ASIA-PACIFIC SOLAR RESEARCH CONFERENCE

PEER REVIEWED
ASIA-PACIFIC
SOLAR RESEARCH CONFERENCE

Electricity Access Challenges and Opportunities in Papua New Guinea (PNG)

Manu Rawali [1,3,4], Anna Bruce[,2,3], Atul Raturi[5], Brian Spak[6], Iain MacGill[1,3]

[1]School of Electrical Engineering and Telecommunications, UNSW Sydney, Australia

[2]School of PV and Renewable Energy Engineering, UNSW Sydney, Australia

[3]Centre for Energy and Environment Markets, UNSW Sydney, Australia

[4]Centre of Renewable Energy, University of Papua New Guinea, Port Moresby, Papua New Guinea

[5]School of Engineering and Physics, University of South Pacific, Suva, Fiji

[6]Energy Centre, CSIRO, Newcastle, Australia

Email: m.rawali@student.unsw.edu.au

Abstract

Electricity access is a key driver of socio-economic development of a nation, and a critical catalyst to achieving the UN's Sustainable Development Goals. Unfortunately Papua New Guinea (PNG) faces an acute electrification challenge with the majority of the population, especially in rural communities living without basic access to electricity. This paper reviews current literature comprised mostly of development-partner reports, to establish the current electricity access context, identify high-level barriers and, given its key role for off-grid access, discuss opportunities for solar photovoltaic systems (Solar PV). Despite the country's abundant energy resources, PNG is reported to have an electricity access of around 10-15% based on the binary access-metric system[1]. Including solar PV pico-lights, the rate of access increases to around 55%, which is still lower than the global average of 89% but demonstrates the already significant impact of PV technology. PNG now has the daunting task of achieving 70% electrification by 2030 and understanding the barriers is critical to driving future growth. The most prominent reported barriers relate to governance, lack of capacity, rugged terrain with sparsely distributed population, lack of finance and law and order issues which include land conflicts. Solar Photovoltaic systems have a huge potential and can assist with driving electrification but need appropriate policy and regulatory support, and financing-mechanisms.

1. Introduction

Energy including electricity is a necessity in today's modern society and an important ingredient to drive economic growth and improves social wellbeing. According to the UN's *Tracking SDG 7 report* (IEA/IRENA/UNSD/WB/WHO, 2019), 840 million people still lack access to clean, reliable and affordable electricity, and that includes a significant proportion of people in impoverished PNG. Despite abundant renewable and non-renewable energy resources, almost 85% of the population either do not have access to electricity or have an insufficient and unreliable supply. A portion of the population still use kerosene lamps for lighting, however, now pico solar-lighting products are rapidly growing in uptake, displacing kerosene. To highlight the importance of increasing electricity access, between 1995 and 2011, Nepal a country that is very similar to PNG in rural-urban population distribution and topography, experienced a sharp decline in poverty due to an increase in electricity access (Bridge, Adhikari, & Fontenla, 2014), achieved via deployment of community-

[1] **Binary access metric: connection to an electricity grid, or have a renewable off- or mini-grid connection of sufficient capacity to deliver the minimum bundle of energy services (IEA)**

based hydro mini-grids, solar home systems and grid extension. Moreover this increased access contributed to significant progress in terms of income generation, education and agricultural production and a less significant improvement in health outcomes.

PNG is one of the most culturally and geographically diverse countries in the world. The country is also rich with natural resources and home to more than 5% of the world's biodiversity in less than one percent of the world's land area (Faith et al., 2001). Based on the 2011 Census of the population and an estimated high average annual growth rate of just over 3%, the population should be well over 9 million this year. Almost 85% of the population reside in rural areas and are mostly subsistence farmers. PNG is a strong export-dependent economy with a 2018 GDP of US$23.4 billion that was dominated by the mineral and petroleum sector followed far behind by agriculture that, nevertheless, employs the majority of the country's workforce.

Despite the relatively large GDP for a small developing country, only a meagre proportion of the population benefit from the mineral and petroleum sector. This concentration of wealth, cultural issues, corruption, bad governance, limited economic infrastructure and many other factors has led to serious social challenges such as high poverty rate, high unemployment, law and order issues, stunted development rates, high infant mortality, a rise in curable diseases, and drop in quality of education. Consequently, PNG is rated very low on the United Nations HDI[2] and World Bank's HCI[3]. Not surprisingly, the other countries that are in a similar plight also have very low electricity access rates, which emphasize the link between modern energy access and socioeconomic development.

Despite this poor progress, there is limited published literature about the electrification barriers in PNG and hence the purpose of this review is to highlight the current electricity situation and identify the main barriers that hinder the provision of electricity. Understanding the barriers is critical to achieving the mammoth target of 70% access (based on binary matrix) by 2030. Moreover the paper will discuss opportunities for the deployment of solar photovoltaic systems to improve electricity access.

2. Methodology

The first step of the process was to implement a desktop survey for literature on electrification or related areas in PNG. Only 3 peer-reviewed journals directly discussed the electrification situation in PNG, all involving a particular researcher exploring the issue of off-grid solar photovoltaic systems (D'Agostino & Sovacool, 2010; Robinson, 1988; Sovacool, 2013; Sovacool, D'Agostino, & Dambawale, 2011). The search was then extended to regional peer-reviewed articles that involved papers and conference proceedings. Unfortunately only a few papers were located, and referred to development-partner reports. Finally a search of country specific development-partner reports was conducted, that uncovered a significant number of reports and proposals relevant to identifying barriers and their causes. Table 1 shows the list of development-partners covered in our literature review that have implemented electrification or related projects in Papua New Guinea in the last decade. Almost all the information from these reports ware collected from stakeholder forums and interviews from within the electricity sector in PNG. Current electricity sector or related policies and plans were also retrieved to assist with overall exercise.

The second step involves a surface analysis to identify the main barriers then discuss some of the root causes of these barriers, and how solar technology could be used to increase access.

Table 1: Organisations that have directly participated in the improving the electricity sector in PNG in the last decade

[2] HDI- Human Development Index
[3] HCI- Human Capital Investment

World Bank	*German Corporation for International Cooperation GmbH* (GIZ)	Asian Development Bank (ADB)
International Financial Cooperation (IFC)	Pacific Community (SPC)	MFAT-New Zealand Government
United Nations Development Programme (UNDP)	Asia Pacific Economic Cooperation (APEC)	Global Green Growth Institute (GGGI)
ANZ Banking Group	International Renewable Energy Agency (IRENA),	Japan International Cooperation Agency (JICA)
Australian Department of Foreign Affairs and Trade	US Agency of International Development	

3. PNG's Electricity Situation, Governance Structure and Energy Resources

3.1 Electricity Access Situation

Going by the binary electricity access measure, about 10-15% of the population of PNG has electricity access, with almost all concentrated in urban areas. The National Energy Policy (NEP2018), Electricity Industry Policy (EIP2011) and almost all development-partner reports/proposals on PNG's electricity sector use this metric (Asian Development Bank, 2018; Department of Petroleum and Energy, 2011, 2018; World Bank, 2018), which essentially counts all households connected to the national grid and diesel-operated mini-grids. Thus at the minimum, government policy suggests that for a household to be electrified it has to be connected the PPL grid or similar systems. Based on this grid-connected concept, the current electricity policies all align with the PNG Development Strategic Plan 201-2030 (PNGDSP2030) target of connecting 70% of households by 2030 (Department of National Planning Monitoring, 2010). The overarching PNG Vision 2050 plan also envisions electricity to be completely provided by renewable energy by 2050(National Strategic Plan Taskforce, 2010), despite the country's INDC[4] report stating that this should be achieved by 2030 (Climate Change and Development Authority, 2015).

A recent IFC report on the off-grid pico-lighting market dynamics in PNG estimated that close to 60% of PNG's households have pico solar-lighting products (Engelmeier & Gaihre, 2019). This access rate is supported by the Tracking SDG7 Report stating that PNG's access was rated at 54.4% in 2017 mostly due to consideration of solar pico-lighting kits (<11W) (IEA/IRENA/UNSD/WB/WHO, 2019). The data on pico solar deployment is primarily collected from import data of solar equipment (IRENA, 2018).Nonetheless the access rate is much lower than the world average access rate of 89% stated in the same report.

3.3 Governance Structure

PNG electricity sector structure is informed by the EIP2011, and mostly regulated according to the Electricity Industry Act 2002 (EIA2002) and the Independent Consumer and Competition Commission Act 2002 (ICCC2002). As of 2018 the Department of ICT & Energy (DICTE) manages the sector and the Independent Consumer & Competition Commission (ICCC) regulates the operations. In 2018, the overarching National Energy Policy (NEP2018) was established and promotes the World Bank-funded National Electrification Rollout Plan (NEROP) (Sustainable Engineering Lab & Economic Consulting Associates, 2017). The NEROP proposes that the least-cost electrification strategy to cover the whole country is to connect 75% of population through the grid and the rest using diesel-minigrid systems.

[4] Intended Nationally Determined Contribution to the UNFCC

The NEP2018 is accompanied by the proposed National Energy Authority Bill which will soon be approved to setup the National Energy Authority (NEA) with the main task of coordinating the sector through creating sub-sector policies with accompanying bills, and regulation. It is anticipated that sub-sector policies, such as the Renewable Energy Policy and Rural Electrification Policy, will promote the focus principles of NEP2018 with more detail, including the review of the existing EIP2011.

3.4 Grid and Offgrid

The electricity sector in PNG is dominated by government-owned utility, PNG Power Limited (PPL), which, apart from generation, has a monopoly over every aspect of the delivery of grid-electricity. PPL manages the three major grids (Port Moresby, Ramu and Gazelle) and 29 diesel-operated minigrids that include all provincial capitals (Figure 2(a)). According to the ADB and World Bank, which are supporting most of the ongoing electricity improvement programmes in PNG, the grids (including minigrids) lack generation capacity, have limited coverage and the quality of service is poor (Asian Development Bank, 2017; World Bank, 2019). Figure 1 (b) shows a breakdown of PNGs installed 580MW generation capacity by technology, of which PPL manages 300MW (including supply from IPPs) with the rest captive power installations in extractive industry project locations and large commercial agriculture farms.

Figure 1 : (a) Existing Grid (Sustainable Engineering Lab & Economic Consulting Associates, 2017) (b) Installed capacity by technology (World Bank, 2019)

In the off-grid standalone space, the International Financial cooperation (IFC) has been promoting quality pico solar-lighting products in PNG through the Lighting Pacific Programme. However, the biggest impact in this space has resulted from the Chinese-operated Lot shops[5] that have increased in numbers throughout the country in the last two decades, that sell a wide range of products including un-certified solar pico-lighting systems at an affordable cost (Engelmeier & Gaihre, 2019).

Going forward, the PNG Government has adopted the NEROP to reach 70% of the population by 2030 but has no clear plans to achieve 100% renewable power by 2050. NEROP utilises a geospatial least-cost modelling tool to identify the least-cost option of electrifying different regions in PNG. The model compares the three electrification options of grid, diesel-minigrid and solar standalone. Table 2 summarises the resultant recommended access options with projected costs. Moreover during the APEC meeting in PNG in 2018 the PNG Electrification Partnership was established between the governments of Australia, New Zealand, Japan and USA to financially

[5] A type of shop, with earliest versions housed in shipping containers, selling generic lighting products, hardware items, toys, clothing, and groceries. Products sold in these shops are typically manufactured in China, and very affordable.

support the electrification goal for 2030 (Post Courier, 2018), despite not having a clear plan for coordination and implementation.

Table 2: NEROP results and costs for 100% electricity access (Sustainable Engineering Lab & Economic Consulting Associates, 2017)

Results of spatial query	Current Grid Access (2016)				Program for 100% Electricity Access (Grid & Off-Grid) by 2030				
	Access Categories	Population (Households)	Percent		Recommended Type of Access and Investments	Population (Households)	Per-cent	Capex per HH	Total Capex (M)
Within range of LV connection: <1 km	**Customers:** grid access **with** PPL account	460,000	6%	19%	**EasyPay meters** for existing customers	460,000	4%	$260	$22
		90,000				90,000			
	Consumers: grid access **w/o** PPL account	460,000	6%		**Improved connections + EasyPay meters** for consumers	460,000	4%	$450	$39
		90,000				90,000			
	No grid access (calculated by difference)	540,000	7%		**Grid Intensification** (LV line + connection)	1,680,000	14%	$990	$272
		100,000				280,000			
Beyond range of LV connection: >1km	**Requires new access** (grid or off-grid determined by geospatial model)	6,030,000	81%		Grid extension (MV, LV, connection)	6,790,000	55%	$1,680	$2,200
		1,160,000				1,320,000			
					Off-grid / Mini-Grid	2,950,000	24%	$1,160	$660
						570,000			
	Population	**7,630,000**	**100%**		**Population**	**12,330,000**	**100%**	**$1,370**	**$3,200**
	(Households)	**1,440,000**			**(Households)**	**2,330,000**			

3.5 Energy Resources

PNG is blessed with both renewable and non-renewable energy resources. However, no detailed studies have been implemented in the renewable energy space and harnessing these resources to increase electricity access is a challenge. Table 3 summarises the energy resources in PNG and current or planned contribution to the electricity sector.

Table 3 : Resource Potential and Contribution to Electricity Sector

Resource	Reserves/Potential	Contribution to Electricity Sector
Crude Oil	Estimated 2P reserve [6]of about 253 million barrels as of 2018 (Oil Search Limited, 2019)	Very limited
Natural Gas	Estimated 2P reserve of about 6,742 billion cubic feet as of 2018 (Oil Search Limited, 2019)	83 MW of Gas fired power plants connecting to Port Moresby Grid (World Bank, 2019), and more planned.
Hydro	No detailed study but, approximately 15,000-20,000 MW (Isaka, Mofor, & Wade, 2013)	• 230 MW worth of power plants connecting to the 3 major grids (World Bank, 2019). • 136 MW Hydro Projects under development - World Bank and ADB currently developing 86 MW (Divune 3MW, Ramazon 3MW and Naoro-Brown-80MW), plus privately developed Edevevu-51MW
Geothermal	No detailed study, but the Geothermal Energy Association estimates PNG's geothermal potential at 21.9 TWh (Zehner, 2015)	54 MW Geothermal power plant on Lihir (Isaka et al., 2013)

[6] proven **and** probable **reserves**

Bioenergy	No detailed study, but major potential with growing commercial agriculture industry and low population density	• 3 MW methane biogas power-plant in one of NBPOL's palm oil mill (Asia Pacific Energy Research Centre, 2017). • PNG Biomass (Oil Search subsidiary) currently constructing a 30 MW biopower plant utilising fast-growing eucalyptus trees, and will be fed into the Ramu grid (PNG Biomass, 2018).
Wind	Good wind resource near Port Moresby and Lae. Currently three 80-metre masts measuring the resource	Very limited
Solar	4.5 ~ 8 sunlight hours daily (Isaka et al., 2013). Refer to Figure 2. Not much ground-based monitoring.	• Utilised with the fast-growing solar pico-lighting products • Currently no grid-connected systems exist, although two (227 kW (Sunergise) and 100 kW) systems have been installed but not successfully synchronised to the grid.

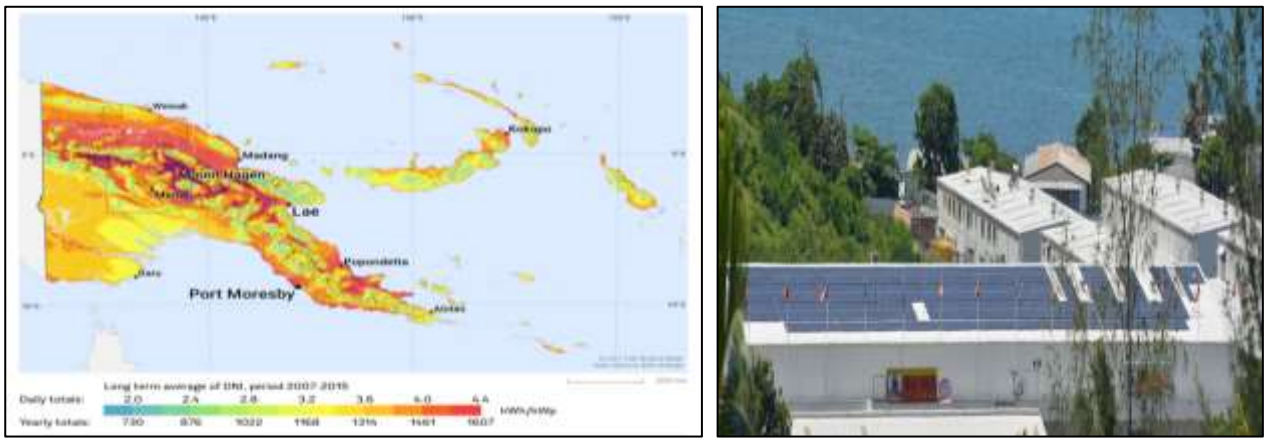

Figure 2: (a) Solar Resource Map of PNG: Photovoltaic Power Potential (SOLARGIS and World Bank, 2017) (b) 227 kW PV-system on CPL Supermarket

4. Barriers to Expanding Electricity Access

There are a myriad of barriers to expanding electricity in PNG. Here we do not provide a comprehensive review, but identify the main barriers. These barriers are not unique to PNG, but while many developing countries have now progressed to high rates of electricity access, PNG has made little progress in overcoming the challenges since independence.

4.1 Governance in the Sector

Political commitment is a key ingredient to achieving the goals of SDG7, which includes increasing electricity access, and thus is vital to drive the sector. However, since Independence in PNG, the downstream energy sector, including electricity has been given lower priority by policymakers. The sector was first managed by the Ministry of Minerals and Energy, however, the emphasis was more on minerals (World Bank, 1986). These responsibilities were then shifted to the Ministry of Petroleum and Energy but again the power sector was neglected, in terms of budget and workforce. During this period, one would have assumed that crude oil and more recently natural gas resources would have been utilised locally to increase affordable and accessible electricity.

Unfortunately, policymakers felt that they would make a bigger impact on driving economic growth with foreign export earnings (D'Agostino & Sovacool, 2010). Despite an Electricity Industry Act established in 2002, prior to 2011 there was no electricity sector policy let alone an energy policy, which gives the strongest indication of the lack of political commitment in the past.

This lack of focus on the electricity sector led to limited funding allocated towards rural electrification by the government, while at the same time it was hoped that cross-subsidization by existing users would drive investment by utilities in the sector, as had occurred in many pacific islands (Dornan, 2014). Nonetheless, due to the lack of policy-design and planning capacity of the responsible department and lack of political will, a number of critical proposed measures in the EIP have not been implemented such as the state-supported Community Service Obligation policy.

In 2017 responsibility for the electricity sector was shifted to the newly created Ministry of ICT & Energy (DICTE), which coincided with the introduction of NEP2018. On a recent and more positive note, the focus on electricity is growing amongst policy-makers, including a recent request for support to APEC partners, and subsequently, announcement of an “Electrification Partnership”, including encouraging the use of abundant natural gas in the national market, particularly in the power sector, through introduction of a proposed Domestic Market Obligation (DMO) facility in new gas projects.

4.2 Lack of Capacity of Government Agencies, the Utility and Rural Communities

Governance challenges in the electricity sector have been exasperated by a lack of capacity in the government department that administers the sector. According to IRENA, the Energy Division lacked research, energy planning and analysis (Isaak, 2013).The lack of sector planning was also highlighted by the World Bank, ADB and UNDP in their recent reports (Asian Development Bank, 2017; United Nations Development Programme, 2016; World Bank, 2018). Specifically, Sovacool identified a lack of capacity to collect data on resources, supply and demand including poor coordination between various government-agencies on energy matters (Sovacool et al., 2011). Furthermore the rural-electrification agenda in the EIP 2017 is focussed purely on grid extension, without including options of offgrid minigrids or standalone systems, which demonstrates limited understanding of offgrid options, particularly those utilising renewable energy sources (Department of Petroleum and Energy, 2011). One of the reasons for the lack of capacity in the Energy division is the shortage of staff, with only 13 out of the 77 positions filled (Asia Pacific Energy Research Centre, 2017) in 2017. It is hoped that with the setup of the proposed National Energy Authority under the NEP 2018, improved capacity for strategic planning and implementation of the agenda will be introduced into the sector.

Under the EIA2002 the role of increasing provision of electricity was left on the shoulders of PPL through their internal community service obligation. However, apart from the limited support from the Government, PPL lacks the technical and financial capacity to extend the grid (Asian Development Bank, 2017; Isaka et al., 2013; World Bank, 2019). PPL has been forced through regulation and obligation to operate mostly in a non-commercially viable environment. The PPL diesel-operated towns, which the provincial governments could not manage, are essentially loss-making centres. To compound the situation, they have not been allowed to raise tariffs to reflect the true costs of providing the service (Asia Pacific Energy Research Centre, 2017). Lastly continuous political interference has significantly affected its operations (Asian Development Bank, 2017). The current access issues and highly unreliable supply are just the end-product of lack of capacity to govern, operate and maintain current infrastructure and plan for the future.

With minimal support from government, offgrid technologies have been introduced by mostly development partners to many rural communities since independence. However most of these projects have been unsuccessful (Isaka et al., 2013) due to the communities’ lack of knowledge and skills to maintain the systems (Robinson, 1988; Sovacool et al., 2011), and inappropriate project design and implementation. Moreover communities have little understanding of the benefits of electricity and thus do not prioritise these projects (Sovacool et al., 2011).

4.3 Rugged Terrain and Sparsely Distributed Population

Two of the most significant technical challenges of increasing provision of electricity in PNG are the rugged geography and the sparsely separated population of PNG. These issues are noted in almost all literature about PNG's acute electrification access issue for the rural majority. PNG's over four hundred thousand square-metres of landmass are mostly mountainous and covered largely by tropical rainforest. The mainland mountain ranges are cut by many fast-flowing tributaries that pour into several rivers that are surrounded by vast swampy regions in the lowlands. In addition, PNG has a coastline of about 5000km with about 600 islands scattered over three million square kilometres of ocean. This physical geography thus creates a major challenge to extend major infrastructure such as transport (roads and bridges), telecommunications and electricity access. The mountains coupled with high rainfall, provide abundant hydro resources but also constrains access to this resource and limits the extension of grid infrastructure (Asian Development Bank, 2017).

Furthermore PNG has a relatively low population density globally with 18 people per square kilometre, with the majority thinly scattered throughout the rural rugged terrain, thus further increasing the technical difficulty of extending electricity services and consequently the cost (Asia Pacific Energy Research Centre, 2017).

4.4 Finance and Affordability

Expanding electrification in PNG is a capital-intensive exercise due to the rugged geography, sparsely distributed population and land compensation issues. Moreover, as alluded to earlier, direct financial support from the government has been very limited. Furthermore, the private sector (including PPL) is reluctant to invest in expanding grid or offgrid options due to limited incentives, and the lack of policy and regulatory clarity. To illustrate the risk of investing in the power sector, PPL is currently running load shedding in all their diesel-operated towns because the major client, the government, is in arears of US$13 million (PNG Power Limited, 2019). To improve electricity access, indirect finance options of incentives and subsidies to encourage private sector investment were proposed in the EIP 2011, through a proposed Community Service Obligation (CSO) policy, however, it has yet to come to fruition again due to capacity issues and political will.

Noting that PNG's poverty rate is around 40%, the general low-income of rural communities contribute to the lack of incentives for private sector to drive electrification into rural areas. Rural communities are mostly subsistence farmers that often encounter logistical challenges to reach urban towns, and thus cannot afford the relatively high upfront cost of offgrid technologies or grid-connection fee, let alone the appliances to utilise the electricity (Asia Pacific Energy Research Centre, 2017; Engelmeier & Gaihre, 2019; Isaka et al., 2013; Sovacool et al., 2011). This is compounded with competing demands where electricity is not seen as a priority.

Uptake of solar-pico lighting systems have increased exponentially according to the IFC (Engelmeier & Gaihre, 2019), concentrated in rural communities that have good access to urban towns, but there is still a significant population that do not have access to even these small-scale technologies. Currently neither financing mechanisms for offgrid systems through banks and microfinance institutions, nor the recently introduced pay-as-you-go system have been successful so far (Engelmeier & Gaihre, 2019; Sovacool et al., 2011).

4.5 Law & Order and Land Issues

Another common issue that has plagued electricity access and many other aspects of development in PNG is the breakdown of law and order in the country. Offgrid technology businesses have suffered from theft and armed hold-ups leading to a high security cost of doing business, and ultimately higher cost of offgrid systems (Engelmeier & Gaihre, 2019). Installed offgrid technologies in communities have been stolen or damaged (Isaka et al., 2013; Sovacool et al., 2011). Theft of electricity on the grid has also played havoc on PPL's efforts to intensify and expand electricity

access. According to PPL, almost 30% of the generated electricity in Port Moresby is stolen (Kama, 2019) and theft rates are probably higher in the Ramu grid.

Land tenure issues are also a hindrance to grid and off-grid electrification efforts. Over 90% of land in PNG is under customary ownership and to set-up power generation or to run new grid lines often involves a struggle with land owners (Adam Smith International, 2018). According to a recent APEC evaluation, this may be partly due to varying expectations of fair compensation (Asia Pacific Energy Research Centre, 2017).

5. Opportunities for Solar Photovoltaic Systems (Solar PV)

It is widely accepted that decentralised systems using renewable sources have an important role to play in providing cost-effective electricity access (IEA/IRENA/UNSD/WB/WHO, 2019). Least-cost modelling showed that the cost of extending grid to connect a PNG village (of less than 2000 people) 5 km away from the grid was more expensive than powering the community with the most expensive standalone-option (a diesel generator) (Port Jackson Partners, 2015). Moreover, modern technologies such as micro-hydro, solar PV and biomass with the support of batteries could be relatively cheaper and more reliable. For instance, for a village setting, solar PV with storage is almost 50% cheaper than diesel (Port Jackson Partners, 2015).

Certainly in the small offgrid standalone market, pico solar-lighting has been very successful in PNG, as shown by exponential growth in the recent IFC report (Engelmeier & Gaihre, 2019). However, a significant population still do not have access, and going forward, affordability, product quality, and scalability to larger systems must be addressed by both private sector and government. Currently a relatively larger Sun King Home 400 system that includes lights, USB charging, radio and a television costs about US$680, and is still too expensive for the rural majority.

In the urban offgrid space, PPL runs unreliable loss-making diesel generators which have significantly contributed to the high tariff costs in PNG. Depending on demand, available resource (Solar and other renewables) and decreasing cost of batteries makes solar PV minigrid with storage a cost-completive and reliable option. Currently a UNDP-coordinated pilot project is now underway to convert a loss-making PPL diesel-minigrid to one that is fully powered by solar PV (United Nations Development Programme, 2016). We found no reported examples of village-based solar PV minigrids. These options would currently be challenging to implement due to lack of capacity and community governance challenges.

Increasing renewables on the existing grid could indirectly assist in increasing electrification efforts. For instance, PV plants could supplement base load from hydropower and gas power systems, to phase out expensive diesel and shore-up supply especially during the normal dry season and those caused by the El Niño effect. Unfortunately, investment in PV is discouraged due to lack of clarity around connection access and regulation, lack of incentives and PPL's limited technical capacity. Currently there is no rooftop programme in the urban centres, although IFC are currently working with PPL to introduce a pilot programme. A couple of organisations have already gone ahead and installed PV systems but cannot synchronise with the PPL system because of both technical limitations of PPL's weak distribution grid and lack of grid access due to the exclusivity of PPL to generate within 10km of the grid, specifically for systems less than 10 MW, according to the EIP2011. The latter policy issue is somewhat confusing when almost every commercial entity has a synchronised backup diesel-generator. It would also make sense for PPL to roll out a rooftop programme to increase generation capacity on the grid, this is especially feasible for residential homes because only a small percentage of their revenue comes from this category as shown on Figure 3 (Blacklock, 2018).

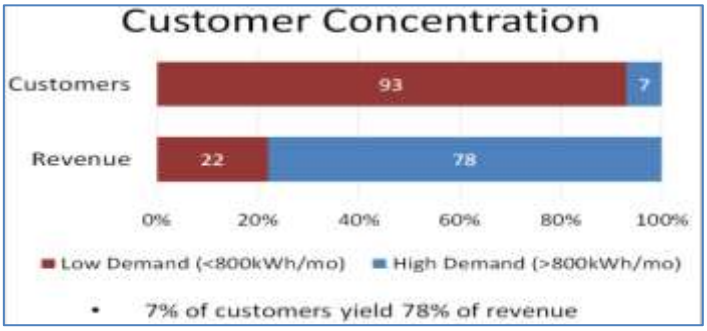

Figure 3: PPL Customer Concentration

6. Discussion and Conclusion

Impoverished PNG has abundant natural energy resources to address the current acute electricity access situation. In this paper we identified barriers such as lack of political will, limited capacity of government departments and agencies that manage and drive the sector, the lack of technical and governance capacity in remote communities, rugged terrain and sparsely distributed population, lack of financing options and challenging law and order issues including land conflicts that have hindered electrification efforts. This paper sets the prelude to a hopefully more examination of the challenges and opportunities of the power sector in PNG.

The downstream energy sector, including electricity, has been neglected until more recently by policymakers. However, still more impetus is required, considering the EIP2011 was created in 2011 to improve reliability and increase access but implementation has been ineffective. Seven years later the overarching NEP2018 has been introduced to give direction to the larger energy sector, but thus far places more emphasis on the power sector, rather than off-grid. There remains a need for the proposed rural electrification policy, renewable energy policy and an improved EIP2011.

The NEP2018 goal is to provide sufficient, accessible, reliable and affordable energy that is competitive, sustainable and environmentally friendly. Key focus areas of NEP2018 are to build institutional capacity through the establishment of the National Energy Authority and Energy Regulatory Commission, and the embedding of effective planning processes that would support the creation of innovative sub-sector policies. These would directly address the current lack of capacity issue in the Energy Division. A third focus area aims to assist in mitigating the land conflict issues, by encouraging landowner participation. The fourth and fifth focus areas emphasize the economic aspects, particularly to create a conducive environment to ensure economic sustainability and encourage private sector investment.

On paper, the NEP2018 addresses almost all the key barriers identified here, however to be successfully implemented it needs a foundation of the political will and successful capacity building. The PNG Electrification Partnership will greatly assist the financing issues to achieve the 2030 target, but early indications show that coordination is lacking between the government and countries involved. The NEROP provides a planning blue-print to electrify PNG but care has to be taken with interpretation of results. For example the model only compares grid supply with solar PV standalone and diesel minigrids, without considering cheaper micro-hydro or solar PV micro-grids with battery storage for which costs are dropping every year. Furthermore the Port Jackson Partners' report in part conflicts with NEROP. There is a clear need for a planning process that is transparent and can accept input from multiple stakeholders, involves continuous collection and analysis of local data (resource, supply, cost and demand), and is conducted by local agencies that can update the plan and implement the outcomes dynamically. To this end, initiatives to support in-country capacity for planning, power sector modelling and associated research capabilities would be of great value.

PPL has a wealth of valuable experience operating in PNG and thus a key entity in electrifying PNG. However, capacity issues need to be seriously addressed within the organisation, including measures to minimise political interference. To assist PPL a strong independent regulator must ensure PPL is accountable if required services are not delivered and tariffs should be set according the true cost of delivery (Dornan, 2014). If tariffs are too high for affordability, there is a role for government supported tariff concessions as per the proposed mechanisms in the EIP2011.

Education and awareness on the importance of using electricity, associated technologies and financial literacy at the community level can also play an important part in increasing access as was seen with the increased uptake of quality-verified pico lighting products through the IFC programme (Engelmeier & Gaihre, 2019; Sovacool et al., 2011). Furthermore community-based electrification projects that look to build on local capacity, other valued community needs (health, water, etc.) and ownership should be encouraged that not only increase sustainability but also mitigate on land tenure challenges and theft/vandalism.

Finally solar PV with battery storage or hydro clearly have the potential to provide access to electricity in unelectrified areas through standalone systems and community-based minigrids, but have not been widely implemented, despite increasing cost-competitiveness. For these reasons, the NEROP focus on expensive-grid-extension through PNG's rugged terrain and sparsely distributed population should be revisited. Moreover grid connected PV can reduce diesel costs in urban town mini-grids, improving profitability. Furthermore PV can be cost-effective on the main grids and play a big part in achieving the country's overarching vision of 100% renewable electricity by 2050.

References:

Adam Smith International. (2018). *Evaluation of New Zealand's Country Programme in PNG*. Retrieved from https://www.mfat.govt.nz/assets/Aid-Prog-docs/Evaluations/2018/PNG-SPB-Version4.pdf

Asia Pacific Energy Research Centre. (2017). *Peer Review on Low Carbon Energy Policies in Papua New Guinea*. Retrieved from https://www.apec.org/-/media/APEC/Publications/2017/12/Peer-Review-on-Low-Carbon-Energy-Policies-in-Papua-New-Guinea/217_EWG_Peer-Review-on-Low-Carbon-Energy-Policies-in-Papua-New-Guinea.pdf

Asian Development Bank. (2017). *Proposed Multitranche Financing Facility Papua New Guinea: Power Sector Development Investment Program Project Number: 47356-002*. Retrieved from https://www.adb.org/projects/47356-002/main

Asian Development Bank. (2018). *Pacific Energy Update 2018*. Retrieved from https://www.adb.org/sites/default/files/institutional-document/425871/pacific-energy-update-2018.pdf

Blacklock, C. (2018). Re: Building a Nation. Message posted to http://upngcore.org/wp-content/uploads/2019/10/PNG-Solar-Conference-29th-October.pptx

Bridge, B. A., Adhikari, D., & Fontenla, M. (2014). Electricity, income, and quality of life. *Social Science Journal, 53*(1), <xocs:firstpage xmlns:xocs=""/>. doi:10.1016/j.soscij.2014.12.009

Climate Change and Development Authority. (2015). *Intended Nationally Determined Contribution (INDC) Under the United Nations Framework Convention on Climate Change*. Independenyt State of Papua New Guinea Retrieved from https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Papua%20New%20Guinea%20First/PNG_INDC%20to%20the%20UNFCCC.pdf

D'Agostino, A. L., & Sovacool, B. K. (2010). UNSOLD SOLAR: A POST-MORTEM OF PAPUA NEW GUINEA'S TEACHER'S SOLAR LIGHTING PROJECT. *The Journal of Energy and Development, 36*(1), 1-21.

Department of National Planning Monitoring. (2010). *Papua New Guinea Development Strategic Plan 2010-2030*. Port Moresby: Independent State of Papua New Guinea Retrieved from https://png-data.sprep.org/dataset/png-development-strategic-plan-2010-2030

Department of Petroleum and Energy. (2011). *Papua New Guinea Electricity Industry Policy*. Port Moresby: Department of Petroleum and Energy Retrieved from http://upngcore.org/wp-content/uploads/2019/10/2011.11.02-EIP-ANNEX-1-Electricity-Industry-Policy.pdf

Department of Petroleum and Energy. (2018). *National Energy Policy*. Port Moresby: Independent State of Papua New Guinea Retrieved from http://upngcore.org/wp-content/uploads/2018/06/NATIONAL-ENERGY-POLICY.pdf

Dornan, M. (2014). Access to electricity in Small Island Developing States of the Pacific: Issues and challenges. *Renew. Sust. Energ. Rev., 31*(C), 726-735. doi:10.1016/j.rser.2013.12.037

Engelmeier, T. F., & Gaihre, N. R. (2019). *Going the Distance: Off-Grid Lighting Market Dynamics in Papua New Guinea*. Retrieved from https://www.ifc.org/wps/wcm/connect/0dc0a258-e9b4-4c4e-9e76-c2b3d67ae2c9/PNG+Off-Grid+Report.pdf?MOD=AJPERES&CVID=mNKWdxh

Faith, D. P., Nix, H. A., Margules, C. R., Hutchinson, M. F., Walker, P. A., West, J., . . . Natera, G. (2001). The BioRap Biodiversity Assessment and Planning Study for Papua New Guinea. *Pacific Conservation Biology, 6*(4), 279-288. doi:10.1071/PC010279

IEA/IRENA/UNSD/WB/WHO. (2019). *Tracking SDG 7: The Energy Progress Report 2019*. Retrieved from Washingthon DC: https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/2019-Tracking-SDG7-Report.pdf

IRENA. (2018). *Measurement and estimation of off-grid solar, hydro and biogas energy*. Retrieved from Abu Dhabi: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Dec/IRENA_Statistics_Measuring_offgrid_energy_2018.pdf

Isaka, M., Mofor, L., & Wade, H. (2013). *Pacific Lighthouses: Renewable Energy Opportunities and Challenges in the Pacific Island Region–Papua New Guinea. IRENA (International Renewable Energy Agency).* Retrieved from https://www.irena.org/-

/media/Files/IRENA/Agency/Publication/2013/Sep/Papua-New-Guinea.pdf?la=en&hash=3E847FD95A91ADAA4CC34614F7A325F80CE36D39

Kama, L. (2019). Blacklock concerned with theft of electricity. *The National* Retrieved from https://www.thenational.com.pg/blacklock-concerned-with-theft-of-electricity/

National Strategic Plan Taskforce. (2010). *Papua New Guinea Vison 2050*. Port Moresby: Independent State of Papua New Guine Retrieved from https://www.treasury.gov.pg/html/publications/files/pub_files/2011/2011.png.vision.2050.pdf

Oil Search Limited. (2019). 2018 Reserves and Resources Statement [Press release]. Retrieved from https://www.asx.com.au/asxpdf/20190409/pdf/4445g5wx57rfx9.pdf

PNG Biomass. (2018). Powering Papua New Guinea. In P. Biomass (Ed.): PNG Biomass.

PNG Power Limited (2019, 27 October 2019). PNG POWER TO CONTINUE LOAD SHEDDING AND CALLS FOR THE GOVERNMENT TO PAY ITS OUTSTANDING BILLS [PNG Power]. Retrieved

Port Jackson Partners. (2015). *Powering PNG into the Asian Century*. Retrieved from https://portjacksonpartners.com.au/wp-content/uploads/2019/03/150811-powering-png-into-the-asian-century-report.pdf

Post Courier. (2018). 70% of PNG to have Electricity. *Post Courier*. Retrieved from https://postcourier.com.pg/290694-2/

Robinson, P. (1988). Microhydro in Papua New Guinea - the experiences of an electrical engineer. *Power Engineering Journal, 2*(5), 273-280. doi:10.1049/pe:19880051

SOLARGIS and World Bank. (2017). Solar resource maps of Papua New Guinea. Retrieved from https://solargis.com/maps-and-gis-data/download/papua-new-guinea

Sovacool, B. (2013). Energy Poverty and Development in Papua New Guinea: Learning from the Teacher's Solar Lighting Project. *Forum for Development Studies, 40*(2), 327-349. doi:10.1080/08039410.2012.736405

Sovacool, B., D'Agostino, A., & Dambawale, M. (2011). The socio-technical barriers to Solar Home Systems (SHS) in Papua New Guinea: "Choosing pigs, prostitutes, and poker chips overpanels". *Energy Policy, 39*(3), 1532. doi:10.1016/j.enpol.2010.12.027

Sustainable Engineering Lab & Economic Consulting Associates. (2017). *Preparation of National Electrification Rollout Plan and Financing Prospectus: Final Report NEROP*. Retrieved from Port Moresby: http://upngcore.org/wp-content/uploads/2019/10/PNG-NEROP-FinalReport-2017-04-11.pdf

United Nations Development Programme. (2016). *Facilitating Renewable Energy & Energy Efficiency Applications for Greenhouse Gas Emission Reduction (FREAGER Project Document*. Retrieved from https://www.thegef.org/sites/default/files/project_documents/05-05-17_Project_Document_PAD_clean1.pdf

World Bank. (1986). *REPORT AND RECOMMENDATION OF THE PRESIDENT OF THE INTERNATIONAL B ANK FOR RECONSTRUCTION AND DEVELOPMENT TO THE EXECUTIVE DIRECTORS ON A PROPOSED LOAN IN AN AMOUNTE QUIVALENTT O US$28.5 MILLION TO THE INDEPENDENTS TATE OF PAPUA NEWG UINEA FOR A YONKI HYDROELECTRIC PROJECT* (P-4323-PNG). Retrieved from http://documents.worldbank.org/curated/en/642801468286784867/pdf/multi-page.pdf

World Bank. (2018). *Delivering Affordable, Sustainable, and Reliable Power to PNGns: Key challenegs and Opportunities in Power and Domestic Gas Sectors*. Retrieved from http://upngcore.org/wp-content/uploads/2019/10/Delivering-Affordable-Sustainable-Reliable-Power-to-PNG-Worldbank-2019.pdf

World Bank. (2019). *Energy Utility Performance and Reliability Improvement Project (P167820): Project Information Document/Integrated Safeguards Data Sheet (PID/ISDS)*. Retrieved from http://documents.worldbank.org/curated/en/909801547764581895/pdf/Concept-Project-Information-Document-Integrated-Safeguards-Data-Sheet-Energy-Utility-Performance-and-Reliability-Improvement-Project-P167820.pdf

Zehner, I. K. a. R. (2015). *Papua New Guinea Country Update.* Paper presented at the World Geothermal Conference, Melbourne.