Chapter 7
The Water-Energy Equation

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Across the Pacific region, there is a statistically-significant relationship between a country's electrification rate and the proportion of that country's population served by a piped drinking water system.

Abstract In 1994, Peter Gleick defined the intricate relationship between water and energy as this: "We use energy to help us clean and transport the fresh water we need, and we use water to help us produce the energy we need." In the Pacific region, where diesel fuel is the primary electricity generation fuel, the water-energy nexus goes further. Globally, large quantities of water are needed to produce the fuel required to electrify the Pacific region. The prevalence of piped water systems in the Pacific region depends on a country's electrification rate. Renewable energy technologies can increase rural electrification rates. A positive statistically significant relationship exists between a country's electrification rate and the prevalence of piped drinking water systems, which gives hope that adopting aggressive renewable energy and climate policies will lead to greater access to improved drinking water sources across the Pacific region.

Keywords Water-energy nexus · Nexus studies · Pacific energy supply chains · Resources interdependencies · Supply chains · Water-for-energy · Energy-for-water · SDG 6 · SDG 7

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7.1 Introduction

The water-energy nexus defines the linked dependency between how societies consume and utilize water and energy, how water is integral to the production of energy resources, and how energy is key to the production of clean drinking water, the development of piped water systems, and the treatment of wastewater. In 1994, Peter Gleick defined the intricate relationship between water and energy as this: "We use energy to help us clean and transport the fresh water we need, and we use water to help us produce the energy we need" (Gleick 1994). Gleick's description of the relationship between water and energy underscores the water-energy nexus's dual nature: we need water to produce energy and we need energy to produce and distribute potable water through piped systems.

The geography of the Pacific basin creates unique challenges for managing resources at the water-energy nexus. The energy supply chains that transport primary energy sources to the Pacific region are long and tenuous, presenting many challenges and vulnerabilities for these countries. Primary energy sources are energy sources that can be utilized without secondary transformation. For example, the US Energy Information Administration lists primary energy sources like fossil fuels such as petroleum, natural gas, coal; nuclear electric power; and renewable energy sources such as geothermal, solar, hydroelectric, wind, and biomass (US Energy Information Administration 2020a). Conventionally, the conversion of primary sources of energy into secondary forms of energy—namely electricity—relies on a thermoelectric process that requires converting water into steam to spin turbines that generate electricity (Kohli and Frenken 2011). Because the challenges presented by long supply chains has hindered diversification of electricity generation fuel sources in the Pacific—a recent estimate showed that imported fossil fuels accounted for 90% of energy use in the Pacific region (Abbasov 2020)—the water-energy nexus has significant implications for water resources consumption in the region.

On its face, the water-energy equation is two-sided; energy is necessary to produce clean water and treat wastewater while water is necessary for energy generation; but it is multifaceted due to feedback loops in these complex coupled natural-human systems (Liu et al. 2007). While it is important to understand how and why water is necessary to produce energy in all its forms, energy is necessary to produce clean, potable drinking water and to clean wastewater. The energy intensity of water treatment to produce potable drinking water is dependent on the initial quality of the water being treated. Not surprisingly, water requiring more treatment is more energy intensive. In a region with limited freshwater resources but abundant access to the ocean for desalination, the energy intensity of water treatment is an important consideration; the desalination of and treatment of ocean water (Chap. 8) can be orders of magnitude more energy-intensive than performing the same process on brackish water (Plappally 2012). In turn, there is a water intensity to our energy, as water (steam) is essential to the production of electricity at thermoelectric power plants; though in geographies where diesel fuel is the primary energy source for electricity generation this relationship is not as intense. Finally, while wastewater treatment is an energy intensive process, wastewater itself is a potential source of energy through the production of biogas via anaerobic digestion (Qadir et al. 2020) and is an underutilized source of energy in area with low levels of wastewater infrastructure development. Hydroelectricity generated through control of rivers via dam construction is not prevalent in Pacific Island Countries and Territories (PICTs) but does exist (Chap. 2) and requires balancing upstream/downstream and seasonal demands for energy and water sectors. Even though the water-energy equation is seemingly straightforward, the numerous touchpoints between these two systems create complexity and opportunities for innovations that increase the sustainability of both systems in tandem.

This chapter will explore both lenses of the water-energy nexus and its implications for water access and security in the Pacific region, with focus mostly on the PICTs rather than the geographically larger and high-income countries of Australia and New Zealand. This chapter will present data on the supply chains that link the water-energy nexus across the Pacific region and present process-level data that quantifies the relationships between energy and water. We will discuss the impact that energy transitions away from fossil fuels will have on water resources. Further, we will discuss how a changing climate affects water availability and quality across the Pacific region and this, in turn, impacts the energy intensity of water production.

7.2 Water-For-Energy in the Pacific Region

Water is essential to the production of energy in all of its forms. Indeed, water itself is a form of energy stored behind dams or when river and ocean currents are utilized to spin turbines that produce electricity (US Department of Energy 2020). For the Pacific region, the water-for-energy relationship takes two forms. First, the direct usage of water to produce energy in the form of electricity. Direct water usage is the physical consumption of water to produce electricity through thermoelectric processes. The second form is indirect water use in the supply chains that produce the region's primary energy resources. Since the Pacific region's largest fuels for electricity generation are fossil fuels, mainly diesel in PICTS and coal in Australia (as detailed in Chaps. 3 and 12), we must also consider the water consumption required to produce these energy commodities. Through the water-energy nexus, water scarcity and other issues that affect the quantity, quality, and availability of water resources can affect the Pacific region's energy supply at the local level where electricity is generated and at the global level where fossil fuels are produced. In this section, we first discuss the direct use of water for energy production, followed by indirect water use in the Pacific region's energy supply chain. The section concludes with a discussion on the water implications of the Pacific region's transition away from fossil fuels.

7.2.1 Overview of Energy Generation Fuels Across the Pacific Region

Numerous challenges exist facing the electrification of the Pacific region. First and foremost, the region's remoteness creates long fuel supply chains to link the countries in the Pacific region to fuel suppliers. These long supply chains have created a dependence of fossil fuel in PICT nation electricity systems, both in the transport of fuel to islands and the utilization of petroleum products (fuel oils and diesel) as a primary fuel source for electricity generation. Population density also presents a large challenge to energy development and diversification. According to the Asian Development Bank (2019), the nations of Papua New Guinea, Fiji, Solomon Islands, Vanuatu, Samoa, Kiribati, Tonga, the Federated States of Micronesia, Marshall Islands, the Cook Islands, Palau, Nauru, Tuvalu, and Niue are comprised of approximately 3,200 islands/atolls. Given these countries' populations, the population per island/atoll ranges from 60 inhabitants per island/atoll in Palau to 21,889 inhabitants per island/atoll in Samoa (Asian Development Bank 2019). Previous studies have indicated that differences in electrification rates across PICT have pointed to geography—the vast number of islands/atolls in the region—along with differences in population density and GDP per capita as primary reasons (Dornan 2014). As shown in Table 7.1, in 2011 there was a weak relationship present between PICT electrification rates and both population density and GDP per capita. However, in 2019, the relationship identified by Dornan (2014) no longer held as many of the PICT nations with low electrification rates had substantially increased electrification rates by 2019. Specifically, the PICT nations of Vanuatu, Solomon Islands, and Papua New Guinea increased electrification rates by 282%, 450%, and 530%, respectively, illustrating the success that these countries have had making progress toward Sustainable Development Goal (SDG) 7, which includes ensuring "access to affordable, reliable, sustainable and modern energy for all," (Wu and Wu 2015). This needed and welcomed SDG electrification progress is due to increases in both fossil fuel-based and renewable energy electricity generation (Chap. 3).

Across the PICT region, fossil fuels, specifically fuel oils and diesel, play an outsized role in electricity generation due to the length of PICT supply chains, the high energy content of these fuels, and the relative portability of these fuels compared to other primary sources of energy for electricity generation. Oil and petroleum product dependence is a well-documented and longstanding concern for PICT nations. For decades, research studies have discussed the vulnerability of PICT nations to oil price shock and supply chain disruptions in their energy systems (Yu and Taplin 1997). A 1998 study evaluated the Fijian energy system oil dependencies and cited trade statistics showing net energy import dependence exceeding 90% as far back as the 1970s (Reddy 1998). Further, Reddy (1998) and Currie (1996) discussed various policy measures to reduce Fijian dependency on imported oil products, underscoring that the current efforts to reduce PICT nation fossil fuel dependency have deep roots.

Table 7.1 Electrification rates across the Pacific region

Country	2011			2019		
	GDP per capita[a] ($2019 USD)	Population density[b] (person per km^2)	Electrification rate[c] (%)	GDP per capita[a] ($2019 USD)	Population density[b] (persons per km^2)	Electrification rate[c] (%)
Guam	31,210	296	100	37,724	310	100
Nauru	6,560	503	100	10,983	538	100
Niue	11,372	6	100	12,095	7	100
Tuvalu	3,643	354	100	4,056	389	100
Northern Mariana Islands	13,497	117	100	20,660	124	100
Cook Islands*	17,837	74	99	28,486	75	100
Samoa	3,933	66	99	4,324	70	99
Palau	11,095	39	97	14,908	39	100
Tonga	4,003	144	95	4,903	145	98
Fiji	4,371	47	89	6,176	49	100
Marshall Islands	3,046	314	95	4,073	327	95
Kiribati	1,735	129	63	1,655	145	100
Federated States of Micronesia	3,009	148	54	3,585	163	75
Vanuatu	3,174	20	17	3,102	25	65
Solomon Islands	1,939	19	14	2,344	24	70
Papua New Guinea	2,407	17	10	2,829	19	63

[a] United Nations Statistics Division (2019)
[b] United Nations, Department of Economic and Social Affairs, Population Division (2019)
[c] Tracking SDG 7: The Energy Progress Report (2021)

Global data gathered by the US Energy Information Administration show on average fossil fuels comprise 80% of country level electricity generation portfolios in the Pacific region (US Energy Information Administration 2020b, 2020c). These data are shown in Table 7.2. According to the Asian Development Bank, the Cook Islands and Majuro, Marshall Islands are almost entirely diesel dependent for energy sources (Asian Development Bank 2019). According to a 2012 profile by the US National Renewable Energy Laboratory (NREL) of the 20.1 MW of nameplate capacity on the Federated States of Micronesia, diesel generators made up 18.6 MW of nameplate capacity (National Renewable Energy Laboratory 2016). In addition, a 2011 technical assessment conducted by NREL on Guam's energy system found an almost 100% reliance on petroleum products to meet energy demands; further, 52% of the petroleum products consumed (by volume) on island were consumed by the Guam Power Authority (Baring-Gould et al. 2011). As will be discussed later, the historic reliance on fossil fuels across the PICT region creates supply chain vulnerabilities with severe energy-water implications.

The heavy dependance of many PICT nations on fossil fuels for the generation of electricity is shown in Table 7.2 (see also Chap. 3). Of the nations with available data, 79% of generated electricity is generated from fossil fuel sources, with many being more than 95% dependent on fossil fuel for generation. Fiji is the outlier among the countries listed in Table 7.2 by generating 55% of electricity from renewable sources. While many PICT nations are listed in Table 7.2, source data only lists combustible fuels, hydropower, nuclear, and other sources as electricity sources, which provides a narrow view on electricity generation sources (United Nations 2020). Data availability has been documented as a limiting factor by regional energy system studies (Mishra et al. 2009; Lucas et al. 2017). However, the future of electricity generation will reduce fossil fuel dependence in electricity generation and shift to near-universal renewable energy development in the near future (Table 7.3). In many cases, the shift away from fossil fuels for electricity generation, which is an expensive fuel source, will positively impact Pacific region nations' economies. In 2012, Tokelau began generating 150% of power demands from renewable energy sources, saving the island approximately $829,000 per year of fuel costs (Government of Tokelau n.d.; Wilson 2012).

7.2.2 The Water Intensity of Electricity Generation

Fossil fuels are not only an expensive electricity generation fuel; they are also a highly water-intensive fuel source for generating kilowatt-hours. Between 2008–2012, the consumptive water use of electricity generation in Oceania (the Pacific Region) was 1,957 m^3 per year (Mekonnen et al. 2015); nearly three fourths (1,405 m^3 per year) of this water consumption occurred during the operational phase of electricity generation and the phase of electricity generation and the remainder (approx. 551 m^3 per year) occurred within the fuel supply chain. For this analysis, most of this water footprint (1,012 million m^3 per year) was from hydropower generation (evaporation occurring at water impoundments), while 584 and 13 million m^3 per year were consumed by coal lignite and oil generation, respectively (Mekonnen et al. 2015). However, this study takes a broad look at Oceania. The data is biased to countries for which data is available for in international data repositories, which may not account for diesel generators' fuel supply chain and energy mix of smaller Pacific region nations.

The reliance on diesel fuel for generation presents a challenge for traditional water-energy evaluations of the Pacific region's electricity generation since diesel fuel is typically treated as a transportation fuel instead of a stationary energy fuel source. A study by Lampert et al. (2016), from Argonne National Laboratories in the

Table 7.2 Fossil fuel dependence in electricity generation across the Pacific region

Country	Fossil fuel generation (2018, million kWh)	Total electricity generation (2018, million kWh)	Fossil fuel generation (%)
American Samoa	163	168	97
Cook Islands	31	41	76
Federated States of Micronesia	65	90	72
Fiji	464	1,042	45
French Polynesia	494	696	71
Gaum	1,663	1,715	97
Kiribati	27	31	87
Marshall Islands	88	90	98
Nauru	35	36	97
New Caledonia	3,077	3,486	88
Niue	3	4	75
Northern Mariana Islands	390	390	100
Palau	95	95	100
Papua New Guinea	3,180	4,482	71
Samoa	90	154	58
Solomon Islands	106	110	96
Tokelau[a]	–	–	–
Tonga	64	68	94
Tuvalu	6	8	75
Vanuatu	62	80	78
Wallis and Futuna	20	20	100
Total	10,123	12,806	79

Source United Nations (2020)

[a] Tokelau's GHG emissions are tabulated as part of New Zealand's GHG inventory (Ministry for the Environment, 2021) and has pledged to generate more renewable energy than is used on island (Government of Tokelau, n.d.)

United States, found that diesel production's lifecycle water consumption is 5.97 L of water/L of diesel produced. In 2012, the Cook Islands spent USD 29.8 million on diesel fuel for electricity generation (Asian Development Bank 2019). During 2012, the average worldwide diesel price was USD 1.265 per L (World Bank 2020), which implies that the Cook Islands consumed approximately 23.56 million diesel L for electricity generation. Given the figures derived by Lampert et al. (2016), the Cook Islands electricity generation's supply chain water consumption was 139,162 m^3 or approximately 16 m^3 per capita. Using the data from Table 7.2, diesel generation on the Cook Islands consumed approximately 4.48 L of water in its diesel supply chain

Table 7.3 Pacific region nations' renewable energy targets

Country	Renewable energy target (%)	Renewable energy target year
Federated States of Micronesia	>30	2020
Fiji	100	2030
Kiribati	23–40	2025
Marshall Islands	20	2020
Nauru	50	2020
Niue	80	2025
Palau	45	2025
Papua New Guinea	100	2030
Samoa	100	2025
Solomon Islands	79	2030
Tonga	50	2020
Tuvalu	100	2020
Vanuatu	100	2030

Note Adapted from Asian Development Bank (2019)

per kWh generated. Diesel fuel for electricity generation also poses risks for energy security with large, coastal storage facilities at risk from both severe storm damage and general age-related decay (Chaps. 10 and 12).

However, what we can see in Table 7.2 is that the Cook Islands is just a small fraction of fossil fuel generation in the Pacific region. Excluding Australia and New Zealand, the Cook Islands make up less than 1% of fossil fuel generation (9 billion kWh) in the Pacific region. Assuming that most fossil fuel generation in the Pacific region, excluding Australia and New Zealand, comes from diesel, and extrapolating from the Cook Island example, the Pacific region consumes 39 million m^3 of water in its diesel supply chain related to electricity generation. The climate policies (Table 7.3) undertaken by the Pacific region countries have a dual impact. Not only will these policies reduce diesel consumption in the region by hundreds of millions of liters, but they will also lessen the region's pressure on global water resources.

7.3 Energy-For-Water in the Pacific Region

For the Pacific region, the other half of the water-energy equation is understanding the energy-for-water relationship. Fundamentally, the amount of energy required to treat water depends on its source and its quality. Water sources with lower initial quality will require more treatment—a wider variety of technologies or more energy-intensive processing—than water sources of higher initial quality. On the most energy-intensive end of this spectrum is seawater (Chap. 8). The desalination of seawater requires large amounts of energy, and the energy intensity of desalination increases with seawater salinity.

However, for the Pacific region, the energy-for-water equation starts with the status of water systems. Piped water systems with centralized treatment are the most energy-intensive water system. According to WHO, in 2015, only 20% of the Pacific region (excluding Australia and New Zealand) had access to piped drinking water directly on their premises; this is the lowest proportion for any region in the world (World Health Organization 2016). In total, 52% of people in the Pacific region have access to improved water systems, while the remaining 48% rely on surface water (34%) and other unimproved water sources (14%) (World Health Organization 2016). Access to piped drinking water into households varies widely across the Pacific region. Niue and Tuvalu have nearly universal access to piped drinking water into households at 98% and 97%, respectively (World Health Organization 2016). On the low end of this spectrum, only 9% of the population of Papua New Guinea and only 3% of the population of the Marshall Islands have piped drinking water into households (World Health Organization 2016). It is important to note that the country-level statistics belie the drastic urban–rural divide between water access in the Pacific region. In all countries in the Pacific region, urban areas have greater access to improved water sources, including piped drinking water systems than rural areas. After factoring the urban/rural divide into these statistics, 67% of the Pacific region's urban population has access to piped drinking water systems, while only 9% of the rural population access the equivalent water access (World Health Organization 2016).

The energy-for-water question for the Pacific region is fundamentally a question of water access (Chap. 2). Where populations are centralized (i.e., the urban areas), there is greater access to piped drinking water systems, the most energy-intensive types of water systems. Where populations are dispersed across the Pacific region's rural areas, there is little-to-no access to piped drinking water (Fig. 7.1). Except for the Marshall Islands, there is a tight relationship between a country's electrification rate and the prevalence of piped water systems. Across the Pacific region, there is a statistically significant relationship between a country's electrification rate and the proportion of a country's population served by a piped drinking water system. This pattern indicates that where electrification occurs across the PICT region, other infrastructure improvements follow, such as the development of piped drinking water infrastructure system, corroborating findings on rural electrification increasing the prevalence of household piped water systems (Grogan and Sadanand 2013). For all countries (listed in Fig. 7.1), the relation has an R-squared of 0.54 ($p < 0.01$); excluding the Marshall Islands from this analysis, the relationship becomes more significant (R-squared: 0.84; $p < 0.01$). This energy-for-water relationship in the Pacific region hinges upon a question of scale. An area's population density must reach a critical point to make the economics of a piped drinking water system viable. The expansion of piped water across the Pacific region will be dependent on the progress of energy efficiency improvements to water treatment and distribution technologies.

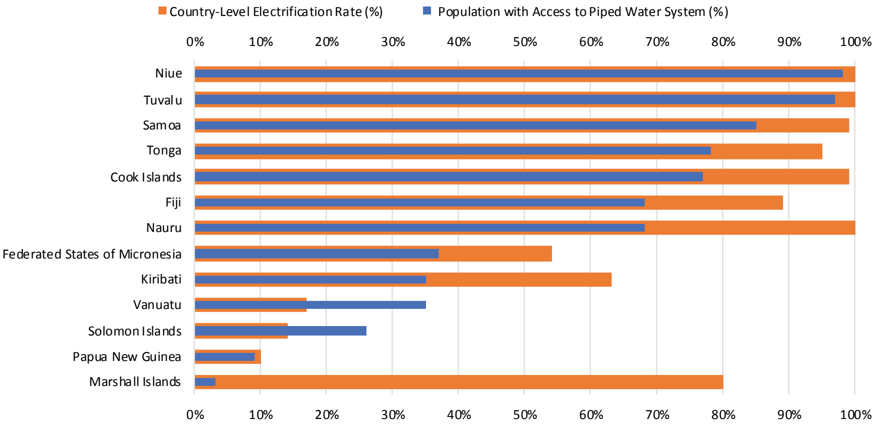

Fig. 7.1 Comparison of electrification rates and prevalence of piped water systems in the Pacific region. Electrification rate data sourced from Dornan (2014) and piped water system access data sources from World Health Organization (2016)

7.4 Using the Water-Energy Equation to Understand Vulnerabilities at the Nexus

Electrification through the development of diesel and fuel oil electricity generation assets has proven to be a scalable solution for PICTs (Table 7.1). However, the almost singular dependence on petroleum products for electricity generation creates systemic vulnerabilities at the nexus points between islanded energy system and water systems, and, moreover, all other critical infrastructure. Across PICTs, and much of the developing world, electrification has led to the investment and improvement of piped water systems. However, these improvements are laden with embedded vulnerabilities. Energy systems that are highly dependent on petroleum products convey petroleum product dependence to the critical infrastructure systems dependent on electrification for functionality. Therefore, and critically, the functioning of PICT water systems is intrinsically and wholly dependent on the functioning of petroleum product supply chains that facilitate the distribution and delivery of fuel across the region. Supply shocks to oil and petroleum products refining, price shocks, and disruptions to distribution systems—either through accidents, natural hazards (Chap. 10), or climate change (Chap. 5)—are also systemic vulnerabilities to PICT water systems. Furthermore, as the fuel inputs into the PICT energy systems are carbon intensive so too are the dependent water systems. Diversifying PICT energy portfolios to include greater levels of renewable energy sources not only makes these systems more resilient, but also lessens the climate burden of these systems. Further, due to the remoteness of some PICTs, the physical length of supply chain linkages becomes a critical system characteristic. Disruptions to PICT fuel distribution systems thousands of miles away through accidents, natural hazards, or climate change can present fundamental challenges to the functioning of energy systems, water systems, health, and human safety for PICTs.

Here, we use a hypothetical PICT nation to illustrate this point. Like many PICT nations, our exemplar sources the majority of its petroleum products through Singapore, but occasionally sources diesel and refined fuel from Japan and South Korea, and sometimes Malaysia and China. Given the remoteness of the island, diesel and refined fuel oil delivery usually takes around two weeks from the tanker leaving Singapore; the tanker journey time is longer if leaving from South Korea, Japan, or China. Due to the length of the delivery time, the PICT has developed on-island fuel reserves, which provide the island a 2–3 day buffer of fuel supplies if a delivery is delayed. The buffer includes a 2–3 day supply of fuel for electricity generation in addition to reserve fuel capacity for the piped water system. Altogether, the water system has 4–6 days of buffer capacity, and can remain operational even after the electricity system is no longer functioning. Nonetheless, long petroleum products supply chains create substantial risk for PICT water systems.

Disruptions can occur anywhere along the delivery route, but the most tangible to envision are at the site of the distribution fuel terminals (e.g., Singapore, South Korea, or Japan) and the on-island fuel terminals at our exemplar PICT nation. Indirectly, the island's energy, water, and other critical infrastructure system are dependent on the continued functioning of shipping lanes in the Strait of Malacca. A tanker accident in the Strait of Malacca that shuts down freight traffic for three weeks would be catastrophic to PICT nation fuel supply chains (ERIA 2016) necessitating for the reorganization of fuel supply chains to source new resources from other Pacific sources, for example, Japan, South Korea, New Zealand, or Australia. However, as Singapore is the major fuel supplier for the Pacific, numerous other countries are also reconfiguring their fuel supply chains, pushing refuel windows longer and longer. In this example, an incident in the Strait of Malacca supply chain reconfiguration could push the island beyond its fuel buffer window, leading to forced rationing in the form of scheduled brownouts/blackouts and the potential disruption to dependent infrastructure systems, like the island's piped water system. Energy supply diversification through the development of on-island renewable sources provides our example PICT nation a source of electricity decorrelated from risks in crowded shipping lanes thousands of miles away. The six-day blockage of the Panama Canal by the *Ever Given* container ship in March 2021 provided an example of how global supply chains can be suddenly and catastrophically disrupted.

Typhoons pose multiple threats to the island's energy and water. As fuel deliveries occur by tanker, the island's main fuel terminals are located on a bay just outside the main city. Fuel is then distributed throughout the island by pipeline and truck. Wind damage from a major typhoon can cause damage to aboveground pipeline infrastructure or fuel racks (Guard et al. 2003). Similarly, storm surges and tsunamis can flood petroleum terminals and fuel racks, causing severe damages through multiple means such as crushing, tie down failures, and sliding (Naito et al. 2013). If these damages, were to result in fuel leakage and combustion, the fuel terminal could remain offline for an indefinite period of time and cause on-island and off-island damages. In 2003, Super Typhoon Pongsona passed over Guam, creating a fire at major terminal that lasted for five days, and disrupted gasoline distribution on-island and across Micronesia (Guard et al. 2003). The impact of Super Typhon Pongsona underscore lessons learned from other typhoons: pre-existing system dependencies and supply chain length matters and can negatively affect recovery time of energy and dependent systems (Palin 2018).

7.5 Conclusions

A reliance on fossil fuels, specifically diesel fuel, for electricity generation has created a significant water dependency across PICT energy supply chains. On average, 5.90 L of water is consumed to produce 1 L of diesel. For nations that consume tens of millions to hundreds of millions of diesel liters to produce electricity, the 5.9 × water multiplier in its diesel supply chain means that the region consumes millions of cubic meters of water to produce electricity annually.

For the Pacific region, the energy-for-water relationship comes down to the fundamental differences between urban and rural communities and electricity access. According to WHO statistics, urban areas across the Pacific region are 7.4 times more likely to have access to piped drinking water systems. Piped water systems are energy-intensive, so there is a strong statistical relationship between a country's electrification rate and the proportion of the population served by piped water systems. There is no question that population density and energy intensity of piped water systems limit the expansion of these water systems across the region. Decentralized approaches such as rainwater harvesting (Chap. 2) and small-scale solar set ups (Chap. 12) will need to play a role in securing water and energy in disparate and rural populations.

The water intensity of the Pacific region's electricity supply will decrease over the near future. Five Pacific region nations—Fiji, Papua New Guinea, Samoa, Tuvalu, and Vanuatu (Table 7.3)—have enacted climate policies to obtain electricity from 100% renewable sources by 2030. Another four countries—Nauru, Niue, Solomon Islands, Tonga (Table 7.3)—have policies to generate more than 50% of electricity from renewable sources by 2030. The diversification of electricity sources across the Pacific region away from diesel will necessarily decrease the region's electricity generation's total water intensity. Governments and electric utilities can leverage renewable energy technologies to increase rural electrification rates (Mofor et al. 2013). The statistically significant positive relationship between a PICT nation's electrification rate and the prevalence of piped drinking water systems (Fig. 7.1) presented suggest that national strategies that pursue increasing electrification rates should have a spillover effect of increasing the prevalence of improved water sources and piped water systems. Therefore, PICT nations can pursue coordinated approaches that address the water-energy equation by taking a coupled approach to improving the status of their populations with respect to SDG 6 ("Ensure access to and sanitation for all") and SDG 7 ("Ensure access to affordable, reliable, sustainable and modern energy for all"). As many PICT nations have aggressive renewable energy generation targets, a coupled approach to SDG 6 and SDG 7 can be achieved in a climate neutral manner, ensuring climate neutral energy and water development for disadvantaged populations.

Finally, the systemic risks and vulnerabilities to PICT nations resulting from disruptions to petroleum products supply chains need to be addressed in a long-term vision to improve energy security in the face of both climate change and increasing human population pressures. Given the length of PICT petroleum products supply chains, a thin margin exists between a disruption being a transitory occurrence or precipitating a cascading failure across other critical infrastructure systems and sub-regional petroleum productions distribution systems. These supply chain risks coupled with the existential threat created by climate change demonstrates the fundamental importance of diversifying PICT energy supply chains. The renewable energy targets set by PICTs (Table 7.3) alleviate the systemic risks of relying on petroleum products for food, energy, and water provision. Renewable energy integration into PICT electricity systems and directly into water infrastructure systems decarbonizes and de-risks both islanded energy and water systems, creating systems that are more resilient (Weir and Kumar 2020) to severe weather (e.g., typhoons, tsunamis), non-local disruptions (e.g., Strait of Malacca disruption, oil price shocks), and climate change.

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