The Case for Green Hydrogen in the Pacific

Draft for Consultation | November 2023

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About the Project

The Efate outcome statement from the Fifth Pacific Regional Energy and Transport Ministers' Meeting held in Port Vila, Vanuatu in May 2023, recognises the need to consider the potential of green hydrogen and its derivatives in decarbonising the region. This included endorsing the development of a timebound Pacific regional green hydrogen strategy. Responding to this request, the Australian Government's Department of Climate Change, Energy, the Environment and Water (DCCEEW) has funded UNSW Sydney consortia, supported by the International Renewable Energy Agency (IRENA) the Pacific Community (SPC), and the University of South Pacific (USP), to lead the development of a Pacific Hydrogen Strategy.

Pacific Hydrogen Strategy

The Strategy will be built across workshops, stakeholder engagement, and series of reports. Report A provides a broad overview of the potential opportunity for hydrogen and derivatives. The findings of this report will be built further upon in Report B, which identifies the H_2 and derivative production and end-use technology, focusing on their applicability and suitability in the PICTs. Report C will focus on mapping the energy resources, land availability, infrastructure, and other feedstocks that would be required to establish the H_2 economy in the PICTs. Subsequently, Report D will then investigate the economics of developing the H_2 economy in the PICTs. The overall findings from these reports will then make the basis of a regional hydrogen roadmap. These reports will be complemented by an open-source tool for technoeconomic assessment of potential projects in the region (in development), and masterclass/knowledge resources to support the PICTs to become H_2-ready. These will be made available through our website (http://pacifich2strategy.com/).

Australian Government
Department of Climate Change, Energy, the Environment and Water

UNSW SYDNEY

IRENA
International Renewable Energy Agency

USP
THE UNIVERSITY OF THE SOUTH PACIFIC

Pacific Community
Communauté du Pacifique

GlobH2E
ARC Industrial Transformation Training Centre for the Global Hydrogen Economy

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Abbreviations

bbl	Barrel of oil/diesel equivalent
CAA	Climate Ambition Alliance
CO_2	Carbon dioxide
DAC	Direct air capture
FSM	Federated States of Micronesia
GDP	Gross Domestic Product
GJ	Gigajoules
GW	gigawatt
H_2	Hydrogen
Ha	Hectares
IDB	Inter-American Development Bank
kg	Kilogram
km^2	Square Kilometres
ktpa	Kilotonnes per annum
kW	Kilowatt
L	Litres
LAC	Latin America and the Caribbean
LCA	Life Cycle Assessment
MW	Megawatt
MWh	Megawatt hours
Mtpa	Megatonnes per annum
NH_3	Ammonia
NDCs	Nationally Determined Contributions
P2X	Power to X
PICTs	Pacific Island Countries and Territories
PNG	Papua New Guinea
PV	Photovoltaic – Solar Panels
RMI	Republic of the Marshall Islands
SAF	Sustainable Aviation Fuel
SIDS	Small Island Developing States
TJ	Terajoules
TRL	Technology Readiness Level
TWh	Terawatt hours

Executive Summary

The increasingly adverse global impacts of climate change, primarily from fossil fuel use, have focused attention on the need to achieve net zero greenhouse emissions in a matter of decades. At the forefront of these climate impacts are the Pacific Island Countries and Territories (PICTs), which despite being a negligible contributor to global emissions and energy use are exposed to ever-increasing climate risks that threaten their ecologies, economies, livelihoods, and cultures. Furthermore, they face energy security challenges due to their heavy reliance on imported fossil fuels which supply the bulk of the region's energy needs.

With an understanding of and being strongly impacted by the effects of climate change, the PICTs have put forth ambitious energy and climate targets in their nationally determined contributions (NDCs), to set forth an example for achieving net zero by 2050 (note that some PICTs are already net negative) and to lead on actions required globally to limit the effects of climate change. The primary goal of these NDCs entails leveraging and increasing the share of regional renewable energy resources in the primary energy supply (electricity and heating requirements) as well as enabling net zero emission energy end use in industry and mobility applications. These ambitious energy goals are based on the understanding that the global energy transition is critical for keeping 1.5°C alive. A key focus is on increasing renewable generation in the region's power sectors, improving energy efficiency, and electrifying key energy use sectors such as land transport. However, due to unique challenges faced by the PICTs, such as the extremely distributed remote and islanded communities, the complete and direct electrification of the energy sector through renewables may not be feasible across the complete energy value chain, providing a pathway for intermediate energy carriers such as hydrogen (H_2) and its derivatives, including as methanol, ammonia, sustainable aviation fuel (SAF), and renewable diesel, to bridge this gap in hard to electrify sectors such as maritime transport and aviation. Additionally, H_2 and derivatives can provide a transitory step in electrification through the use of drop-in fuels or fuel blending in existing infrastructure, proving a short-term stopgap solution.

These fuels can potentially be generated through regional renewable resources (boosting regional energy self-sufficiency) and used to decarbonise energy supply and use, bridging the gap between renewable energy and hard to electrify/abate sectors, and increasing the share of renewable energy supply and helping to achieve NDCs/climate goals. A collaborative market could be developed in the region, whereby the regional renewable energy potential is distributed equitably amongst the PICTs through a regionally integrated hydrogen and derivatives supply chain, leading to regional energy self-sufficiency and security.

This report provides a broad overview of the potential opportunity for hydrogen and derivatives to displace fossil fuels in the PICTs in these hard to electrify sectors, undertaking a preliminary analysis for 13 selected countries and territories in the region (herein, the PICTs refer to a specific group of countries/territories including Fiji, Samoa, Vanuatu, Solomon Islands, Papua New Guinea (PNG), New Caledonia, Kiribati, Federated States of Micronesia (FSM), Tonga, Cook Islands, Republic of the Marshall Islands (RMI), Tuvalu, and Nauru). This is accompanied by a discussion on the PICT's renewable energy resources (including solar, wind, and bioenergy resources), the energy demand by sector, and NDCs/energy policy, in order to provide a high-level overview for the potential of H_2 and derivatives.

Our preliminary investigation highlights the reliance on fossil fuels in region, with an average total energy usage of around **82% fossil fuel-based** energy supply amongst the assessed PICTs**.** Domestically, these fossil fuels are notably used across the mobility (land, maritime, and aviation) sector, and electricity generation sector, altogether accounting for at least **23 million bbl** of diesel equivalent fossil fuels (corresponding to at least **10 million tonnes** of CO_2 emissions, at a cost of **US $2.1 billion per annum**, around **4-5% of the combined PICT's GDP**). Nevertheless, the PICTs are committed to a policy and target driven approach to decarbonise their energy supply and use (almost all PICTs have a 100% renewable electricity target and ambitious NDC commitments), highlighting a considerable opportunity for H_2 and its derivatives for (i) meeting national commitments to reduce emissions, (ii) enhancing local clean energy supply, leading to import savings, and (iii) delivering new opportunities for a regional energy industry. The transition to H_2 and derivatives in the PICTs requires renewables deployment in the region, that can leverage local resources (including wind, solar, hydro, and biomass) to generate bulk amounts of H_2, methanol, ammonia, renewable diesel, and sustainable aviation fuel, that can be employed as carriers of renewable energy to sectors that cannot be directly electrified.

This report maps out the overall potential for hydrogen in the region, through engagement with stakeholders and an in-depth review of the regional energy statistics and policy scenarios. Particularly, the stakeholder consultations carried out during workshops hosted by the consortium in Vanuatu, Fiji, and Northern Mariana Islands support this work, recognising the potential role of hydrogen and its derivatives in the region for decarbonisation. Based on our assessment, H_2 (with methanol, ammonia, and renewable diesel) can be used to generate clean on-demand power and heat through specialised fuel cells or as a drop-in fuel replacement for diesel and gas energy generators. Methanol, ammonia, renewable diesel, and SAF can also be used as a direct drop-in replacement for mobility applications including the maritime and aviation industries. Additionally, a regional collaborated trade market might be created where resource rich PICTs can generate bulk amounts of green fuels, that can be transported to the more remote and resource deficient regions across the Pacific to yield mutual benefits. **Figure A** provides a high-level overview of the current energy outlook and potential demand for H_2 and derivatives (on an equivalent energy basis with current fossil fuels demand) across the PICTs region.

It should be acknowledged that H_2 and its derivatives may not currently be technically and economically viable to completely displace the fossil fuels in the PICTs. This opportunity to explore the partnership of hydrogen and derivatives with energy efficiency improvements and renewables implementation will ensure that the Pacific Islands region is well placed to continue to play an active role in climate leadership and advocacy for decarbonisation, strengthening the PICTs role as a leader in the global energy transition. Together, accelerated renewable energy deployment complemented by hydrogen is therefore a critical step towards decreasing the exposure to external price shocks in the fossil fuel market and the dependency on fuel imports. Subsequent reports will provide an assessment of the technical readiness and corresponding advantages and challenges of a hydrogen economy in the region (**Report B**), as well as in-depth mapping and economic assessment of the hydrogen economy in light of the regional resources and competing decarbonisation pathways (**Reports C and D**).

PICT	Current energy outlook	Hydrogen potential (ktpa)	Resource potential	Role(s) in a potential hydrogen economy
Fiji	Energy: **7.2 TWh** Renewable: **8%**	**116**	High	▪ Potential producer and export hub ▪ Average to high solar, wind, biomass, and land availability
Samoa	Energy: **1.6 TWh** Renewable: **5%**	**26**	Average	▪ Potential producer and export hub ▪ Average to high solar, wind, biomass, and land availability
Vanuatu	Energy: **0.9 TWh** Renewable: **2%**	**17**	Average	▪ Potential producer and export hub ▪ Average to high solar, wind, biomass, and land availability
Solomon Islands	Energy: **2.1 TWh** Renewable: **<1%**	**30**	Average	▪ Potential producer and export hub ▪ Average to high solar, wind, biomass, and land availability
PNG	Energy: **55 TWh** Renewable: **10%**	**480**	High	▪ Potential producer and export hub ▪ Average to high solar, wind, biomass, and land availability
New Caledonia	Energy: **18 TWh** Renewable: **3%**	**345**	High	▪ Potential producer and export hub ▪ Average to high solar, wind, biomass, and land availability
Kiribati	Energy: **0.45 TWh** Renewable: **1%**	**6.3**	Low	▪ Potential net importer
FSM	Energy: **0.60 TWh** Renewable: **1%**	**16**	Low	▪ Potential net importer
Tonga	Energy: **0.64 TWh** Renewable: **2%**	**17**	Average	▪ Potential net importer
Cook Islands	Energy: **0.35 TWh** Renewable: **4%**	**8.5**	Low	▪ Potential net importer
RMI	Energy: **0.35 TWh** Renewable: **<1%**	**9.9**	Low	▪ Potential net importer
Tuvalu	Energy: **0.04 TWh** Renewable: **5%**	**1.1**	Low	▪ Potential net importer
Nauru	Energy: **0.20 TWh** Renewable: **<1%**	**4.5**	Low	▪ Potential net importer

High
Average
Low

FIGURE A. CURRENT ENERGY OUTLOOK AND ROLES IN A POTENTIAL HYDROGEN ECONOMY[i].

[i] Current energy outlook is the total annual energy use and percentage of total energy use that is renewable. Hydrogen potential estimates an energy equivalent value of H_2 that would be required to completely displace the fossil fuels used across key energy sectors (See Appendix B for further details). Note these values are provided for an indicative H_2 demand, the actual values would differ based on the technical and economic viability of displacing the fossil fuels with H_2 and derivatives. Detailed assessments of the potential for hydrogen and derivatives generation within each PICT will be conducted in subsequent reports. Resource potential provides a guide on the availability of solar, wind, biomass, and land availability (See **Table 9** for further details). The role in a potential hydrogen economy is an indication based on the resource potential. It should be noted that all PICTs may be potential importers depending on economics and scales.

1. Decarbonisation Challenges in the Pacific

1.1. Regional Fossil Fuel Dependency and its Risks

The Pacific Island Countries and Territories (PICTs) are a fossil fuel dominated region. Fossil fuels are deeply embedded in the regional energy supply; 67% of all energy needs are currently supplied by fossil fuels and only 8% provided by renewables, with biomass making up the bulk of the remainder[ii]. For all countries and territories other than PNG, these fossil fuels are imported from outside the region.

This reliance on fossil fuel exposes the PICTs to two major risks:

1. **Exposure to a volatile market and energy dependency** – Regionally, the production of fossil fuels is limited and restricted to a few countries (with almost all the PICTs importing fossil fuels, ~37 million barrels of fossil fuel p.a. are used for energy in the assessed PICTs). Thus, the regional markets are exposed to energy dependency, fossil fuel imports, and the associated global market pressures such as supply fluctuations, geopolitical conditions, etc. (**Figure 1**). The fallout of this has been seen by recent rising prices of fossil fuels (influenced by factors such as the global pandemic, the war in Ukraine, and political tensions between OPEC members) and its impact on economies. Energy imports account for a considerable portion of the PICTs GDP, and are heavily linked to other commodity prices – the cost of fuel, food, and other essential goods have seen significant spikes due to rising energy costs.[1] As small and open economies, the recent volatility in global fossil fuel prices has exposed the vulnerability of the PICTs, causing substantial impacts on domestic inflation (estimated at around 12% for Samoa and 9% for Tonga), and the price of energy and food products.[2]

FIGURE 1. THE CORRELATION BETWEEN GLOBAL FOOD AND ENERGY PRICES (2000 – 2022).[2]

[ii] See Appendix C for all calculations.

2. **Climate change commitments** – Global CO_2 emissions from fossil fuels have reached an unprecedented level that threatens the stability of our climate. Recent estimates on climate change and global temperature show that the world is heating up and has essentially reached a "boiling phase".[3] Overall, while the contribution of the PICTs to the global emissions is negligible, they are heavily exposed to climate change that will impact the regional stability and threaten the eco-diversity of the region.[4] The PICTs are amongst the highest at-risk regions, the majority of which (as elaborated later in the report) rely heavily on imported fossil fuels, threatening their long-term energy security.[5,6] These island nations are also being exposed to climate change through rising sea levels, weather changes (impacting local agricultural activities which are critical to local food supply and economy), and the rising frequency of violent storms, which are alarming risks to some of the most ecologically and biologically diverse regions of the world (**Figure 2**).[5,6] While significant work has been undertaken to build climate resilience, there is still much to do to support the remote and economically hampered PICTs, who are taking an active leadership against climate change.

Impacts of climate change on the PICTs include higher average temperatures, greater frequency of extreme rainfall events, more extreme and frequent natural disasters, rising sea levels. ocean acidification, and coastal erosion. For example:

- In 2020, Cyclone Harold destroyed 80-90% of homes in Vanuatu, displacing over 27% of the nation's population. Cyclone Pam caused economic loss and damage estimated at 64% of GDP.[7,8]
- The percentage of Fijians suffering from food insecurity increased from 4.2% in December 2020 to 11.4% in February 2021 due to Tropical Cyclone Ana. Cyclone Winston in 2016 caused around 80% of the population to lose power, totalling almost US $1.0 billion in damages.[7,8]

It has been estimated that the total cost of climate impacted changes in the Pacific region could range from 2.9% to as high as 12.7% of GDP equivalent by 2100.[8]

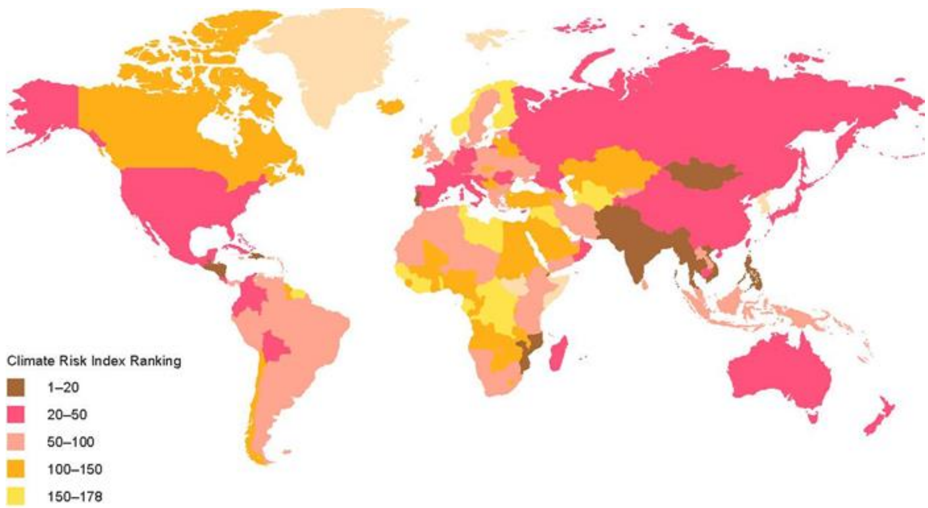

FIGURE 2. CLIMATE RISK INDEX MAP.[9] MOST PICTS HAVE BEEN ASSIGNED A RISK RATING OF 20 – 50, REFLECTING A HIGHER LEVEL OF EXPOSURE AND VULNERABILITY TO WEATHER RELATED EVENTS. IN PARTICULAR, PNG, SOLOMON ISLANDS, VANUATU, AND FIJI ARE HIGH RISK COUNTRIES BASED ON IMPACTS ON FROM CLIMATE RELATED IMPACTS.[5]

1.2. Transitioning From a Fossil Fuel Economy in the PICTs

Realising the impact that the fossil fuel dominated energy supply on the Pacific region and the world, the PICT communities and governments are committed to a decarbonised future. A rapid global transition is required to keep 1.5°C alive, avoiding escalating climate impacts that increasingly threaten the region's economies, ecologies, communities, and cultures. A primary concern for the PICTs, as evidenced by their targets outlined in their Nationally Determined Contributions (NDCs), is to both (i) increase the access to clean-renewably sourced electricity/energy in remote and isolated communities, and (ii) enhance the penetration of clean energy across the entire end use spectrum. However, there are still complex implementation challenges involving technical, social, and financial barriers facing these ambitious energy targets.[10]

As such, deployment of fundamentally and economically sound regional renewable energy resources is critical for the present and the future of the PICTs. There are several key advantages of these resources, including:

- An even spread compared to the more inequitably spread fossil fuel resources (of the assessed PICTs, only Papua New Guinea produces more energy than it currently uses.[11]
- Renewable electricity generation from solar and wind has already become the lowest-cost energy source globally.[12]
- The benefits of long-term sustainability and zero CO_2 emissions generation of power and end use.[12]

The ageing energy generation infrastructure in many PICTs is assisting in driving this shift to renewables.[13,14] Almost all the major PICTs have set a 100% renewable electricity generation target between 2030 and 2050 (**Table 1**). Aside from grid electricity generation, a significant proportion of fossil fuel use in the PICTs is in industry, domestic transportation (maritime, aviation, and land transport), and international aviation. Realising this, the PICTs have set ambitious decarbonisation and emissions targets for these end use sectors (**Table 1**).

TABLE 1. KEY EMISSIONS AND ENERGY-RELATED TARGETS AND COMMITMENTS [iii]. NOTE: NDC; NATIONALLY DETERMINED CONTRIBUTIONS. CAA; CLIMATE AMBITION ALLIANCE.[15,16]

	PICT	Key emissions and energy sector targets	Net Zero target
	**Fiji**	▪ 30% emissions reduction by 2030, 10% unconditionally and 20% conditionally ▪ By 2030: 100% renewable power generation, 10% reduction in energy sector emissions, 40% reduction in domestic maritime shipping	2050 (NDC)
	**Samoa**	▪ 30% emissions reduction by 2030 ▪ 100% renewable electricity by 2025	2050 (CAA)
	**Vanuatu**	▪ 30% emissions reduction by 2030 ▪ 100% renewable electricity by 2025	2050 (CAA)
	**Solomon Islands**	▪ 33% emissions reduction by 2030 (unconditional) or 78% (conditional) ▪ Targeted sectors are electricity generation (39%) and domestic land and maritime transport (61%)	2050 (NDC)
	**PNG**	▪ Increasing the share of installed capacity of renewable energy from 30% in 2015 to 78% in 2030 ▪ Carbon neutrality in the energy industries subsector	2050 (CAA)
	**New Caledonia**	▪ 10% reduction in emissions in the mining and metallurgy sector ▪ 15% reduction in emissions in the transport sector	2050 (CAA – France)
	**Kiribati**	▪ 9.5% emissions reduction by 2025 (unconditional) or 16.7% (conditional) ▪ 8% emissions reduction by 2030 (unconditional) or 23.8% (conditional)	2050 (CAA)
	**FSM**	▪ 70% renewable electricity generation by 2030 ▪ 65% reduction in emissions from power generation by 2030	2050 (CAA)
	**Tonga**	▪ 13% reduction in GHGs by 2030 ▪ 70% renewable electricity by 2030 and 100% by 2035	2050 (CAA)
	**Cook Islands**	▪ 100% of islands transformed from diesel-based to renewable energy sources by 2020 ▪ 38% emissions reductions by 2020	2050 (CAA)
	**RMI**	▪ Emissions reduction of 32% by 2025, 45% by 2030, and 58% by 2035	2050 (NDC)
	**Tuvalu**	▪ Reduction of GHGs from the power sector by 100% by 2030 ▪ Energy sector GHG reduction of 60% by 2030	2050 (CAA)
	**Nauru**	▪ Achieve 50% renewable energy capacity	2050 (NDC)

[iii] For further detail on these targets and commitments, see Appendix B.

1.3. Challenges for a PICTs Translation to a Renewable Future

It is accepted that hydrogen will not play a major role in the decarbonisation of the PICTs – it is estimated that on a global scale, hydrogen and derivatives will account for only 12% of CO_2 emissions abatement by 2050, whilst energy conservation and efficiency (i.e., measures to reduce energy demand and increase energy efficiency of end-use applications), and renewables and electrification (i.e., the use of renewable electricity generation sources such as solar PV and wind, and the direct use of renewable energy such as solar thermal and biomass) will account for a combined ~70%.[17] For example, the electrification of land transport can be mostly carried out through adoption of small battery electric vehicles, whilst grid electricity can be decarbonised via solar PV or wind energy coupled with battery storage. As such, deployment of renewables is key in the energy transformation, as it is also a pre-requisite for the generation of green hydrogen and derivatives.

In the Republic of Palau: Renewable Energy Roadmap 2022-2050, analysis considered various energy scenarios capable of achieving 100% renewable energy in the power sector by 2050.[18] It was found that the addition of green hydrogen, to a power system predominantly comprising solar PV and wind, provides flexibility through the large-scale storage of renewable power in the form of hydrogen, reducing the need for battery storage, highlighting the challenges of energy storage in a 100% renewables system.

A key point to note is the diverse energy needs and circumstances (including geographic, political, and economic) of the PICTs, which, together with the current energy landscape, may provide a promising environment for hydrogen and derivatives, and may play a role in a future energy scenario in which hydrogen plays a greater role in the PICTs than the 12% value estimated as a global average. For example, domestic maritime and aviation comprise over 6% of the region's energy use in key sectors[iv], excluding both international aviation and maritime and aviation fuel bunkering. Such sectors are challenging to electrify, as extremely large batteries would be required, taking a long time to charge.[19] The large distances between remote and islanded communities poses further challenges to electrification, which may not be technically or economically viable at certain scales. As such, an assessment of the role that hydrogen and derivatives can actually play in the PICTs (considering the varying challenges and dynamics of the region) is the target of the Pacific Hydrogen Strategy[v].

[iv] See Appendix C for all calculations.

[v] This report A aims to provide a state of play of the PICTs energy use and policy and provide a high-level estimation of how H_2 and derivatives can address decarbonisation opportunities across the region's energy chain. The subsequent series of the reports will then determine the best way forward for H_2 and derivatives.

1.4. Role of Hydrogen and Derivatives

Unlike the use of mature renewable energy generation technologies (such as solar and wind) to decarbonise the electricity sector, decarbonisation of hard-to-abate/hard-to-electrify industries and end use sectors faces significantly more challenges.[20] Several key challenges for renewables implementation in the PICTs include generation at scale, issues of intermittency and storage of excess energy, remoteness of communities, limited financial capacity, lack of technical support, and the regulatory and policy environment.[21,22]

Several of these issues can be aided by Power to X (P2X or PtX). P2X technologies involve the use of excess or underutilised renewable energy and abundant feedstocks (such as water, nitrogen from air, or captured CO_2 from air, industry, or biomass) to generate green chemicals and fuels.[23] At the heart of P2X are pure hydrogen and its carriers such as renewable methanol, green ammonia, renewable diesel, and sustainable aviation fuels (SAF). These fuels and chemicals are essentially synthetic alternatives for fuels or chemicals derived from fossil fuels, that can be used to displace fossil fuels in hard-to-abate sectors that cannot be directly electrified, or in locations that cannot make use of conventional renewables technologies. These fuels are briefly outlined below[vi]:

- **Green hydrogen** is produced without the emission of CO_2, primarily through the electrolysis of water powered by renewable energy. The primary advantages of hydrogen are that it can be produced and used without the emission of CO_2. Key application areas of hydrogen in the PICTs include power storage and generation.
- **Ammonia** is produced through the combination of hydrogen and nitrogen. If the hydrogen is produced without CO_2 emissions (such as through electrolysis), and nitrogen is separated from air without CO_2 emissions, the product is termed "green ammonia".[24] Ammonia is a useful hydrogen carrier as it has a high volumetric energy density. It can be converted back to hydrogen via "ammonia cracking", or used as is. Key applications of ammonia in the PICTs include power storage and generation and maritime fuel.
- **Methanol** can be produced via green hydrogen and captured CO_2 (e-methanol) or via biomass gasification (bio-methanol). CO_2 emissions from combustion are offset during its production.[25] Key applications of methanol in the PICTs include power storage and generation, maritime fuel, and domestic heating and cooking.
- **Sustainable aviation fuel and renewable diesel** can be generated through various biomass-to-liquid (making use of biomass) or power-to-liquid (making use of green H_2 and CO_2) pathways. SAF and renewable diesel can be distributed, stored, and used like conventional jet fuel and diesel, allowing them to be directly utilised without the need for retrofitting the energy supply/use.[26] Key application areas in the PICTs include aviation fuel, land mobility fuel, and as a CO_2 sink.

Some key application areas of these P2X technologies in the PICTs is shown in **Table 2**.

[vi] For further details on hydrogen and derivatives, see Appendix A. An in-depth discussion on these fuels and related technologies is provided in Report B.

TABLE 2. SOME RELEVANT P2X TECHNOLOGIES. HYDROGEN AND DERIVATIVES ARE MOST APPLICABLE IN THE PICTS PRIMARILY IN MOBILITY (LAND, MARITIME, AVIATION, AND HEAVY INDUSTRIAL MOBILITY SECTORS), ENERGY STORAGE, AND ENERGY GENERATION.

Application	Hydrogen	Methanol	Ammonia	Renewable Diesel	SAF
Seasonal power storage	✓	✓	✓	✓	
Fuel cell power generation	✓	✓	✓		
Combustion power generation	✓	✓	✓	✓	
Land mobility fuel	✓	✓		✓	
Maritime fuel		✓	✓	✓	
Aviation fuel					✓
Domestic heating and cooking	✓	✓			
Chemical manufacturing	✓	✓	✓		
Sink for CO_2 sequestration		✓		✓	✓

Current Pacific Hydrogen Initiatives

There are currently only a few announcements on early-stage hydrogen projects in the Pacific. This is of course expected to increase as there is more awareness of the potential of green hydrogen and derivatives, as indicated by preliminary stakeholder consultations. A few of current initiatives include:

1. The Pacific Green Hydrogen Project aims to connect small-to-medium German enterprises that manufacture hydrogen technologies for an off-grid application in the Pacific Islands. The project comprises of an analysis which investigates the potential for green hydrogen and fuel cell mini-grid technologies in the markets Cook Islands, Fiji, Tonga, and Samoa.[27]

2. New Caledonia is targeting the use of hydrogen in transport and industry. The country aims to become a supplier of green Nickel for battery technologies. Key mining companies in New Caledonia (Prony Resources, Engie NC, and Gazpac) all have hydrogen projects in the works.[28]

3. The HDF Energy Australia team is currently developing a green hydrogen project on Fiji's Viti Levu group (**Figure 3**). The plant could generate 6 MWe of electricity during the day and evening, and 1.5 MWe throughout the night.[29]

FIGURE 3. CONCEPT IMAGE OF THE HDF SOLAR PV FARM AND THE HYDROGEN GENERATION, STORAGE, AND FUEL CELL FACILITIES.[29]

2. Energy Outlook of the PICTs – The Case for H_2 and Derivatives

Hydrogen and its derivatives can play a role in the energy transition within the Pacific region, alongside energy efficiency improvements and direct use of renewables as primary decarbonisation levers. To elaborate on these opportunities, the following sections discusses the energy and emissions outlook of the PICTs and estimates the potential demand for hydrogen and derivatives to displace the fossil fuel demand in these sectors.

2.1 Regional Energy Use Breakdown

As highlighted above, the total energy usage of the PICTs is ~87 TWh, which is an average of 82% fossil fuel based energy per PICT, or 67% of the total energy use of the region, due to higher renewables penetration amongst the larger energy users such as Fiji and Papua New Guinea (**Table 3**)[vii]. The import dependence of these significant volumes of fossil fuel exposes the region to risks with supply chain and price volatility and considerable outflow of foreign currency for balance of payment.

Overall, the highest share of fossil fuel power is in the relatively smaller regions of FSM, Tonga, Tuvalu, Nauru, Cook Islands, and RMI (all more than 90% share of fossil fuels in total energy use). However, they have a relatively small energy demand of ~2.2 TWh compared to the rest of the PICTs combined (i.e., 2.5% of the overall PICTs energy use). The highest overall consumers of fossil fuels are Papua New Guinea (56% share of fossil fuels supplying ~31 TWh, around one third of the of the overall PICTs energy use), New Caledonia (97% share of fossil fuels supplying ~17 TWh of energy, around one fifth of the overall PICTs energy use), and Fiji (75% share of fossil fuels supplying ~5.4 TWh of energy, around 6% of the overall PICTs energy use). The larger industrial base in these countries may lend a potential role as a regional hydrogen generator and exporter (elaborated below).

Correspondingly, the average renewables penetration (of solar, wind, hydro, and geothermal) is only ~3% per PICT and is around 8% in total across the region. A key bottleneck for renewables deployment in this region is the difficulty in implementing grids for electrification of remote and islanded locations, leading to a dependence on imported fossil fuels. In such scenarios, hydrogen and derivatives can play a role in closing the gap to 100% decarbonisation.

[vii] See Appendix C for all calculations.

TABLE 3. PICTs TOTAL ENERGY USE AND DEPENDENCY ON FOSSIL FUELS.[30]

PICT	Total energy use (TWh)	Fossil-fuel based (%)
Fiji	7.24	75
Samoa	1.58	70
Vanuatu	0.90	72
Solomon Islands	2.11	56
PNG	54.88	56
New Caledonia	17.48	97
Kiribati	0.45	63
FSM	0.60	94
Tonga	0.64	98
Cook Islands	0.35	91
RMI	0.35	99
Tuvalu	0.04	94
Nauru	0.20	99

Lower Dependency | Average Dependency | Higher Dependency

PICT average	Fossil fuels: 82%	Biomass derived: 15%	Renewables: 3%
Region total	Fossil fuels: 67%	Biomass derived: 25%	Renewables: 8%

Renewable Energy in the PICTs

Overall, the PICTs employing the lowest share of fossil fuel energy (~60% share) are the Solomon Islands, Papua New Guinea, and Kiribati, each. Aside from renewables[viii], the remainder of the energy for each is mostly supplied by traditional biomass usage, which under some circumstances can be considered sustainable, however still generates CO_2 emissions on end use (though these are balanced out by the emissions sequestered during the growth of biomass).

The highest share of renewable energy is observed in Papua New Guinea and Fiji, with a share of ~10% (5.5 TWh) and ~8% (0.6 TWh) of total energy use contributed by renewable sources, respectively.

In PNG, around 35% of electricity is generated via hydroelectricity, including the Ok Menga (57 MW) and Ramu (77 MW) hydroelectric schemes. Around 3-8% of electricity is supplied by the Lihir geothermal power station (50 MW), the only large-scale geothermal power source of the assessed PICTs.[31] Papua New Guinea has committed to increasing the installed capacity of renewables from 30% to 78% by 2030, although this was downgraded from 100% due to project lag time, as well as the expanding LNG sector.[32] However, overall energy access is low, and by investing in large-scale renewable hydrogen and derivatives generation, PNG could improve overall energy access and social and economic welfare.

In Fiji, almost 60% of electricity is produced through hydroelectric schemes, the largest of which are the Nadarivatu (40 MW) and Monasavu (80 MW) schemes on the Viti Levu group. There are also several small solar PV farms and a single wind farm.[33] Fiji is targeting 100% grid-connected renewable power generation by 2030 in their NDC, which they are capable of achieving, however their ambitions to become net zero by 2050 will require significant effort in hard-to-abate sectors such as transportation.

Many PICTs are implementing solar PV and wind technologies for decarbonising electricity generation, due to the availability of these resources and the technology maturity. Whilst most PICTs are progressing in their targets for 100% renewable electricity generation, their wider net zero goals are being held back by factors including (i) lack of suitable energy storage options, (ii) difficulties due to remote and isolated communities, and (iii) decarbonisation of hard-to-abate sectors such as transportation and emitting industries.

[viii] The sources of energy considered renewable include solar PV, wind, geothermal, and hydroelectricity. Note that biomass when used as a traditional fuel source is not considered renewable.

2.2 Regional Emission Breakdown

The fossil fuel dominated energy supply contributes to a footprint of around 17 million tonnes per annum (Mtpa) of domestic CO_2 emissions (**Figure 4**) from the assessed PICTs[ix].[34] Reduction of these emissions is targeted through NDCs, requiring renewable electricity integration and replacement of fossil fuels, which can be assisted by H_2 and derivatives.

Overall, Papua New Guinea is responsible for half of all CO_2 emissions from the assessed PICTs (8.5 Mtpa), whilst ten of the thirteen PICTs combined comprise less than 10% of emissions from the region (**Figure 4**).[30,34] Domestic emissions in the PICTs are mostly associated with electricity generation, use in industry, and transport (land, maritime, and aviation). Minor contributors include agriculture, household emissions, and unspecified emissions that may occur in any of these sectors.

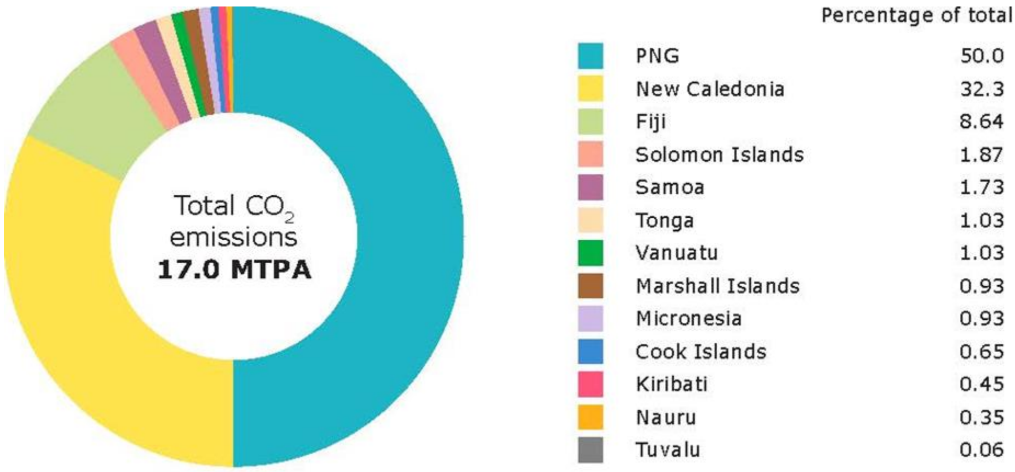

FIGURE 4. PICTS TOTAL DOMESTIC CO_2 EMISSIONS.[x]

The following table (**Table 4**) outlines the overall domestic energy demand and fossil fuel cost as a percentage of GDP for each of the assessed PICTs. Key energy uses include primary industries (such as nickel mining in New Caledonia, which accounts for over 70% of energy use in the territory, and minerals and natural gas extraction in Papua New Guinea), electricity generation (which accounts for approximately 25-30% of total energy use in the PICTs), and land transport (which accounts for approximately 15-20% of total energy use in the PICTs). Whilst domestic maritime and aviation account for only around 3% of total energy use, international aviation and shipping between the islands is a key contributor to energy use and associated emissions[xi]. International emissions from fuel bunkering are also not included in these domestic emission values.

[ix] See Appendix C for all calculations and data sources.
[x] These are domestic emissions only. International emissions (i.e., those of national air carriers, international shipping, or fuel bunkering) are not considered in these values. These values are mostly energy-related CO_2 emissions, and do not include other GHG emissions (such as CH_4 or N_2O) from the waste or agricultural sectors. See Appendix B for further information.
[xi] See Appendix B for detailed information on domestic energy use by sector for each of the assessed PICTs.

TABLE 4. OVERVIEW OF ENERGY DEMAND, FOSSIL FUEL USE AND COST, AND CO_2 EMISSIONS FOR THE ASSESSED PICTS.[xii]

PICT	Total energy use (TWh)	Fossil fuel-based energy (%)	Fossil fuel cost (% of GDP)	Total CO_2 emissions (Mtpa)
Fiji	7.20	75	5.7	1.50
Samoa	1.60	70	6.9	0.29
Vanuatu	0.90	72	3.8	0.17
Solomon Islands	2.10	56	4.2	0.32
PNG	55.00	56	5.8	8.50
New Caledonia	17.50	97	9.6	5.50
Kiribati	0.45	63	7.4	0.08
FSM	0.60	94	8.0	0.16
Tonga	0.64	98	7.0	0.17
Cook Islands	0.35	91	5.6	0.11
RMI	0.35	99	7.1	0.16
Tuvalu	0.04	94	3.6	0.01
Nauru	0.20	99	7.7	0.06

[xii] These estimates are based on publicly available data and stakeholder engagement, refer to Appendix C for further details on calculation.

3. Role of H_2 and Derivatives in the PICTs – Demand Estimation

Green hydrogen and hydrogen derivatives can play the following key roles of:

- Penetration of renewables into electrical power generation where conventional renewable energy may not be feasible (such as remote islands, areas with low solar and wind, or areas with no land availability) and in industry.
- Displacement of fossil fuels for mobility (primarily maritime transport, with application for land transport and aviation).

The use of fossil fuels in these key domestic sectors roughly equates to US $2.1 billion worth (at a fuel price[xiii] of ~US $92 per bbl of diesel[35]) of fossil fuel imports per year (**Figure 5**), around 4-5% of the combined GDP of the assessed PICTs[xiv]. This is equivalent to at around[xv] 23 million bbl of diesel equivalent per year, as well as ~10 Mtpa of CO_2 abated (of the total 17 Mtpa that is emitted domestically).

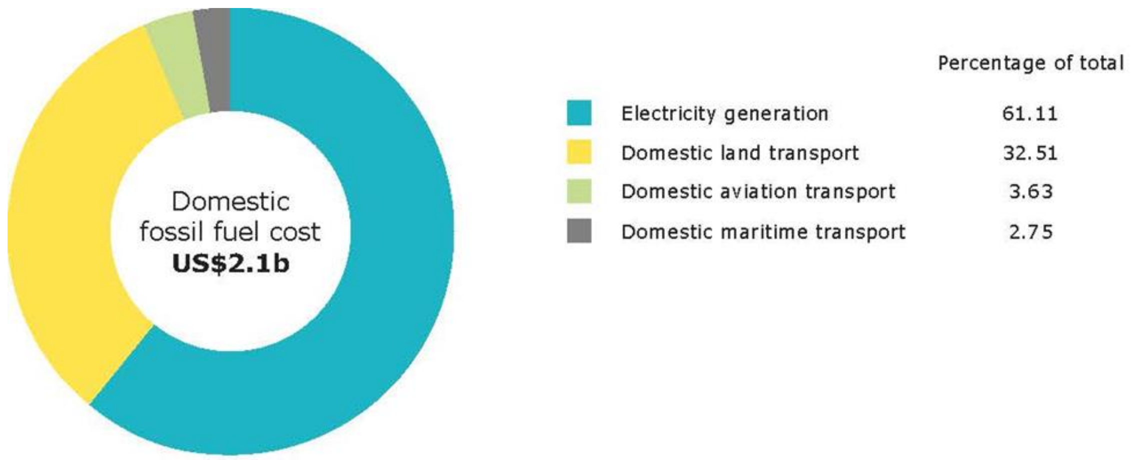

FIGURE 5. ESTIMATE OF THE TOTAL DOMESTIC FOSSIL FUEL COST IN THE PACIFIC IN KEY SECTORS.

The potential application of hydrogen derivatives in key sectors is expanded upon below. Potential application of hydrogen to sectors outside of typical domestic sectors (i.e., fuel bunkering and international aviation and shipping) are also briefly discussed, however they are not considered in the estimated demand for hydrogen in key sectors, due to uncertainty around energy use by national airline carriers, the wide-ranging refuelling locations for international aviation and shipping, and the uncertainty involved in national responsibility for fuel bunkering emissions. An indicative hydrogen potential is calculated

[xiii] Note that this value may not be accurate at the time of publishing. Note that this value is used throughout for estimate of fossil fuel costs.
[xiv] Note that these demand and saving values are based on preliminary desktop research assuming 100% of the fossil fuel used in this sector can be replaced with hydrogen or derivatives to provide a baseline case. Detailed assessments of the potential for hydrogen and the subsequent economic and environmental impact will be conducted in subsequent reports.
[xv] Fossil fuel use classified as "household, commerce, and public services", "agriculture", "construction, manufacturing, and mining", "unspecified", or "other" are not included in this estimate, however in reality it is likely that hydrogen and derivatives will find application to some percentage of these sectors. Note that "electricity generation" covers some fossil fuel use in these sectors.

based on the fossil fuel use in key sectors. The potential role of each PICT in a potential future hydrogen and derivatives scenario is provided[xvi].

3.1. Domestic Land Transport

It must first be noted that there are many direct electrification options for domestic land transport applications (such as battery-electric light vehicles).[36] It is likely that hydrogen and derivates such as methanol and renewable diesel will play only a complementary role in this sector, however indicative values based on the total energy use in the land transport sector are discussed as an example. These derivatives can potentially save US $680 million worth of fossil fuel import savings per year, displacing around 7.4 million bbl of diesel equivalent per year in this sector, and corresponding to 3.2 million tonnes of CO_2 abated.[xvii]

Papua New Guinea, Fiji, and New Caledonia comprise over 80% of energy use for domestic land transport applications of the assessed PICTs. These values are mostly correlated to the population size and concentration, land area, and availability of transportation (**Figure 6**).

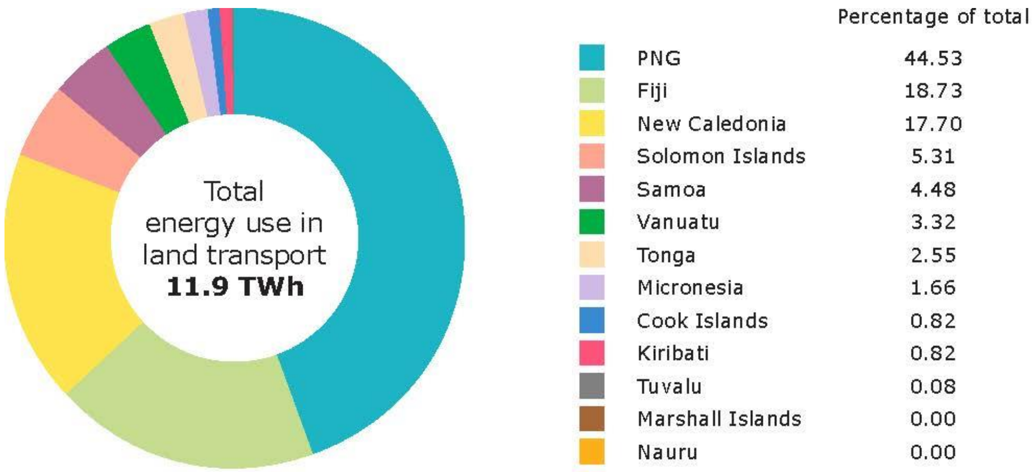

FIGURE 6. ESTIMATE OF THE TOTAL ENERGY USE IN DOMESTIC LAND TRANSPORT.

Current commercial heavy hydrogen fuel cell vehicles include short haul, long haul, and garbage trucks, as well as single and double decker buses.[37–42] Suppliers include Hyzon, Enginius, Quantron, Wrightbus, Caetano, and Van Hool. Methanol-powered vehicles have seen recent interest, including the Geely Emgrand 7 cars and the Volvo DME-fuelled truck, whilst Swedish cars have been powered by a combination of methanol (56%) and gasoline (44%).[25] China is developing its M100 (100% methanol) fuel, and methanol-derived fuels such as A20, a 15% methanol and 5% bioethanol blend, being trialled in Italy.[43] The use of drop-in fuels or fuel blending can allow the use of hydrogen derivatives in existing infrastructure, improving energy security as a stopgap solution on the path towards 100% replacement of fossil fuels. For example, Neste supplies renewable diesel to the West Coast of the United States, which can reduce GHG emissions by 75% compared to fossil fuel diesel and is fully compatible with current diesel and aircraft engines and fuelling infrastructures.[44]

[xvi] Note that these roles depend on a more robust analysis that will be evaluated in detail in accompanying reports. These reports provide an indication only, for informing future decision making.
[xvii] For specific data on each PICT, see Appendix B.

3.2. Domestic Maritime Transport

The PICT region as a whole operates a diverse fleet of domestic maritime vehicles, from small boats with outboards to inter-island shipping. As for domestic land transport, electrification may be possible for some use cases in this sector (such as for short distance shipping), however may not be suitable for long distance shipping.[45]

As such, derivatives including methanol, renewable diesel, and ammonia can also potentially replace fossil fuels for domestic maritime applications. Around US $58 million worth of fossil fuel imports can be saved per year, corresponding to 0.6 million bbl of diesel equivalent and 0.3 million tonnes of CO_2 abated in this sector[xviii]. Of the total 3,600 TJ of energy used in domestic maritime in the assessed PICTs, 1560 TJ is used by Fiji (43%), whilst 670 TJ is used by New Caledonia (18%), however, data is lacking for some nations.

Methanol and ammonia refuelling for large maritime vessels can also be strategically positioned along international trade routes (**Figure 7**). Most PICTs have one major international maritime port. These locations can provide a hub for refuelling stations for large maritime vessels, significantly increasing the potential fossil fuels offsetting opportunity. Advantages of methanol as a shipping fuel include that it is the lowest-cost carbon-neutral shipping fuel, it has a high energy density compared to LNG, ammonia, and hydrogen, it is easily scalable, and it lowers emissions of sulphur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter.[46] Advantages of ammonia as a shipping fuel are that it does not release CO_2 during combustion, it has a high energy density compared to hydrogen, and it is easily scalable, however new infrastructure (such as ammonia engines) is required.[47] Alternatively the PICTs could provide refuelling locations for trade and cruise ships. The primary advantage of renewable diesel is the ability to be easily blended with conventional diesel at high ratios.[48]

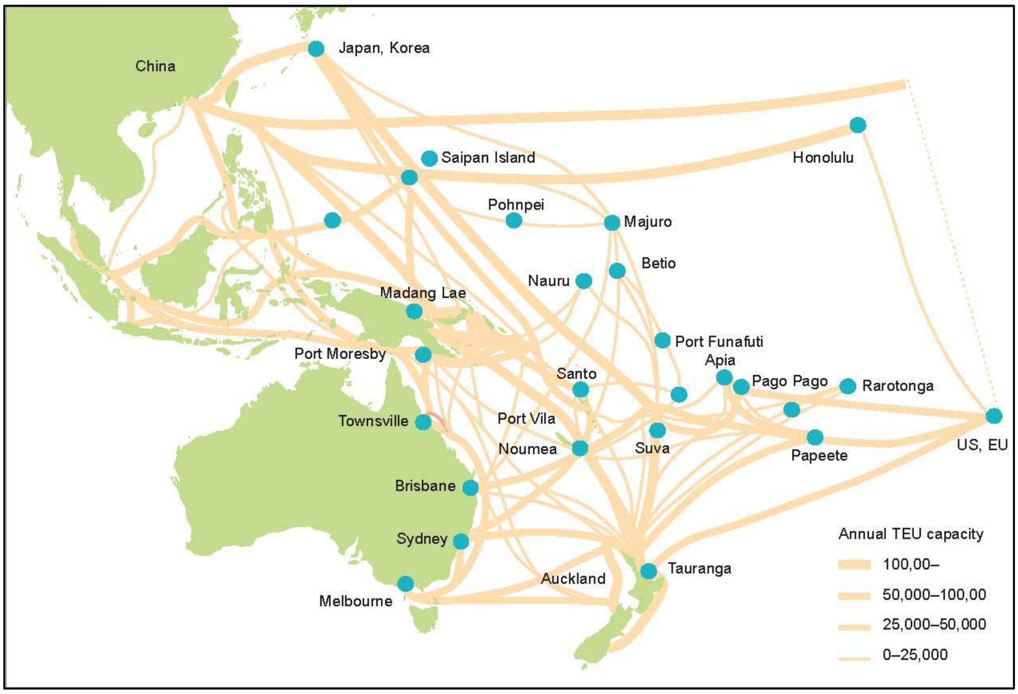

FIGURE 7. PRIMARY SHIPPING ROUTES IN THE PACIFIC.[49]

xviii Note that these values include domestic maritime only. International operations are not included. For specific data on each PICT, see Appendix B.

Leading shipping companies have committed to marine methanol, including AP Moller-Maersk, CMA CGM, China COSCO Shipping Corporation Limited, Methanex Waterfront Shipping and Stena.[46,50] For example, Maersk is spending US $7 billion on upgrading a fleet of 19 ships to be powered by methanol, featuring a methanol propulsion configuration developed in collaboration with makers including MAN Energy Solutions, Hyundai, and Alfa Laval.[46]

Yara Clean Ammonia (YCA) and Bunker Holding Group have signed an MOU establishing the intention to collaborate to accelerate the development of the market for clean ammonia as a shipping fuel.[51] CMA CGM and Maersk are also researching into ammonia for maritime applications.[52] Wartsila, a manufacturer of marine technologies including methanol fuelled engines, has developed an engine that can run on a blend of 70% ammonia and plans to design a concept engine that can run on pure ammonia.[53]

Neste has supplied renewable diesel to Airbus for carrying major components for the A320 family by sea between production sites. Renewable diesel will comprise around one third of the fuel blend during an 18-month test campaign, potentially reducing emissions by ~20%.[54]

3.3. Domestic and International Aviation

Electrification of aviation poses significant challenges due to the battery weights required for long distance transport.[45] SAF can potentially replace fossil fuels for domestic aviation and international aviation in the PICTs; US $76 million worth of fossil fuel imports are spent in the domestic sector[xix] per year, corresponding to around 0.8 million bbl of diesel equivalent, and 0.4 million tonnes of CO_2 abated, Of the total 4800 TJ of energy used in domestic aviation in the assessed PICTs, 3800 TJ (~80%) is used by Papua New Guinea, whilst 550 TJ (~11%) is used by Fiji. However, data is lacking for some nations.

Preliminary calculations indicate that up to 8.0 million bbl of diesel equivalent can be replaced by SAF per year in the international aviation sector[xx], corresponding to 3.4 million tonnes of CO_2 abated, and US $740 million worth of fossil fuel import savings per year. The key players in this space include Fiji Airways, Samoa Airways, Air Vanuatu, Solomon Airlines, Air Niugini, Air Calin, Air Kiribati, Lulutai Airlines, Air Rarotonga, Air Marshall Islands, and Nauru Airlines. Of these, Fiji Airways and Air Niugini are two of the largest airlines in the Pacific Region.

The benefits of SAF include (i) SAF can be a net-zero fuel, as it produces CO_2 when burned, however absorbs CO_2 during production, (ii) SAF has similar energy density and physical characteristics to kerosene and does not suffer the same energy density limitations of batteries or hydrogen, which are unsuitable for the aviation sector, and (iii) SAFs are already in production.[55]

Airlines in the region are yet to announce any SAF procurement targets, however, Air Niugini has purchased four Trent 1000 engines to power two new Boeing 787-8 Dreamliner aircrafts, which can technically operate at up to 50% SAF blend.[56]

[xix] Domestic refers to any flights that depart and arrive in the same national territory. For specific data on each PICT, see Appendix B.
[xx] The values for estimated fuel use for national carriers is an estimate subject to variation pending updated data.

3.4. Electricity Generation

The first key step for renewables penetration in the PICTs is the direct use of renewables for grid electricity generation. However, due to issues of resource availability in some cases (such as land, solar, or wind) and the requirement for long term energy storage for extended periods of low solar or wind, there is a case for the generation of hydrogen or derivatives for energy storage and electricity generation.

Methanol, ammonia, and renewable diesel can potentially displace fossil fuels for electricity generation, saving US $1.3 billion worth of fossil fuel import savings per year. Around 14 million bbl of diesel equivalent could be replaced per year in this sector, corresponding to 6.0 million tonnes of CO_2 abated. Papua New Guinea and New Caledonia comprise almost 90% of total electricity usage of the assessed PICTs (**Figure 8**). In Papua New Guinea, this is due to the large population and developed industry. Heavy industries (such as mining) are a significant contributor to overall electricity consumption in PICTs including New Caledonia and Fiji.

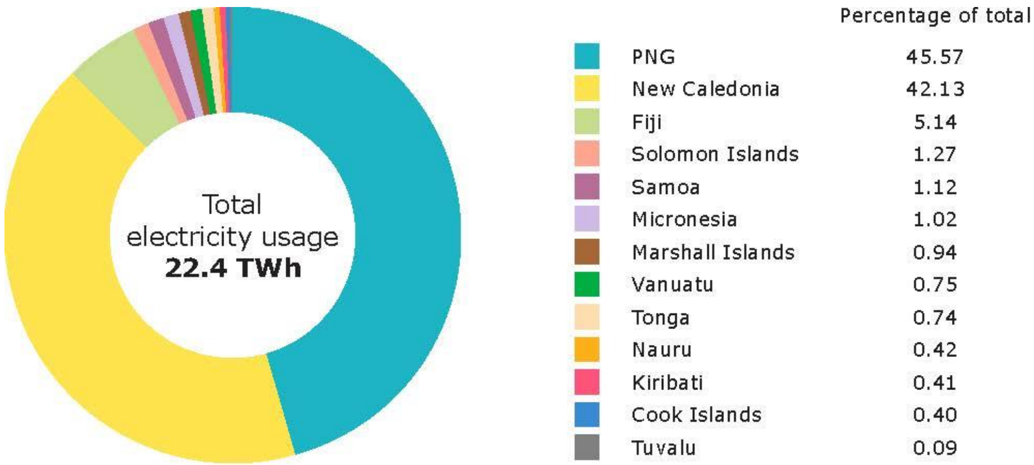

FIGURE 8. ESTIMATE OF THE TOTAL ENERGY USED IN DOMESTIC ELECTRICITY GENERATION.

Gaseous hydrogen could be shipped for power generation using fuel cells; however, this may not be desirable due to the challenges of transporting hydrogen (as either a liquid or gas). Conversely, as liquid fuels at standard temperature and pressure, methanol, ammonia, and renewable diesel can be generated and more easily transported for use in remote and isolated communities where conventional renewable energy generation is unsuitable, or to areas with insufficient wind or solar for consistent electricity generation. Renewable diesel can be employed as a stopgap solution in the current energy infrastructure for grid electricity generation, during the transition to renewable electricity.

Mitsubishi has commenced development of the world's first ammonia-fired 40 MW Class Gas Turbine System for use in remote locations,[57] whilst there are several manufacturers of methanol fuel cell systems for stationary power generation, such as Blue World Technologies, Palcan, and SFC Energy.[58]

3.5. Other Potential Uses

There are several further uses of these chemicals and fuels that may apply to the PICTs:

- Use of hydrogen for small-to-medium scale energy storage. For example, hotels and resorts in the region are well placed for decarbonising their operations through hydrogen storage and use in fuel cell technology for electricity.
- Use of methanol as a direct replacement of fossil fuels for commercial applications such as cooking, particularly in remote and isolated communities.
- Use of methanol, ammonia, or renewable diesel for the replacement of fossil raw materials in manufacturing and chemical synthesis. Relevant companies in the region could include Fiji Chemicals, Solomon Breweries, mining companies, such as Societe Minere du Sud Pacifique (New Caledonia), Dome Gold Mines (Fiji, PNG), Vatukoulia Gold Mines (Fiji), Lion One Metals Limited (Fiji), Ok Tedi Copper and Gold Mine (PNG), Porgera Gold Mine (PNG), and Lihir Gold Mine (PNG).
- Use of ammonia in the production of synthetic fertilisers for the agricultural sector. Fertilisers are not extensively used in the PICTs due to their expense to produce and ship.[59,60] Further, soil fertility is poor in the PICTs, and considering the importance of agriculture to the livelihood and GDP of many PICTs, local production of synthetic fertilisers could alleviate these issues. For example, South Pacific Fertilizers Limited (Fiji) currently imports ammonia in very small quantities.
- Use of ammonia in the production of explosives for construction and mining. See the mining companies listed above.

Table 5 provides a high-level outlook of the key domestic sectors that could be decarbonised through either direct renewables or through hydrogen and derivatives. The energy equivalency is provided as a hydrogen value for reference only (corresponding to ~1.1 Mtpa of H_2 total across the region)[xxi].

[xxi] Note that the estimated demand figures have been established based on the desktop analysis of potential energy demand sectors across the PICTs and the subsequent H_2 requirement assuming 100% energy conversion. While this is a highly simplified overview, it provides a baseline demand figure. Actual H_2 demand will be vary depending on end use technology (energy conversion efficiency) and the H_2 derivative used (i.e., the H_2 conversion efficiency and energy conversion efficiency). This detailed demand modelling will be conducted in accompanying studies. These calculations are provided in Appendix C. Note that some data on energy use in key sectors is incomplete for several PICTs.

Table 5. Estimated demand of hydrogen and derivatives to key sectors for the assessed PICTs. The H_2 potential was calculated based on the desktop analysis of potential energy demand sectors across the PICTs and the subsequent H_2 requirement assuming 100% energy conversion. This value is provided as an illustration of the potential application of H_2 and derivatives only, and actual demand values will vary by PICT, by sector, and by derivative employed.

PICT	H_2 potential (ktpa)	Electricity generation (%)	Domestic land (%)	Domestic maritime (%)	Domestic aviation (%)	All transport (%)
Fiji	116	29	56	11	4	-
Samoa	26	28	61	11	0	-
Vanuatu	17	28	56	6	0	-
Solomon Islands	30	27	62	10	1	-
PNG	480	62	32	0	6	-
New Caledonia	345	80	18	2	1	-
Kiribati	6.3	42	45	8	5	-
FSM	16	41	36	21	2	-
Tonga	17	28	52	20	0	-
Cook Islands	8.5	31	43	9	17	-
RMI	9.9	62	-	-	-	38
Tuvalu	1.1	52	33	15	0	-
Nauru	4.5	62	-	-	-	38

4. Resources for Green Hydrogen and Derivatives Generation

A critical limiting factor for large scale H_2 and derivative production in the PICTs is the availability of resources including solar, wind, and hydro power potential, biomass, CO_2, and water feedstocks, and land availability. Resource allocation for P2X faces further challenges with sectors such as electricity generation and agriculture[xxii]. This section highlights the resource distribution across the PICTs.

4.1. Solar Availability

Overall, the PICTs receive around the global average solar energy of 1.5 GWh MW^{-1} yr^{-1}, however, land availability issues may hinder the use of solar PV as an energy source in some PICTs (see below) The PICTs that receive the highest solar energy include:[15]

- Nauru (1.7 GW MW^{-1} yr^{-1})
- Kiribati (1.7 GW MW^{-1} yr^{-1})
- Cook Islands (1.6 GW MW^{-1} yr^{-1})
- Samoa (1.5 GW MW^{-1} yr^{-1})
- Tonga (1.5 GW MW^{-1} yr^{-1})
- Tuvalu (1.5 GW MW^{-1} yr^{-1})

Figure 9 shows a high-level map of the solar availability across the Pacific Region B.[xxiii]

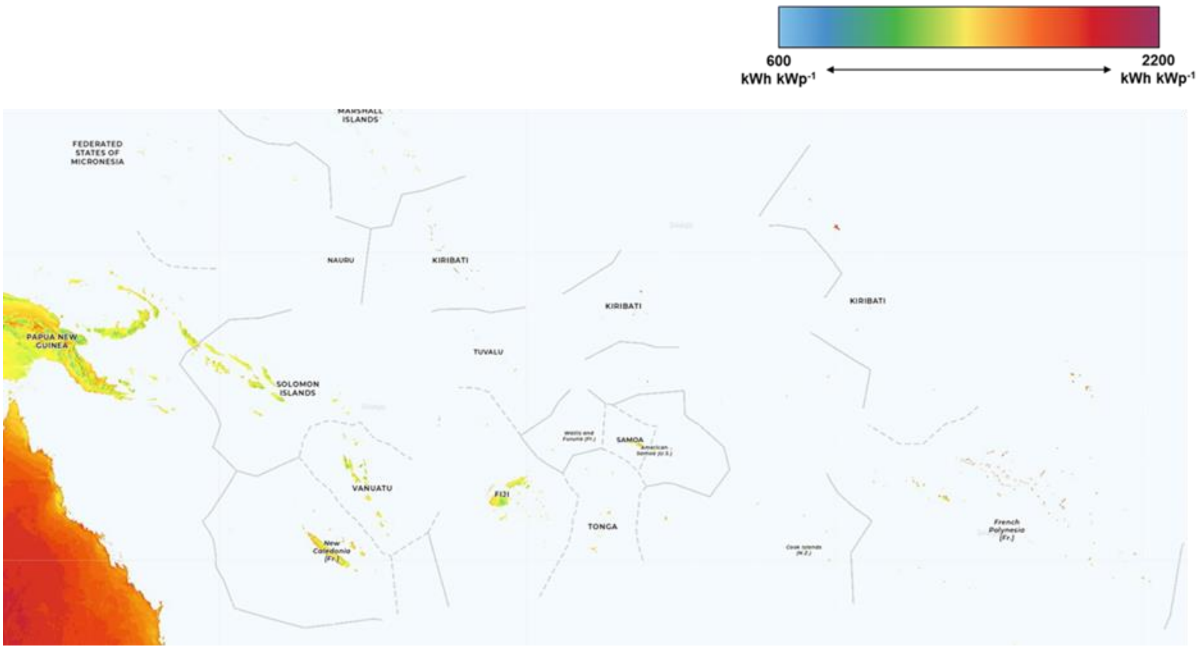

FIGURE 9. A HIGH-LEVEL MAP OF THE SOLAR AVAILABILITY ACROSS THE PACIFIC REGION.[61]

[xxii] These challenges are not discussed in detail in this report but will be evaluated in detail in accompanying analysis.
[xxiii] For specific data, mapping, and analysis on the solar availability for each PICT, see Appendix B.

4.2. Wind Availability

Wind availability is much more variable amongst the Pacific regions. Compared to the global average wind energy of around 2.2 GWh MW^{-1} yr^{-1}, the PICTs that receive the highest wind energy include:[15]

- Tonga (3.9 GW MW^{-1} yr^{-1})
- Fiji (3.5 GW MW^{-1} yr^{-1})
- FSM (2.6 GW MW^{-1} yr^{-1})
- New Caledonia (2.6 GW MW^{-1} yr^{-1})
- Vanuatu (2.6 GW MW^{-1} yr^{-1})

Kiribati, Solomon Islands, Nauru, and Papua New Guinea experience around only 1.0 GW MW^{-1} yr^{-1}. **Figure 10** shows a high-level map of the wind availability across the Pacific Region[xxiv]. However, due to factors such as the higher wind energy off-coast for many PICTs, as well as the frequent occurrence of cyclones and hurricanes, wind power may not the preferred source of renewable energy.

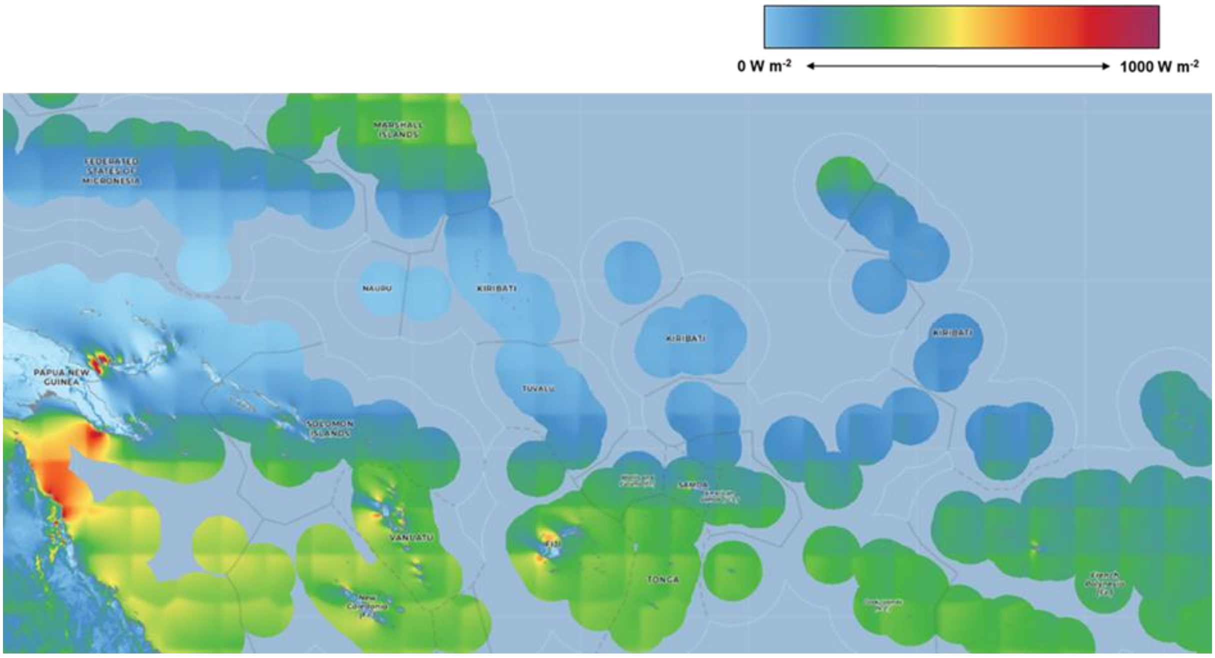

FIGURE 10. A HIGH-LEVEL MAP OF THE WIND AVAILABILITY ACROSS THE PACIFIC REGION.[62]

[xxiv] For specific data, mapping, and analysis on the wind availability for each PICT, see Appendix B.

4.3. Biomass Availability

Biomass is an important resource for the generation of fuels such as methanol, renewable diesel, and SAF, that can be synthesised through various pathways involving hydrogen and biomass. The primary sources of biomass in the PICTs are wastes from industry (including logging and sugarcane), coconut oil, and vegetable oils. Biogas production from agriculture or waste is also a potential avenue. However, bio feedstock lifecycle assessments (LCA) may be required on a case-by-case basis to ensure that the relevant green fuel certification requirements are met. The following table (**Table 6**) provides a brief overview of the biomass availability for each of the assessed PICTs.[15]

TABLE 6. OVERVIEW OF BIOMASS AVAILABILITY IN THE ASSESSED PICTS.

PICT	Biomass availability
Fiji	▪ Large volumes of wastes from wood and sugarcane industries ▪ Large areas of forest land
Samoa	▪ Forests mostly cannot be used, and potential for future logging is low ▪ Coconut oil forms a very small part of energy generation
Vanuatu	▪ Large volumes of wastes from wood industries ▪ Large areas of forest land
Solomon Islands	▪ Heavily forested, however difficulties exist between landowners and potential biomass products ▪ Large volume of coconut oil
PNG	▪ Coconut oil, palm oil and sugarcane are potential sources for biofuel production ▪ Large areas of forest land
New Caledonia	▪ Logging industries have reduced forested land, however still high ▪ High potential for vegetable oil or coconut oil derived biofuels
Kiribati	▪ 70% of the land is covered by coconut trees ▪ Only 10% of the produced coconut oil is used by Kiribati, with the rest exported
FSM	▪ Loss of forests through logging and agriculture ▪ Possible production of coconut oil
Tonga	▪ Over half the country is tree crops, primarily coconut ▪ There are small amounts of logging residues
Cook Islands	▪ Almost no industries that produce biomass wastes ▪ Coconut oil is mainly used at a household level
RMI	▪ Biomass, mostly consisting of coconut, is a primary source of energy for cooking ▪ Outer islands lack resources. Kerosene and LPG are replacing biomass for household use
Tuvalu	▪ Large coverage of coconut trees, however they are a valuable food source
Nauru	▪ Almost no potential for bioenergy

4.4. CO_2 Feedstock Availability

CO_2 feedstocks necessary for converting H_2 to methanol and SAF could potentially be sourced from direct air capture (DAC) or waste emissions from bioenergy plants. Another option is the utilisation of unavoidable fossil fuel or industrial flue gas emissions[xxv], although the certainty of these sources meeting stringent sustainability and certification standards remains to be fully established. This underscores the need for thorough and case specific LCAs, and review of certification requirements where these feedstocks are being considered. Fuels derived from sustainable biomass and direct air capture are commonly recognized as renewable. However, the status of recycled CO_2 from unavoidable sources as renewable is less clear. While their potential for substantial emission reduction is acknowledged, they have yet to be consistently categorised due to the absence of universally accepted standardised classifications.

Therefore, (i) there is likely to be a lower availability of CO_2 following the shift to renewables and to hydrogen and derivatives, and (ii) the capture of CO_2 emissions from these end use sectors is challenging and costly. It is estimated that the cost of carbon capture from power generation facilities is in the order of US $50 – 100 per ton of CO_2.[63] Development of these facilities will then impact the cost of electricity generated, placing further strain on the local economy.

Alternatively, CO_2 from the atmosphere can be separated from ambient air (DAC) and used to generate these e-fuels. DAC technology has been demonstrated for use in different applications. However, the cost of capture that is currently significantly high (>US $200 per ton of CO_2 captured) and is therefore a major barrier for mass adoption.[64] Moreover, there is also a concern of high energy demand for DAC (~6 – 10 GJ/tCO_2 or ~1.6 – 3 MWh/tCO_2),[65] which will subsequently create additional competition for renewable energy resources and decarbonisation efforts. Due to land requirements and the low technology readiness level (TRL) of this technology, it is unlikely that a favourable technoeconomic analysis would be achieved.

Provided the emissions can be effectively and economically captured, **Table 7** provides estimates of the volumes of fuels that could be potentially generated, using the current values from the region's fossil fuel-based power sector as an example.

[xxv] It is important to note that such CO_2 resources are non-sustainable, as a transition away from fossil fuels in the PICTs could see these powerplants being replaced with renewable and non-emission producing facilities (unless fuels such as methanol, SAF, or renewable diesel are used as drop in replacement fuels and the CO_2 generated is recaptured to produce these fuels).

TABLE 7. ESTIMATED POTENTIAL FOR PRODUCTION OF METHANOL AND SAF USING WASTE CO_2 EMISSIONS FROM THE PICTS' FOSSIL FUEL BASED POWER SECTOR[xxvi].

Emission Capture Scenario	Emissions Captured (tpa)	Methanol Production		SAF Production	
		Methanol Production (tpa)	H_2 Required (tpa)	SAF Production (tpa)	H_2 Required (tpa)
10% of emissions	600,000	437,000	82,000	218,000	109,000
25% of emissions	1,500,000	1,092,000	206,000	544,000	272,000
50% of emissions	3,000,000	2,184,000	412,000	1,088,000	544,000
75% of emissions	4,500,000	3,276,000	618,000	1,631,000	816,000
100% of emissions	6,000,000	4,368,000	825,000	2,175,000	1,088,000

4.5. Land Availability

Solar and wind energy require large land availability (0.5 – 3.0 ha/MW),[66,67] a key issue for the implementation of Power to X in the PICTs. Issues relating to land use may include:

- Low land availability for some PICTs.
- Leasing or acquisition of land from traditional landowners.
- High levels of forested land or agricultural land that may require deforestation or land clearing, potentially hindering LULUCF targets.

These challenges may lend to the concept of a regional hub for supply of Power to X fuels, in place of domestic production. **Table 8** (on the next page) outlines the total land area, and percentage of land that is either agricultural or forested land, for each of the assessed PICTs.

[xxvi] Note that these estimates are based on the conversion factors of kg CO_2/kg of Methanol + kg H_2/kg of Methanol and kg CO_2/kg of SAF + kg H_2/kg of SAF. Emissions are estimated as the total CO_2 emissions from electricity generation in the PICTs (5.98 Mtpa). These estimates assume that the technology for capturing the emissions can be economically and technically deployed at 100% conversion efficiencies. In reality these estimates will vary based on the intrinsic carbon capture and subsequent conversion limits. These aspects will be discussed in detail in the subsequent reports.

TABLE 8. TOTAL LAND AREA OF EACH PICT, AND PERCENTAGE THAT IS EITHER AGRICULTURAL OR FORESTED LAND.[68]

PICT	Total land area (km^2)	Agricultural and forest (%)
Fiji	18,274	79
Samoa	2,831	73
Vanuatu	12,189	51
Solomon Islands	29,896	83
PNG	462,840	66
New Caledonia	18,575	56
Kiribati	811	57
FSM	702	100
Tonga	747	56
Cook Islands	236	73
RMI	181	52
Tuvalu	26	93
Nauru	21	20

4.6. Water Availability

Additionally, water is a critical feedstock for hydrogen and subsequent derivative generation, requiring around 20 – 30 L per kg of hydrogen generated.[69,70] However, water availability is a critical issue amongst the PICTs, with only 55% of people having access to basic drinking water. Small catchments, shallow aquifers, inadequate water storage, and the dependence on rainwater to supplement traditional surface water and groundwater resources, are key challenges that must be addressed, particularly in the low-lying islands, such as Nauru, Kiribati, Tonga, Tuvalu and RMI.[71] Climate change is further exacerbating water stress within the region, particularly in isolated regions and small islands that rely on seasonal rain for freshwater.

Desalination facilities may be considered for generating the freshwater required for hydrogen and derivatives generation, simultaneously assisting in achieving water security. Small scale water desalination plants using membrane and RO technologies (up to 7,000 litres per day) have been demonstrated in Southeast Asia, powered by off-grid renewable energy.[72] Companies in this space include InnoDI and Boreal Light.[73,74]

4.7. Emerging Roles in a PICT's Hydrogen Economy

Depending on the discrepancy in resources and potential energy demands across the PICTs, a wide variety of roles could potentially be realised. Particularly, the resource and infrastructure rich countries in the region can emerge as production hubs that can generate bulk amounts of H_2 and derivatives to fulfill local energy demand, as well as exporting them to smaller, more remote, or more resource/infrastructure deficient nations. Such collaboration can enable a H_2 economy in the PICTs that strives to achieve the regional renewable energy and NDC targets, as well as reaping economic benefits and energy self-reliance for the region.

Table 9 provides an example of such a potential H_2 economy based on the resource availability amongst the assessed PICTs. Note that a range of factors (outlined below) will determine a realistic supply chain model, and that a consideration of local production versus import of hydrogen and derivatives must be made based on economics and scales, before potential trade arrangements are realised.

Renewable Energy and Hydrogen in the Latin American and Caribbean SIDS – *Lessons for the Pacific Islands*

The SIDs Lighthouses Initiative[75] (coordinated and facilitated by IRENA) brings together 40 SIDS from the Caribbean, the Pacific, and the Atlantic, Indian Ocean and South China Sea (AIS) regions, as well as 37 other partners, in order to support the SIDs' energy transition targets in alignment with several priority areas, including:

- Supporting SIDs in reviewing and implementing NDCs.
- Extending technical assistance and capacity building.
- Implementing effective, innovative solutions, with continued technical and regulatory advisory services.
- Support the development of bankable projects, fostering access to finance and closer co-operation with the private sector.
- Strengthen institutional and human capacity development in all segments of the renewable energy value chain.

A key target of the Initiative is 10 GW of installed RE capacity in all SIDS by 2030. In the Caribbean region, a recent project is the 148 MWp solar PV project in Trinidad and Tobago, which began construction in early 2023. The knowledge and experience gained from these projects can be directly applied to current and future projects in the Pacific Islands region.

The Inter-American Development Bank (IDB) has published a series of reports on the opportunities and challenges for the implementation of green hydrogen in Latin America and the Caribbean (LAC).[76–78] The IDB provides both technical assistance and financial support, playing a similar role to the Asian Development Bank in the Pacific region. Parallels can be drawn between the challenges that this region faces in terms of over-reliance on imported fossil fuels, as well as geographic and economic contexts, and to the Pacific Islands region, allowing key takeaways and strategies to be considered:

- **Hub and H_2 Cluster Models**: Due to the relatively small projected hydrogen demands in the Caribbean and therefore the lower attractiveness to establish local operations, the IDB has identified potential hubs for green hydrogen and various clusters for supply dynamics. *A similar outcome for PICTs is also likely given the distribution of resources and end use demands.*

- **Economic and Support Levers:** The IDB assessment is based on examination of 33 countries, and considers current renewable energy potential, logistics competitiveness, renewable energy regulations, existing H_2 and derivative projects, port infrastructure, and opportunities for specialisation in key sectors.[78] Overall, the estimated levelised cost of green hydrogen is highly variable within the region as a function of local renewable energy resource and infrastructure, e.g., Trinidad and Tobago's existing infrastructure can be leveraged for a H_2 economy, leading to favourable economics. In addition, the scale up of demand and cost reduction in technology will make regionally generated H_2 and derivatives in SIDs economic and competitive over the long run, especially in a global H_2 export market.[78] Although the PICTs may not play a significant role in the global H_2 market, effective deployment of technology to leverage a suitable scale, high renewable energy potential, existing infrastructure, along with upcoming cost reductions will likely make a H_2 market viable in the PICTs region.

- **H_2 Certification Schemes:** As part of their efforts, IDB is also developing a hydrogen certification scheme for the LAC. This certification scheme builds on important attributes highlighted in global H_2 policy and certification schemes. A similar scheme can be adopted and developed for the PICTs to make the region compliant with global H_2 standards. In the Pacific, H_2 certification schemes are also being developed. For example, the Australian Guarantee of Origin (GO) scheme would provide (i) a mechanism to track and verify emissions associated with hydrogen and other products, and (ii) an enduring mechanism for renewable electricity certification which could support a variety of renewable energy claims.[79] Similar schemes can be adopted by the PICTs.
- **Economic Support:** Additionally, the LAC region faces economic constraints similar to those of the PICTs. Further, there is a necessity of sector coordination to identify and exploit industrial synergies which could make for better business cases. A key consideration is the time taken for green hydrogen to be economically competitive, during which institutions and governments must put mechanisms in place to boost local demand in multiple applications, e.g., mobility, power, heat, and feedstock.[77,78] The IDB has suggested financing models that can leverage funding from global lending and public/private entities to finance projects. The IDB has already used this framework to provide a US $400 M financing facility for green hydrogen projects in Chile. Similar frameworks could be developed to streamline financing and investments in the PICTs.

Current Projects: The HDF Energy PV and hydrogen storage plants in Barbados and French Guiana will provide power for around 10,000 households in each country.[80] In French Guiana, the plant will be located on hilltops rather than biodiverse lowland forests, avoiding any major environmental issues. In Barbados, due to limited agricultural land, the plant will also be home to a flock of sheep that will not only serve as natural lawnmowers and keep the land fertile, but also increase local production of meat and hide.[81] These aspects can be applied to the HDF Energy project in Fiji.

In Dominica, there are plans to harness significant geothermal resources to generate both green hydrogen and green energy both for export and local consumption.[82] PNG is currently the only PICT using geothermal energy, however PICTs including Fiji, Vanuatu, Samoa, Tonga, and the Solomon Islands have the potential to employ geothermal resources.[83]

In Guadeloupe, Martinique, and Saint Lucia, the MAGHIC (Maritime Green H_2 Infrastructure in the Eastern Caribbeans) project aims to produce H_2 by offshore energy ships, which is then transferred to onshore storage for distribution on the islands.[84] This project can be used as an example for regional export market and distribution of hydrogen to islanded communities in the PICTs.

The viability of converting waste to hydrogen is also being explored in Martinique, with the aim of transforming up to 9,000 tons of Martinican waste into renewable hydrogen every year.[85] Similar guidelines and project designs can be adopted to manage waste resources in the PICTs region.

TABLE 9. OUTLOOK OF A POTENTIAL COLLABORATED H_2 ECONOMY IN THE PICTS BASED ON RESOURCE AVAILABILITY AND PICT PROXIMITY[xxvii].

PICT	Solar potential	Wind potential	Biomass potential	Land availability	Potential role
Fiji	Average	High	High	High	▪ Production and net export hub ▪ PICTs for export include Cook Islands, Tonga, Samoa, Tuvalu, Vanuatu, Nauru, RMI
Samoa	Average	Low	Average	High	▪ Production and net export hub ▪ PICTs for export include Cook Islands, Tonga, Tuvalu, Vanuatu, Nauru, RMI
Vanuatu	Low	High	High	High	▪ Production and net export hub ▪ PICTs for export include Solomon Islands, Nauru, Tuvalu
Solomon Is	Average	Low	High	High	▪ Production and net export hub ▪ PICTs for export include FSM, Kiribati, RMI, Vanuatu, Nauru
PNG	Average	Low	High	High	▪ Production and net export hub ▪ PICTs for export include FSM, Kiribati, Vanuatu, Nauru
New Caledonia	Average	High	High	High	▪ Production and net export hub ▪ PICTs for export include Cook Islands, Tonga, Samoa, Tuvalu, Vanuatu, Nauru
Kiribati	High	Low	Average	Low	▪ Net importer ▪ PICTs to import from include Papua New Guinea, Solomon Islands, Vanuatu
FSM	Average	High	Low	Low	▪ Net importer ▪ PICTs to import from include Papua New Guinea, Solomon Islands, Vanuatu
Tonga	Average	High	Average	Average	▪ Net importer ▪ PICTs to import from include Fiji, Samoa, New Caledonia
Cook Islands	High	Average	Low	Average	▪ Net importer ▪ PICTs to import from include Fiji, Samoa, New Caledonia
RMI	Average	Average	Low	Low	▪ Net importer ▪ PICTs to import from include Samoa, Fiji, Vanuatu, Solomon Islands
Tuvalu	Average	Low	Low	Low	▪ Net importer ▪ PICTs to import from include Samoa, Fiji, Vanuatu, Solomon Islands
Nauru	High	Low	Low	Low	▪ Net importer ▪ PICTs to import from include Fiji, Solomon Islands, Papua New Guinea, New Caledonia

High | Average | Low

[xxvii] Note that this figure is an example of a potential H_2 economy in the PICTs based on resource distribution, proximity of the PICTs, and current shipping routes. In practice, in addition to the resource constraints, market drivers and overall economics will determine the ideal supply chain model. Note that there is currently little data on the solar and wind potential for RMI. Note that water security is an important consideration that is not included here and is considered through detailed assessments and stakeholder engagement in future reports.

5. Conclusion

A significant expense (around US $2.1 billion) is associated with import of fossil fuels to the PICTs, for use in key domestic sectors of electricity generation and land, maritime, and aviation transport. These costs, predicted to increase significantly over the coming decades, can be considerably offset through the primary decarbonisation pathways (i.e., improving energy efficiency and renewables implementation, which underpins potential opportunities for Power to X). In the aims of achieving the PICTs' climate and energy-based targets, the decarbonisation of sectors that are hard to abate and electrify, or where direct use of renewable electricity is not a technically viable or cost-effective solution, can be achieved through the partnership of renewable energy with hydrogen and derivatives. Assessing this gap is a key target in the Pacific Hydrogen Strategy assessment report.

Opportunities for the use of green hydrogen and derivatives include energy storage of intermittent renewable energy, electricity generation, and replacement of diesel in transportation, in isolated communities, and during natural disasters. There is also an opportunity for collaboration between the PICTs, as nations with suitable infrastructure and favourable resource potential can become production and export hubs for green hydrogen and derivatives, whilst smaller nations could import these fuels, replacing expensive long-distance import of fossil fuels, avoiding volatile oil prices, and improving region-wide energy self-sufficiency and security.

There are also many challenges that must be overcome in the implementation of Power to X, including the local geography, consideration of natural disasters, and low diversification of economies in the PICTs, as well as the requirements for human capacity, technical assistance, and an enabling framework for providing a suitable environment for decarbonisation through hydrogen. With Australia's ambitions in green energy export, this comes an obligation to share knowledge and expertise in a way that will benefit Pacific-led decision making, ensuring that the PICTs benefit from all opportunities that the energy transition brings, including hydrogen. These challenges and opportunities are further detailed in subsequent reports, in order to map a technically and economically sound hydrogen strategy in the Pacific.

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