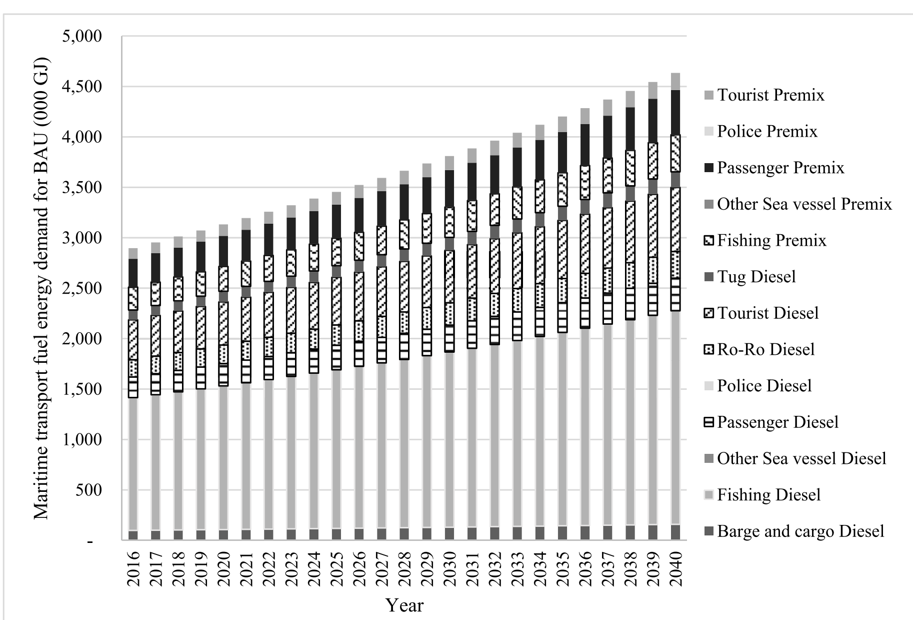

Fig. 7. Energy demand for fossil fuels in maritime transport for BAU.

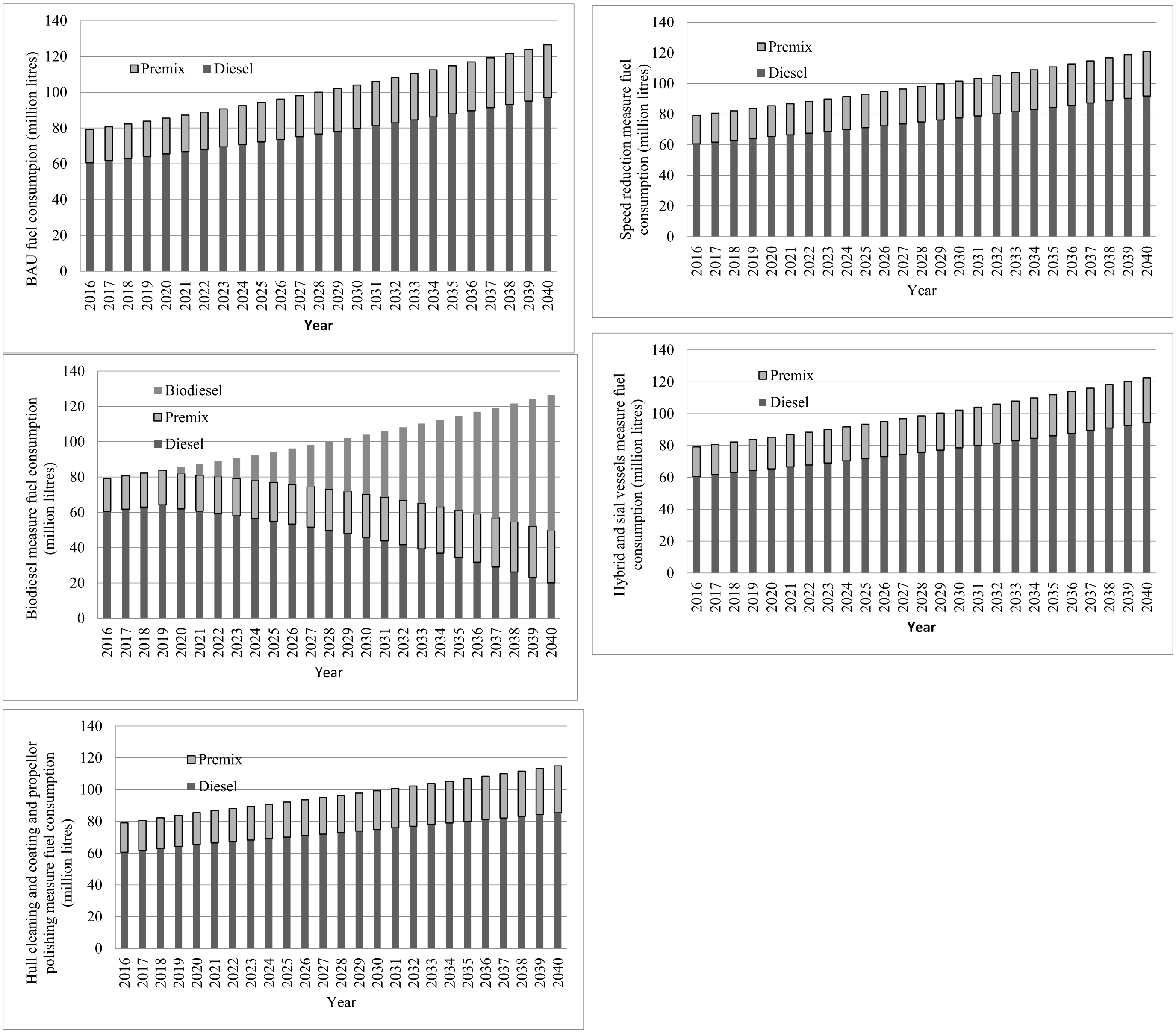

Fig. 8. Fossil fuel consumption in different measures for maritime transport.

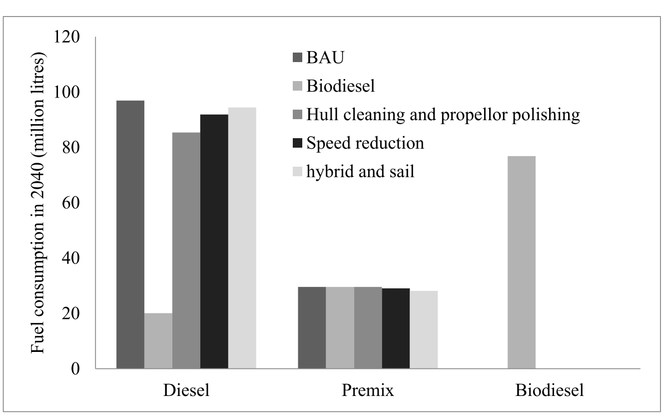

Fig. 9. Volume of fuel consumed in maritime transported in 2040.

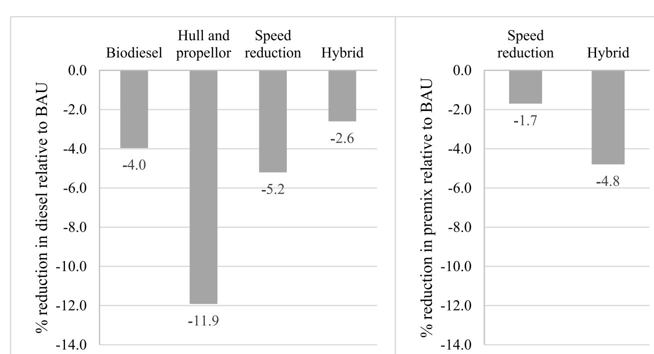

Fig. 10. Percentage reduction in diesel and premix consumption in maritime vessels in 2040.

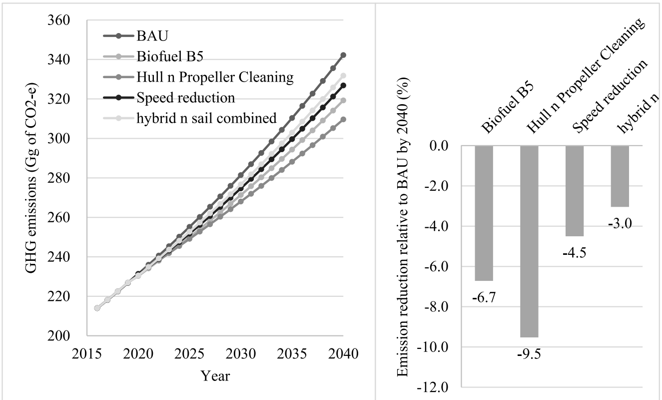

Fig. 11. Maritime transport GHG emissions from different measures and its reduction relative to BAU for maritime transport in 2040.

29.6 to 28.1 million litres, (Fig. 9). Cleaning and coating hull and polishing propeller of maritime vessels reduces diesel fuel consumption to 85.4 million litres in 2040. Reducing speed of certain vessels reduces diesel consumption by 5.2% relative to BAU.

With these reductions in diesel fuel oil, there is an associated decrease in GHG emissions compared to BAU, Fig. 11. From 214 Gg of CO_2e emissions in 2016, BAU scenario has 342 Gg of CO_2e emissions by 2040. This 2040 BAU value reduces to 319, 310, 327 and 332 Gg of CO_{2}-e emissions for biodiesel B5 introduction, hull and propeller cleaning, speed reduction and hybrid and sail vessel measures respectively, (Fig. 11). These are significant reductions in GHG emissions compared to BAU by 2040, Fig. 11.

5. Discussions

Green Growth Framework for Fiji mentions that due to international regulations set by IMO on pollution from ships and also to reduce its fuel import bill, Fiji will need to explore renewable energy technologies, retrofitting of existing vessels and improved designs of new vessels [33]. It further proposes a way forward in achieving sustainable sea transport in short-, medium- and long-term. The draft national energy policy also recommends improving energy efficiency in transport sector [6]. This policy prioritizes land transport initiatives to reduce fossil fuel consumption with recommendations to review the potential for improving energy efficiency in maritime transport [6]. Fiji's Nationally Determined Contribution (NDC) envisages a 30% reduction in GHG emissions by the year 2030 with 10% coming from energy efficiency measures. Although the NDC does not mention marine transport explicitly, it is obvious that this sector has a major role to play in overall decarbonisation efforts for Fiji.

A majority of ships that operate on Fiji domestic routes are pre-used and are not given Engine Efficiency Design Index (EEDI) to local buyers unless demanded [34]. This calls for stringent regulation on importation of used vessels. Similar to age restriction on land transport, age limit has to be set for maritime vessel importation. Under the current Ship Regulation Decree 2013, MSAF does not register overseas purchased ships that are over 20 years old to avoid Fiji being used as a dumping ground for old ships [35]. Most 20-year-old vessels have lower fuel economy especially if not maintained properly. In addition, there can be incentives on importation of vessels whose engines are certified to operate with biodiesel or blend of biodiesel with diesel. This will promote potential vessel owners to opt for these certified vessels.

Another incentive would be for the government of Fiji to put stricter sulphur emission standard from maritime vessels (currently 500 ppm). Once these standards are enforced, biodiesel blend B5 can be promoted to be used. Moreover, there should be regulations on the mandatory maintenance of vessels. These regulations have to be enforced and effectively monitored. The reduction in duty for importation of maritime vessels that have improved fuel economy or hybrid maritime vessels and no duty charged on importation of materials and equipment used for hull coating and cleaning and propeller polishing can promote improvement in fuel efficiency of maritime vessels in Fiji.

This study does not include high penetration of renewable energy technologies such as soft sails, solar PV, kites, rotors or fixed wings because these improvements or retrofits require high investments, more labour during voyages and existing Fijian maritime vessels are old with owners hesitant to make investments in these new technologies. It is highly probable that these or similar technologies will be commercially viable in the near future and become regular part of maritime industry. “Low hanging fruits” such as hull cleaning and coating, propeller polishing and speed reduction with one clean fuel measure (biodiesel blend B5) and hybrid vessels with low penetration were considered in this study to quantify fuel and emission reduction. Implications for these measures are discussed below.

Hull cleaning and coating and propeller polishing can reduce emissions and volume of diesel fuel consumption on vessels by almost 12% relative to BAU by 2040. Currently MSAF does routine checks on hull and propeller conditions as stipulated under Maritime legislations [34]. Despite this regulation, fuel economy of some vessels was found to be very low. It is known that fuel consumption depends on the engine conditions, hull and propeller conditions and maintenance and servicing of vessels. Hence, this measure recommends propeller polishing twice a year, hull cleaning once a year while hull coating can be done every 5 years on dry dock. The government can provide financial benefits such as tax incentives or subsidies for importation of quality products for propeller polishing, hull cleaning and coating. In addition, capacity building for vessel technicians, engineers, or owners on the optimum product to use for hull coating and cleaning and propeller polishing will be useful. Maritime transport stakeholders' awareness programs on this measure is vital to build a greener shipping sector in Fiji. Existing businesses or new entrepreneurs practicing maritime maintenance should be given incentives for use of quality products for hull cleaning and coating and propeller polishing.

Speed reduction in maritime vessels has the potential to reduce 5.2% of the volume of marine diesel oil demand and 1.7% of premix fuel demand compared to BAU by 2040. This option would demand vessel operators to cater for the long journey times. Hence, in this analysis, tourist, passenger, police and tug vessels are not considered for speed reduction. Tests should be carried out to determine the relationships between speed and fuel consumption, journey time, distance travelled and loads carried. In the present analysis this measure was introduced in 2010 where 5% of the transport activity is taken up through speed reduction that gradually increased to 50%. If future studies find that speed reduction is a viable option for Fijian domestic vessels, then appropriate incentives need to be developed to make this acceptable to operators and vessel owners.

Introduction of hybrid vessels for new registered vessels for more than 15 m length and sail boat for new less than 15 m length have the potential to reduce diesel consumption by 2% and premix consumption by 4.8%. Newly registered hybrid vessels are considered to use wind for propulsion and have solar PV on board to cater for part of electrical load. Geertsma et al. [36] recommends studying the current operational profile of marine vessels before retrofitting. They further recommend that hybrid propulsion is economically beneficial when the vessel is running 40% below its top speed for most of the time. In addition, Lan et al. [37], have developed a methodology to determine the optimal size of solar PV, diesel and battery on hybrid vessels which reduce costs and emissions. In this study, hybrid vessels measure is considered at very low penetration level. Currently, there is a group of traditional craftsmen and academics who are designing hybrid vessels which mainly operate using sails in Fiji. For instance, sail boats named Adi Eta (8 *m*), FNU Babale (9.8 *m*) and Drua (8 *m*) were designed and built by one FNU academic and four traditional craftsmen. Each of these vessels cost

Fig. 12. FNU Babale taking part in a race. Source: [38].

around Fijian Dollar[2] (FJD)8000. Adi Eta and FNU Babale have been used for fishing and for racing, Fig. 12 [38].

Drua was also deployed for two years before making its trip to COP23 in Germany and then to National Museum in Greenwich, UK [38]. These vessels have been made out of mahogany and native wood with sail made from canvas and require two crew members and can carry up to 10 passengers. There is a need to subsidize costs for sustainable vessel building and enhance human capacity for the development of sailboat design and construction.

Introduction of biodiesel use in shipping vessels can reduce volume of marine diesel oil consumption by almost 4% relative to BAU by 2040. Biodiesel (FAME- Fatty Acid Methyl Esters) use in maritime vessels is safe to use, reduces sulphur emissions, does not need expensive retrofits to existing vessel and conversion to biodiesel from diesel is manageable [39]. Despite these advantages of biodiesel in maritime vessels, there has been very limited experience in biodiesel use with some researchers and organizations promoting the use of biofuels in ships [39–42]. Biodiesel blends are technically feasible on maritime vessels operating with MDO or MGO [43]. The major drawback of biodiesel from vegetable oil is availability of feedstock and supply chain issues. There are reports of corrosion of fuel tank metal surface in US Navy ships and microbial growth on one of US Coast Guard vessels which prevented the vessel from sailing [39]. A recent trial done by ExxonMobil [44] showed positive results for use of B5 biodiesel on two maritime vessels which were not fitted with any new equipment or system. This trial showed no microbial growth and no storage and stability problem. Technical fuel standards for marine fuel ISO8217:2017 now allows 7% of FAME by volume to be introduced in marine diesel oil [45,46].

Fiji will need to first set a biodiesel standard to be used in replacement of marine diesel oil. This will encourage use of biodiesel in maritime vessels. There is also a need to enhance investments in biodiesel production in Fiji. GoF already has some policies to support investors in biodiesel production. According to the results of present study, biodiesel demand in maritime transport will reach 3.8 million litres by 2040, Table 3. A Study by The World Bank in 2008 revealed that with the current resources in coconut plantations and oil production, taking out the demand for human consumption, on average 5 million litres of biodiesel can be produced at a small scale biodiesel plant [47]. This size plant would be sufficient to supply for biodiesel demand in maritime transport. However, if biodiesel is also to be used in land transport sector then significantly more biodiesel production would be required.

In order to promote use of B5 standard biodiesel in maritime vessels, pilot projects need to be developed that show the promise of reduced fuel consumption as well as gain consumer/vessel owner confidence of no/low technical issues to usage of biodiesel on ships. Pilot projects can be run on government vessels as well as any volunteering vessel to operate on biodiesel blend B5. In addition, there need to be public/stakeholder awareness programs/workshops to promote B5. Stakeholders such as land owners, farmers, vessel owners/operators and government officials need to work coherently to create significant investment into biodiesel market in Fiji. For the use of biodiesel blend B5 on vessels, the price of fuel needs to be subsidized by government if its sales price is more than the MDO. Hence, a detailed feasibility study has to be carried out to consider technical and economic potential for biodiesel production and the supply chain issues should also be investigated.

Table 3
Demand for volume of B100 fuel in million litres at intermediate year.

Transport	2020	2025	2030	2035	2040
Maritime	0.2	0.9	1.7	2.7	3.8

5.1. Capacity building for maritime shipping stakeholders in Pacific region

Having a fully trained cadre of technicians is a major requirement for taking Fiji's maritime industry towards a greener future. The University of the South Pacific (USP) and the Republic of Marshall Islands (RMI) joined hands in 2016 to establish the Micronesian Centre for Sustainable Transport (MCST). The MCST framework provides “space for willing partners to collaborate on research, analysis and implementation of practical projects” [48] to propel Pacific States maritime industry towards low-carbon future. This Centre is now being supported by a number of international organizations and universities.

In 2017, IMO together with European Union has started a global capacity-building project for climate change mitigation in maritime industry. This project has established Maritime Technology Cooperation Centres (MTCC) in five developing regions; Africa, Asia, the Caribbean, Latin America and Pacific and the project is now known as Global MTCC Network (GMN) [49]. The main goal of MTCC is to build necessary human capacity and use new and innovative technologies to reduce or limit emissions in shipping industry [50].

For the Pacific region, the Pacific Community (SPC) is the host institution for the MTCC which was officially launched on 12th December 2017. MTCC-Pacific has conducted three workshop so far in the region, the first in Fiji, the second in Solomon Islands and the third in Vanuatu with upcoming similar workshop are being planned for Tuvalu, Kiribati, Marshall Islands and Samoa [51]. These workshops aim to provide and train Pacific islands maritime shipping stakeholders ways and technologies of improving energy efficiency in shipping, innovative and new technologies to reduce emissions and fuel and at the same time keep safety a priority. MTCC-Pacific aims to transfer technology and knowledge in mitigating climate change in maritime industry by (i) collecting and analyzing data on energy consumption, (ii) creating and maintaining a data base for the region and (iii) providing public access to these data.

In addition, MTCC-Pacific will provide technical assistance for the

[2] FJD – Fijian Dollars. 1 FJD = 0.48 USD.

implementation of adapted Ship Energy Efficiency Management Plan (SEEMP) on domestic ships and energy audits at ports [52]. These actions and approach taken by Pacific community as a whole will pave a way for improved energy efficiency in maritime vessels as well as use of new technologies for low carbon transformation of shipping industry.

5.2. International stand on shipping emissions

As stated in section 1, IMO has declared a 50% reduction in international shipping emissions by mid-century [1]. The initial push for this strategy came from the small Pacific island countries with the Marshall Islands in the lead role. During the Maritime Environment Protection Committee's 68th session in May 2015, Tony De Brum, former RMI minister said [53].

“We are an island nation and shipping is one of our lifeline – we cannot survive without it. At the same time, carbon emissions, including those from shipping, pose an existential threat to our people and our country.”

This statement together with Tony deBrum declaration which around 44 countries have supported prompted IMO to set an emission reduction target for international shipping. This target of 50% reduction in emissions is an ambitious target and as Dan Rutherford, Program Director for Marine and Aviation of ICCT says “even though the target is set for 3 decades away, immediate actions are needed with medium and long-terms solutions taken later to achieve this target” [54]. Immediate actions include tightening energy efficiency requirements for ships and reducing speed while innovative technologies such as wind, solar, air lubrication and more can be solutions for the medium and long term [54].

With this significant commitment from IMO driven by long standing demands from the Pacific island countries to reduce shipping emissions and the recent capacity building initiatives in enhancing energy efficiency in shipping industry, the shipping industry in the Pacific is on the verge of a paradigm shift for cleaner and safer maritime sector.

6. Conclusion

The shipping industry in the Pacific is totally dependent on imported and polluting fossil fuels at present. It uses marine diesel oil and premix for almost all maritime activities. Under the assumptions that (i) all registered vessels are operational annually and (ii) all vessels more than 15 *m* in length use diesel while those less than 15 *m* long mainly use premix, the current study estimates domestic maritime transport to use 79 million litres of fuel in 2016 out of which 77% is marine diesel oil while remaining is premix. The total emissions from maritime transport in 2016 is estimated to be 214 Gg of CO_2e. At 2% annual growth rate in maritime transport passenger and freight activities, the total annual fuel consumption will increase to 127 million litres by 2040 with corresponding GHG emissions of 342 Gg of CO_2e.

This study attempted to quantify fuel usage and emission reductions under various energy efficiency measures of maritime vessels in Fiji. There can be a 2–12% of emission reduction for each individual intervention. Hence, Fiji needs to develop a comprehensive policy for maritime transport. In addition, high fuel demand and emissions by fishing vessels are due to their low fuel economy. Future studies can be done on fishing vessels exclusively on their current fuel usage and measures to reduce future demand. One of the possible solutions could be solar charged electric motors. It is recommended that MSAF together with other relevant government departments update their database on registered vessels.

This preliminary study on Fiji maritime transport can pave a way for further research on improving fuel efficiency of maritime transport sector well as developing enabling policies in the transport sector to promote GHG emissions reduction.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2019.01.008.

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