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Clean fuels for maritime decarbonisation in Pacific Island Countries and Territories

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Maritime shipping supports the transportation of roughly 80% of international trade by volume and is a crucial component of global economies and supply chains (UNCTAD, 2018). In particular, shipping plays a crucial role in Pacific Island Countries and Territories (PICTs), where inter-island shipping services are connected to strong seafaring traditions and enable fundamental transportation, commerce, and economic development opportunities (Shibasaki et al., 2021). However, conventional shipping methods largely depend on carbon-intensive marine distillates such as marine diesel oil (MDO), marine gasoil, and heavy fuel oil (HFO) – contributing to roughly 3% of global greenhouse gas emissions (CAIT, 2019). As a result of this fossil fuel dependency, the International Maritime Organisation (IMO), a specialised United Nations agency responsible for regulating maritime shipping, has determined various regulations, conventions, and protocols to control and reduce shipping emissions – including a net-zero target by 2050, an alternative fuel penetration target by 2030, a prescription to reduce maximum sulphur content in marine fuels ("IMO 2020" regulation – which has resulted in higher fuel costs), and plans to adopt of a carbon price by 2025 – a proposition first brought forward by the Marshall Islands and Solomon Islands in 2021 (Alamoush et al., 2022, MEPC, 2023, Lin, 2023).

However, decarbonising shipping and navigation is a complex and wide-ranging challenge which can be addressed through a variety of approaches such as hull design improvements, alternative fuels and energy sources (including hydrogen, ammonia, and methanol), innovative propulsion systems and operational procedures, emissions capture and storage, and enforcing regulatory compliance at scale (Balcombe et al., 2019, Bouman et al., 2017, Newell et al., 2017). In particular, clean fuels can enhance wider energy transition goals and open up to new export opportunities and markets for PICTs through coupling with energy and its related sectors (Englert et al., 2021). Key processes relating to alternative fuel production (including non-clean pathways), conversion, and consumption in the maritime industry, as well as onboard technologies for vessel propulsion, are summarised in Figure 1. As such, this short study preliminarily explores the energy, cost, and emissions implications of transitioning to clean fuels for decarbonising maritime shipping in PICTs.

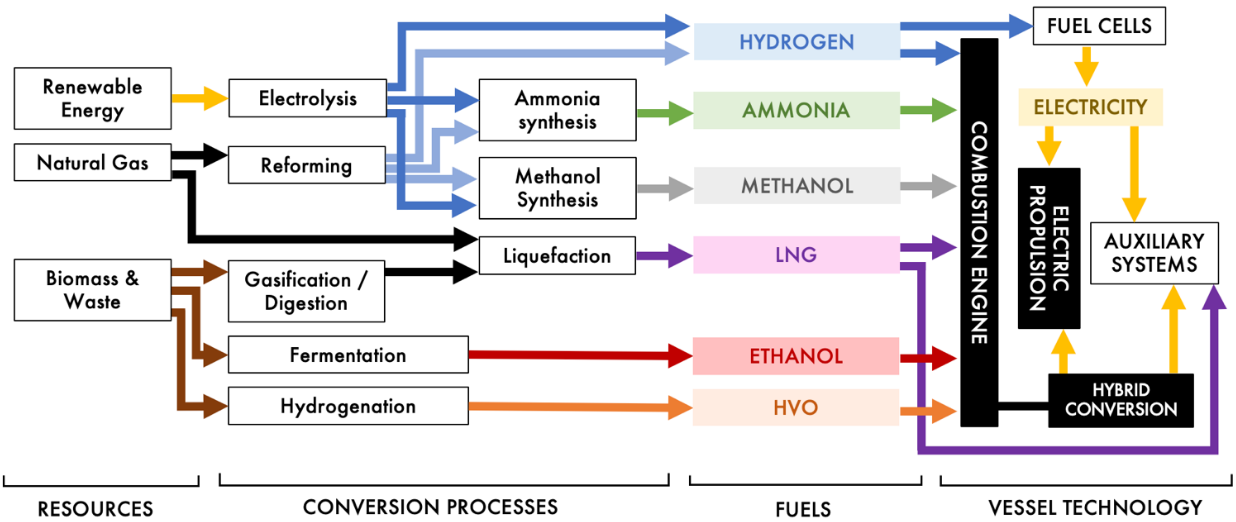

Figure 1. Maritime fuel production processes

Context: Domestic maritime shipping and navigation in PICTs

Shipping and navigation in PICTs play an essential role in economic development, connecting a vast and widely dispersed array of islands with a variety of demographic profiles, infrastructure capacities, and economic structures – all factors which heavily influence supply chains and thus regional maritime traffic and functionality (Nuttall et al., 2021, Bola, 2017). Most vessels are relatively small – with few bearing carrying capacities that exceed 500 DWT. Small fibreglass boats with outboard motors, as shown in Figure 2, constitute a large portion of domestic fleets and are the primary mode of transport and shipping in remote coastal communities across the Pacific. Inter-island travel is often carried out by ageing vessels with dual passenger and cargo functionality (also shown in Figure 2), with a few services running frequently through national shipping franchise schemes.

Figure 2. Fibreglass boat in remote island (Left) and old dual-functionality vessel (Right), Fiji

Some of the key challenges relating to domestic shipping in the region include large travelling distances with unideal population distributions (entailing large fuel consumptions and far-reaching trading routes), an ageing fleet with poor fuel efficiencies and safety, small and underequipped ports, low trade volumes mostly focused on imports (which also has implications on port operations and equipment), limited disaster risk mitigation strategies relevant to navigation, and lack of funding for infrastructure operation, maintenance, and upgrades (Riku et al., 2021, Nuttall et al., 2021, UNCTAD, 2014). Furthermore, fleet and fuel consumption data for shipping and navigation in PICTs is either lacking or inconsistent with registered levels of marine traffic (Prasad and Raturi, 2019).

Estimating domestic fleet sizes and fuel consumption

The most effective way to reduce shipping emissions for a specific vessel depends on its size, function, route, and age – all of which vary significantly across fleets (Smith et al., 2019). As such, this study comparatively reviewed 10 key datasets (*UNCTAD Stats, VesselFinder, Marine Traffic, Baltic Shipping, VesselTracking, ShipSpotting, Ocean Logistics, Trusted Docks, Fleetmon, ShipAtlas*) for 9 PICTs (Fiji, Papua New Guinea, Cook Islands, Tonga, French Polynesia, Vanuatu, Solomon Islands, Tuvalu, Federated States of Micronesia) to estimate domestic fleet sizes in terms of carrying capacity and map key fleet characteristics for all types of carrier vessels (such as container and Ro-Ro ships), tankers, and passenger ships. Fishing vessels, high speed crafts, military vessels, yachts, sailing vessels, and tugboats were not included in this review. 334 ships were surveyed and filtered for currently active vessels engaged in domestic or regional trade across PICTs using AIS position data and reported shipping routes. Additional articles or reports regarding vessel decommissioning (sometimes left berthing in relevant trading areas) or damages (such as ones caused by fires) were also used to determine a vessel's status. Results are shown in Figure 3 – with only roughly 40% of surveyed vessels still being active or relevant for Pacific trade. Besides typical inconsistencies regarding reported fuel/energy consumptions, listed active vessels in each domestic fleet and their types are also found to be inconsistent across databases. Nonetheless, a large proportion of vessels are consistently landing crafts – typically well equipped to service remote areas with limited infrastructure, as is the case in most PICTs. In fact, these vessels usually have a shallow draft, can carry a wide variety of cargo, and can operate in challenging weather conditions. Specialised and functional cargo vessels, such as refrigerated cargo and self-discharging vessels, are very limited.

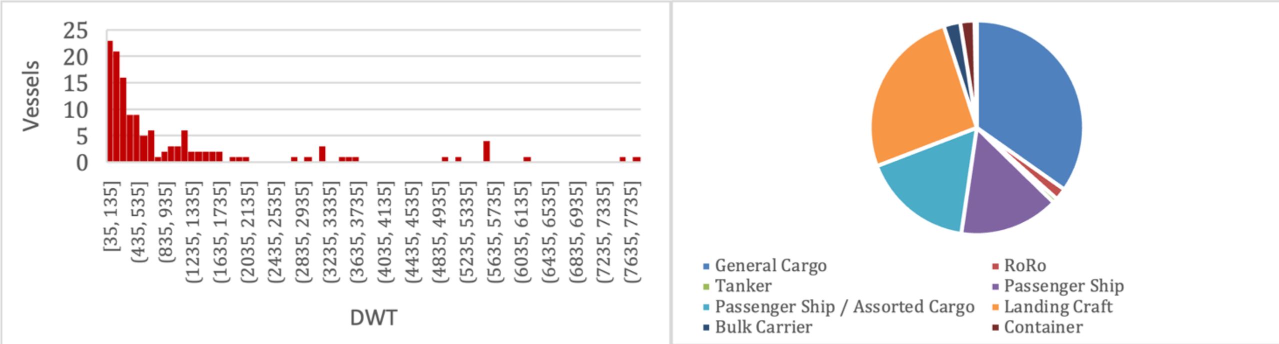

Figure 3. Vessels by carrying capacity (bin size: 100 DWT) (Left) and type (Right) in 2023

To estimate fuel consumption for each vessel, a sample of 5 ships were selected to determine a broad linear association between a ship's carrying capacity and its fuel consumption (R^2=0.9894) – as shown in Figure 4. Fuel efficiency discrepancies due to differing ship sizes, speeds, routes, and ages are considered negligible due to similar sample ship speeds (within 8% of each other) and a comparatively small range of vessel sizes (Notteboom and Cariou, 2009). Each ship is assumed to be at full carrying capacity, having a 1.5 GT/DWT ratio (broadly volume to weight) as per industry standards (LiveBunkers, 2023), and spending an average of 21 days at sea – based on a comparison between the estimated daily fuel consumption for Fiji's domestic fleet and its reported energy consumption by the *UN Energy Balances* dataset (UN, 2019). Results are shown in Figure 4 – primarily suggesting that energy consumption in most PICTs is underreported in reviewed datasets.

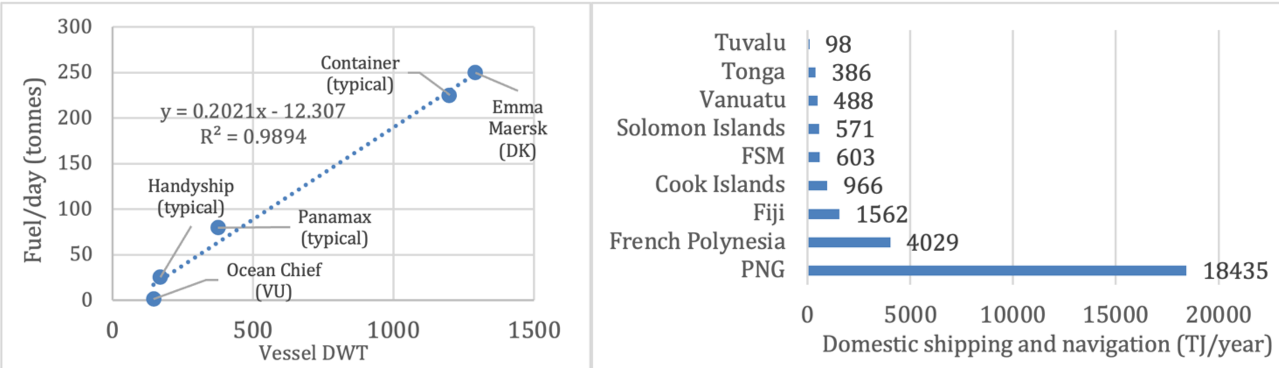

Figure 4. Ship samples (Left) and estimated fuel consumption for PICTs in 2023 (Right)

Preliminary assessment of clean fuel transition

This study assesses the transition to clean fuel alternatives in terms of resource/renewable energy requirements and annual costs and emissions savings. Fuels considered for this study are ammonia, hydrogen (combustion), methanol, liquefied natural gas (LNG), ethanol, hydrotreated vegetable oil (HVO), as well as electricity (obtained from fuel cells operated with hydrogen) (Wang and Wright, 2021). Table 1 summarises the assumptions regarding vessel engine efficiencies using different fuels, lifecycle efficiencies for fuels that can be produced via renewable energy ("RE to propeller efficiency"), emissions intensities for various production and conversion processes (seen previously in Figure 1), and their resultant costs (which include renewable energy costs where relevant). Other production/extraction emissions are not considered in this study. All vessels are assumed to have been previously operating on marine diesel oil (MDO). When converting MDO requirements into alternative fuels, engine efficiency variations for combustion are used to further scale primary energy requirements, though costs associated with engine replacements or retrofits are not considered. Results are shown in Figure 5. Ammonia produced via RE+HB is also roughly 15% more emission intensive than MDO, suggesting that feedstocks and production methods for each alternative fuel play a key role in decarbonisation and that electrifying conversion processes is crucial. Fuel cells present the lowest energy requirements out of all options, although extensive vessel overhauls are required for their implementation and smaller vessels may not be suitable. Furthermore, ethanol and ammonia have the highest mass requirements out of all fuels – potentially requiring higher productive throughputs and higher capacity and functionality of storage (e.g. compression or cooling). All these aspects require high upfront investments and technical capacity, which are typical barriers to development across PICTs. Due to ethanol's low energy density, poor combustion efficiency, and emissions associated with land use (e.g. corn feedstock), traditional MDO is still a better choice. Cost savings are experienced with all fuel alternatives except LNG (with the biomass pathway being the most costly), most likely due to scalability issues associated with liquefaction (Neill, 2023). The cheapest fuel is SMR hydrogen destined to combustion.

Table 1. Model assumptions

Fuel	MJ/kg	Engine Efficiency	RE to Propeller Efficiency	Emissions intensity (tCO2/tfuel)	Price (US$/kg)	Source
Ammonia	19	36%	17%	1.87 (Haber-Bosch) | 2 (Steam Methane Reforming)	1 (SMR+HB) | 1.5 (RE+HB)	(IEA, 2022b, Machaj et al., 2022)
Hydrogen	142	40%	28% (with electrolysis 70%)	8 (Steam Methane Reforming) | 0 (RE)	2.5 (SMR) | 3 (RE)	(IEA, 2022b, IEA, 2022a)
Methanol	22	43%	/	0.9 (Reverse Gas-Water Shift) + 1.64 (Combustion)	0.6 (SMR+RWGS) | 1 (RE+RWGS)	(IEA, 2022b)
LNG	54	40%	/	1 (Flaring) | 0.5 (Gasification) + 0.2 (Methanation) + 0.3 (Liquefaction) + 0.52 (Combustion)	10 (Natural) | 15 (Biomass)	(IEA, 2022b)
Ethanol	27	31%	/	0.77 (Tillage) + 0.69 (Fermentation) + 1.44 (Combustion)	1.2	(IEA, 2022b, Ates and Bukowski, 2023)
HVO	43	43%	/	1.5 (Hydrogenation – waste) + 0.25 (Combustion)	1.5	(IEA, 2022b)
Fuel Cells	/	50%	35% (with electrolysis 70%)	8 (Steam Methane Reforming) | 0 (RE)	2 (SMR) | 3 (RE)	(IEA, 2022b)
MDO	44	40%	/	3.15 (Combustion)	7.5	(IEA, 2022b)

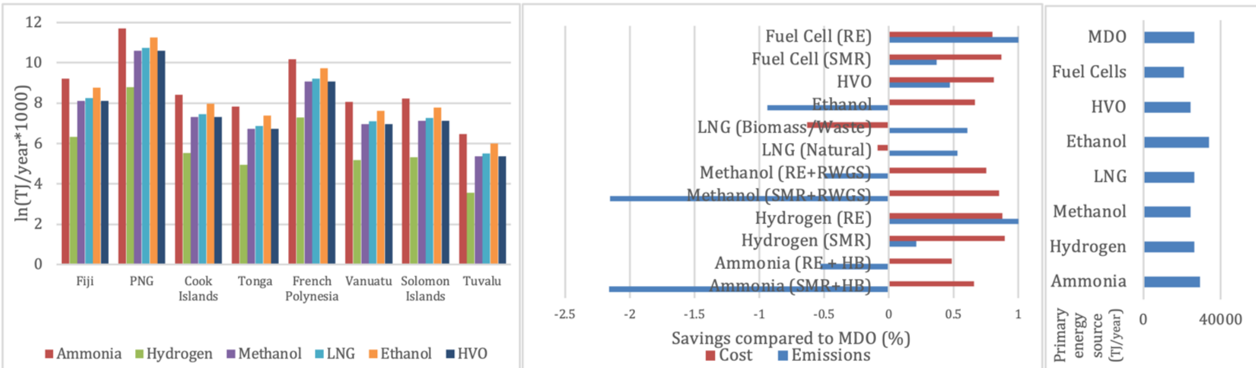

Figure 5. Energy per PICT and fuel (Left, Middle) and emissions and cost savings (Right)

Conclusions

This short study has attempted to bridge the data gap that exists regarding energy consumption in domestic navigation and shipping across PICTs, subsequently demonstrating some preliminary implications relating to transitioning towards cleaner fuel alternatives – suggesting that fuels associated to renewable energy can achieve close to zero emissions within comparable costs. However, transitioning to clean fuels in PICTs presents several barriers relating to technology transfer, financing arrangements, and availability of local renewable energy for fuel production. Given current uncertainties in the reviewed datasets, a key improvement to better estimate clean fuel requirements is to match each vessel to a specific shipping route to map travelled distances and route frequency via AIS location data – thus enabling better estimates for fuel consumption and emissions on a vessel-by-vessel basis. Future studies may also include scenario explorations, implications on port infrastructure and operations, and marine policy and legislation prescriptions at both national and international levels. In terms of infrastructure requirements, some consideration must also be given to international bunkering fuels to assess potential economies of scale.

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