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Chapter working title: The case for field trialing and technology/knowledge transfer of emerging low carbon maritime technologies to Pacific Island Countries.

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Introduction

The global maritime industry today faces some of the most demanding and novel challenges that it has ever known. Most pressing of these is the challenge of climate change, a defining issue of our era which calls for innovative technological solutions to meet new emissions reduction targets. Pacific Small Island Developing States (P-SIDS) face this challenge hampered by a heavy dependency on imported fuel, combined with high transport costs that are caused in part due to their remote geographical location. The impact of these challenges is felt in sustainable development efforts and climate change adaption measures.

Despite the maritime transport industry being a dominant energy user and emitter, a range of complex barriers have prevented priority being given – and action being taken – at both the local and international levels to implement a proportionate response to climate change (Nuttall et al, 2014a; Rojon and Dieperink, 2014; Lloyds Register, 2015; Rehmatulla and Smith, 2015; Rehmatulla et al, 2015). Progress in developing and implementing low carbon technologies has lagged significantly behind innovation advances in land transport and electricity generation.

This chapter argues the case for the prioritized demonstration and implementation of low carbon technological innovations in the Pacific region. The need to advocate on this issue has arisen given the growing impact being felt at this front line of climate change, combined with sea transport's centrality to regional development and climate change adaption. This chapter presents P-SIDS as an ideal proving ground capable of demonstrating existing and emerging low carbon maritime technologies. The case for a low carbon transport transition in P-SIDS is made based on a conclusive body of work investigating sustainable sea transport for Oceania (Prasad et al, 2013; Nuttall, 2015; Newell et al, 2016). Trialing these emerging low-carbon technologies in frontline regions of global climate change will serve to: (i) promote a localized adaptation agenda in the Pacific region; (ii) accelerate the development and short-term market penetration of renewable energy technology; and (iii) open up new global markets to technology developers and suppliers in Europe.

This chapter specifically puts forward the case for scalable, low-cost 'proof of concept' modeling that is urgently required to pave the way for the future market demand of low-emission maritime technology. Four specific mature technologies are examined which have been selected for discussion based on their suitability for application in the unique context of the Pacific region. These four technologies have also been rigorously tested to the point of being extensively developed through both public and private investment initiatives. These investments are further supported by ongoing research efforts from leading German, Dutch, Norwegian and Korean research agencies that have staked a vested interest in the viability of these particular technologies as a concrete tool with which to combat climate change. At the time of writing, these technologies are at a 'proof of concept' stage for which real world trailing is required to determine their economic viability within a real-world scenario (as ideally provided by the P-SIDS setting) before market uptake can be achieved.

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These four technologies are: (i) Flettner rotors; (ii) soft sail cargo carriers; (iii) Wing-In-Ground vessels; and (iv) biofuel.

The chapter concludes with an open invitation to all willing partners to join a 'Coalition of Higher Ambition' to advance – in active concrete terms – the pressing agenda of climate change within the global maritime industry. It is argued that field-testing innovative technologies in P-SIDS is a valid and viable development approach to supporting both the Pacific region and the broader maritime industry through the evaluation of small-scale demonstration models for subsequent scalability further afield across the global maritime stage.

1. The challenge of climate change facing the maritime industry

Financial globalization since the mid-1980s has been marked by an abandonment of protectionist trade policies leading to an international flow of capital and investment with unprecedented reach and velocity (UNTDC, 2009; Tomlinson, 2010; Lassere, 2013). The result is growing international interdependence and enmeshment along economic and political lines, characterized by a more integrated and interdependent global marketplace (Feeny and Rogers, 2003; Milliot and Tournois, 2010; UNTDC, 2011). The internationalization of value chains has in turn led to rising global trade volumes which have increased over 20-fold since 1950 (OECD, 2009; UNTDC, 2010).

Today there is a common acceptance in the academic literature that human economic activity has added substantially to levels of GHGs – and particularly carbon dioxide (CO_2) – in the Earth's atmosphere (Tisdell, 2008). It is therefore high time for influential actors on the platforms of politics, industry, economics and environmental protection to address the global goal of reaching 'net zero' emissions, as stated and agreed upon under the 2015 Paris Agreement (FCCC/CP/2015/L.9/Rev.1). Tragically, history has shown that human beings have been all too slow in recognizing the environmental dangers of greenhouse gas (GHG) emissions. As a result, the shipping industry today is a large and growing contributor to global GHG emissions, representing over 800 million tons of CO_2 being released into the atmosphere each year. Of course, it is worth noting that economic growth has been reliant on carbon fuels for a wide range of purposes since the Industrial Revolution when timber and other biomass variants were the first carbon fuels to be used, followed thereafter by coal, oil and subsequently natural gas. In exploring the viability of new low carbon technologies, this chapter makes the point that the advancement of economic progress growth itself does not need to be impeded in any way, but rather the escalating rate of GHG emissions that has paralleled this growth must by all means be curbed in the short term. Incising these two factors is indeed the only chance to ensuring a sustainable world economy for future generations.

Looking ahead at the situation as it currently stands, the International Maritime Organization (IMO) projects overall maritime tonne-miles to grow further by approximately 45 per cent by 2020 and by up to 300 per cent by 2050 (UNCTAD, 2015). In 2009, the Organization for Economic Co-operation and Development (OECD) was predicting container activity to follow past trends and grow much more vigorously with 65-95 per cent growth by 2020 and an astounding 425-800 per cent growth predicted by 2050 (OECD, 2009). Such predictions did not allow for the Global Financial Crisis (GFC) which slowed global demand to 4.7 per cent in 2013 up from 3.2 per cent in 2012 (UNCTAD, 2014). The effect of the GFC on long-term growth trends is not yet clear, but current predictions indicate a recovery to previous growth targets is highly likely. The IMO forecasts increases of 50-250 per cent by 2050 under all modeled scenarios if no drastic changes are implemented (Smith et al., 2014). Reduction curves consistent with achieving global warming of less than 1.5 degrees Celsius and 2 degrees were modeled by Smith et al. in 2015. These predictions demonstrate that if targets from the Paris Agreement are to be met and all sectors accept their fair share of reductions, then it will be necessary to peak shipping emissions by 2020 and then to de-carbonize by 2045 and 2077, respectively (see Figure 1; Smith et al., 2015). It is hence eminently clear that the shipping industry needs to make haste in developing and implementing innovative solutions to severely curb GHG emissions in the short term.

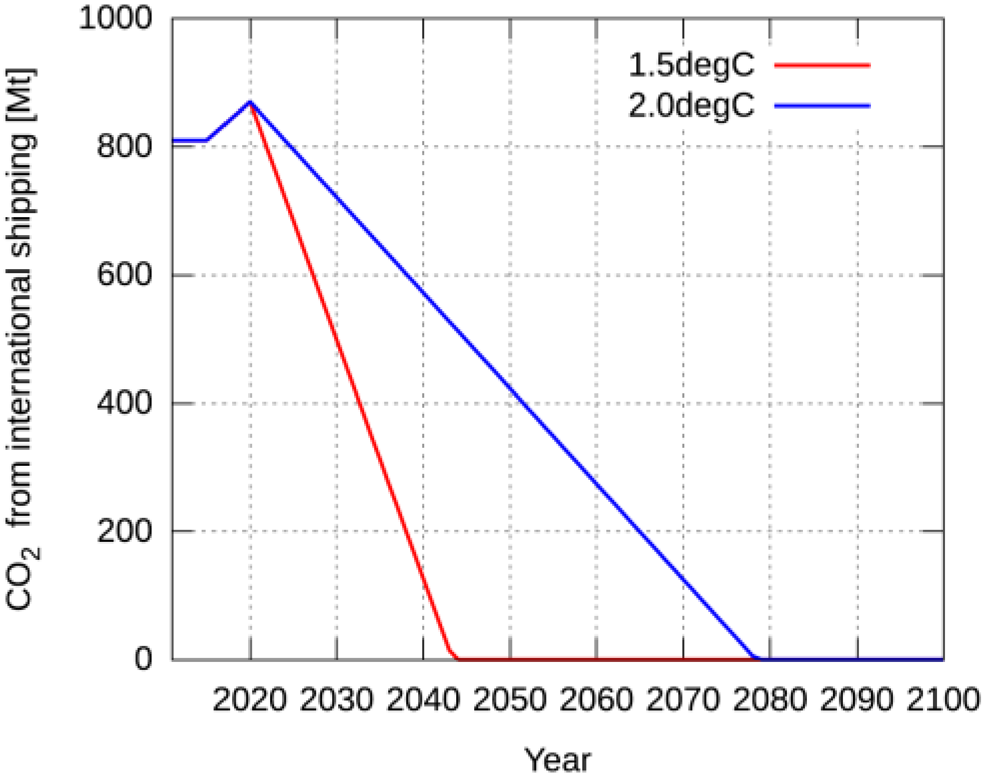

Figure 1: CO_2 emissions trajectories for international shipping consistent with a 2°C temperature rise (blue curve) and a 1.5°C temperature rise (red curve). The trajectories assume emissions as in the reference scenario from the Third IMO GHG Study 2014 to 2020, followed by constant reductions, with the year-on-year reduction determined by the remaining CO_2 emissions budget of 33Gt and 18Gt, respectively (Smith et al., 2015).

As environmental sustainability is increasingly recognized as a vital element to the future success of the maritime industry, there is mounting pressure to alter the course of previous resource-intensive and environmentally-damaging growth patterns (Anderson and Bows, 2012). The goal therefore, is to make a shift towards greener and increasingly carbon-neutral energy sources. At the policy level in Europe over the past decade, sustainability imperatives have enforced significant limitations on airborne emissions from ships' exhausts with a major focus on sulfur oxides, nitrogen oxides, ozone depleting substances and volatile organic compounds. This has in turn prompted the freight transport industry to seriously address the question of sustainability, thus triggering researchers and technology developers to provide innovative solutions towards fuel-efficient, cost-effective, environmentally friendly, low-carbon and climate-resilient transport systems (UNTDC, 2013). The consequent proliferation of innovative low carbon technological solutions being developed for maritime applications in key innovation fields for research and development are increasingly paving the way for a market-based response that will enable vessel operators to simultaneously reduce both their emissions and lower their operating costs. While these measures have provided the necessary impetus for innovation activities in the maritime industry, there remains the challenge to trial these technological solutions at the frontline of climate change before wide scale market penetration can be realized. To this end, technology developers in key innovation fields of Europe and the United States have expressed their willingness to participate in such technology transfer initiatives for which global partners, financing and political support remain key factors which are currently being sought out.

The disruption of the Earth's delicate biophysical system is today being felt in the form of an emerging and escalating pattern of extreme disasters such as floods and hurricanes (Tisdell, 2008). This chapter focuses particularly on exploring solutions for P-SIDS given that these are regions that are suffering the full brunt of climate change (Wong et al, 2014). Of course, the Pacific Islands region is historically not unfamiliar with extreme weather events; however, the scale and magnitude of natural disasters has been intensifying in recent decades, leading to very real concerns over rising sea levels and the pertinent threat of climate change (Albert et al, 2016). In March 2015, the category 5 '*Tropical Cyclone (TC) Pam*' devastated Vanuatu, causing more than US$450 million in damage (UNESCO, 2015). Then on February 20th 2016, '*TC Winston*' – the strongest cyclone ever recorded in the southern hemisphere, with peak winds of 306 km/h recorded before the weather station failed (Wikipedia, 2016) – swept across the island nation of Fiji killing 44, flattening communities and causing damage in excess of US$1.4 billion (Fiji Government, 2016). According to the Fiji Government, an estimated 32,000 homes, 88 health facilities and 750 schools were damaged or destroyed and 350,000 people (40 per cent of the total population) were affected by the cyclone.

While the impact of this extreme weather has led to the tragic loss of life and capital damage, it has also revealed major vulnerabilities in maritime transport infrastructure. Damage in these areas has been suffered by terminals, intermodal facilities, freight villages, storage and warehousing areas, as well as containers and cargo (UNTDC, 2010). '*TC Winston*' alone damaged 55 per cent of jetties in the affected region (Fiji Sun, 2016) and numerous boats were lost, many of which served as the sole source of livelihood for small-scale and subsistence fishing. The Intergovernmental Panel on Climate Change conservatively predicts sea levels to continue to rise by nearly 1 meter by 2100, thus placing the safety and reliability of global supply chains under threat, including intermodal connections via hinterland ports to affect entire multimodal supply chains (IPCC, 2014). Meanwhile, Hansen et al. (2016) consider these estimates to be extremely conservative, arguing that sea level rises of up to several meters by 2050 are far more likely. This weather damage has so far been most felt in developing island nations with low elevation, low adaptive capacity and whose trades depend heavily on well-functioning transportation networks in transit island states (Tisdell, 2008; UNCTAD, 2009; UNTDC, 2010).

2. Specific challenges facing P-SIDS

P-SIDS represent some of the smallest and most remote communities on Earth. Facing a future whose only certainty is change, P-SIDS remain a special case for sustainable development. This is not only due to their unique vulnerabilities, but also because they remain constrained in meeting key development goals in all dimensions of sustainable development (Moon, 2013; Nuttall and Veitayaki, 2015). The Pacific region faces multiple obstacles; however local and foreign leaders have consistently identified two predominant development challenges to development.

The first of these challenges is the increasing effects of climate change, which in extreme cases poses an existential threat to the survival of entire P-SIDS and their ancient cultures (see: "Majuro Declaration" PIF, 2013; and "Suva Declaration" PIDF, 2015). The impact of the threat posed by climate change in the Pacific region is enormous and arguably catastrophic to the local communities living there. In addition to the well-publicized forecasts of the loss of land and homes to rising sea levels in low-lying atoll and small island states, the reality is that all communities will be dramatically and irreversibly affected by climate change. Increased severity of extreme weather events is linked to heightened threats to water and food security in many parts of the region. Sea surface temperatures in the eastern tropical Pacific during late 2015 and early 2016 have so far matched previous records for the strongest El Niño events (previous records being 1982-83 and

1997-98[4]), leading to unprecedented rates of coral bleaching and damage to marine life. For a region where fish and seafood is the primary protein source, and where there is often insufficient land for alternatives, this alone is likely to be catastrophic if such incidents are repeated in the near future.

In developing a response to climate change based on innovative green shipping technologies, it is important to recognize that P-SIDS are characterized by their geographical remoteness, small population sizes, micro national economies and even smaller internal markets. The result is considerable natural economic disadvantage compared to their international counterparts throughout Australasia (Tisdell, 2002; UNCTAD, 2014).

The second challenge is the Pacific region's almost total dependency on imported fossil fuel. The lack of indigenous fossil fuel resources means that these nations are completely dependent on imported fossil fuel fuels for transport (on average approximately 3/4 of all fuel consumption) (SPC, 2011; Mofor, et al, 2013). Fuel dependency therefore places the region at the mercy of swings in oil prices, thus increasing transport costs and contributing to economic instability. This is further compounded by the geographical remoteness of P-SIDS from fuel sources, thus creating supply chain problems in a region where the maritime logistics infrastructure is increasingly vulnerable to extreme weather events (UNCTAD, 2014). Unlocking this stalemate to alleviate energy problems can only be achieved through an innovative technological and operational response in the form of renewable energy, energy efficiency and conservation (Singh, 2012). Indeed, technology transfer in the field of renewable energy is therefore commonly touted as part, if not the only part, of the solution for P-SIDS.

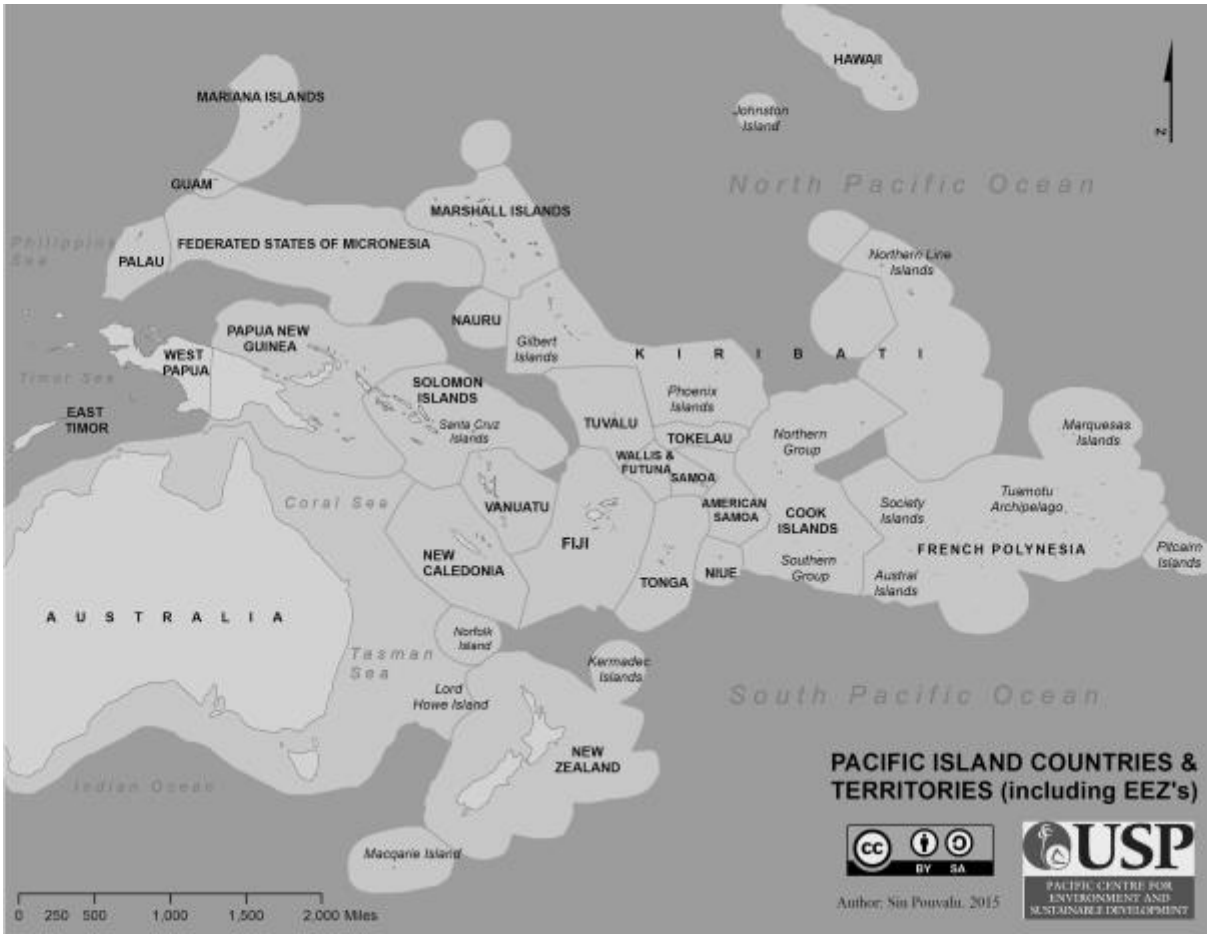

Figure 2: Pacific Island Countries and Territories and their EEZs (Source: Newell, et al, 2016)

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[4] https://wunderground.atavist.com/el-nino-forecast

The small scale of P-SIDS economies severely limits their capacity to achieve internal economies of scale in production. This problem is greatly compounded by national fragmentation in the region. The flow-on effect is an adverse impact on the cost of supply of public services and utilities, thus placing P-SIDS at an extreme cost disadvantage (as compared to larger and more developed economies) in supplying public administration as well as public utilities such as educational and health services. These obstacles are not easily overcome, although there is evidence to suggest that technological innovations can relieve scale diseconomies to facilitate more efficient, more cost-effective and flexible maritime transport that promotes self-sufficiency (in terms of energy supply and maintenance) at the local level (Tisdell, 2000). The broader impact of these economic inefficiencies is reflected in a relatively high human poverty index (HPI) and a low human development index (HDI) in island states. For example, the HPI for the Solomon Islands is higher than for all the South Asian and Southeast Asian least developed countries (LDCs) and the HPI for Vanuatu is about the same as that of Bangladesh (Tisdell, 2002). For these reasons, P-SIDS are highly vulnerable to natural and ecological disasters and take considerable time to recover despite extreme weather patterns which have proven themselves to be both recurring and increasing in their severity (UNCTAD, 2014).

The small population size of P-SIDS also limits their ability to specialize in key technological areas. When it comes to scientific research and development, P-SIDS find themselves with a debilitating disadvantage. The paucity of research institutions and network clusters for science and technology in the region makes it extremely difficult to develop their own innovative technological solutions for uptake by the local maritime industry, let alone further afield. The multi-national corporate entities that are capable of carrying out their own research and development initiatives generally have little or no presence in these countries, thus leading to an extremely high degree of technical dependence on the supply of foreign expertise (Tisdell, 2000 and 2002). The relatively small gross-tonnage capacity of the existing transport infrastructure is also often inadequate in P-SIDS meaning that in many cases ships must load and unload at sea (UNCTAD, 2014). The low availability – and poor quality – of transport and its associated cost and travel times are a major barrier to all sustainable development and climate change adaptation agendas (Newell, et al; 2016). Most islands states are poorly serviced by donated and aged vessels running uneconomic routes and relying on government subsidies for the continuation of their day-to-day operations (ADB, 2010; Nuttall, et al, 2014a).

The availability of technology and infrastructure are also significant factors in determining a nation’s adaptive capacity and resilience in response to disasters. A number of the adaptive strategies developed globally to manage climate change include technological components such as the existence of warning systems, protective structures, crop breeding and irrigation, settlement and relocation or redesign and flood control measures (Cuevas, 2011). Throughout the Pacific region, sea transport is often the largest budget line in implementing climate change adaptation projects. It is often also the largest cost in disaster response for cyclones and drought events health immunization and other essential government service delivery programs (Goundar, et al., in press).

In the Pacific region, maritime and air transport modalities are much more highly utilized and relied upon than land modalities – the inverse of continental and large landmass country scenarios. In Fiji for example, where transport uses approximately 66 per cent of total imported fuel, 27 per cent is used for aviation, 23 per cent for maritime transport and 16 per cent for land transport. For some countries, maritime bunkering accounts for the majority of transport fuel, with Tuvalu reporting in 2012 that 38 per cent of its total fuel imports (equivalent to 64 per cent of all transport fuel) was used for maritime purposes (Newell, et al, 2016).

Nevertheless, given the remote geographic location and the dominant maritime nature of P-SIDS, sea transport remains a vital lifeline for the region. It plays a crucial role in trade and economic development, as well as being responsible for moving the vast majority of freight and people. For P-SIDS, waterborne transport is arguably more critical for connectivity than for any other society. Yet for many of its inhabitants, existing maritime transport services have become increasingly unaffordable and unsustainable. Pacific shipping is characterized by micro economies positioned at the end of long maritime trade routes with imbalanced inward/outward loadings which are further complicated by financing barriers, high operational risk, and high infrastructural costs. This array of challenges often leads to a vicious cycle of poor commercial returns resulting in old vessels being replaced by more old benevolently donated vessels. This means that all current options are fossil fuel powered, while the chances of local innovation projects for lower carbon emissions are extremely unlikely to take place without external collaboration and funding. This operational context poses marked inefficiencies at the domestic local and national levels, resulting in the highest per capita transport costs in the world. These unique characteristics present a greater challenge than for most other countries and regions and have been well documented (UNESCAP, 2010; SPC, 2011; Nuttall, et al, 2014b; UNCTAD, 2014; Newell, et al, 2016). Within the maritime theater, the international transport service is generally described as adequate, whereas the domestic situation is agreed to present the greatest challenge (ADB, 2010; SPC, 2011; Nuttall, et al, 2014).

The vulnerability of P-SIDS to natural disasters leaves many island inhabitants facing a repeated cycle of disaster recovery and increasing reliance on scant national resources for transport infrastructure repair. At the completion of a recent assessment of five P-SIDS following the devastation caused by '*TC Pam*' in 2015, the World Food Programme (WFP) declared that "*…shipping is the single issue which has clearly emerged as being of vital importance to the overall development of the region, its ability to respond to emergencies and to build resilience in the recovery phase*" (WFP, 2016). Despite the region's relatively minute contribution to global emissions, adaptation to a fast changing environment is no less urgent. Building or enhancing community resilience to such change is often cited as the preferred pathway towards sustainable and locally-driven economic development. Ensuring clean, affordable, appropriate and accessible transport therefore needs to be an essential element of future initiatives which into account the unique context of P-SIDS. Unfortunately, however, the urgent need for sustainable transport solutions is seldom recognized as a legitimate and central component of adaptation programming in current donor priorities or climate financing criteria, instead being considered as merely a 'mitigation measure' (Newell, et al, 2016). This misperception must be both challenged and remediated with compelling research and industry-based case studies if the growing discourse on climate financing for adaptation is to have a meaningful impact on the design and application of policy and financial instruments for this critical issue of climate change.

The unique challenges faced by P-SIDS as described above highlight the need for an urgent transition to low-carbon transport futures. Failure to achieve such a transition in the coming years will mean continued – or increased – imported fuel dependency and the associated vulnerability to global oil price shocks, higher transport costs, increasing economic penalties from continued reliance on outmoded technologies and future technology slip in an already marginal sector (Nuttall, 2015). The critical and cross-cutting importance of the sea transport sector to the advancement of most P-SIDS' development goals has been consistently recognized (Moon, 2013; UNCTAD, 2014). However; while the developmental and social costs of not being able to provide affordable, accessible transport is recognized, market-ready and economically viable solutions have proven slow to arrive.

The transition to low carbon transport solutions presents a logical and rational pathway if it can be achieved within a sustainable and systemic manner. Nevertheless, this is an issue which has so far been overlooked in the regional development agenda. The barriers for the discussion around renewable energy technologies are complex and poorly recognized (Nuttall, et al, 2015). To an increasing degree, the high-level policy vacuum is being overcome as demonstrated by the S.A.M.O.A. Pathway (UNSIDS, 2014). However the flow-on to operational national and regional policy is still yet to come. While all Pacific countries have enacted some degree of policy change calling for a transition to low carbon electricity generation, the consideration of transport still lags disconcertingly far behind in contemporary discussion. Of the 14 P-SIDs that submitted Intended Nationally

Determined Contributions (INDCs) to the Paris Agreement, only the Republic of the Marshalls Islands (RMI) included specific (and unconditional) transport emissions reduction targets of 16 per cent by 2015 and 27 per cent by 2030 (Goundar, et al., in press).

Policy and financing alongside imbedded perceptual barriers and the protectionist strategies evident among leading regional institutions remain as key constraints to progress in this area. What remains clear is that the technology itself is not the impediment. Rather, numerous technological and operational approaches offer relatively inexpensive, mature and available options for sea transport (Mofor, et al, 2015; Lloyds, 2015; Rehmatulla, et al, 2015). Indeed, Mofor, et al. (2015) found that "*…the development of renewable energy solutions for shipping has been hampered by over-supply of fossil fuel-powered shipping in recent years and the related depressed investment market… Ultimately, market forces working within a tightening regulatory regime will govern the speed of uptake of renewable energy technology for shipping, although this will also be tempered by infrastructure lock-in and other non-market factors… For quick-win solutions, support should focus on small ships (less than 10,000 dead weight tonnage), which are more prevalent worldwide, transporting less of the total cargo but emitting more of the greenhouse gases per unit of cargo and distance travelled, compared to larger ships*." To this end, this chapter will now move on to consider the contribution that P-SIDS can make through the demonstration of small vessels leading to viable business cases that will facilitate a future wide scale market uptake of low emission maritime technology.

3. The value of P-SIDS as demonstration fields for renewable energy solutions

It can be argued that nowhere is there a more urgent need for existing and emerging low carbon maritime technologies than at the front line of climate change where the very existence of P-SIDS is directly threatened. Demonstrating market feasibility in developing economies places downward pressure on production costs for new technologies and paves the way for broader market demand of low-emission maritime technology. If a concerted effort was to be made to develop low carbon solutions for P-SIDS, then this could be leveraged positively to create a real world 'test bed' for technology development and refinement to benefit other LDCs as well as the wider global maritime industry.

Almost all international initiatives and priorities relating to transport currently do not address or provide for the unique challenges and needs of P-SIDS. There is little correlation between the transport dilemma facing P-SIDS and those of the continental world. Mega urban, rapid rail, inland waterways and electrification dominate global transport priorities, while energy efficiency in sea transport is targeted almost exclusively towards promoting further investment in large-scale and new-build assets. It is therefore of vital importance to develop locally-appropriate and customized solutions that will have wider application in other regions to support a global effort towards realizing a low carbon economy. The development of this technological response needs to be proactively and assertively instigated by targeted actions, rather than continuing the passive course of waiting for low carbon energy technologies to filter down from global to local (Nuttall, 2015).

As discussed above, the maritime transport requirements of most P-SIDS are characteristically small-scale. Vessels of 10,000 dead weight tonnage are at the top end of the regionally-operating fleets, while most national fleets consist of vessels well under 5,000 dead weight tonnage and generally less than 1,000 dead weight tonnage. At the village level, open or partly-covered skiffs powered by outboard engines of 15-75 horsepower are the normal mode of connectivity for intra and inter-island/atoll work. While village vessel sizes are small, they are required to work in blue water conditions, often on routes of up to 100 nautical miles or more.

The small scale of the countries themselves (RMI for example has a population of some 60,000) means that they provide a suitably-sized 'scale model' for attempting something as ambitious as a 'whole of country' approach to low carbon transition. Domestic fleet sizes are generally small, with Tuvalu accounting for only two small cargo/pax freighters, a patrol vessel and a tuna long-liner, and RMI laying claim to only five government boats of under 500 dead weight tonnage, two local government vessels of similar size and 30 smaller private vessels.

For these reasons, the Pacific presents itself as an ideal proving ground for emerging low-emission maritime technologies. If new build or retro-fitted technologies can be demonstrated to have commercial and economic viability in commercial deployment in Pacific islands, then it is reasonable to assume that they can also be scaled-up for larger craft deployed in more populous regions further afield. This would also represent a turning of the tables with regard to the previous utilization of the region as a testing ground for 'negative' technologies including nuclear weapons and large-scale extractive fishing. Utilizing the Pacific as a proving ground for new and emerging low emission technologies in sea transport offers a positive alternative, while the potential advantages and benefits to the P-SIDS make it a low cost and low-risk testing environment.

4. Responding through technical innovation

Over the past decade, high oil prices and widespread environmental concerns for the shipping industry's contribution to GHGs have spurned on technology developers to facilitate a timely and proportionate response to climate change. Coordinated actions involving key experts from academia and industry have already made significant progress in developing technological innovations for the maritime industry. A strong and growing research base spanning key European innovation fields is today laying the foundation for new technological solutions in response to emerging market demand. Innovative solutions have in this way been successfully demonstrated to reduce carbon emissions and fuel consumption, thus fulfilling long-term environmental and economic objectives.

These ambitious goals are being achieved within a two-pronged approach, although in reality these two approaches may also be combined on the same vessel. The first approach is to reduce the unwanted loss of energy from ships by reducing hull resistance in travelling through the water. Examples of technologies with demonstrated results in meeting this objective are: (i) improved hydrodynamic hull designs; (ii) low friction paint coatings; (iii) greater efficiencies from energy-consuming machinery on-board from main engines to the generators; and (iv) the shape, number and positioning of propellers. The second approach is to utilize renewable energy for ship propulsion to reduce the power demand from the main drive system. As the first approach is based on existing technology that has to be refined by continuous research, the second approach demands much more effort as the use of renewable energy has not been used in commercial shipping since wind power was replaced after a commanding reign of more than 3,000 years.

The success of renewable energy in shipping will depend on competitiveness against established fossil fuel propulsion. It seems unlikely that renewable energy will take over a major share of the energy consumption for shipping in the future when compared with the production of electric energy onshore in many countries[5]. While national and global politics have received strong and very public support in the transition towards renewable electricity, a closer look reveals that the use of fossil fuels in the shipping industry has so far been protected from any form of carbon tax or other levy on environmental damage. Thus renewable energy in shipping has a rather unfavorable starting position in comparison to its shore-based counterparts.

There are two ways of using renewable energy for ship propulsion. Energy produced ashore may be stored and consumed on ships such as biofuels, synthetic fuels or electric power in batteries. Alternatively, wind and solar (and potentially wave) energy can be converted directly into propulsive

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[5] For example 27.8 per cent of the electric power in Germany was generated from renewables in 2014 and is predicted to rise to 50 per cent by 2030 according to government policy (BDEW, 2014 and 2015).

thrust or electric power. For stored energy there are relatively high production costs for conversion of surplus wind energy into fuel. The use of the fuel on board also requires specially-designed dual-fuel engines and/or fuel cells. Fortunately, however, the most common ship designs seen today do not need to be drastically altered to accommodate alternative forms of propulsion apart from the re-allocation of space on board. While ships reliant on wind and solar power face significant – and oftentimes limiting – capital costs to be equipped with sails and/or PV-panels, the operational cost of wind and solar energy on board a ship can be substantially reduced. This helps to make investments in renewable energy solutions more attractive over the long term, whilst enabling vessels to maintain normal service speeds, even under unfavorable wind conditions. In some cases, where service speed and delivery times are of lesser importance, the size of a vessel's main propulsion system may even be reduced to that which is needed only for maneuvering operations.

Nevertheless, the incorporation of innovative propulsion systems and adaptations can also come into conflict with existing ship designs and potentially create extra training costs to transition from old to new technologies. Therefore, it must be kept in mind that changing the established system based on fossil fuels into low carbon shipping will demand an extra effort from all involved parties. At the same time however, there is no real alternative if the goals of climate policy are to be acted upon within an earnest and targeted approach to addressing the challenges of climate change by the maritime industry.

Indeed, the achievements that have been made to date in the development of wind and solar energy are extremely encouraging and provide a strong indication of the steps to be taken going forward. The past decade in particular has seen some ambitious – yet not always successful – projects being undertaken based on the use of wind and solar energy to reduce onboard electricity consumption for extraneous ship functions such as lighting and AC power. The shipping line NYK received official recognition as '*Ship of the Year'* at Lloyd's List 2009 Global Award for the experimental installation of 328 solar panels on the car carrier *Auriga Leader.* One of the key lessons from this undertaking however, was that the production of up to 40kW electric power which amounts to a mere 0.05 per cent of the main engine's power, thus revealing a major limitation of solar power that requires large panel areas to generate significant quantities of power to cover ships' demands.

Meanwhile, the power density contained within wind flow has been demonstrated to be capable of meeting the full power demand of vessels for propulsion (depending on prevailing wind conditions and the required speed). This has been demonstrated by the *E-Ship 1*, an innovative 10,000 dead weight tonnage cargo carrier developed by the German wind turbine manufacturer Enercon. This vessel demonstrated its capability to sail with a speed of up to 12 knots under optimal wind conditions when 100 per cent powered by four Flettner-rotors utilizing the 'Magnus-effect' (Schmidt and Vahs, 2013). Research and innovation initiatives in this area have taken the form of projects to trial different wind propulsion technologies (e.g. traction kites, soft wings, rigid wings and Flettner-rotors) on yachts and commercial ships. A selection of these results, as well as the suitability of wind propulsion technologies for the small-scale shipping scenario of the P-SIDS is discussed in further detail below.

Given the growing importance of punctuality in time schedules to support modern just-in-time sea logistics, it is important to note that a dependence on wind and solar energy is always associated with the risk of unfavorable weather conditions. This makes backup propulsion based on stored energy an indispensable component of modern wind propulsion systems.

5. Viable maritime technologies

In order for a transition to a low carbon transport to occur on a significant scale, a coordinated strategic response must be undertaken in the form of technology transfer from global innovation fields to P-SIDS. Introducing technological innovations from the world's leading technology developers means not only opening up an expanded global market for these products, although this is already an attractive market-based incentive in itself. Rather, technology transfer to P-SIDS means combating the challenges of climate change with the best available arsenal and ensuring that these technologies achieve the maximum impact for which they were initially designed. This strategy also needs to be compatible with – and complementary to – existing regional and national transport frameworks and work programs and also build further upon the existing research within a 'whole of sector' multi-disciplinary approach (Nuttall, 2015).

For specific innovative solutions that are both capable of and suitable for addressing the challenges described above, it is critical to select technologies that are appropriate to the operating environment, and the specific needs and constraints of the local contexts in which they will be deployed. High-tech and complicated designs that require a high degree of sophisticated human resource capacity to operate and maintain are unlikely to succeed in a region where the availability of highly-skilled technicians and access to spare parts and servicing networks are lacking. Rather, mature, market-ready and operationally viable solutions must therefore meet the following criteria:

- **Clean (low emissions)** - Pacific leaders have consistently stated their intention to advocate for the strengths and unique advantages of the region on broader global platforms and to lead by example for other developing states;
- **Affordable –** it must be possible for both clients (local communities to national governments) and service providers from local to international shipping operators to sustain the operational costs of new technological solutions;
- **Accessible –** in terms of access to finance, technology, maintenance, human and logistical capacity;
- **Maintainable –** low-skilled maintenance, simple technology, parts can be easily obtained (locally or at least close by) and at reasonable cost;
- **Reliable –** highly robust under extreme tropical weather conditions and Pacific operational constraints; and
- **Achievable –** in terms of implementing the technology on a scale large enough to make a significant impact.

The following case examples sketch four potentially game breaking solutions for which demonstrated technology exists in Europe and Korea:

Flettner Rotors

The generic term 'Flettner Rotor' refers to all forms of rotor technology harnessing the 'Magnus effect' by which a spinning cylinder (or ball) curves away from its principle flight path. Anton Flettner first applied the Magnus effect to ship propulsion in the 1920s. This work proved that the Magnus effect could be harnessed as an effective method to reduce fuel use and automatize sail technology for commercial blue-water shipping. In principle, the technology is relatively simple in both construction and operation and it is considered to have potentially high application across a range of shipping scenarios, including small and large-scale transport and fishing vessels, see Figure 3 below of *E-Ship 1*.

Figure 3: Rotor-ship *E-Ship 1* in sea trials (Source: Cassenswerft, 2011)

Despite Flettner rotors being demonstrated to be an effective innovative response capable of reducing both cost and energy consumption during the energy crisis of the 1920s, the technology failed to achieve significant market uptake when real oil prices fell to their lowest ever level at the end of that decade. The low cost of fossil fuels and emerging technologies in diesel ship propulsion meant that the idea did not progress beyond the initial operational prototypes. Flettner rotor technology was thereafter largely forgotten about until the 1970/80s oil crisis when it was briefly re-examined. In the wake of a pressing agenda to respond to climate change, a number of leading shipping designers and researchers have over the past decade begun to investigate modern applications of this technology. Today there is growing international research in this field up to the stage of 'proof of concept' designs. The application of this technology for P-SIDS, however, has not been previously considered until now (Nuttall and Kaitu'u, 2016).

At the time of writing, there are three projects known to the authors which trial Flettner rotor technology on demonstration vessels. The results are so far very positive with regard to technical reliability and aerodynamic performance, both of which are fulfilling expectations of their impact on vessel propulsion. In 2010, the leading German wind turbine manufacturer Enercon developed a new design of the Flettner rotor that has been integrated into the design of their own *E-Ship 1* (Figure 3), an 10,000 dead weight tonnage cargo carrier specially optimized for the transport of wind turbines. Enercon rationalized this investment decision in Flettner rotor technology based on its advantages of high aerodynamic thrust, robust design and its capability of fully automatic operation. Another advantage is that the generated thrust is proportional to the rotor rotational rate (RPM) which can be controlled so that ship safety is not impeded by excessive lateral thrust in strong winds. The emergency stop function rounds out the technology as a very safe wind propulsion system. Following a rigorous evaluation phase involving more than two years and about 170,000 nautical miles of operational experience, Enercon reports average fuel savings for the *E-Ship 1* in the order of 25 per cent, of which 15 per cent results directly from the Flettner rotors alone. In sea areas with favorable wind conditions, Enercon reports even higher fuel savings of up to 36 per cent at a ship speed of approximately 17 knots and a wind speed of 24 knots. A ship speed of up to 12 knots was reached with 100 per cent propulsion coming from the Flettner rotors.

Inspired by *E-Ship 1* and the identified market need for technical solutions specifically for smaller ships, a Dutch-German research and development consortium took the initiative in 2014 to develop the *Wind Hybrid Coaster*[6], a vessel specially suited for coastal trades. After an analysis of all relevant criteria, the consortium decided to develop a new type of Flettner rotor based on lightweight materials and using a different drive configuration delivering a higher RPM and increased aerodynamic performance. The *Wind Hybrid Coaster* was part of the MariTIM project, a German-Dutch cooperation initiative co-funded by the European Union under the framework of INTERREG IVA. A follow-up project, MariGreen[7], is currently underway and also being managed by the same lead partner, the MARIKO Competence Center based in Leer, Germany. Within this project the new rotor will be installed and trialed on board a 4,000 dead weight tonnage multipurpose cargo carrier.

In comparison to other wind propulsion technologies, Flettner rotors generate high aerodynamic thrust with a small deck space requirement. In current motor ship designs, available deck space is very limited due to large cargo holds and cargo gear such as cranes. This makes Flettner rotors an extremely attractive option as an auxiliary propulsion system, particularly when installed at the ends of the ship's hold. At the time of writing, Flettner rotors have been developed to the point that they are ready for application on ships upwards of 50 meters in length and have high relevance as a low-cost and low-emission technology on the routes connecting P-SIDS. For ships below this size, a new design of smaller and lighter rotors still needs to be developed. A design objective would be the use of available standard parts and materials enabling maintenance and repair service, particularly in remote areas. Smaller rotors could even possibly use cheaper and more readily available parts sourced from the automobile industry.

Soft Sail Cargo Carriers

To ensure the successful market uptake of sail technologies on low carbon vessels in P-SIDS, an extremely demanding set of criteria must be met. Beyond the basic requirement of a safe and reliable operating system, the economic competitiveness of the solutions must be proven to demonstrate real-world viability within a range of different operating environments. Sailing performance must be evaluated against cost structures for production, installation, maintenance and operational demands and the training requirements of the ship's crew. In this regard, simpler technologies such as soft sails with lower performance indicators can still be more cost effective than high-tech innovations. Recent cost-benefit analyses have indicated that soft sails could be more competitive than more sophisticated sail technology such as Flettner-rotors if the installation of masts and sails does not interfere with other design and operational criteria of the ship. Soft sails seem to be a particularly suitable solution for smaller vessels (up to 50 meters), given that larger sail areas come with higher demands on safety requirements, particularly in construction and handling.

It is important to note that modern soft sail technology differs significantly from traditional applications of the past. Recent projects in yachting indicate the feasibility of fully automatic operation, such as that demonstrated by the so-called '*Dynarig*' on the 90-meter mega-yacht christened the '*Maltese Falcon*'. However, for application on commercial ships, technical concepts still need to be adapted for greater reliability and rigor in the system configuration, as well as improved safety and also greater simplicity in operation. For commercial applications, the degree of automation may have to be less, unless the cost structure can be reduced significantly to enable the work load of system operations to be handled without additional crew. Even additional crew demand can become feasible if the overall cost structure is competitive and a positive socioeconomic impact can be achieved.

There have been some projects where soft sail rigs have been optimized for use in commercial shipping. One example is the development and trial of the *'Indosail Rig'* in the 1980s, intended specifically for Indonesian inter-island trade (Schenzle, Weselmann & Weiss, 1985). Trials in Fiji in 1984-86 with soft sail retrofits to existing 300 gt general purpose government vessels recorded

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[6] http://www.maritim-de-nl.eu/projekte/wind-hybrid-coaster/

[7] http://www.mariko-leer.de/projekte/marigreen/

average fuel savings of 23-30 per cent combined with reduced operational costs at attractive rates of return on investment. Unfortunately, however, these trials were curtailed by the sharp fall in oil prices in 1986 (Newell et al, 2016). Results from such trials and innovations in the field of material and aerodynamics provide a good basis for new concepts suitable for small-scale low carbon shipping.

Wing-In-Ground Vessels

'Wing in-ground effect' vessels (WIGs) is a generic term used to describe vessels which are designed to attain sustained flight over a level surface (usually over water) by making use of the '*ground effect'*, the aerodynamic interaction between the wings and the surface (see Figure 4 below). For this reason, WIGs do not achieve true flight as such, given that that the vessel makes use of a cushion of air between the wing and the water surface, resulting in greatly reduced fuel consumption. While the 'ground effect' has been known since aircraft began flight, it was not until the 1960s that serious investigation into its concerted application began in the Soviet era. In more recent years, research and development into the ground effect has been dominated by German and Korean technology developers.

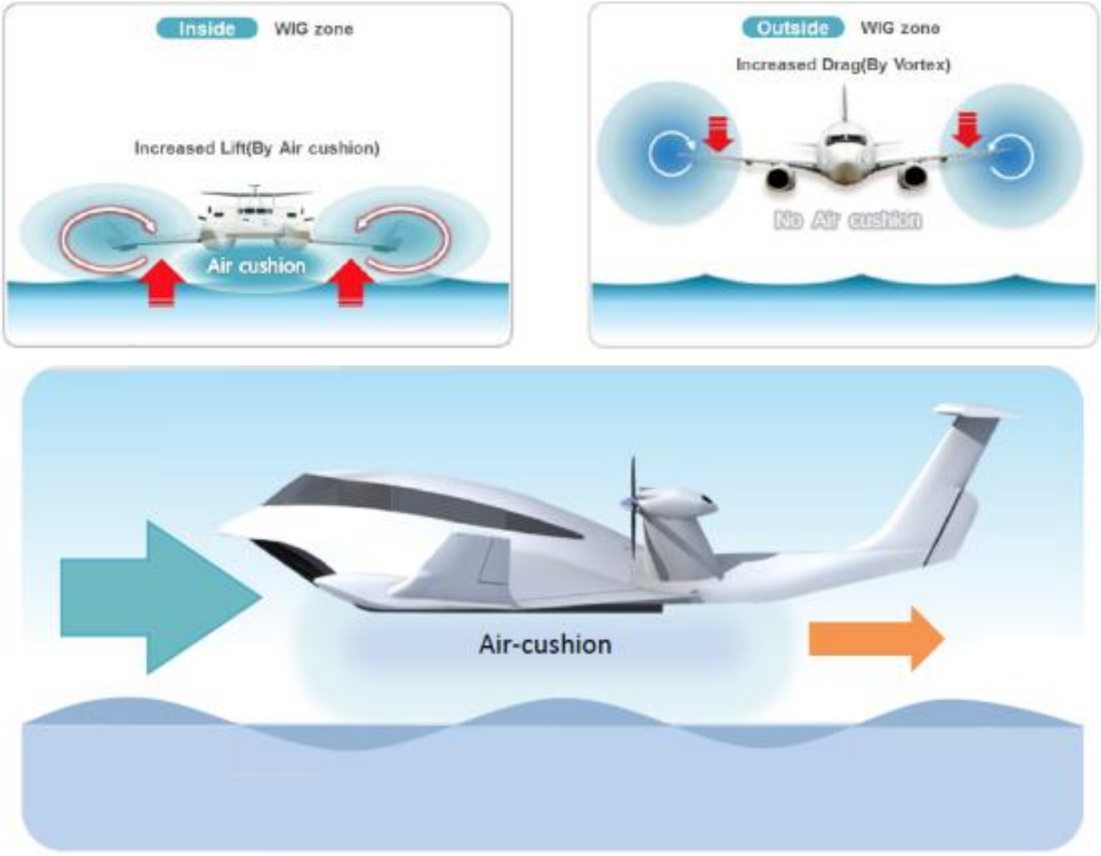


Figure 4: Wing-in-ground Effect (Source: Kang, 2016)

Inter-island air travel in P-SIDS, especially for small island and atoll states, generally involves small aircraft with limited passenger and freight-carrying capacity, travelling relatively long distances (200 nautical miles and more). The disadvantage of this form of transport is that it is dependent on expensive runway infrastructure that is also vulnerable to natural disasters and takes up valuable land space in a region where access to land is at a premium. For this reason, the size of aircraft in P-SIDS Pacific is determined by journey distances and the small sizes of available runways. Nonetheless, there remains a large and growing demand for a fast mode of transport within and between island states which also has capacity to carry larger passenger and freight loads than that currently available with the small 12 and 20 seat twin engine craft common throughout the region for domestic use. An alternative form of transport therefore presents an imminent need in P-SIDS, especially given that many island locations have sheltered adjacent waters suitable for landing and takeoff of WIGs.

Recent WIG designs include the Korean *'Wingship 500'* which is now nearing commercial deployment and capable of carrying passenger loads of 50 people or 10 ton of cargo on 500-kilometer hops. Using a reported one-third of the fuel of an equivalent-sized high-speed vessel, the *'Wingship 500'* promises to become true game-changing technology, particularly if its introduction can be proven in a commercial operating environment, with application potential as a direct competitor for general local fast transport and tourism service delivery, maritime surveillance and search and rescue operations.

Specification of WSH-500

· Dimension	29m · 27m · 7m(Length · Width · Height)
· Cruising Speed	180km/h
· Cruising Altitude	2~5 m
· Materials	Aluminum alloy
· Payload	50 persons
· Max. Range	1,000km
· Operation Limit	
- Normal Take-off/Landing	Sea State 3
- Extreme Landing	Sea State 4
· Propulsion	1,400HP × 2EA Turboprop
· Fuel Consumption	460kg/h
· Certificate	Lloyd's Register
· Design Life	20 years

Figure 5: Wingship 500 (Source: Kang, 2016)

Other forms of application for WIG technology include specialized disaster response and medical evacuation functions in which WIGs could be revolutionary. There are numerous outer-island and remote locations across P-SIDS where a ship must be specially chartered or re-routed for a single passenger in cases of medical emergency, often entailing a long and uncomfortable journey for the patient and great expense, usually fully or heavily government-subsidized. In disaster response situations, the benefits are obvious: the capability to deliver emergency response teams along with several tons of emergency relief supplies quickly and directly to beachheads following cyclones, tsunami and flooding events means that WIGs could be a cost effective life-saving technology.

As with other technologies, the challenge now is to fully ascertain the economic costs versus benefits in real world operating scenarios. This needs to form the foundation of careful planning in terms of crew training, maintenance and associated infrastructure over full vessel lifetimes to really determine the appropriateness of WIGs for P-SIDS. As with rotors and soft sail applications, the unique Pacific operating environment offers as an ideal proving ground for these technologies.

Biofuel propulsion

Biofuels have long been touted as a leading candidate for the substitution of fossil fuels. Increasingly the aviation industry is promoting biofuels as one of the few contenders for reducing carbon footprints of aircraft. However, thus far, this technology has yet to see significant uptake on a large scale commercial level.

Mofor et al. (2015) examine the case for biofuels in the maritime sector and find that experience with their use and the scale of their application in the shipping sector is still minimal. A comprehensive evaluation of alternative fuels for marine applications, including biofuels, is given in the Annex 41 report of the *Advanced Marine Fuels Implementing Agreement of the International Energy Agency* (IEA-AMF, 2013). Other studies have also assessed the potential use of biofuels in the shipping sector (see DNV, 2014; Lloyds Register and UCL, 2014; EffShip, 2013; Ecofys, 2012). Biofuels can be used in the sector in the form of biodiesel, bioethanol, biomethane, straight vegetable oil (SVO), dimethyl ether (DME), pyrolysis oil, hydrogenated vegetable oil (HVO) and other derivations. The pathways for producing these fuels from biomass-based feedstock is summarized below.

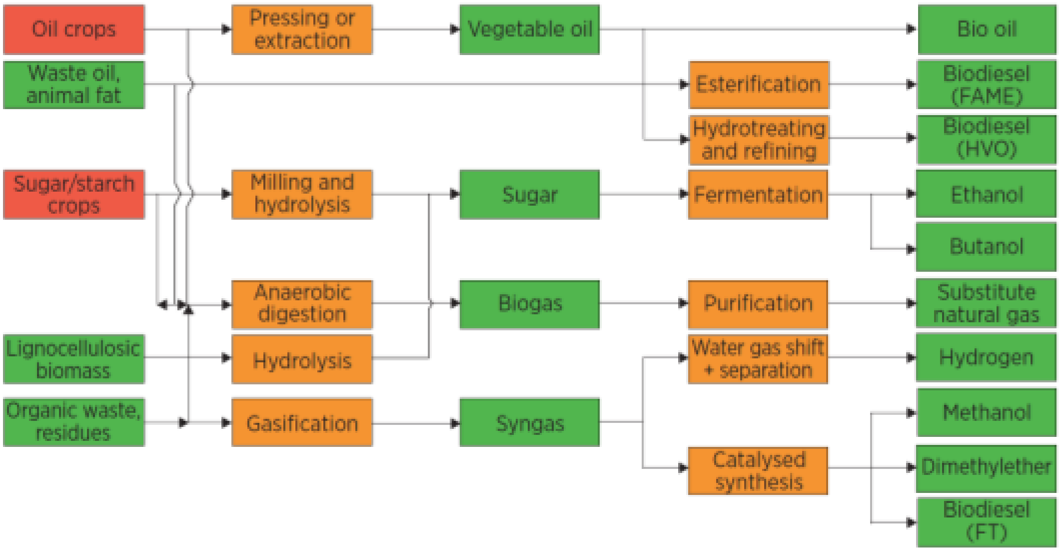
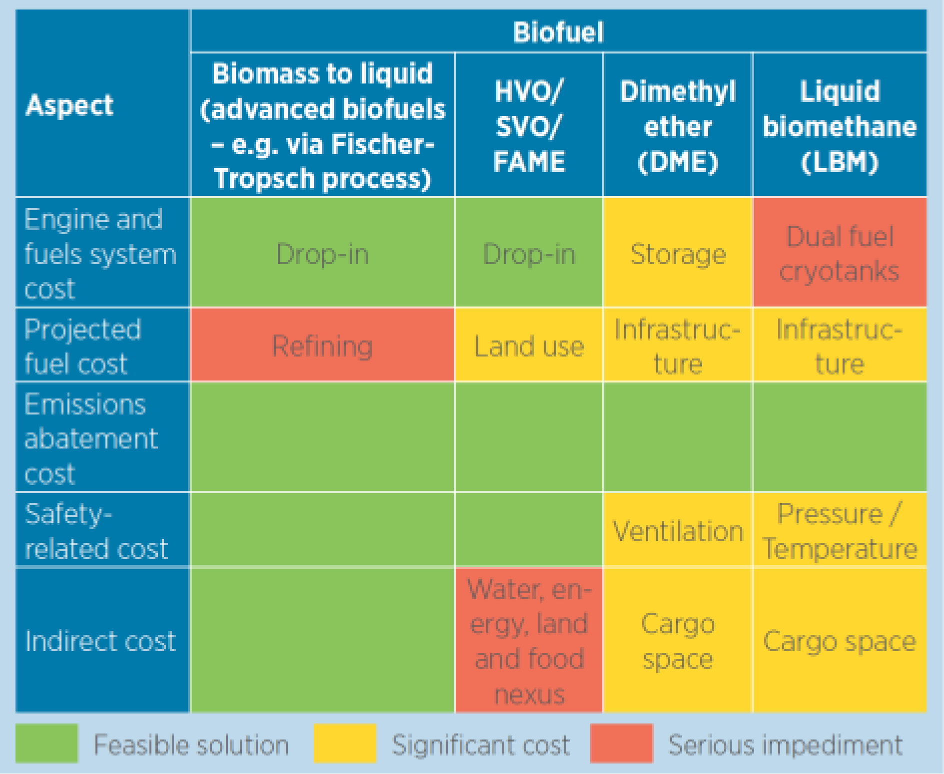


Figure 6: Summary of pathways for conventional and advanced biofuels production (Source: Mofor et al, 2015)

For propulsion fuel, three basic options exist: (i) bio and conventional fuel can be blended and then bunkered; (ii) dual fuel tanks can be used onboard; or (iii) 100 per cent biofuel can bunkered. Then there are two primary engine choices between custom built and modification of existing power plants. Significant advancements in biofuel technology have been made, particularly in Europe and development centers such as Korea, which can be immediately applied to a Pacific maritime research agenda.



Aspect	Biofuel			
	Biomass to liquid (advanced biofuels – e.g. via Fischer-Tropsch process)	HVO/ SVO/ FAME	Dimethyl ether (DME)	Liquid biomethane (LBM)
Engine and fuels system cost	🟩 Drop-in	🟩 Drop-in	🟨 Storage	🟥 Dual fuel cryotanks
Projected fuel cost	🟥 Refining	🟨 Land use	🟨 Infrastructure	🟨 Infrastructure
Emissions abatement cost	🟩	🟩	🟩	🟩
Safety-related cost	🟩	🟩	🟨 Ventilation	🟨 Pressure / Temperature
Indirect cost	🟩	🟥 Water, energy, land and food nexus	🟨 Cargo space	🟨 Cargo space

🟩 Feasible solution 🟨 Significant cost 🟥 Serious impediment

Figure 7: Summary of applications and issues for biofuels in shipping (Source: Mofor et al, 2015)

While the required technology is generally available based on existing applications in other sectors, there is strong international debate over the actual impact that such fuels would make with respect to the global climate change agenda. Such discordance generally involves questions related to the supply of feedstock, economic viability of production and impacts on trade and competing needs for land resource and food security.

For P-SIDS, the question arises as to whether there are local resources that could cover the demand such as fuels from coconut or algae farming. While exploration in this field could potentially open up a future of self-sufficient supply, such efforts need to be approached with caution, with any development based on valid scientific research and rigorous economic analysis. Previous trials using coconut derivatives have so far proved to be unsustainable over the long-term due to technological and operational issues. The economics of coconut fuel substitution is not made in the current low petroleum base cost environment. Third generation biofuel from marine feed stock appears attractive in concept, however there is only minimal available research that is specific to island locations that can underpin further studies in this area. Korea is currently preparing a large program in Fiji using cultivated woody species for feedstock for biodiesel and Samoa has announced intentions to apply for financing through the Green Climate Fund to develop biodiesel for land transport substitution.

In a recent study, Bijay and Singh (2015) discuss the increasing attention that is being given to the uptake of first generation biofuels in the Pacific, indicating that they provide the region with an available means to reduce dependence on costly fossil fuel imports. It should be noted that this generality cannot be ascribed equally across the entire region, but instead applies specifically to those countries with high-elevation islands and a naturally high prevalence of biota. The study argues that if implemented properly, an indigenous biofuels production program would contribute to social and economic development, improve energy access and provide a valuable means for satisfying the region's emissions reduction obligations. Parts of the region offer important advantages, including a favorable climate and the apparent availability of marginal land. Successful realization of a biofuel industry for the region must seek answers to critical questions and overcome persistent barriers to market uptake, not least of which is a demonstrated economic viability and maintained supply and quality of production and blending.

For those P-SIDS with minimal landmass, such as the atoll states of Tuvalu, Kiribati, RMI and Tokelau, terrestrial feed stock is not an option. However, aquatic sources provide high potential, especially if numerous forms of invasive marine species including seaweeds, starfish and algae, could be harvested with a dual marine conservation benefit. The scientific process of converting such carbon forms into usable energy is both well-known and achievable (N'Yeurt and Lese, 2015). The remaining barriers lie in achieving economies of scale within a sustainable market-based framework and employing this technology aboard small-scale vessels. In this instance, the technology itself is only a marginal barrier given that it already exists in other sectors; instead the real barriers stem from the lack of policy and financing available to adapt existing knowledge within a Pacific maritime operational context as described above.

6. Call to advance this agenda of climate change through renewable energy technology in the maritime industry

2015 was the hottest year since records began (WMO, 2016) due to the self-perpetuating nature of global warming and the escalating extremity of its destructive impact on P-SIDS. To this context, P-SIDS are facing incalculable losses in both life and costs associated with rebuilding transport infrastructure and also in fleets that are lost or damaged in severe tropical cyclones, floods, coastal inundation events. The case for the transfer of technology and knowledge makes economic sense not only as a proportionate and desperately overdue response to natural disasters, but also as an effective method of achieving sustainable development in the Pacific region and beyond. Achieving these ambitious goals relies on the fundamental cornerstone of collaboration – within and between nation states, private industry, academia, civil society, and international and regional agencies. Research and education in this regard provides a building block upon which to begin the transition to a low carbon future – now, before it is too late.

This urgent call for collaboration on the agenda of climate change through renewable energy technology recognizes that substantive barriers certainly do exist, particularly for P-SIDS where the barriers of geographic isolation play against the difficulty of attracting high caliber expertise, technical engineering and research financing. The scale and complexity of these challenges and the broader implications that they have in forming a global response to climate change calls for a proportionate response based on concerted, high quality and targeted support from state and industry actors in upholding the spoken and written commitments made in Paris Agreement (UNFCCC 21st Conference of Parties).

The key impetus for change behind this call is climate change, whereby the spotlight now shines squarely on the theatre of the Pacific Ocean. Pacific islanders are the front line, and yet they have contributed nothing to the crisis at hand. Nothing short of a paradigm shift will limit the existential threat they face on a daily basis. To an increasing degree of concern and engagement, leading researchers and partners are answering the call for a 'Coalition of Higher Ambition' for low carbon shipping. In 2015 Micronesian Presidents endorsed a call from RMI to establish a '*whole of country'* strategy to transition to low carbon transport (Nuttall, 2015; Goundar et al., in press). The successful implementation of such a strategy in just one P-SIDS would have the potential to start a ripple in the Pacific that causes a cascade when the ocean wave reaches continental shores.

References

Anderson, K and Bows, A. (2012) Executing a Scharnow turn: reconciling shipping emissions with international commitments on climate change *Carbon Management* (2012) 3(6), 615–628.

Albert, S., Leon, J.X., Grinham, A.R., et al (2016) Interactions between sea-level rise and wave exposure on reef island dynamics in the Solomon Islands. Published 6 May 2016 IOP Publishing Ltd. Environmental Research Letters, Volume 11, Issue Number 5.

Asian Development Bank (2010) *Responding to Climate Change in the Pacific: Moving from Strategy to Action*. Mandaluyong: Asian Development Bank.

Baunto, A. and Arquiza, Y. (2009)*How much did Ondoy cost? For starters, try P23 billion*. Available at: www.gmanews.tv/story/174251/how-much-did-ondoy-cost-for-starters-tryp23-billion (accessed 8 March, 2016).

Bijay, P. and Singh, A. (2015) Progress towards low carbon fuels in the Pacific – prospects and challenges. In: Climate Change in the Asia-Pacific Region. *Climate Change Management*. Springer International Publishing, Switzerland, pp. 335-356. ISBN 978-3-319-14937-0 or 978-3-319-14938-7.

Bundesverband der Energie und Wasserwirtschaft e.V. (BDEW) statistics 2014, 2015

Cuevas, S.C. (2011) Climate change, vulnerability, and risk linkages. *International Journal of Climate Change Strategies and Management,* 3(1), pp. 29 – 60.

Diez-Picazo, M. F. (2007) Climate Change and the Future Maritime Policy for the EU. *Journal of Maritime Affairs, Vol. 6*(2), pp. 241–247.

DNV (2014) *Alternative Fuels for Shipping*. DNV Position Paper, 1-2014.

Ecofys (2012) *Potential of Biofuels for Shipping*. Utrecht: Ecofys.

EffShip (2013) *Work Package 2 Report: Present and Future Maritime Fuels*. EffShip Project.

Feeny, S. and Rogers, M. (2003) Innovation and performance: Benchmarking Australian firms. *Australian Economic Review, 36*, pp, 253–264.

Fiji Government (2016) *Speech by the Hon Prime Minister at the 72nd Session of UNESCAP (Thailand)* 17 May 2016, http://www.fiji.gov.fj/Media-Center/Speeches/SPEECH-BY-THE-HON-PRIME-MINISTER-AT-THE-72ND-SESSI.aspx

Fiji Sun (12 March 2016) http://fijisun.com.fj/2016/03/12/western-homes-worst-hit/

Goundar, A., Newell, A., Nuttall, P. et al (in press) King Canute Muses in the South Seas: why aren't Pacific Islands Transitioning to Low Carbon Sea Transport Futures? http://pace.usp.ac.fj/Portals/18/OCST/Press/Breaking%20News/King%20Canute.pdf

Griffin, S. N'Yeurt, A.D.R. ; Dumas, P. & Iese, V. (2016). Sustainable biofuel and organic fertiliser from the anaerobic digestion of Crown-of-Thorn starfish (*Acanthaster planci* L.) in Fiji. Journal: *Biofuels* (Taylor& Francis).

Hansen, J., Sato, M., Ruedy, R. et al (2016) Global Temperature in 2015 http://www.columbia.edu/~jeh1/mailings/2016/20160120_Temperature2015.pdf

IEA-AMF (2013) *Annex 41 Report: Alternative Fuels for Marine Applications* [online]. Available at http://www.iea-amf.org/app/webroot/files/file/Annex%20Reports/AMF_Annex_41.pdf

Intergovernmental Panel on Climate Change (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kang, C. (2016) Wingship Industry in Korea. Presentation to *3rd Blue Green Economy Symposium*, 5 May 2016, Suva, Fiji. Korean Embassy

Lassere, P. (2003). *Global Strategic Management (1st Ed.).* UK: Palgrave Macmillan.

Lloyds Register and UCL (2014) Global Marine Fuel Trends 2030 [online]. Available at http://www.lr.org/en/_images/213-34172_Global_Marine_Fuel_Trends_2030.pdf

Lloyds Register (2015) *Wind-powered shipping: a review of the commercial, regulatory and technical factors affecting uptake of wind-assisted propulsion*. Lloyd's Register, London.

Michaelowa, A. and Krause, K. (2000) International Maritime Transport and Climate Policy. INTERECONOMICS, May/June, pp.127-136.

Milliot, E. and Tournois, N. (2010) *The Paradoxes of Globalisation*. London: Palgrave Macmillan.

Mofor, L., M. Isaka, H. Wade et al (2013) *Pacific Lighthouses: Renewable Energy Roadmapping for Islands.* IRENA, Bonn.

Mofor, L., Nuttall, P., and Newell, A. (2015) *Renewable Energy Options for Shipping: Technology Brief*. IRENA, Bonn.

Moon, J. R. (2013) *Strengthening Interisland Shipping in Pacific Island Countries and Territories. Background paper*. http://www.unescap.org/sites/default/files/Background-Paper.pdf

Newell, A., Nuttall, P., Prasad, B., et al (2016) Turning the Tide: the need for sustainable sea transport in the Pacific. *Marine Policy* DOI: 10.1016/j.marpol.2016.01.009.

Nuttall, P., Newell, A., Prasad, B., et al (2014a) A review of sustainable sea transport for Oceania: Providing context for renewable energy shipping for the Pacific. *Marine Policy*, 43:283-287 http://dx.doi.org/10.1016/j.marpol.2013.06.009.

Nuttall, P., Newell, A., Bola, A., et al (2014b) Policy and financing—why is sea transport currently invisible in the search for a low carbon future for Pacific Island Countries? *Front. Mar. Sci.,* 15 July 2014, doi: 10.3389/fmars.2014.00020.

Nuttall, P. and Veitayaki, J. (2015) "Oceania is vast, Canoe is centre, Village is anchor, Continent is margin". In H.D. Smith, et al. (eds) *Routledge Handbook of Ocean Resources Management*. Earthscan Publications Ltd, Cardiff.

Nuttall, P. (2015) The Case For Immediate Prioritization Of A Transition To A Low Carbon Freight Future For Pacific Islands States. Presented at the *Multi-year Expert Meeting on Transport, Trade Logistics and Trade Facilitation: Sustainable Freight Transport Systems: Opportunities for Developing Countries* 14-16 October 2015, UNCTAD, Geneva. http://unctad.org/meetings/en/Presentation/Peter%20NUTTALL.pdf

Nuttall, P. and Kaitu'u, J. (in press) The Magnus Effect and the Flettner Rotor: potential application for Oceanic Shipping. *Journal of Pacific Studies Vol 1(1) 2016.*

N'Yeurt, A.D.R. and Iese, V. (2015) The invasive brown alga Sargassum polycystum in Tuvalu, South Pacific: Assessment of the bloom and applications to local agriculture and sustainable energy. *Journal of Applied Phycology* 27(5): 2037-2045 (DOI: 10.1007/s10811-014-0435-y).

Organization for Economic Cooperation and Development (2009) *Transport Outlook 2009 - Globalisation, Crisis and Transport. Discussion Paper No. 2009-12*. Joint Transport Research Centre of the OECD and the International Transport Forum.

Pacific Islands Development Forum (2015) *Suva Declaration on Climate Change* 2–4 September 2015, Pacific Islands Development Forum Secretariat, Suva. http://pacificidf.org/wp-content/uploads/2013/06/PACIFIC-ISLAND-DEVELOPMENT-FORUM-SUVA-DECLARATION-ON-CLIMATE-CHANGE.v2.pdf

Pacific Islands Forum (2013) *Majuro Declaration for Climate Leadership* http://www.majurodeclaration.org/the-declaration

Prasad, B. Veitayaki, J. Holland, E. et al. (2013) Sustainable Sea Transport Research Programme: Toward a Research-based Programme of Investigation for Oceania. *Journal of Pacific Studies (33) 78-95.*

Rehmatulla, N. and Smith, T. (2015) Barriers to energy efficient and low carbon shipping. *Ocean Engineering 110 (2015) 102–11* http://dx.doi.org/10.1016/j.oceaneng.2015.0 9.030

Rehmatulla, N., Parker, S., Smith, T., et al (2015) Wind technologies: Opportunities and barriers to a low carbon shipping industry. *Marine Policy*.doi:10.1016/j.marpol.2015.12.021

Rojon I., and Dieperink C. (2014) Blowin' in the wind? Drivers and barriers for the uptake of wind propulsion in international shipping. *Energy Policy*, Volume 67, April 2014, 394–402.

Schenzle, P., Weselmann, G., & Weiss, F. (1985). THE" INDOSAIL" PROJECT.

Schmidt, A. and Vahs, M. (2013) Final Research Report *Entwicklung eines innovativen Schiffsantriebes gekennzeichnet durch den Einsatz von Magnus-Rotoren zur Windenergienutzung in Kombination mit einem hierauf abgestimmten Antriebspropeller.* Abschlussbericht zum Entwicklungsprojekt gefördert unter dem Az.: 25741 -24/0 von der Deutschen Bundesstiftung Umwelt, Aurich.

Secretariat of the Pacific Community (2011) *Framework for Action on Transport Services 2011–2020, Improving the Efficiency, Effectiveness and Sustainability of Pacific Transport Services*. Secretariat of the Pacific Community, Suva.

Singh, A. (2012) Renewable energy in the Pacific Island countries: Resources, policies and issues. *Management of Environmental Quality: An International Journal, Vol. 23*(3), pp. 254 – 263.

Smith, T., Traut, M., Bows-Larkin, A. et al (2015) *CO_2 targets trajectories and trends for international shipping*. Shipping in Changing Climates, 12 May 2015, University College London and University of Manchester.

Soreh, C., N'Yeurt, A.D.R. and Iese, V. (2016) Sustainable organic fertilisers from two pest marine seaweeds for Pacific Islands food security. *Agronomy for Sustainable Development.* Springer.

Svensson, G. (2001) Glocalization of business activities: A 'glocal strategy' approach. *Management Decision 39*(1), pp. 6-18.

Tisdell, C. (2000) Poverty in the Pacific Islands. *International Journal of Sociology and Social Policy, 20*(11/12), pp. 74 – 102.

Tisdell, C. (2002) Globalisation, development and poverty in the Pacific Islands. *International Journal of Social Economics, 29*(12) pp. 902 – 922.

Tisdell, C. (2008) Global warming and the future of Pacific Island countries. *International Journal of Social Economics, 35*(12), pp. 889 – 903.

Tofinga, V. & N'Yeurt, A.D.R. (2016) Bioenergy through anaerobic digestion of two pest Pacific seaweeds: *Gracilaria edulis* and *Sargassum polycystum*. *Biomass & Bioenergy* (Springer).

Tomlinson, P. (2010) Co-operative ties and innovation: Some new evidence for UK manufacturing. *Research Policy, 39*, pp. 762–775.

United Nations Education, Scientific and Cultural Organization (2015) *Commencement of Restoration Work - Malekula Culture Centre in Vanuatu* (13 November 2015) http://www.unesco.org/new/en/apia/about-this-office/single-view/news/commencement_of_restoration_work_malekula_culture_centre_in_vanuatu/#.V0Jn odJnIU

United Nations Trade and Development Commission (2009) Maritime Transport and the Climate Challenge: Issues Under Negotiations On the Road to Copenhagen. Paper presented at the *Multi-*

Year Expert Meeting on Transport and Trade Facilitation: Maritime Transport and the Climate Change Challenge, Feb. 2009, Geneva.

United Nations Conference on Trade and Development (2009) *Multi-Year Expert Meeting on Transport and Trade Facilitation: Maritime Transport and the Climate Change Challenge Summary of Proceedings.* 16–18 February 2009, Geneva. United Nations. http://unctad.org/en/Docs/dtltlb20091_en.pdf

United Nations Trade and Development Commission (2010) Oil Prices and Maritime Freight Rates: An Empirical Investigation. *Technical report by the UNCTAD secretariat, UNCTAD, April*. Geneva.

United Nations Trade and Development Commission (2011) Recent developments and trends in international maritime transport affecting trade of developing countries. Paper presented at the *Multi-year Expert Meeting on Transport and Trade Facilitation (Fourth session*), Dec. Geneva.

United Nations Trade and Development Commission (2013) *Recent developments and trends in international maritime transport affecting trade of developing countries.* Technical report by the UNCTAD secretariat, UNCTAD, June. Geneva.

United Nations Conference on Trade and Development (2014) *Closing the distance: partnerships for sustainable development and resilient transport systems in SIDS.* United Nations Publication.

United Nations Conference on Trade and Development (2015) *Review of Maritime Transport, October.* Geneva: United Nations Publications.

United Nations Economic and Social Commission for Asia and the Pacific (2010) Sustainable development in the Pacific: progress and challenges. In *Pacific Regional Report for the 5 year Review of the Mauritius Strategy for Further Implementation of the Barbados Programme of Action for Sustainable Development of SIDS (MSI+5)* Suva: UNESCAP Sub-Regional Office for the Pacific.

UNSIDS (2014) *Small Island Developing States Accelerated Modalities Of Action (S.A.M.O.A.) Pathway Outcome of the Third International Conference on Small Island Developing States* (SIDS Conference). 1–4 September 2014, Apia http://www.sids2014.org/index.php?menu¼1537

Wikipedia (2016) https://en.wikipedia.org/wiki/Cyclone-Winston

Wong, P.P., Losada, I.J., Gattuso, J.P., et al (2014) *Coastal systems and low-lying areas Climate Change 2014: Impacts, Adaptation, and Vulnerability Part A: Assessment Report of the Intergovernmental Panel on Climate Change* (Ed: Field, C.B. et al) Cambridge: Cambridge University Press.

World Food Programme (2016) Transport and Disaster Response in the Pacific. Presentation to *3rd Blue Green Economies Symposium*, 5 May 2016, Suva, Fiji.

World Meteorological Organization (2016) *2015 is hottest year on record*. Press Release http://public.wmo.int/en/media/press-release/2015-hottest-year-record