



Green Growth Potential Assessment Papua New Guinea Country Report

July 2019



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Green Growth Potential Assessment Papua New Guinea Country Report

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Executive Summary

The Green Growth Potential Assessment (GGPA) is a diagnostic tool developed by the Global Green Growth Institute (GGGI). It consists of a combination of data analysis and stakeholder consultation in order to identify and prioritize a country's opportunities for green growth. In the context of Papua New Guinea, the methodology was adapted to identify priorities in relation to climate change.

For each of the identified priorities, specific recommendations were developed, building on conclusions from existing empirical research and international case studies as well as publicly available data sets, examples, and estimates from within Papua New Guinea (PNG). A crucial input to the analysis was a series of expert interviews conducted in PNG. This report presents the findings of the GGPA of Papua New Guinea and details the recommendations, each supported by a solid rationale.

Data analysis and stakeholder consultation identified four priorities related to climate change in Papua New Guinea. The following priorities served as the basis for this report:

- Increasing Papua New Guinea's resilience toward the adverse impacts of climate change, given the country's high vulnerability.
- Deploying renewable energy as an opportunity to increase the country's low electrification rate.
- Improving agricultural productivity, due to the high importance of agriculture for the country's mostly rural population, as well as food security and Papua New Guinea's economy.
- Conserving the country's extensive forests, due to their global significance for carbon storage, the role they play in sustainable agriculture, their provision of ecosystem services, and their economic potential.

First, given the breadth of areas involved in addressing Papua New Guinea's vulnerability to climate change, this report provides a systematic overview of the phenomena the country is exposed to and their potential impacts. The assessment concludes that PNG is highly exposed to climate change, as evidenced in a rise in temperature and sea levels, increase in rainfall and ocean acidification, and decline in frequency but increase in intensity of droughts and cyclones. The report also shows that Papua New Guinea's economy is very sensitive to these phenomena, given its dependence on sectors that experience considerable impacts from climate change—such as fisheries and agriculture—and its lack of essential infrastructure—including transportation, health, electricity, water, and sanitation.

Second, the report provides a detailed assessment of the potential for electricity generation from renewable sources in Papua New Guinea. PNG is characterized by a dual economy. The country has an export-oriented extractive industry, producing oil, gold, copper, silver, and—more recently—natural gas. Despite this, more than 80% of the country's population lives in rural areas with minimal services and infrastructure, mainly relying on subsistence agriculture.

Given these conditions, this report concludes that renewable energy appears to be most relevant for two purposes. First, it increases access to electricity in remote rural areas to support basic applications, such as electric lighting and phone charging. This would help more than four-fifths of the population currently living without access to electricity to move up the energy ladder, with feasible improvements to their livelihoods and well-being. Additionally, the deployment of renewable energy appears to be relevant for the energy-intensive extractive industries as well as for agricultural processing. These private sector companies are already mostly auto-producers of electricity and do not rely on the country's utility. Depending on the physical conditions at individual sites, geothermal energy and biomass are regarded as the most promising technologies.

To support the deployment of renewable energy, this report recommends designating areas for off-grid electrification, given the high costs of grid extension to remote areas. For that purpose, a focus on solar energy is suggested, with solar home systems showing clear advantages compared to mini-grids.

This report sees a decisive role for the private sector in off-grid electrification. It is recommended for the Government of Papua New Guinea (GoPNG) to support the private sector by introducing consistent legislation and providing regulatory certainty for the (off-grid) electrification, facilitating access to finance for private sector players, and strengthening quality control of off-grid renewables equipment sold in Papua New Guinea. Finally, it is recommended for the administration to strengthen its capacity to collect, compile, verify, and disseminate data relevant to the energy sector in order to conduct reliable analyses to develop relevant policies, monitor their impacts, and evaluate their effectiveness.

Third, agriculture and forestry are essential sectors in Papua New Guinea. The country's forests are of global importance, covering more than two-thirds of PNG's land mass and—together, with forests in the neighboring Indonesian province of Papua—comprising the third largest tract of intact tropical forest in the world. Forests provide essential ecosystem services, from soil fertility to water quality and regulation. They also play an important role in mitigating and adapting to the adverse impacts of climate change, constituting important carbon reservoirs and reducing the impact of natural disasters related to climate change. Agriculture, forestry, and fisheries are critical to Papua New Guinea's economy and the livelihoods of its people, contributing approximately a fifth of the country's GDP while more than 80% of the population depends on subsistence farming and resource extraction from local forests.

This report provides recommendations for improving the sustainability of the agriculture and forestry sector in Papua New Guinea. In line with the energy sector, it recommends for the Government of PNG to strengthen the administration's capacity to collect, monitor, and verify agriculture and forestry data. Forests need to be delineated consistently, clearly distinguishing user rights to strengthen conservation efforts and to provide regulatory certainty for legal commercial activities. Assessing Papua New Guinea's forest stock is also essential to support the country's efforts toward obtaining carbon payments for reducing greenhouse gas emissions in the context of REDD+.

Changes in agricultural practices and the forestry sector are required in order to reduce deforestation and forest degradation. Commercial logging is identified as the lead cause of forest degradation in Papua New Guinea while commercial agriculture is estimated to be responsible for up to 30% of deforestation in the country. Therefore, the report suggests for the GoPNG to monitor and enforce compliance with regulations on commercial logging and commercial agriculture. It further recommends for the government to obligate the industry to adhere to internationally recognized certification schemes and sanction non-compliance.

Moreover, subsistence agriculture is the principal cause of deforestation in Papua New Guinea. The traditional practice of shifting cultivation is rendered unsustainable by a rapidly growing population, demanding an urgent improvement in agricultural techniques. For that purpose, it is recommended for the Government of Papua New Guinea to strengthen extension services, providing support to communities to adopt sustainable agricultural practices. Such practices should aim to maximize the use of natural processes and ecosystems, enhance the diversity of production, tailor production intensity to the capacity of the landscape, and use a mix of traditional and new technologies.

Finally, to reduce demand for fuel wood as a driver of local deforestation, the report recommends for the GoPNG to support the sustainable production of fuel wood and the use of clean cooking technologies.

The recommendations discussed in this report directly support achieving the goals set out in Papua New Guinea's Vision 2050. They are relevant for informing national, sectoral, and sub-sectoral planning as well as designing specific interventions and investment activities toward sustainable development and the mitigation of and adaptation to climate change. Furthermore, the recommendations are also intended to support the Government of Papua New Guinea in achieving its international commitments, such as the Sustainable Development Goals (SDGs) and the Nationally Determined Contributions (NDCs).

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List of Abbreviations

°C	degree Celsius
ADB	Asian Development Bank
APAARI	Asia-Pacific Association of Agricultural Research Institutions
CCA	Clean Cooking Alliance
CCDA	Climate Change and Development Authority
CCDS	Climate Compatible Development Strategy
CCI-LC	Climate Change Initiative – Land Cover
CEPA	Conservation & Environment Protection Authority
CFSR	Climate Forecast System Reanalysis
CLUA	Clan Land Use Agreement
cm	centimeters
CO	carbon monoxide
CO ₂	carbon dioxide
CO ₂ eq	carbon dioxide equivalent
COP	Conference of Parties
COPD	chronic obstructive pulmonary disease
CSO	Community Service Obligation
DALYs	disability-adjusted life years
DMPGM	Department of Mineral Policy and Geohazards Management
DNPM	Department of National Planning and Monitoring
DP&E	Department of Energy and Petroleum
DFA	Department of Foreign Affairs
ECOWAS	Economic Community of West African States
EFIC	Export Finance and Insurance Corporation
ENERCOM	Energy Regulatory Commission
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
FCA	Forest Clearance Authority
FCPF	Forest Carbon Partnership Facility
FIMS	Forest Inventory Mapping System
FLEGT VPA	Forest Law Enforcement, Governance and Trade Voluntary Partnership Agreement
FRIP	Finance and Investment Plan
FRL	Forest Reference Level
FSC	Forest Stewardship Council
GCF	Green Climate Fund
GDP	gross domestic product
GGGI	Global Green Growth Institute
GGPA	Green Growth Potential Assessment
GHG	greenhouse gas
GOGLA	Global Off-Grid Lighting Association
GoPNG	Government of Papua New Guinea
GST	general service tax
HAP	household air pollution
ICCC	Independent Consumer and Competition Commission
IEA	International Energy Agency
IFC	International Finance Corporation
ILG	incorporated land group
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producers

IPPC	International Plant Protection Convention
ITTO	International Tropical Timber Organization
kg	kilogram
km	kilometer
kW	kilowatt
kWh	kilowatt hour
LCOE	levelized cost of electricity
LED	light-emitting diode
LLG	Local Level Government
LMIC	Lower Middle-Income Country
LPG	liquid petroleum gas
m ³	cubic meter
MAC	Mining Advisory Council
M&A	mergers and acquisitions
mm	millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
MRA	Mineral Resources Authority
MRV	monitoring, reporting, and verification
Mt	megaton
MTCS	Malaysian Timber Certification Scheme
MVB	Markham Valley Biomass Limited
MW	megawatt
NEA	National Energy Authority
NDCs	Nationally Determined Contributions
NEROP	National Electrification Rollout Plan
NGO	non-governmental organization
NRS	National REDD+ Strategy
Ω_a	Ohm (measure for aragonite concentration)
OCCD	Office of Climate Change and Development
OCCES	Office of Climate Change and Environmental Sustainability
OGS	off-grid solar
OSL	Oil Search Limited
pH	potential of Hydrogen
PAYGO	Pay-As-You-Go
PPAP	Productive Partnership for Agriculture Programme
PEFC	Programme for the Endorsement of Forest Certification
PM _{2.5}	particulate matter of a diameter of 2.5 micrometers
PNG	Papua New Guinea
PNGDSP	Papua New Guinea Development Strategic Plan, 2010–2030
PnP	plug-and-play
PPL	PNG Power Limited
ppm	parts per million
PV	photovoltaic
R&D	research and development
REDD+	Reducing emissions from deforestation and forest degradation and the role of conservation
RSPO	Roundtable on Sustainable Palm Oil
SABL	Special Agricultural Business Leases
SDGs	Sustainable Development Goals
SE4All	Sustainable Energy for All
SHS	solar home systems
SIS	Safeguards Information System
StaRS	National Strategy for Responsible Sustainable Development
TFC	Total Final Consumption
TPES	Total Primary Energy Supply
TV	television

TWh	terawatt hours
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
UNSD	United Nations Statistics Division
USD	United States dollar
V	volt
VAT	value added tax
W	watt
WASH	water, sanitation and hygiene
Wp	watt peak
WRF	Weather Research and Forecasting

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Climate Change and Development Authority
Daulo District Administration (Eastern Highlands Province)
Department of Mineral Policy and Geohazards Management
Department of Petroleum and Energy
East Sepik Provincial Administration
Independent Consumer and Competition Commission
Lufa District Administration (Eastern Highlands Province)
Mineral Resources Authority
PNG Power Limited (state-owned utility)

Representatives from several private sector companies provided valuable insights, including:

PNG Biomass
PNG Solar Association
Solar Solutions PNG

Representatives from the University of PNG, as well as a number of development partners, contributed to the analysis, including:

Asian Development Bank
Australian High Commission
New Zealand High Commission
USAID Climate Ready
World Bank

1. Introduction

Papua New Guinea (PNG) is among the most vulnerable countries to the adverse impacts of climate change. Adapting to and mitigating the effects of climate change remains a high priority for the government. Efforts in this direction are guided and supported by existing policies and strategies, such as the Vision 2050 Plan, National Strategy for Responsible Sustainable Development for PNG, PNG Climate Change Management Act, and National Climate Compatible Development Management Policy.

The Government of Papua New Guinea (GoPNG) places a high priority on accessing climate finance to assist the country in mitigating its contribution to climate change and adapting to the adverse impacts of climate change. These efforts are led by the Climate Change and Development Authority (CCDA), which was established in 2016 as the coordinating entity for all climate change-related policies and actions in the country. PNG has been a member of the Global Green Growth Institute (GGGI) since 2012. Working closely with CCDA, as well as the Department of Foreign Affairs (DFA), GGGI has recently started providing *Readiness and Preparatory Support* to facilitate accessing funds from the Green Climate Fund.

In this context, the Green Growth Potential Assessment (GGPA) was used to provide valuable analysis to strengthen the ongoing efforts. The GGPA is a diagnostic tool, developed by GGGI, consisting of a combination of data analysis and stakeholder consultation in order to identify and prioritize a country's opportunities for green growth (figure 1). In the context of Papua New Guinea, the methodology was adapted to identify priorities in relation to climate change.

Figure 1. Conceptual schematic of the GGPA process



Source: GGGI

The GGPA process consists of the following three stages: (1) the preliminary assessment based on data analysis and literature review; (2) consultation with stakeholders to validate and/or revise the priorities identified during the preliminary assessment; and (3) the final analysis built around a set of recommendations covering the identified priorities (figure 2). This design aims to ensure that the assessment process is systematic, objective, and participatory.

Figure 2. Overview of the GGPA process



Source: GGGI

This report presents the findings of the GGPA of Papua New Guinea. For each of the identified priorities, it presents a set of recommendations, building on conclusions from existing empirical research, international case studies, and publicly available data sets as well as examples and estimates from within Papua New Guinea. A crucial input to the analysis was a series of expert interviews conducted in PNG. Paucity of reliable data and uncertainty of planned projects being implemented represented a considerable challenge to conducting the analysis; this is an obstacle highlighted throughout the report and reflected in the recommendations.

The set of recommendations is meant to inform national, sectoral, and sub-sectoral planning as well as to support the design of specific interventions and investment activities toward sustainable development and the mitigation of and adaptation to climate change. Furthermore, the recommendations are also intended to support the Government of Papua New Guinea in achieving its international commitments, such as the Sustainable Development Goals (SDGs) and the Nationally Determined Contributions (NDCs).

2. Methodology

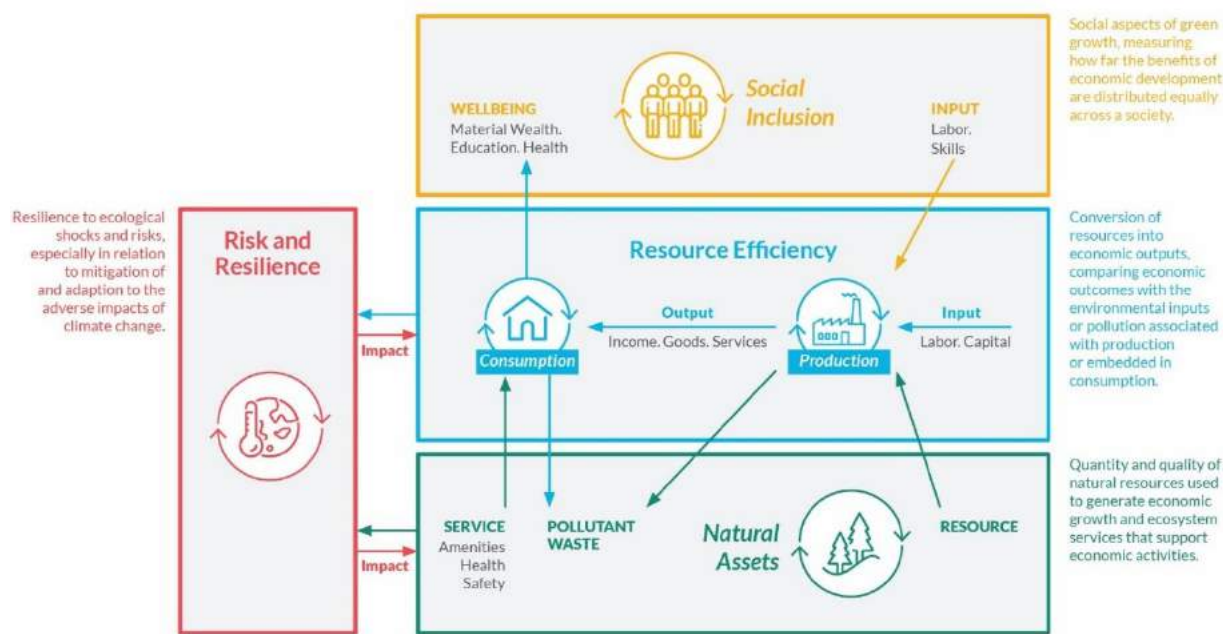
2.1 Data analysis

To analyze Papua New Guinea’s current performance in the context of climate change, the country was benchmarked against selected peers, drawing on a set of more than 100 comparative indicators. These indicators covered four dimensions relevant to climate change and green growth; namely natural assets, efficient use of resources, risk and resilience, and social inclusion. Each indicator represented an area that included more than the corresponding data point captured by the individual indicator. For example, the indicator *electricity losses* was used as a proxy to measure the efficiency and reliability of the electricity system overall.

All indicators were normalized to make PNG’s performance comparable across different areas. Each indicator was benchmarked against a group of peer countries that were agreed on by stakeholders. Peers included the average score of Lower Middle-Income Countries (LMIC), Fiji, Indonesia, and Timor-Leste. A selected subset of indicators was illustrated in four distinct radar charts; one for each dimension relevant to climate change and green growth (figure 3). Supported by more detailed information on individual indicators and the areas they represent, the charts helped to introduce the results of the preliminary assessment and facilitate discussion with stakeholders. A list of the indicators with details including their definitions and sources is provided in Appendix A1.

The preliminary analysis served as a starting point for identifying the priorities of the assessment, causes for low performance in specific areas, and possible remedies. Emphasis rested on areas that showed comparatively lower scores, as these could represent a higher potential for improvement at moderate costs.

Figure 3. Framework of the preliminary assessment



Source: GGGI

Natural assets

The results of the data analysis showed that, compared to the LMIC average, Papua New Guinea scores relatively high for water stress, air quality, soil conditions, and fish stocks. However, it should be noted that the results for water stress and soil condition are misleading as the data does not reflect geographical and seasonal variations (water stress) or is largely outdated (soil condition).

The country received comparatively low scores for protected areas, with accelerating levels of habitat loss as a major threat to biodiversity. There is a lack of consistent, reliable, and up-to-date data on forest cover and forest cover change in PNG. For example, the University of Papua New Guinea (UPNG) (2015) reported an annual rate of deforestation of 0.1% for the period 2002 to 2014. FAO (2019a) indicates 0.01% for total forest cover loss between 2000 and 2015. Given their global importance and the paucity of data, forest cover loss was identified as a priority.¹

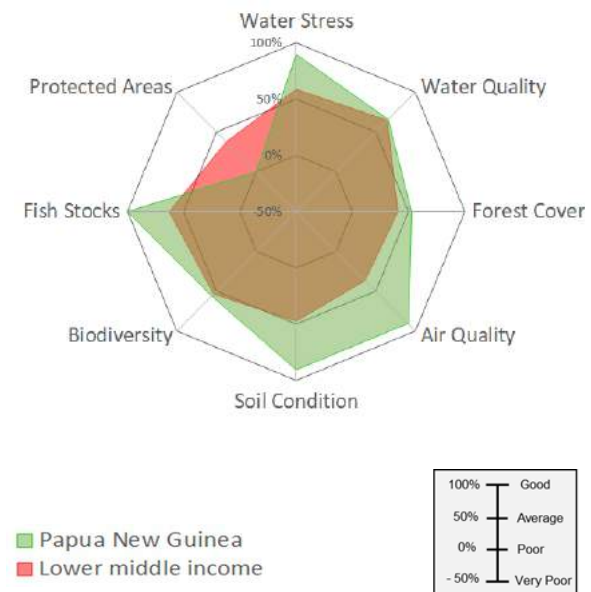
Efficient use of resources

According to the indicators used for the GGPA, Papua New Guinea generally scored lower than its peers regarding the efficient use of resources. Energy consumption, measured as Total Primary Energy Supply (TPES) per unit of Gross Domestic Product (GDP), and electricity losses were high.

Estimates suggest that industry and transport are the dominant consumers for fossil fuels, with biomass being the main fuel in the residential sector (APEREC 2016; IRENA 2013). Access to electricity is low and the existing network is inefficient and under severe stress (ADB 2015a; GoPNG 2016; IRENA 2013; Kuna and Zehner 2015; Lowy Institute 2017).

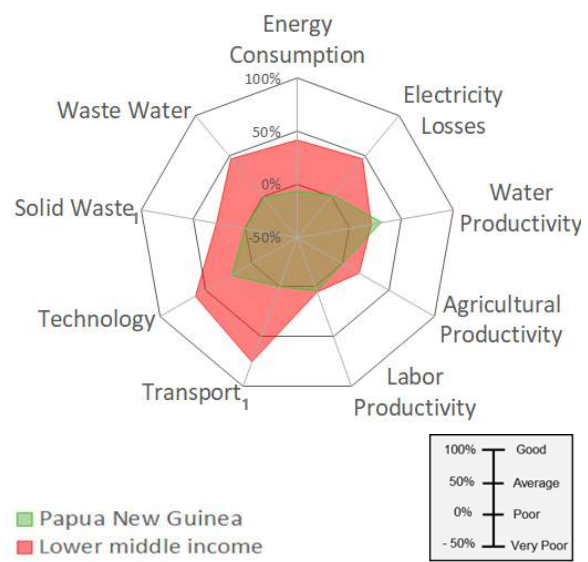
Data on agricultural productivity is highly uncertain. Productivity was estimated to be comparatively low, due to the high share of subsistence farming, little utilization of inputs

Figure 4. Natural assets



Source: Global Green Growth Institute

Figure 5. Efficient use of resources



Source: Global Green Growth Institute

¹Comparative data for PNG is not available.

¹ Papua New Guinea's forests are globally significant, covering more than two-thirds of the country's land mass and—together, with forests in the neighboring Indonesian province of Papua—comprising the third largest tract of intact tropical forest in the world (CIFOR 2013).

and technology, lack of extension services, and limited transport and marketing infrastructure (IMF 2017; UNDP, UNEP, and GEF 2018).

No comparative data is available, but coverage and quality of PNG's transport networks is low, with geography and topography being severe challenges (Lowy Institute 2017). Similarly, the share of population with access to improved sanitation (wastewater indicator) is low (WHO and UNICEF 2018). While nearly 90% of the population is covered by a mobile network (IUN 2018), service outages are common, and connections are not affordable for a large share of the population (Lowy Institute 2017).

Risk and resilience

Papua New Guinea performed well, regarding the carbon intensity of its economy, and has a high carbon stock in its extensive forests. The country received low scores for growth of CO₂ emissions, vulnerability, and cost of climate change. Climate change has severe impacts on agriculture, fisheries, infrastructure, public health, and biodiversity in the country through coastal and inland flooding, droughts, and ocean acidification, directly affecting a large share of the population (IOM 2014; GoPNG 2014).

There is a high uncertainty regarding the country's CO₂ data, often excluding land use as the potentially largest source. Absolute CO₂ levels (excluding land use) are comparatively low, estimated at 5 Mt to 10 Mt (GoPNG 2014; GoPNG 2016).

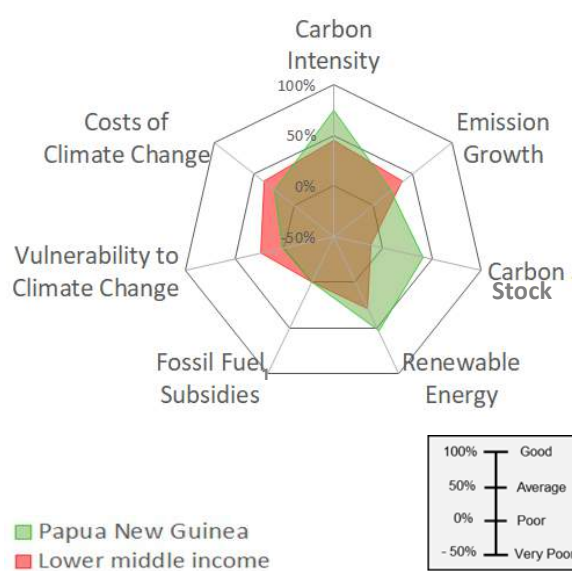
Notwithstanding the country's comparatively high performance regarding the share of renewable energy in its electricity mix (which under the GGPA methodology excludes hydropower), renewable energy was identified as a potential priority, given the country's high potential (IRENA 2013; GoPNG 2014).

Social inclusion

For indicators measuring social inclusion, Papua New Guinea scored consistently lower in a variety of areas compared to its peers. This included poverty, access to electricity, education, income, and gender inequality.

Poverty and material inequality are directly linked to Papua New Guinea's dual economy, with extractive industries providing a large share of GDP and subsistence agriculture supporting 80% of the population (ADB 2017; IMF 2017; UNDP, UNEP, and GEF 2018). Despite strong

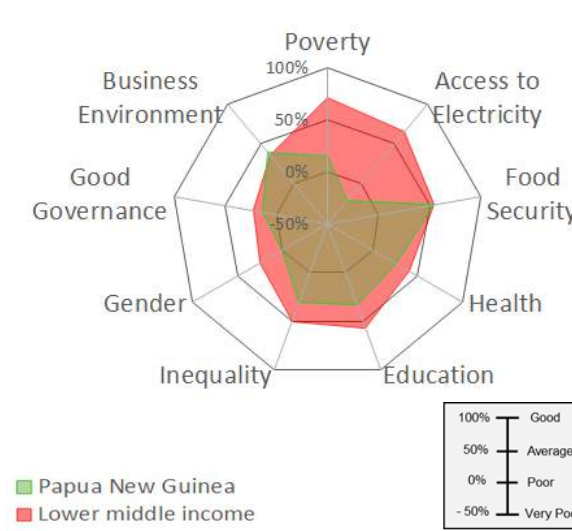
Figure 6. Risk and resilience



Source: Global Green Growth Institute

¹Comparative data for PNG is not available.

Figure 7. Social inclusion



Source: Global Green Growth Institute

¹Comparative data for PNG is not available.

economic growth, the poverty level is considerably higher compared to neighboring countries (World Bank 2018a).

Both good governance and education are basic necessities to reduce poverty and raise income levels. The country's education system suffers from a lack of funding, infrastructure, governance, and qualified personnel. Low education levels translate into a labor force lacking the skills to meet labor market requirements (Lowy Institute 2017). Corruption often figures prominently among the main obstacles to business activities and investment (IMF 2017).

2.2 Stakeholder consultation

An essential part of the GGPA is to gather inputs from a broad range of stakeholders through an interactive Delphi-based workshop. This workshop serves to validate and/or revise the findings of the preliminary assessment. Presenting the results of the data analysis, coupled with a systematic and participatory process, is essential to ensure stakeholder consensus on the priorities.

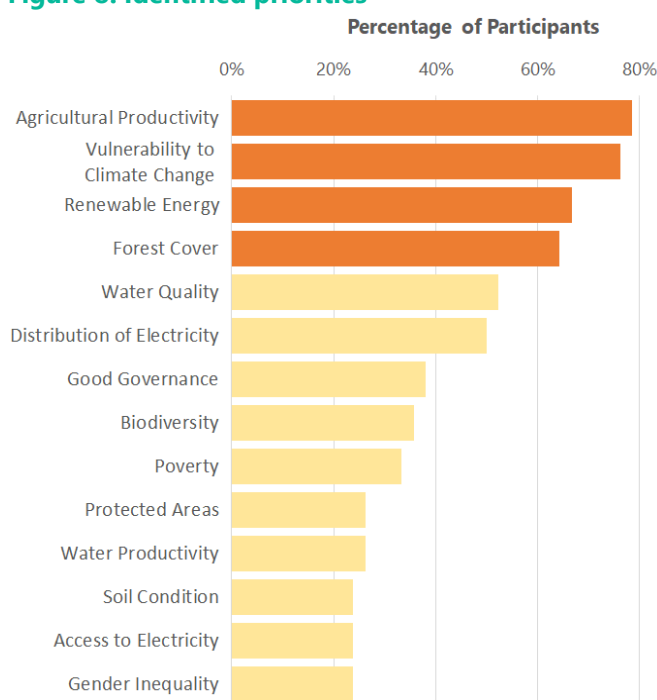
The GGPA consultation workshop was held on July 26, 2018 in Port Moresby, bringing together about 50 participants representing different ministries and departments of the Government of Papua New Guinea as well as development partners, NGOs, academic institutions, and the private sector.

Participants identified the following four priorities for climate change and green growth in Papua New Guinea (figure 8):

- Agricultural productivity was selected by participants, due to the high importance of agriculture for rural livelihoods, food security, and Papua New Guinea's economy.
- Renewable energy was regarded as an opportunity to increase electrification, particularly in rural areas with mini-grids and stand-alone systems. Participants emphasized the high potential for renewable energy in PNG, given the country's abundant renewable energy resources.
- Increasing the country's resilience toward the adverse impacts of climate change was considered a priority for two reasons. First, the country is highly exposed to climate change as evidenced in frequent droughts, landslides, and floods as well as a rise in sea levels, soil erosion, and changes in weather patterns. Second, the country's economy was considered sensitive to climate change, given its dependence on sectors that experience considerable impacts from climate change, such as fisheries and agriculture.
- Forest conservation was regarded as a priority due to the global importance of Papua New Guinea's extensive forests, the role they play in sustainable agriculture and provision of ecosystem services, and their economic potential.

Participants consistently mentioned financial resources, technical capacity, and technology, as well as good governance, as critical enablers for progress regarding the identified priorities.

Figure 8. Identified priorities



Source: Global Green Growth Institute

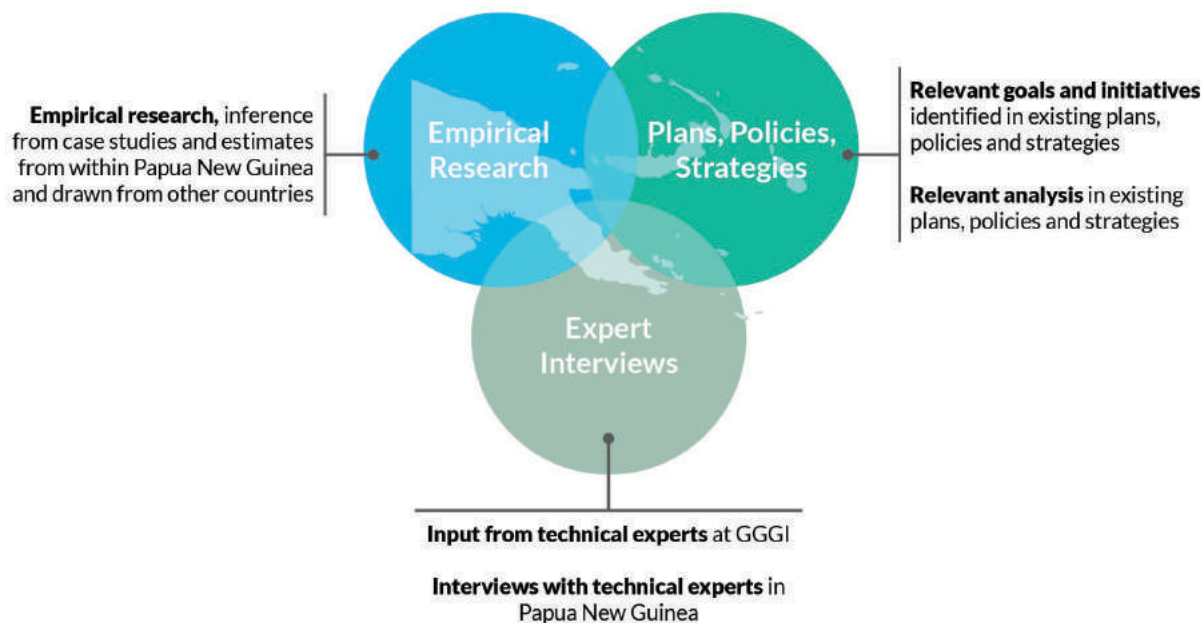
2.3 Final analysis

The identified priorities served as the basis for this report. Given the large spectrum of issues involved regarding Papua New Guinea's vulnerability to the adverse impacts of climate change, this report summarizes what can be regarded as consensus in the existing literature and highlights where there is uncertainty and the need for further research.

Recommendations have been developed to address three of the more specific priorities: renewable energy, agricultural productivity, and forest conservation. Given the close relationship between agriculture and forests/deforestation, the two are addressed together. Where relevant, the report considers aspects that are closely related to but go beyond these priorities, in line with suggestions made during the consultation workshop or the findings of the preliminary assessment.

Each recommendation is supported by analysis, based on three principal sources of information. First, the assessment is based on existing empirical research, case studies and estimates from within Papua New Guinea, and relevant examples from other countries. A lack of reliable data and uncertainty of planned projects being implemented represented a considerable challenge to conducting the analysis; this is an obstacle highlighted throughout the report and reflected in the recommendations. Second, the assessment considers existing policies, strategies, plans, regulations, goals, and initiatives identified in these documents as well as any relevant analyses they contain. Finally, in addition to input provided by technical experts within GGGI, a series of interviews with technical experts in Papua New Guinea were conducted to inform the analysis (figure 9).

Figure 9. Schematic of the analytical framework for the GGPA final report



Source: Global Green Growth Institute

This report proposes specific initiatives and interventions, each supported by a solid rationale and based on empirical evidence. The aspiration is that a portion of the proposed initiatives and their underlying rationale will lead to project proposals for GCF financing. Finally, the results of the GGPA will directly feed into GGGI's activities within the country.



3. Climate Change

Located near the Pacific Rim of Fire, Papua New Guinea is one of the most vulnerable countries to natural disasters in the world, affected by seasonal monsoons, rising sea levels, tropical cyclones, earthquakes, and tsunamis. This chapter assesses the impact of five different phenomena related to climate change in the country: changes in temperatures, shifts in rainfall patterns, a rise in sea levels, ocean acidification, and the occurrence of tropical cyclones. It summarizes what can be regarded as consensus in the existing literature, highlights areas of uncertainty, and indicates areas in need of future research. This chapter does not discuss the impacts of geophysical events (earthquakes, volcanic activity, and tsunamis) or the impacts of human activity (excessive logging, unregulated fishing). Rather, it focuses on how global climate change exacerbates existing risk factors that hinder development and growth.

There is a lack of data regarding the magnitude and socioeconomic impacts of climate change in Papua New Guinea. Given the paucity of reliable data, this report relies on projections made by the Australian Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (BoM and CSIRO 2014). In contrast to other documents discussing the extent of climate change in Papua New Guinea, BoM and CSIRO (2014) disclose the methodology behind their projections and provide confidence levels for their results. There is high confidence that climate change will result in increasing temperatures, heavier rainfall, rising sea levels, and increased ocean acidification, with serious implications for agriculture, fishery, infrastructure, and human populations. While climate change is also assumed to result in less frequent but more intense cyclones and droughts, there is considerable uncertainty around these projections (table 1).

Table 1. Climate change-related phenomena in Papua New Guinea

Phenomenon	Confidence (direction of change)	Projections in existing literature		Potential Impacts
		BoM & CSIRO 2014	ADB 2013	
Rise in temperatures	Very high	Increase in annual temperatures of approximately 0.8°C by 2030, 1.4°C by 2050, and 3°C by 2090.	Increase in average temperatures of more than 2.5°C by 2070.	<ul style="list-style-type: none"> • Decreased yield and quality of agricultural crops. • Reduced fish catch and increased destruction of corals. • Increase in vector-borne and respiratory diseases.
Increase in rainfall	High	Increase in average rainfall of 4% by 2030, 8.5% by 2050, and 16% by 2090.	Decrease in rainfall due to anomalies in sea surface temperature and the ENSO phenomenon.	<ul style="list-style-type: none"> • Increase in flooding and damage to infrastructure. • Decrease in agricultural productivity. • Degradation of coral reefs. • Increase in vector- and waterborne diseases.
Decline in frequency but increase in intensity of droughts	Medium	Decline in frequency of droughts.	Increase in number of droughts under El Nino conditions.	<ul style="list-style-type: none"> • Decrease in agricultural productivity. • Reduced access to drinking water and reduced food security.
Rise in sea levels	Very high	Rise in sea levels by approximately 0.13 meters by 2030, 0.25 meters by 2050, and 0.4 - 0.85 meters by 2100 (in Manus).	Rise in sea levels.	<ul style="list-style-type: none"> • Increase in coastal flooding, decrease in agricultural productivity, and damage to infrastructure. • Migration of population. • Contamination of drinking water.
Increase in ocean acidification	Very high	Decrease in aragonite saturation to 3.5 Ω_a by 2030 and a further decrease to <3.0 Ω_a .	Decrease in ocean pH and aragonite levels.	<ul style="list-style-type: none"> • Destruction of coral reefs. • Reduced catch of calcifying invertebrates and demersal fish.
Decline in frequency but increase in intensity of cyclones	Medium	Decline in frequency but increase in intensity of cyclones (globally)	Decrease in number and intensity of cyclones.	<ul style="list-style-type: none"> • Destruction of infrastructure. • Decrease in agricultural productivity. • Reduced fish catch and increased destruction of corals. • Increase in vector- and waterborne diseases.

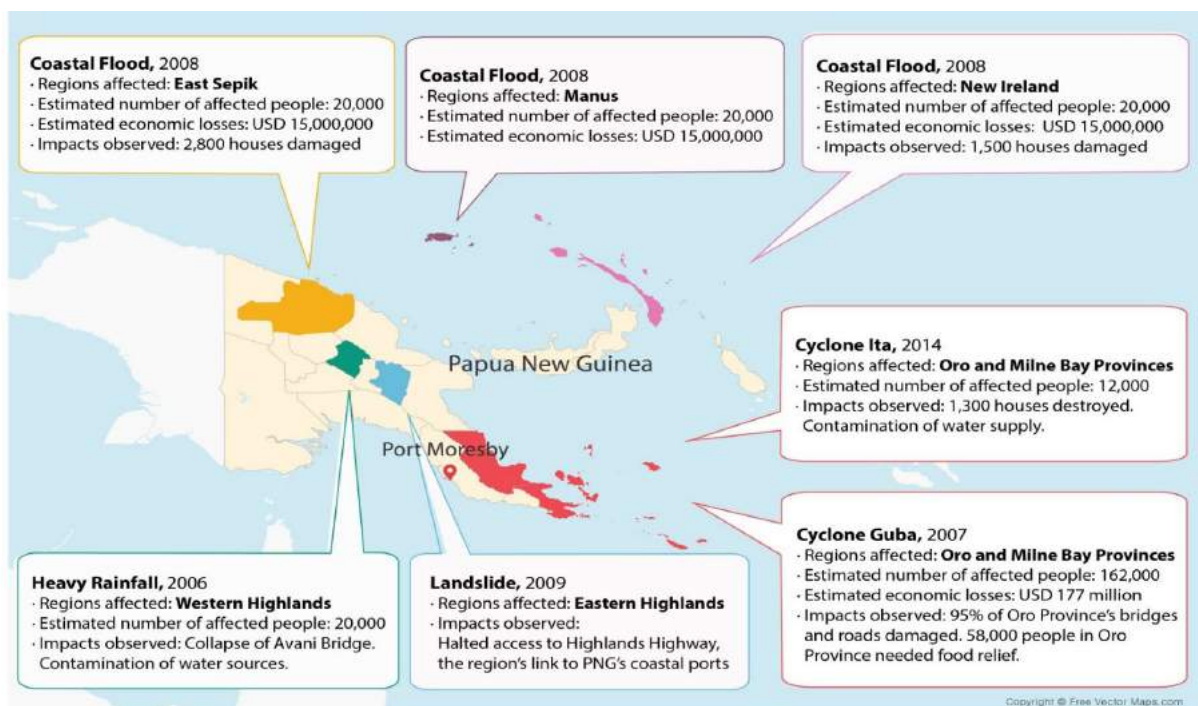
Source: BoM and CSIRO 2014; ADB 2013; last column compiled by GGGI

The El Niño Southern Oscillation (ENSO) phenomenon is a major variable in projecting future climate. Years witnessing El Niño are generally drier whereas years with the occurrence of La Niña tend to experience higher precipitation levels.² The difficulty in predicting the ENSO phenomenon has implications for the level of uncertainty in climate projections for droughts (BoM and CSIRO 2014).

In Papua New Guinea, the combined effects of climate change reduce the agricultural yield and quality of crops, destroy coral reefs that are important sources of food and income, damage important infrastructure, and adversely impact human health (table 1).

Papua New Guinea’s sensitivity to climate change is evidenced by the economic and human losses from climate change-related events. The country is prone to disasters, including heavy rainfall, floods, landslides, and cyclones. Figure 10 provides an overview of major climate-related disasters in the past 15 years.

Figure 10. Climate-related disasters in Papua New Guinea (2006–2014)



Source: IOM 2015, CFE-DM 2016, GoPNG and UN Country Team in Papua New Guinea 2017

² The El Niño Southern Oscillation (ENSO) phenomenon is a periodic fluctuation in sea surface temperature (El Niño and La Niña) and the air pressure of the overlying atmosphere (Southern Oscillation) across the equatorial Pacific Ocean (NOAA n.d.). During El Niño years, rainfall increases over the tropical Pacific Ocean and usual winds that blow from east to west (“easterly winds”) weaken or even reverse their direction (“westerly winds”). During La Niña, rainfall decreases over the central tropical Pacific Ocean and usual easterly winds along the equator become stronger (L'Heureux 2014).

3.1 Increasing temperatures

Mean temperatures in Papua New Guinea are rising. The Australian Bureau of Meteorology reports that annual mean temperatures at Port Moresby have increased at the rate of 0.22°C per decade since 1943 (BoM & CSIRO 2015), indicating a 1.3–1.4°C increase over the past 25 years. This is larger than the global increase in average annual temperature of 0.9–1.0°C around the same period (NASA 2018).

While maximum annual temperatures in PNG have increased at a rate of 0.13°C per decade, minimum annual temperatures have increased at 0.3°C per decade (BoM & CSIRO 2015). Also, warm days and warm nights at both Port Moresby and Kavieng have increased in number since 1943 whereas the number of cool days and cool nights has decreased over the same period (BOM and CSIRO 2015).

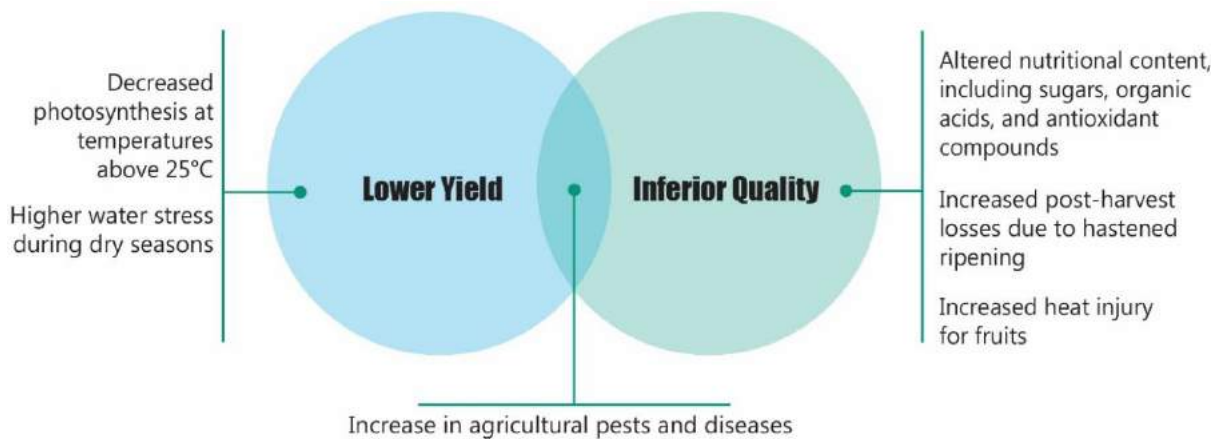
Annual average air and sea surface temperatures are projected to increase in the future under all IPCC carbon emissions scenarios. By 2030, under a very high emissions scenario, temperatures in PNG are projected to increase by 0.5–1.1°C (BoM and CSIRO 2015). The average surface air temperature in the country is expected to increase by more than 2.5°C, under both moderate and high emissions scenarios, by the end of this century.

The increase in temperatures has direct repercussions for agriculture, fishery, and human health.

Agriculture

The direct impacts of increased temperature on agriculture include a lower yield and lower crop quality caused by decreased photosynthesis, higher water stress, and increased exposure to pests and diseases (figure 11).

Figure 11. Impacts of higher temperatures on crops



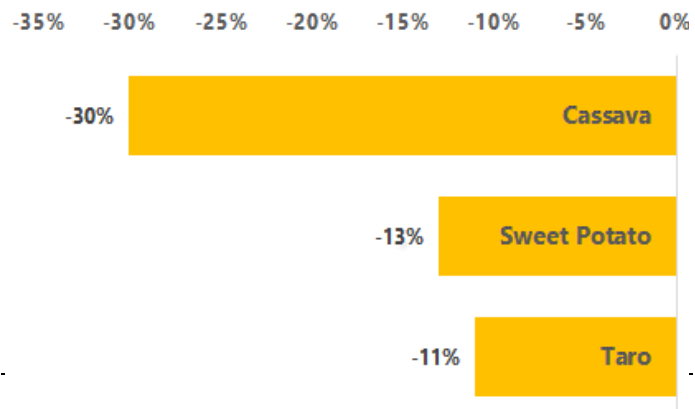
Source: GGGI

First, higher temperatures often lead to a lower crop yield because levels of photosynthesis decrease at temperatures above 25°C for tropical crops, like sweet potato, cassava, taro, and yams (GEF, UNDP, and SPREP 2009). For example, biomass formation in sweet potato, PNG’s most important staple food crop, reaches its maximum at 30°C and significantly decreases at temperatures above 34°C (Reddy et al. 2015; Bourke and Harwood 2009). The photosynthesis rate of plants like rice and wheat is highest at temperatures between 20–32°C (DaMatta et al. 2010). As maximum temperatures in PNG’s lowlands

reportedly reach up to 32°C, an increase of 2.0–4.5°C within the next century would significantly reduce sweet potato, rice, and wheat production in these areas (Bourke and Harwood 2009).

For PNG, climate models have projected a 13% decline in yield in sweet potato, 11% in taro, and 30% in cassava (Hay et al. 2003). In the nearby Solomon Islands, warmer temperatures and wave overtopping in coastal areas have already caused tubers in taro to be reduced, leading to a decline in the overall taro yield (GEF, UNDP, and SPREP 2007). Other temperature-sensitive crops, like soybean and sugarcane, also experience disruption in sucrose and starch content, ultimately resulting in lower yields (Ganpat and Isaac 2014).

Figure 12. Projection for decrease in yield of cassava, sweet potato, and taro



Source: Hay et al. 2003

Second, higher temperatures can undermine productivity by causing water stress in plants. When temperatures increase, the capacity of air to absorb water vapor rises as well. Higher evapotranspiration³ rates lower—and even deplete—water reservoir in soils, causing water stress in plants during dry seasons (Moretti et al. 2009). Since irrigation agriculture in PNG is not widely practiced, increased water stress in lower-lying limestone areas, as well as highlands, may cause reduced crop productivity.

Third, the agricultural yield, as well as crop quality, is compromised by higher temperatures as this leads to the incubation of agricultural pests and fungal diseases. Temperature is one of the most important factors affecting the occurrence of bacterial plant diseases, such as *Ralstonia solanacearum*, *Acidovorax avenae*, and *Burkholderia glumea*. Such bacteria could proliferate in areas within PNG, where temperature-dependent diseases have not been previously observed (Kudela 2009).

As agricultural pests and diseases tend to migrate to warmer temperatures, farmers in PNG might also have to deal with more severe and frequent outbreaks in the future. One recent example is that of the coffee berry borer (*Hypothenemus hampei*), an insect recognized to be the most destructive coffee crop pest in the world (Jaramillo et al. 2011). Endemic to Africa, the coffee berry borer first appeared in PNG in early 2017 (Oxford Business Group 2017) in Banz, Jiwaka Province. Prior to the 2000s, there were no reports of coffee berry borer attacks on coffee plantations above 1,500 meters anywhere in the world (Davis et al. 2006). Due to recent increasing temperatures in coffee growing regions globally, the insect can now be found at higher altitudes (Jaramillo et al. 2011). This is of particular importance for *C. Arabica*, which grows within a preferred altitude range of 1,400–1,600 meters (cultivated) and 1,200–2,000 meters (naturally occurring), respectively (Davis et al. 2006). Arabica coffee is a major cash crop, accounting for 95% of the Papua New Guinea’s coffee production and contributing significantly to the country’s exports (PNG Coffee Industry Corporation Ltd 2017).

Approximately kina 10 million was spent as of January 2018, and trees were cut down to keep the pest contained in the Eastern Highlands and Jiwaka Province (Pokiton 2018). Although the Government of

³ Evapotranspiration is the process of transferring moisture from the earth into the atmosphere (Hydropoint n.d.). It can be broken down into evaporation (water vapor leaving the soil or the surface of a plant) and transpiration (water passing through a plant from root to leaf).

PNG has been successful in hindering the pest from spreading into the Western Highlands and Chimbu and Morobe Provinces, affected farms often suffered more than 50% losses when they first experienced the pest (Pelley 1968; Pokiton 2018), with severe implications for their income and livelihoods.

Higher temperatures increase humidity levels, providing ideal conditions for fungal diseases, which are capable of endangering crops. For example, taro blight, a disease that significantly reduces the taro yield, is caused by the fungus *Phytophthora colocasiae*. As the fungus is sensitive to temperature during its incubation, a small rise in temperature can lead to more frequent outbreaks of taro blight disease and to a shift in production areas (Bourke and Harwood 2009). While PNG has successfully adapted to dealing with the disease that has plagued the country's taro farms since the 1940s (APAARI 2009), rising temperatures may compromise recent progress.

Outbreaks of plant diseases due to higher temperatures are particularly concerning for PNG because the genetic bases of the country's staple crops are narrowing (Kambuou 1996). Local sweet potato varieties are already showing difficulty in adjusting to increased disease pressure under warmer and moister conditions. For example, there has been a salient increase in leaf scab disease (*Sphaceloma batatas*) over the past decade, which can reduce crop production by more than 50% (Bourke and Harwood 2009). Potato late blight, a disease that virtually wiped out PNG's potato harvest in 2003, causing financial losses of nearly USD 5.5 million, has been observed to rebound a decade later (Ganpat 2014).

Finally, increasing temperatures are also known to affect the quality of crops by altering nutritional content and ripening. Higher temperatures adversely impact significant quality parameters, like the synthesis of sugars, organic acids, antioxidant compounds, and firmness of crops after harvest (Moretti et al. 2009). Various fruits—including pears and avocados—have been observed to suffer from heat injury at temperatures above 35°C (Maxie, Mitchell, and Sommer 1974; Lee and Young 1984).

Exposure to high temperatures, both prior to and after harvest, is likely to hasten ripening in fruit and vegetable crops, making it more difficult for farmers to manage shelf life (Sargent et al. 2000). As hastened ripening usually indicates a shorter life cycle in non-perennial plants, it also results in smaller plants, shorter reproductive duration, and lower yield potential (Hatfield et al. 2008). Post-harvest losses in Port Moresby are estimated to amount to up to 30–50% for sweet potato and 20% for fruits and vegetables due to the lack of adequate conservation and storage, transportation, processing, and access to market (World Bank 2014). Higher temperatures are likely to increase these losses.

Fishery

Warmer sea surface temperatures caused by global warming will have major consequences for Papua New Guinea's ocean ecosystems, fishing industry, and aquaculture. Fish is a crucial protein source in the country. It is estimated that the 2010 fish supply would need to increase by two-thirds to satisfy nutrition needs by 2030 (Bell et al. 2009)

First, higher sea surface temperatures in the Pacific may adversely impact the catch of oceanic and coastal fish species, as well as invertebrates, in Papua New Guinea. With catches averaging 150,000–200,000 million tons per year (representing about 10% of the global catch), tuna is PNG's most significant fish resource (Oxford Business Review 2017). However, the tuna yield is expected to decrease as skipjack and bigeye tuna populations relocate to areas further east within the Pacific due to changes in temperatures, currents, and food chains (Bell et al. 2011). The skipjack tuna catch is expected to decrease by as much as 30% by the end of the century and bigeye tuna catch up to 28% (table 2). This has major implications for the country's industrial fishing fleets and canneries as well as food security at the local level.

Table 2. Projected percentage changes in catches of skipjack and bigeye tuna

Area	Skipjack tuna			Bigeye tuna		
	B1/A2 2035	B1 2100	A2 2100	B1/A2 2035	B1 2100	A2 2100
Fiji	25.8	24.0	33.1	0.8	0.7	-1.4
New Caledonia	22.5	18.7	39.4	1.1	1.2	6.0
Papua New Guinea	3.1	-10.6	-30.2	-4.5	-13	-27.9
Solomon Islands	3.2	-5.5	-15.4	0.1	-2.9	-7.3
Vanuatu	18.4	15.1	26.1	-3.0	-6.1	-9.7

Source: Bell et al. 2011

Note: Projected percentage changes in catches of skipjack and bigeye tuna, relative to recent catches (20-year average 1980–2000), under the B1 and A2 emissions scenarios in 2035 and 2100, derived from the SEAPODYM model. Likelihood and confidence values for all estimates are provided in Bell et al. (2011).

Catch of demersal fish⁴ and non-tuna nearshore pelagic fish species—such as Spanish mackerel, rainbow runner, wahoo, and mahimahi—are also expected to decrease as higher temperatures will result in habitat loss, reduced recruitment, and reduced production of zooplankton in food webs (Bell et al. 2011). While a number of species may be able to adapt to the changes in temperatures by settling larvae in places with cooler temperatures, such adaptation will be difficult for species that depend on coral reefs if there are no reefs available within the relocated optimal temperature range (Bell et al. 2011).

Table 3. Projected changes in coastal fisheries production in Papua New Guinea

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment due to increasing sea surface temperature and reduced currents
Nearshore pelagic fish	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

Source: Bell et al. 2011

⁴ Demersal fish are bottom-dwelling fish associated with coral reef, mangroves, and seagrass.

Second, an increase in sea surface temperatures will negatively impact the productivity of phytoplankton. Located at the bottom of the marine food chain, phytoplankton is the primary source of food for fish and other food web organisms like zooplankton. Phytoplankton productivity is negatively impacted by higher temperatures because increased stratification and a shallower mixed ocean layer cause the nutrient supply for phytoplankton to decline (Bell et al. 2011).⁵ A decrease in phytoplankton productivity would adversely impact the entire marine food chain in Papua New Guinea.

Third, rising ocean temperatures have a pernicious impact on coral reefs. Thermal stress on reefs is the biggest cause of coral bleaching. Coral bleaching leads to severe coral reef degradation, a decline in reef organisms, and depletion of fish stocks. More than 1,500 species out of approximately 2,900 total fish species in Papua New Guinea rely on coral reefs, many of which are vital sources of food and income to local communities (Drew, Amatangelo, and Hufbauer 2015).

The country's local fisheries rely heavily on coral reefs for demersal fish, some nearshore pelagic fish, and invertebrates for export and as a source of food (Bell et al. 2011). Friedman et al. (2008) estimate that Papua New Guineans are consuming approximately 48 kg of fish per person annually in coastal areas.⁶ The projected decline in coastal fish and invertebrate populations, combined with a growing human population, will result in a shortage of fish as a protein source. Consumption levels are expected to fall far behind the recommended 35 kg of fish per person per year by 2035 (Bell et al. 2011).

Public health

Increasing temperatures are known to facilitate the spread of vector-borne diseases like malaria. Malaria generally thrives at temperatures of 22°C at an altitude of 650–1300 meters above sea level (World Bank 2011; Müller et al. 2003). Most of Papua New Guinea's population is concentrated in the highland areas at altitudes of 1300–1500 meters (Müller et al. 2003). Rising temperatures would likely enable fatal malaria species, which are currently limited by altitudes and temperatures, to spread and affect a larger share of the population. While malaria was the fourth most prominent cause of death in PNG in 2005, the country has made considerable progress in dealing with the disease effectively in the past decade, with death rates from malaria dropping by 80% between 2005 and 2016 (IHME 2018a). However, rising temperatures may undermine some of this recent progress.

Another example of the health impacts of climate change is pneumonia. As of 2016, lower respiratory infections were the fourth most prominent cause of death in PNG, with a 10% increase in the number of fatalities during the past decade (IHME 2017). Common in the tropical regions—especially during rainy seasons—pneumonia is closely associated with climactic conditions in its development. Kim et al. (2016) observed that the pooled risk of pneumonia incidence in children under five years of age in PNG was nearly 5% higher per every 1°C increase in the monthly mean of maximum daily temperatures. Childhood pneumonia already accounts for nearly a quarter of total child deaths in PNG (Kim et al. 2016). Climate change-induced higher temperatures may exacerbate its impact further.

⁵ The mixed layer of the ocean is the top 200 meters of the ocean where there is active turbulence and mixing of oceanic waters due to winds, heat fluxes, evaporation, and salinity fluxes (Sprintall, and Cronin 2009). As temperatures increase due to climate change, ocean water becomes more stratified, decreasing the amount of nutrients traveling up to the surface layer of the water and the amount of oxygen sent to the deeper parts of the ocean (Arrigo et al. 1999; Shepherd et al. 2017).

⁶ The annual intake of fish per person in coastal areas is considerably higher than the national average intake of 13 kg person (Bell et al. 2011).

3.2 Heavy rainfall

While variability in rainfall trends over the years makes it difficult to forecast rainfall patterns in Papua New Guinea,⁷ average rainfall is projected to increase in most areas, accompanied by more extreme rainfall events (BoM and CSIRO 2011). Heavier rainfall patterns can be expected to adversely impact agriculture, fishery, infrastructure, and public health in PNG.

Infrastructure

Heavy rains often damage roads, bridges, and buildings, blocking important arteries of transport and generating considerable economic losses. While data to systematically assess economic losses due to climate change is scarce in Papua New Guinea, figures for individual events indicate that losses are considerable.⁸ Public records estimate that intense rainfalls cause an annual damage of USD 8–12 million, mostly affecting the underprivileged in the country. For example, total damages and losses caused by heavy rainfall in June and September of 2012 amounted to approximately USD 28 million (CFE-DM 2016). At the same time, more than USD 300,000 for humanitarian aid came from the government budget (CFE-DM 2016). Another USD 1.5 million was spent on providing alternate road access to recompense for damaged road infrastructure (GFDRR 2013).

Heavier rainfall, both through an increased average precipitation and more frequent extreme rainfall events, can cause recurrent and destructive inland floods, which are already taking a significant toll on the country and its populations. Inland flooding triggered by heavy rainfall regularly affects valleys and wetlands in both the lowlands and highlands of PNG. The effects of inland flooding are aggravated by topography and deforestation. Estimates suggest that 22,000–26,000 people are affected annually by inland floods and that 6,000–8,000 are displaced (CFE-DM 2016).⁹ In March 2015, intense rainfall caused river overflows in the provinces of the Western Highlands, Central Highlands, Southern Highlands, and Jiwaka, affecting a total of about 100,000 people (CFE-DM 2016).

In January 2012, heavy rainfall resulted in a landslide in Tumbi Village, Hela Province, killing dozens of people and severely disrupting trade and transport in the country (IRIN 2013). In January 2013, floods and landslides destroyed homes, food gardens, water sources, and infrastructure, affecting an estimated 35,000 people in several provinces during the rainy period (IRIN 2013b).

Although recent incidences are not well documented in Papua New Guinea, sedimentation resulting from heavy rainfall and flooding poses a threat to the electricity supply from the country's hydropower plants. Sedimentation reduces the storage capacity of a water reservoir, damages expensive hydro-mechanical equipment, and causes significant operations and maintenance issues that lead to costly outages (Entura 2018). In July 2006, the Rangit River in India flooded a hydropower plant during the monsoon season, choking several turbines, cooling water systems, and valves with sediment and trash. Operation was restored only in mid-October, reducing electricity generation and causing supply gaps

⁷ Variability in the amounts of precipitation can be observed in any location around the world; the pronounced impact that the ENSO phenomenon (El Niño) exercises in Papua New Guinea exacerbates fluctuations (BoM and CSIRO 2014).

⁸ There have been efforts to systematically capture data on economic losses caused by climate change, such as the Munich Reinsurance Company and their NatCat Database (Munich RE 2018). However, estimated losses are based on insurance data. With insurance coverage being low in Papua New Guinea (Munich RE 2018), estimated losses only reflect a marginal share of the actual material losses incurred in the country.

⁹ The estimate is based on data covering the period from 1996 to 2015.

in the region (Hydro Review 2014). Older examples dating back to the 1990s suggest that Papua New Guinea's dams are equally sensitive to damage incurred by cyclones and extreme rainfall (Fridriksson 1995). With about 30% of the country's electricity supply being generated from hydropower (APERC 2016) and the stress that many of these plants are experiencing (ADB 2015b; Kuna and Zehner 2015; Lowy Institute 2017), the situation is unlikely to have changed since then.

Agriculture

While there is limited empirical data on the isolated impact of prolonged and heavier precipitation on agriculture, changes in rainfall patterns are known to affect planting time, growing stages, harvest periods, and post-harvest storage of crops. Such factors are likely to reduce total agricultural yield (Ganpat 2014). Other risk factors caused by heavier rainfall are soil erosion and increased sedimentation by floods during monsoons, which undermines the agricultural productivity of Papua New Guinea's coastal plains (World Bank 2011).

Coral reefs

Higher amounts of rainfall and rainfall-induced floods threaten corals by causing higher turbidity, nutrient enrichment, and lower salinity in ocean waters. Sediment and nutrient loads delivered to coastal reefs as a result of heavy rain hinder their photosynthesis. They also create favorable conditions for epiphytic algae that compete with corals, chronically affecting coral growth and recovery after storm damages (Bell et al. 2011). As coral reefs are important habitats for more than half of the fish species found in Papua New Guinea's waters, the degradation of these reefs will have major implications for the country's fisheries.

3.3 Rising sea levels

Sea level rise is caused by global warming in ocean waters and melting of glaciers and ice sheets. Sea levels near Papua New Guinea have risen by approximately 7 mm per year since 1993, considerably more than the global average of 2.8–5.6 mm per year (BoM and CSIRO 2015).

Sea levels in PNG's waters are projected to rise further under all emissions scenarios. Under a very high emissions scenario, sea levels near PNG are expected to rise in the range of 7–17 cm by 2030 (BoM and CSIRO 2014).

Rising sea levels have negative consequences for agriculture, freshwater resources, coral reefs, and infrastructure.

Land loss

Of Papua New Guinea's total land area, an estimated 18% of the land is permanently inundated or regularly flooded (CIF 2012). Approximately 4,500 km of the total 17,100 km of shoreline are subject to moderate to severe inundation, affecting up to a third of the country's population (GoPNG 2000). Inundation events can significantly change shorelines, damage infrastructure, contaminate freshwater reserves, destroy food crops, and, in the severest of cases, take human lives (Barnett 2011). The permanent or periodic inundation of deltaic flood plains, swamps, and low-lying areas could affect up to 50% of the Papuan coastline and 10% of the northern shorelines for a 1-m sea level rise—IPCC's highest estimate (GoPNG 2000).

In addition, some very low-lying islands, including barrier islands, are likely to become completely submerged in the next few decades. While the Carteret Islands represent the most widely recognized case, there is evidence that this is occurring in the outer-lying atolls of the Duke of York Islands as well (CIF 2012).

Agriculture

Sea level rise is problematic for agriculture because it causes inundation, salinization, and erosion of farmlands. Atolls in PNG, like the Carteret Islands and Takuu, are threatened by periodic inundation from extreme events, such as high waves and storm surges, causing freshwater contamination and crop destruction (Connell 2015). For example, groundwater salinization resulting from sea level rise is destroying traditionally important pit and swamp taro gardens in Andra and other atolls of Manus by changing water quality parameters (Ganpat 2014).

Sea level rise has already destroyed freshwater trees and crops and inhibited access to freshwater along rivers in the Western Province. For example, sea water inundation of narrow strips of farmland along the Fly River creates saline soil conditions that destroy many garden crops in the country's Western Province (Ganpat 2014). Additionally, in 1992, the Binaturi floodplain experienced considerable saltwater intrusion, inundating a forest 15 km inland (World Bank 2011). Inundation of sago, mangroves, and other low-lying coastal agricultural land due to sea level rise and storm surges will continue to affect food security as well.

Fishery

Sea level rise is problematic for fisheries in Papua New Guinea because many nursery grounds for commercially important fish and shellfish are located in shallow reefs near the coast and within mangrove forests (CIF 2012). Both areas are extremely vulnerable to coastal flooding and storm surges. Mangrove trees that offer protection from storms are projected to decrease by 60% by the end of the century under a high emissions scenario (Bell et al. 2011). Finally, the growth rate of coral reefs, important habitats of PNG's fish species, may not be able to keep up with the rapid rise in sea level (Perry et al. 2018).

Infrastructure

From 2000–2015, four catastrophic flood events and coastal floods affected, on average, 8,000 people a year (CFE-DM 2016). The floods caused an annual loss of USD 10–20 million on average (CFE-DM 2016). Rising sea levels have resulted in more destructive coastal floods, necessitating the evacuation of people from the Carteret Atolls and Duke of York Islands (CFE-DM 2016). Salinization and flooding in these areas are inhibiting access to drinking water, making them uninhabitable.

3.4 Ocean acidification

Higher concentrations of carbon dioxide in the atmosphere causes more CO₂ to be absorbed by the world's oceans. As more CO₂ dissolves in the sea, ocean pH decreases and aragonite saturation levels fall. This process is commonly referred to as *ocean acidification*. Coral reefs are highly vulnerable to projected decreases in ocean pH and aragonite saturation levels, as corals and crustaceans use aragonite to build their skeletons. At atmospheric concentrations of CO₂ above 450 ppm, aragonite levels could fall to levels that make it impossible for corals to sustain building their skeletons (Bell et al. 2011).

Papua New Guinea's oceans have been acidifying since the eighteenth century. Ocean acidification is captured by aragonite concentration (Ω_a). Aragonite concentrations in PNG waters have declined from 4.5 Ω_a in the late eighteenth century to about 3.8–4.0 Ω_a as of 2000 (BoM and CSIRO 2011). Ocean acidification is projected to continue decreasing, with values below 3.5 Ω_a maximum aragonite concentration expected by 2030 (BoM and CSIRO 2011). This puts into question the longer-term survivability of the entirety of Papua New Guinea's coral reefs, as coral reefs have historically not been found at levels of less than 3.0 Ω_a (BoM and CSIRO 2011).

Moreover, acidification leads to weaker and more brittle skeletons in organisms like corals, clams, and mussels, which rely on calcium carbonates to build their shells (Bell et al. 2011). Marked decreases in calcification are likely to result in more fragile and degraded reef frameworks (Bell et al. 2011). As of now, there is little evidence of calcifying organisms adapting to the changes of oceanic conditions under acidification in the twenty-first century.

Ocean acidification will continue to destroy Papua New Guinea's coral reefs, the fifth largest in the world. Coral reefs are vital to PNG. They play an important role in the country's economy through fisheries, medicine, and tourism. Furthermore, they protect the country's coastlines from storms and prevent land loss (CFE-DM 2016). Finally, between 50,000 and 70,000 coastal inhabitants rely on coral reefs for their food and livelihoods. This dependence makes Papua New Guinea one of the most vulnerable countries to ocean acidification in the Pacific (Johnson, Bell, and Gupta 2015).

Ocean acidification also affects calcifying invertebrates—including mollusks, crustaceans, and echinoderms—because, like corals, their shells, exoskeletons, or skeletal elements are composed of aragonite (or high-magnesium calcite in some species) (Ries, Anne, and McCorkle 2009). Calcifying mollusks grown in an environment with lower pH levels form thinner shells and show lower rates of growth and survival than those grown under normal pH conditions (Shirayama and Thornton 2005; Watson et al. 2012; Gazeau et al. 2013). Lower rates of calcification will lead to declines in the size and growth of mollusks for export—including trochus, green snail, and pearl oysters—as well as a reduced catch of bivalves and gastropods gleaned for local consumption (Johnson et al. 2017). Among shellfish important for aquaculture, the most vulnerable to ocean acidification are expected to be pearl oysters, shrimp, and marine ornamentals (CME-Programme 2018).

3.5 Cyclones

Tropical cyclones affect large areas of southern Papua New Guinea, usually between November and April. Sixty-four tropical cyclones developed in or crossed into the country's Exclusive Economic Zone from 1969 to 2010 (BoM and CSIRO 2015). While tropical cyclones are projected to occur less frequently in the future as part of a global trend, they are assumed to become more intense (BoM and CSIRO 2015). Maximum tropical cyclone wind speeds have been projected to increase by 5–10% by 2050. Similarly, peak precipitation rates are estimated to increase by 25%, causing higher storm surges (Mimura et al. 2007).

Infrastructure

Tropical storms cause considerable damage to infrastructure in Papua New Guinea. Should the adverse impacts of climate change cause an increase in the intensity of cyclones—as suggested by current projections—the economic losses associated with them are likely to increase as well. As with other climate change-related phenomena, there is a paucity of data, preventing the systematic assessment of economic losses as the result of tropical storms in Papua New Guinea. However, figures for individual events indicate that losses are considerable.

For example, Cyclone Ita in April 2014 caused extensive damage in the Northern provinces, displacing many villagers and disrupting the livelihoods of more than 12,000 people (IOM 2014). Moreover, 1,285 houses were reported to be destroyed and 67 classrooms had to be closed (IOM 2014). In 2007, rainfall and floods accompanying Cyclone Guba destroyed 95% of bridges and roads in Oro and Milne Bay provinces, at an economic loss of an estimated kina 500 million (USD 177 million) (O'Brien 2007). Over 56 bridges and culverts were washed away or severely damaged (IFRC 2009), and final estimates by the provincial government stated that 1,800 to 2,000 homes were destroyed, leaving approximately 9,500 people displaced (IFRC 2009). About 58,000 people in Oro Province were classified as needing immediate assistance during the emergency phase, and the government responded by setting up 41 care centers and 15 food distribution centers (IFRC 2009).

Agriculture

Cyclones are accompanied by heavy winds, rainfall, and storm surges that devastate crops, trees, and agriculture infrastructure, like farm buildings and fences (FAO 2010a). They contribute to soil erosion and salinization. Both lead to loss of soil nutrients in coastal areas and stream catchments, creating unfavorable conditions for crop cultivation (FAO 2010a).

When Cyclone Ita hit the southeastern province of Milne Bay in 2014, it destroyed nearly 3,500 food gardens (IOM 2014). The World Bank estimates that more than half of future economic losses resulting from tropical cyclones will consist of losses in cash crops like oil palm, coffee, and cacao (World Bank 2011). While approximately 85% of PNG's population is reliant on subsistence agriculture, cash crops still play an important role in the country's economy. PNG was the world's seventh largest producer and third largest exporter of palm oil in 2008—accounting for 1.3% of global exports—and the world's 17th-largest producer of coffee in 2010, accounting for almost 1% of global production (Oxford Business Group 2017). The agricultural export of cash crops represented up to 25%–40% of GDP over the last four decades (Oxford Business Group 2018). As a result, losses in cash crops will have a critical impact on the country's economy.

Cyclones are also responsible for the transboundary movement of agricultural pests and diseases across land and bodies of water in the Pacific (IPPC 2018). While specific occurrences in PNG are not well documented, transmissions of weather-borne taro leaf blight and myrtle rust disease have been reported in New Zealand and other Pacific countries (IPPC 2018; Biosecurity New Zealand 2018).

Fishery

More intense cyclones could also reduce fish supply as extreme weather events make fishing trips dangerous and less productive (FAO 2008). As a large number of people in Papua New Guinea rely on coastal subsistence fishing, this deprives local fishers of important sources of both protein and income (Preston 2001).

Tropical coral reefs are highly sensitive to the physical damage from cyclones, particularly in shallow reef environments, taking 10–50 years to fully recover. While reefs regularly exposed to cyclones and storms usually adapt by assuming stout growth forms and hosting fast-growing species, like *Acropora* spp., these corals have had thousands of years to adapt, and no level of adaptation shields coral reefs from damage caused by more extreme (category 4 or 5) cyclones (Bell et al. 2011).

More intense cyclones will also bring heavy financial losses to the little aquaculture that is practiced in PNG and hinder its expansion. Furthermore, when aquaculture infrastructure is damaged, marine ecosystems may be permanently altered due to culture species escaping into the wild. For example, this occurred in fisheries in northern Australia during a cyclone in 2011 (Noble, Smith-Keune, and Jerry 2014).

Public health

As tropical cyclones bring heavy rainfall and provoke flooding, water treatment plants tend to be overwhelmed, leading to cross-contamination between sewage and drinking water pipes, sewage overflow, or bypass into local waterways (Semenza and Nichols 2007). This is of particular concern in rural PNG, where water infrastructure is poorly planned and inaccessible, and open defecation is ubiquitous (ADB 2015b).

Floods from Cyclone Guba in 2007 contaminated the freshwater supply in Oro Province, thereby inhibiting access to clean drinking water and leaving 58,000 people in need of emergency food relief and assistance. Water and food supplies were also reported to be contaminated or damaged during Cyclone Ita in 2014 (CFE-DM 2016).

Freshwater contamination and increased moisture levels created by cyclones can lead to outbreaks of vector- and waterborne diseases, like malaria, dengue, cholera, and diarrhea (World Vision 2013). While such diseases require immediate intervention of medical aid, severe cyclones often disrupt and damage hospitals, cut off access to electricity and fuel, and destroy roads and bridges in cases where they are accompanied by landslides (Reliefweb 2007). This blocks major communications and transportation arteries, making it difficult for the medical aid to reach affected and vulnerable populations. Milne Bay Province and parts of the Northern and Central Provinces have already experienced such conditions due to cyclone activity in 2007 (World Bank 2011).

Table 4. Vulnerability of different sectors to climate change-related events

	Higher temperatures	Heavy rainfall	Rise in sea level	Higher ocean acidification	More intense cyclones
Agriculture	Red	Yellow	Red	Green	Red
Fishery (coral reefs)	Red	Yellow	Yellow	Red	Red
Infrastructure	Green	Red	Red	Green	Red
Human health	Red	Yellow	Yellow	Green	Red
Land loss	Green	Green	Red	Green	Green

Source: GGGI

Note: Red indicates high vulnerability, yellow indicates moderate vulnerability, and green indicates low vulnerability.



4. Renewable Energy

There is large agreement that the deployment of renewable energy brings economic benefits, reduces greenhouse gas (GHG) emissions, improves public health, and creates jobs. However, quantifying these benefits is a challenge. The models used to estimate these benefits—as all models—simplify reality. As a consequence, the validity of the results is closely correlated to the validity and accuracy of the underlying data and assumptions (World Bank and ClimateWorks Foundation 2014). However, data availability is a constant challenge in Papua New Guinea, with considerable uncertainty of the most basic information, such as population size, GDP, and energy supply.

The deployment of renewable energy solutions delivers two kinds of benefits, which can be largely categorized as (1) local socio-economic benefits and (2) services from a global public good. First, local socio-economic benefits include cost savings per household due to avoided expenses on fossil fuels, higher incomes due to increased electricity access, and the creation of employment. Second, renewable energy provides a public good by avoiding CO₂ emissions and the related adverse impacts from climate change; improving public health due to lower air pollution; reducing environmental degradation and associated loss in GDP as a result of cutting forests for biomass, mining of coal, and drilling for oil and gas; and generating greater social inclusiveness (IRENA 2017b; OECD/IEA and IRENA 2017; UNEP 2017; Lighting Global 2016).

It is important to note that renewable energy solutions in themselves can deliver some of these benefits. However, well-designed policies are needed for the full potential for these improvements to materialize (OECD/IEA and IRENA 2017).

4.1 Access to electricity

First, renewable energy allows increased access to electricity. The benefits of renewable energy solutions are particularly pronounced in Papua New Guinea where currently only about 8–15% of the population have access to electricity.¹⁰ Electricity access is largely limited to urban areas, with access in rural areas being estimated below 4% (DNPM 2010). While increasing access has been recognized as a priority, with the PNG Development Strategic Plan 2010–2030 setting the goal of achieving a 70% electrification rate by 2030,¹¹ little progress appears to have been made during the past decades. A 1996 household survey found that 12% of the population at the time had access to electricity, with fewer than 9% having either a refrigerator or a television (IRENA 2013).

Gaining access to electricity would particularly benefit the country's rural population that largely depends on agriculture. It would allow an increase in productivity through water pumping and irrigation, to reduce post-harvest losses by improving storage, drying, refrigeration, and ultimately contribute to greater food security (IRENA 2016b). For example, in the country's drier zones, irrigation can considerably increase agricultural yields compared to rain-fed farming while using renewables-powered—instead of diesel-powered—pumps would allow for considerable fuel savings. In India, the deployment of 4,000 solar pumps led to savings of 2.4 million liters of diesel fuel. Refrigeration and solar-powered drying can help prevent the spoilage of perishable foods. Replacing diesel generators with electricity from renewables in agricultural processing—such as milling and grinding grains—would permit considerable fuel and time savings. In Nepal, improved water mills saved around USD 750 per farmer per year for de-husking rice. Experiences in sub-Saharan Africa show that solar rice threshers are six times as productive as manual threshers (IRENA 2016c).

Box 1. Defining access to electricity

There is no universally agreed-upon definition of access to electricity. Traditionally, access to electricity has been measured on the basis of household connections to the national electricity grid. This approach limits assessing access to electricity to a binary measure (i.e., a household either has or does not have access). The measure is insufficient to capture issues such as the quantity, quality, and adequacy of service as well as questions around affordability. It is also unable to capture progress in electrification through off-grid solutions. However, lack of data—particularly in developing countries where access is an issue—often confines the analysis to a binary metric (Lighting Global 2016; Lighting Global 2018; World Bank 2013).

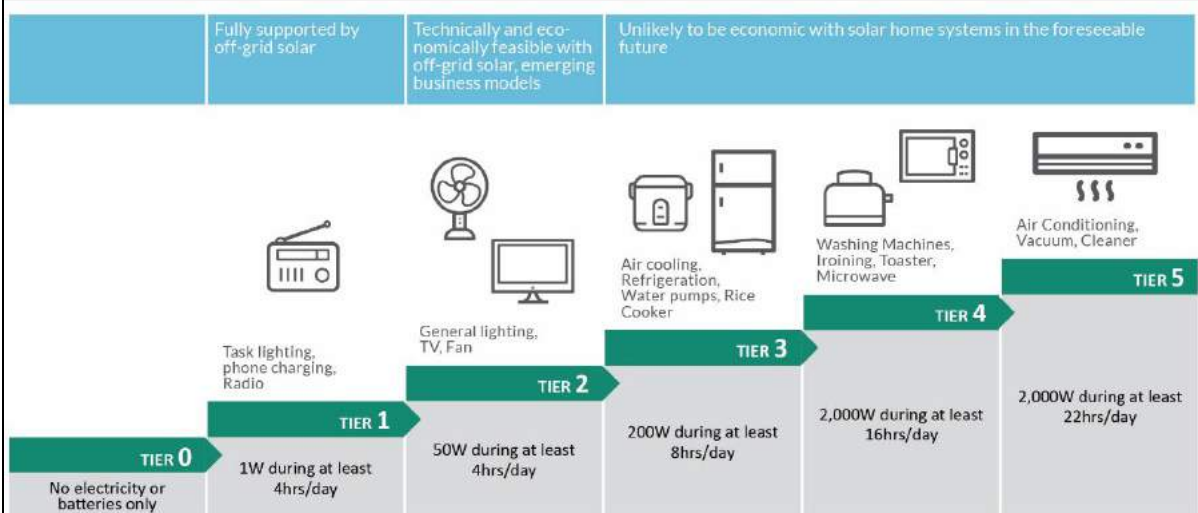
¹⁰ Estimates of electricity access in PNG generally vary between 10% and 15%. On the low end, the Intended Nationally Determined Contribution refers to almost 90% of the population not having access to electricity (GoPNG 2016). IRENA (2013) estimates approximately 13% of the population having access to electricity as of 2010. On the high end, the Department of National Planning and Monitoring (2014) reports 15% of the population having access. However, in-country interviews suggested that official data likely considerably underreports the country's population and, as a result, overestimates access rates. Based on a population number of approximately 10 million people, access is estimated at 8% or lower (in-country interviews).

¹¹ The Papua New Guinea Development Strategic Plan, 2010–2030 (PNGDSP) set the target of 70% of households having access to electricity by 2030 (DNPM 2010). The Medium Term Development Plan for the period 2018–2022 reaffirms that target (DNPM 2018).

Box 1. Defining access to electricity (continued)

A more accurate metric would measure the degree of access to electricity supply along various dimensions. There are examples of recent efforts to move to such a more granular metric. The IEA Energy Access Outlook 2017 includes renewable off- or mini-grid connections with sufficient capacity to provide a minimum of energy services, including several lights, phone charging, and a radio (OECD/IEA 2017a).¹² The UN's Sustainable Energy for All (SE4All) Multi-Tier Framework for electricity access seeks to capture electricity access not as a binary measure but as a continuum of service levels considering capacity, duration of supply, reliability, quality, affordability, legality, and safety. For that purpose, the Multi-Tier Framework distinguishes between six tiers of electricity access (figure 13, World Bank 2013).

Figure 13. SE4All electricity access tiers

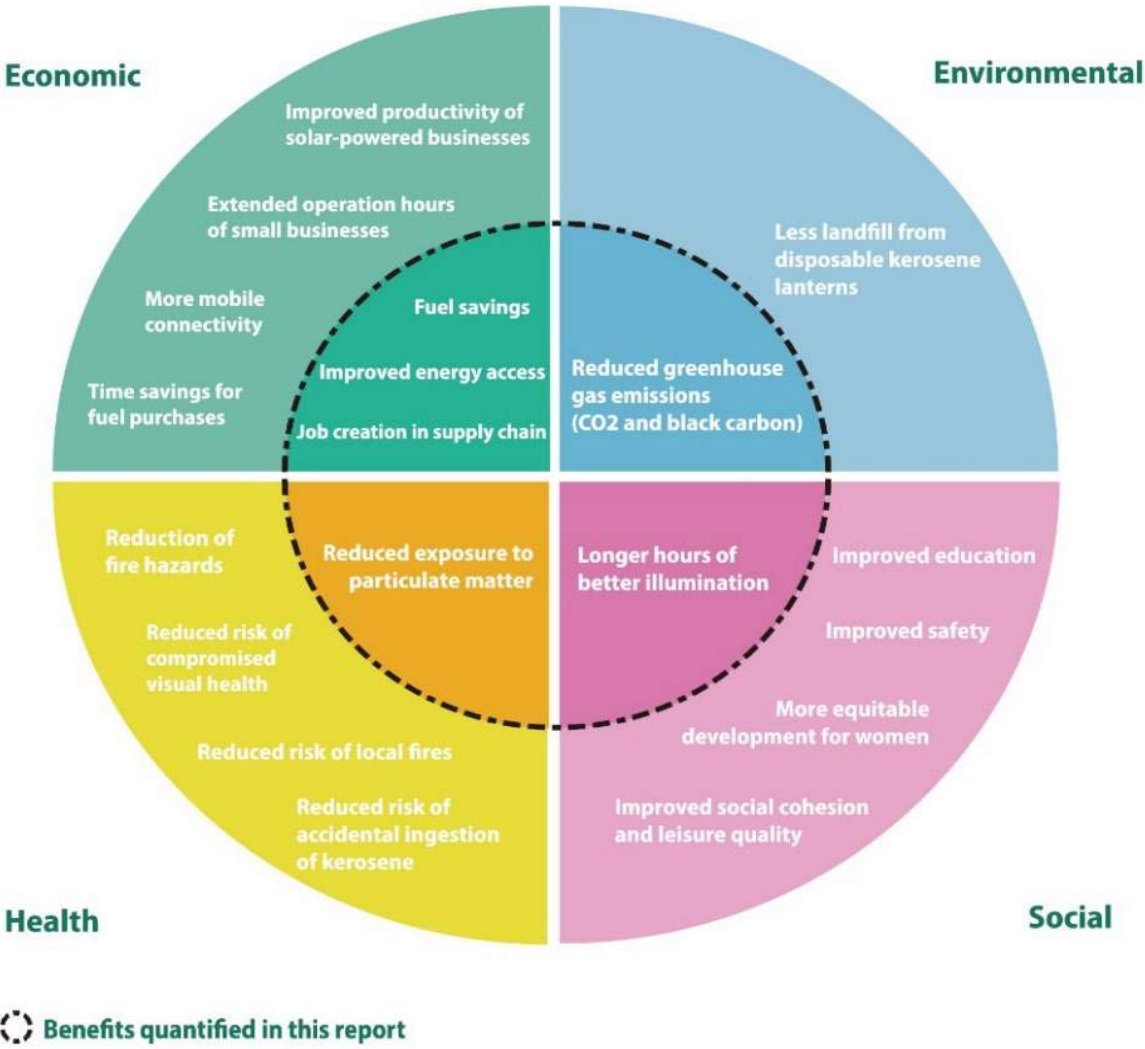


Source: Adapted from *Lighting Global 2016*

Figure 14 provides an overview of the multiple benefits associated with households gaining access to electricity when generated from renewable fuels.

¹² For the full definition, see World Energy Outlook Methodology for Energy Access Analysis (OECD/IEA 2017b).

Figure 14. Direct and indirect impacts of tier 1 electricity access from renewables



Source: Adapted from Lighting Global 2016

4.2 Fuel savings and reduced household expenditures on energy

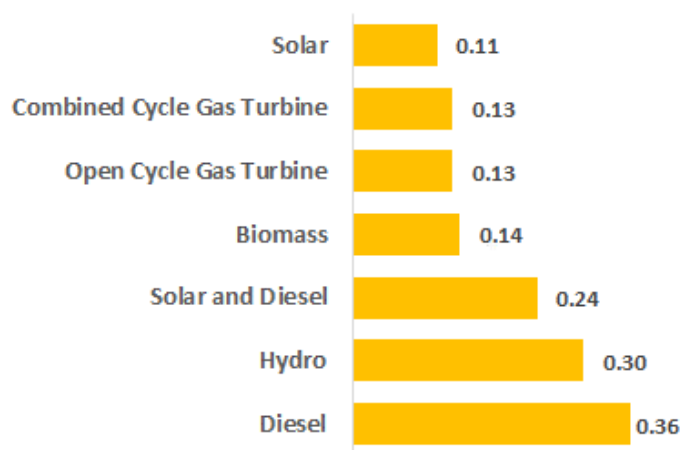
Second, using electricity from renewable sources can result in fuel savings and reduced household expenditures on energy.¹³

On a global level, biomass, hydropower, geothermal, and onshore wind can all provide electricity that is competitively priced compared to fossil fuel-fired electricity generation. Electricity from solar PV is also increasingly competitive with conventional power generation technologies at utility scale. Most of these technologies are expected to experience further substantial cost reductions in the coming decade (IRENA 2016a).

Cost estimates for Papua New Guinea suggest that when operating at capacity, large-scale hydro plants of 100 MW and above are the cheapest source of electricity available. Biomass and gas-fired power plants are comparatively cheaper to hydropower when smaller increments of capacity in the range of 15–50 MW are needed. There is little available information to estimate costs for utility-scale solar power (ANZ 2015; in-country interviews).

Given the country's low electrification rate, as well as the prohibitively high financial costs of extending the grid to remote areas, off-grid renewable energy solutions appear particularly relevant in Papua New Guinea. Estimates for mini-grids suggest that renewables compare favorably with diesel, which is currently widely used to supply local grids. While diesel-fired generation is comparatively cheap to build and install, when considering the entire life cycle, the cost of fuel makes it the most expensive option. Although many renewables-based technologies have large upfront investments, operating and maintenance costs are comparatively low, leading to lower

Figure 15. Levelized cost of electricity by generation type for 15 MW capacity (in USD per kWh)



Source: ANZ 2015

Note: Solar and diesel represents 50% of electricity generated from solar and 50% from diesel.

¹³ When assessing the financial impact of renewable energy on household expenditures, it is necessary to distinguish between (1) electricity generated from renewables at utility-scale that is fed into the national grid or a local mini-grid, and (2) off-grid technologies, such as solar lanterns and household systems.

Utility-scale electricity generation from renewables requires a cost comparison based on the levelized cost of electricity and an assessment of their impact on electricity tariffs. Levelized cost of electricity (LCOE) is a metric that allows electricity generation costs to be compared across generation technologies that have different cost or generation profiles. LCOE represents the cost per unit of electricity generated (in discounted real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating LCOE include capital costs, financing costs, fuel costs, fixed and variable operations and maintenance costs, and an assumed utilization rate for each plant type (EIA 2018). Solar household systems need to be compared with relevant fossil fuel-based stop-gap technologies, such as kerosene lighting and small diesel generators.

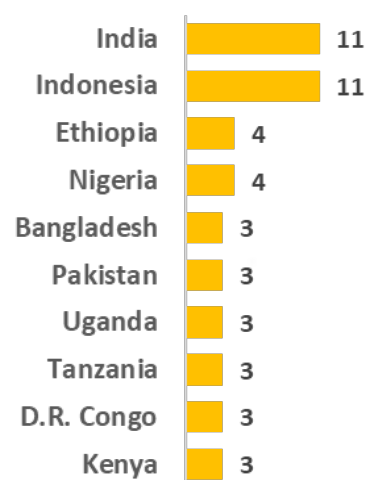
overall costs. Independent of whether biomass or solar is considered, potential savings exceed 30% compared to diesel-powered generation. Hydro presents a mixed picture, being generally competitive with diesel above 10 MW (ANZ 2015; in-country interviews). For example, ANZ (2015) estimates that for a provincial center, like Wewak, current diesel generation is 20% more expensive than an alternative supply from micro-hydro and 150% more expensive than biomass (figure 15).¹⁴

In addition to the lack of relevant data, a critical obstacle to assess household savings from the adoption of renewable energy in Papua New Guinea is the fixed national electricity tariff, which does not reflect actual generation, transmission, and distribution costs (IRENA 2013; in-country interviews). The current tariff distorts market prices and makes renewables less competitive. A fixed electricity tariff below the level of cost recovery prevents consumer savings as a result of increasing the share of renewables in the electricity mix. Given the lack of data for PNG, it is difficult to estimate the impact of current tariffs on potential household savings from switching to electricity generated from renewable sources. However, reducing the gap between utility-scale generation, transmission, and distribution costs and the consumer tariff would allow for a financially healthier utility that is more likely to make the necessary investments for upgrading the current electricity grid, improving the quality of supply, and expanding its service.

Regarding household systems, while no detailed figures are available for Papua New Guinea, Lighting Global (2016) estimates that every year the approximately 1.2 billion people worldwide living without access to electricity spend about USD 27 billion on lighting and mobile phone charging with kerosene, candles, battery torches, and other fossil fuel-powered stopgap technologies. This figure is even higher when adding the number of people with unreliable access to the electricity grid who resort to the above-mentioned alternatives temporarily. Estimates suggest that, worldwide, households could save about USD 5.2 billion if they switched from kerosene and other fossil fuels to affiliated off-grid solar devices. When considering non-affiliate products and component-based systems, total savings could amount to more than double that figure (Lighting Global 2018).¹⁵

Household expenditures vary across countries and regions, but examples ranging from Nigeria to India and from Ethiopia to Indonesia show that significant potential for cost savings exists when replacing current lighting and phone charging stopgap technologies with renewables-powered alternatives. Based on UNEP data on local usage patterns and regional costs differentials, Lighting Global (2016) estimates that

Figure 16. Payback period for a USD 13 solar light (in months)



Source: Bloomberg New Energy Finance, UNEP, Lighting Africa, Adkins Opielstrup and Modi 2012, Mills 2003
 Note: Assumes kerosene is the reference technology. Kerosene use estimated at 3.85 hours per day, a fuel use rate of 0.03 liters/hour, and latest available retail kerosene prices.

¹⁴ ANZ (2015) does not provide a detailed list of sources and assumptions on which cost estimates are based. In particular, there is no information on how construction, maintenance, and operational costs were estimated and whether or not land acquisition and transportation costs have been considered.

¹⁵ Affiliates are companies that are Lighting Global Program Associates, companies with products that meet Lighting Global Quality Standards, or companies that are members of the Global Off-Grid Lighting Association (GOGLA). These companies report sales data to GOGLA on a quarterly basis (Lighting Global 2018).

expenditures on lighting with fossil fuels range between USD 72 per year in Ethiopia and USD 186 per year in Mauritania, with most countries falling within a range of USD 100–140 per year. These differences in costs are reflected in different payback periods for solar lighting products. However, assuming a conservative price estimate of USD 13 for a portable solar light and a lifetime of only two years, even in a low fossil fuel price environment, with maximum payback periods of one year, customers can enjoy lighting at no cost for a least one year after purchasing a basic solar lantern before a replacement is needed (Lighting Global 2016; figure 16).¹⁶

Potential household savings are likely to increase in the future. Off-grid renewables have experienced cost reductions at similar levels as grid-connected renewables. This trend is projected to continue over the coming years—albeit at a slower pace—as the result of ongoing technological improvements, efficiency gains, and decreasing prices for components and appliances (Lighting Global 2018). Hardware—including PV modules, batteries, light-emitting diodes (LED), etc.—have all seen prices drop over the past years (Lighting Global 2016).¹⁷ In addition, the trend of reducing hardware prices is supported by a growing number of companies operating in the off-grid renewables sector, resulting in increased competition and lower end-user prices. For example, recognized off-grid solar companies comprised more than 300 players in 2017, compared to only 60 in 2010 (Lighting Global 2018).

4.3 Reduction of GHG emissions

Electricity generation from renewable sources reduces greenhouse gas emissions by displacing the combustion of fossil fuels with cleaner alternatives. OECD/IEA and IRENA (2017) estimate that almost 60% of the global GHG emissions reduction needed to remain within the boundaries of the Paris Agreement can be met by the accelerated deployment of renewable energy (figure 17).¹⁸

Data on GHG emissions for Papua New Guinea is sparse and subject to considerable uncertainty. Estimates obtained from the country's Climate Change and Development Authority (CCDA) suggest that PNG's total emissions amounted to 26.2 Mt of CO₂ equivalent (CO₂eq) in 2015 (in-country interviews). This is equivalent to per capita emissions of around 2.6 to 3.3 tons per capita per year.¹⁹ These numbers

¹⁶ On average, in African countries, consumers ultimately save USD 3.15 for every dollar spent on solar lighting. As a result, money that would have otherwise been spent on fossil fuel-based lighting is available for other purchases in the local economy, such as more electricity services, education, food, or other consumer goods. In Asia, the ratio is less favorable, at an estimated one dollar saved for every dollar spent, due to considerable subsidies for kerosene, reducing the scope for savings from solar lanterns. However, when considering avoided government spending on subsidies that can be redirected toward other purposes, total savings would be similar to those in Africa (Lighting Global 2016).

¹⁷ It should be noted that standard PV modules of 200–300 W are not the same used in off-grid lighting, as their capacity is too large for many of the technically and economically feasible applications. Panels for solar home systems in developing countries usually have a capacity of 5–100 W. Costs of these smaller modules have reduced less than for modules using standard panels. This is because the production process is the same with only marginal differences in the time required. Furthermore, every module requires its own junction box and cable, independent of its size. However, part of the general cost reductions for solar panels comes at the level of the constituent cells (4–5 W). Those reductions are reflected in smaller-sized panels, as manufacturers of big modules also provide an increasing supply of cheaper cells or even part-cells for very small applications (Lighting Global 2016).

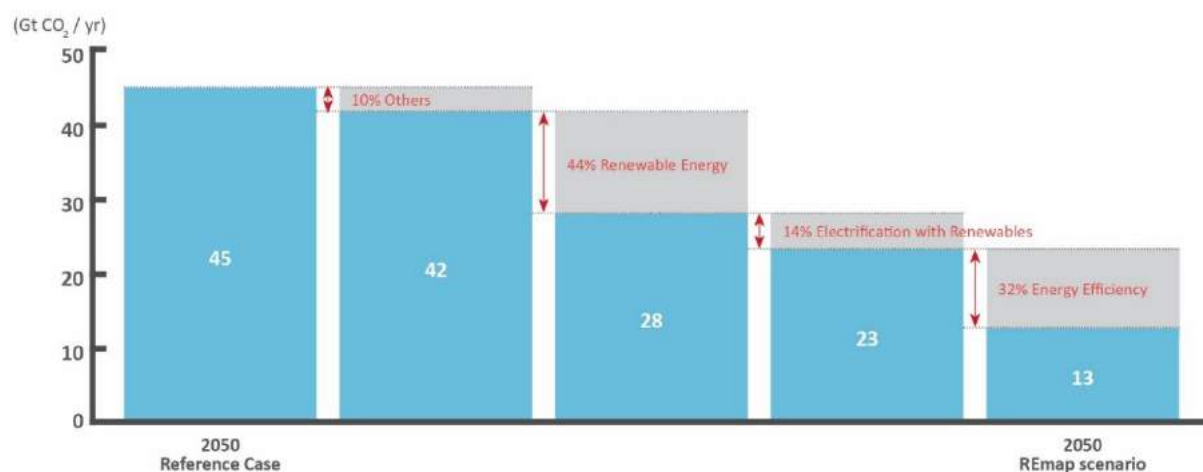
¹⁸ Energy efficiency measure would contribute approximately another third (OECD/IEA and IRENA 2017).

¹⁹ The range is based on an estimated population of 8,000,000 to 10,000,000 people.

are considerably higher than earlier official estimates, placing the country's total emissions between 5 Mt (GoPNG. 2014) and 10 Mt of CO₂eq in 2014 (GoPNG 2016).

CCDA estimates that emissions from the energy sector amounted to approximately 11.8 Mt of CO₂eq in 2015, equivalent to 1.2 to 1.5 tons per capita per year.²⁰ This is about twice the amount estimated by the World Bank (2018b) for 2014, of 0.8 tons per capita. Emission levels are comparable to the lower-middle income countries' average (1.5 tons per capita per year) and potential peers, such as Indonesia (1.8 tons per capita), but considerably higher than in the Lao PDR (0.3 tons per capita) (World Bank 2018b).²¹

Figure 17. Potential of reductions in CO₂ emissions under current plans and policies compared to ab accelerated uptake of renewables



Source: OECD/IEA and IRENA 2017

Note: CO₂ emissions include energy-related emissions (fossil fuels, waste, gas flaring) and process emissions from industry. The Reference Case is based on current and planned policies and expected market developments. It reflects NDCs when they are already an integral part of a country's energy plan. This condition covers about 60% of the total global primary energy supply. The REmap scenario is a low-carbon technology pathway that goes beyond the Reference Case for an energy transition in line with the aims of the Paris Agreement.

The relevance of the energy sector in emitting greenhouse gases and the potential role renewable energy can play to reduce emissions is also visible in Papua New Guinea's electricity mix, which is dominated by fossil fuels. While fossil fuels (i.e., the sum of diesel, fuel oil, and natural gas) accounted for less than 40% of installed electricity generation capacity in 2016, generated electricity came to more than 60% from fossil fuel sources (figure 18).²²

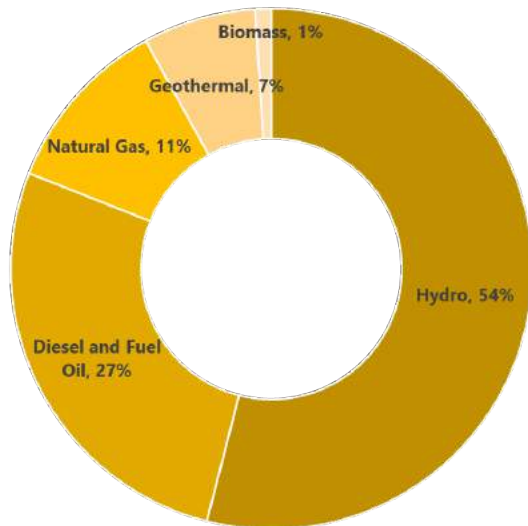
²⁰ It should be noted that CCDA data includes GHG emissions from electricity and heat production, transportation, and buildings under the energy sector (in-country interviews).

²¹ It should be noted that World Bank data for CO₂ emissions includes gases from the burning of fossil fuels and cement manufacture.

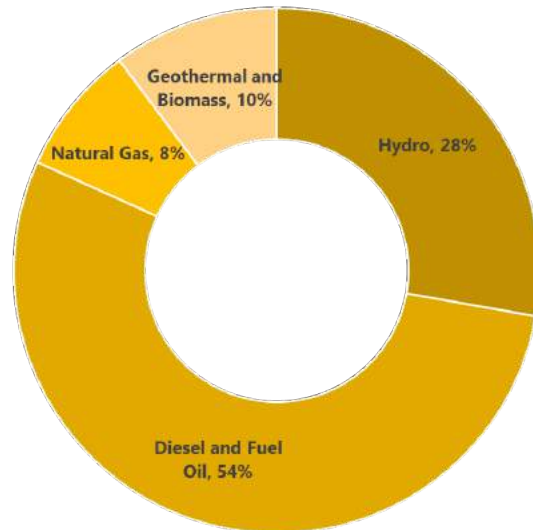
²² It should be noted that these figures contain considerable uncertainty, given the lack of data and inconsistency in available data. First, while generation capacity and sources of electricity generation should be compared for the same year, the small amount of generation capacity that has been added

Figure 18. Electricity generation capacity and electricity mix

Electricity Generation Capacity, 797MW (2016)



Electricity Mix, 3.6TWh (2013)



Source: Electricity mix data from APERC (2016). Electricity generation capacity data from DPE and DP&E (2017)

It is estimated that emissions from the energy sector represented nearly half of the country's total emissions.²³ These figures confirm the assessment of the INDCs (GoPNG 2016) that one of the principal opportunities for PNG to reduce its GHG emissions exists in the country's electricity sector. Expected demand growth as a result of economic growth (ADB 2015a; GoPNG 2016; Lowy Institute 2017) and in light of plans to considerably expand electricity access (DNPM 2010) further highlight the sector's potential to contribute to lower emissions.

Looking specifically at lighting, Lam et al. (2012) and Lighting Global (2014) estimate that, worldwide, burning kerosene for lighting produces emissions equivalent to 240 million tons of CO₂, or 0.5% of global emissions.²⁴ The comparatively high contribution of kerosene lamps to the global greenhouse effect means that replacing them with renewable alternatives, such as solar lanterns, offers a cost-effective opportunity to reduce GHG emissions (Lighting Global 2016). Lighting Global (2018) estimates that a cumulative 28.6 million tons of greenhouse gas emissions have been avoided through replacing traditional lighting sources with solar devices affiliated with the Lighting Global Program.²⁵ Given the

in PNG between 2013 and 2016 reduces the time gap as a source of error (compare ADB (2015) and DPE and DP&E (2017)). Second, considerably more severe is the internal inconsistency between numbers published for both capacity and generation mix within the same documents. Examples include APERC (2016) and DPE and DP&E (2017), among others.

²³ This estimate is based on CCDA data obtained during in-country interviews. This share is in line with earlier estimates based on PNG's Second National Communication, which estimated GHG emissions for the energy sector at 2.4 Mt and total emissions of 5 MT of CO₂ equivalent in 2000 (GoPNG 2014).

²⁴ The reason behind this comparatively large contribution are emissions of black carbon as a result of the incomplete combustion of kerosene. Black carbon particles absorb light and heat thousands of times more effectively than CO₂. Therefore, they contribute disproportionately to the global greenhouse effect, despite settling to the ground within a period of days (Lighting Global 2016).

²⁵ Congruent with this figure, Lighting Global (2016) estimates 1.4 million tons of CO₂-equivalent being avoided in 2014 alone.

large market share of non-affiliate products, avoided emissions from kerosene lighting due to the deployment of off-grid solar devices may be up to three times higher.²⁶ However, there are limited incentives for governments to support the replacement of kerosene lighting as the current UNFCCC framework does not include black carbon in its GHG accounting methodology (IPCC 2006).

The potential to reduce GHG emissions by replacing traditional fuels for lighting with solar-powered alternatives appears particularly high in Papua New Guinea, where more than half of the households use inefficient kerosene lamps as their main source of light and a quarter relies on open fires. In addition, with approximately 90% of the country's population using fuelwood for cooking, potential reductions in emissions are even higher when replacing traditional biomass with improved cookstoves and clean cooking fuels (IRENA 2013; Jeuland and Tan 2016). Access to clean cooking technologies reduces deforestation and associated soil erosion as well as emissions of greenhouse gases and black carbon. Improved cookstoves either use biomass more efficiently or replace it entirely with other fuels, such as LPG and biogas (USAID and WINROCK 2017).²⁷

Other examples for reduced GHG emissions due to the deployment of renewable energy can be drawn from a diverse list of pilot projects in Papua New Guinea, including a 30-MW biomass power plant in the Markham Valley in Morobe Province.²⁸ The proposed plant has very low net CO₂ emissions. Estimated savings amount to 100,000 tons of CO₂ emissions per year, compared to thermal electricity generation from coal, diesel, or fuel oil. Total emissions reduction over the plant's entire operating lifetime are estimated at more than 5 million tons of CO₂ emissions (PNG Biomass 2017).

There is prominent political recognition of the potential to reduce GHG emissions within the country's energy sector. PNG's Vision 2050 sets the goal of the country's entire electricity generation to be based on renewable fuels by 2050 (GoPNG 2009a). The Intended Nationally Determined Contributions (GoPNG 2016) acknowledge the need to reduce emissions from the combustion of fossil fuels in the electricity sector and deploy renewables. The document repeats the goal of generating 100% of PNG's electricity supply from renewable sources but makes it "contingent on funding being made available."

4.4 Mitigation of health risks

The deployment of renewable energy, replacing traditional fuels for lighting, might have significant health benefits, to the extent that it reduces indoor air pollution, which causes the death of an estimated 2.6 to 4.4 million people worldwide every year (IRENA 2017b; Lighting Global 2016). This is particularly relevant in Papua New Guinea, where lung and respiratory diseases figure among the most prominent causes of death, with chronic obstructive pulmonary disease (COPD) being ranked third, lower respiratory infections fourth, and asthma ranked sixth (IHME 2018a). The Institute for Health Metrics (2018a) sees air pollution as the most important environmental and occupational risk driving death and disability in the country, being ranked among the top five risk factors for the past ten years. Estimates suggest that air pollution is associated with more than 10,000 premature deaths and more than 400,000

²⁶ Lighting Global (2018) estimates a market share for non-affiliate sales of approximately 70% globally, based on a weighted average of 16 countries for which estimates were developed.

²⁷ Improved cookstoves do not count as renewables, except when powered from renewable energy sources. However, independent of the fuel that is used, improved cookstoves are highly relevant when discussing emissions-saving technologies.

²⁸ The project's designation is "PNG Biomass Markham Valley Project". Oil Search Limited (OSL), through its wholly-owned subsidiary Markham Valley Biomass Limited (MVB), is the sole developer of the project (PNG Biomass 2017).

disability-adjusted life years (DALYs) in Papua New Guinea (IHME 2018b). The high number of premature deaths due to indoor air pollution mostly affect women and children in rural areas where health care facilities and services are almost nonexistent.

However, the evidence of health benefits from solar lighting is mixed. It appears intuitive that renewable energy benefits health conditions in households where it replaces kerosene and avoids the negative effects associated with it. However, quantifying these health benefits is inherently difficult as the effects from burning kerosene are either long term and can have other causes (e.g., respiratory illnesses) or they are rarely documented (e.g., accidents). While existing case studies suggest that the impact of renewable energy replacing kerosene as a fuel for lighting is limited (unless households also use an improved cookstove), solar lantern users report improved well-being (Lighting Global 2016).²⁹

Lighting Global (2016) assumes that health improvements from lighting with renewable energy are largely limited to children who spend considerable time studying in the direct vicinity of a kerosene lamp. Moreover, exposure to indoor air pollutants from burning kerosene is estimated to be outweighed by the toxic materials released from burning fuelwood. Confirming this analysis to some extent, Lim et al. (2013) found that cooking with biomass had a higher contribution to health issues related to poor indoor air quality than lighting with kerosene.

Therefore, health benefits seem most evident when fuel switches in household lighting are complemented with the introduction of improved cookstoves (IRENA 2017b; UNEP 2017). Studies undertaken in Uganda and Mozambique suggest that clean cooking technologies can provide considerable improvements in public health (URBANET 2017; UNEP 2017). While figures for Papua New Guinea are scarce, high levels of fuelwood use for cooking suggest a comparable potential for improved cookstoves in the country, with disproportionate benefits for the health of women and girls (Clougherty 2009; Khushk, Fatmi, and Kadir 2005; UNEP 2011; McCracken et al. 2007).

4.5 Job creation

While numerous recent reports look at the potential of the renewables sector to create employment,³⁰ there are no estimates or scenarios for Papua New Guinea as a whole. Therefore, evidence is largely drawn from research that fits the country's context as well as a very limited number of individual projects providing estimates on job creation.

Existing estimates—though largely based on data from developed countries—show substantial potential for job creation from the adoption of renewable energy (UNEP 2017). OECD/IEA and IRENA (2017) estimate that net employment in the global energy sector will increase by 6 million workers in 2050, compared to the reference case (IRENA 2017d; IRENA 2017e; OECD/IEA and IRENA 2017). A considerable share of these jobs would be created in the manufacturing of wind turbines, solar panels, and other equipment, which would likely not benefit employment in Papua New Guinea. However, the

²⁹ For example, studying 300 households in Rwanda, Grimm et al. (2014) found that 45% of households that replaced kerosene with solar lighting reported perceiving indoor air quality as having improved. However, the study did not find a quantifiable improvement in health indicators over a six-month period. A different study covering 852 households in Bangladesh found that solar lighting had no impact on respiratory health but led to significant improvements in eye irritation (Kudo, Shonchoy, and Takahishi 2015).

³⁰ Examples include Lighting Global (2018), IRENA (2017b), OECD/IEA and IRENA (2017), UNEP (2017), Lighting Global (2016).

majority of employment created by the deployment of renewable energy infrastructure involves construction and maintenance, which would likely benefit the local labor market. In particular, activities around constructing and setting up the required infrastructure locally do not entail highly trained labor skills and, therefore, are estimated to largely benefit local employment (IRENA 2017b; IRENA 2017c). For example, IRENA (2017c) found that, on average, the installation, operation, and maintenance for a 50-MW solar photovoltaic project account for more than half of the required person days.³¹

Based on survey data covering the Economic Community of West African States (ECOWAS), UNEP (2014) estimates that moving from kerosene lighting to alternative technologies and associated value chains could create as many as 30 jobs per 10,000 people living in off-grid areas. Applying this estimate to Papua New Guinea's off-grid population of an estimated 7 to 9 million people translates into a potential of creating about 20,000 to 27,000 additional jobs alone by replacing kerosene with solar lighting.³²

The planned biomass power plant in Morobe Province mentioned above is an example for job creation through the deployment of renewable energy in PNG. The project, including up to 16,000 hectares of associated plantations of eucalypt to provide biomass as the fuel source for the plant, would create additional local employment, support the local service industry, offer opportunities for business development, and provide sustainable financial income streams for landowners. An independent economic assessment estimates that the project will create over 500 direct jobs and support an undisclosed number of indirect jobs in a region that has traditionally faced significant unemployment for youth and women. Furthermore, the project aims to support the education of young people, introducing them to skilled labor jobs in agriculture, forestry, engineering, and business (PNG Biomass 2017).

Beyond the direct benefits of employment from building, setting up, and maintaining renewable energy infrastructure, access to electricity from renewable sources can support income-generating activities. For example, estimates suggest that approximately 10% of all deployed pico-PV systems are used for small business operations, such as lighting to extend opening hours or offering mobile phone charging to customers (Lighting Global 2016). That means that as many as 800,000 worldwide might be using off-grid solar devices to support their business activities.³³ A BBOXX-sponsored study conducted in 2012 estimated that,³⁴ in Uganda, deploying the company's solar home system for lighting added an average of USD 45 per month in revenue to small businesses, as a result of longer operating hours and additional time for preparing and selling goods. More than two thirds of small business owners

³¹ The construction, installation, and manufacturing each represent approximately another fifth of person days (IRENA 2017c).

³² Papua New Guinea's off-grid population is estimated based on a total population of 8 million to 10 million people (World Bank 2018c; in-country interviews) and an electrification rate of 8-15% (DNPM 2014; IRENA 2013; in-country interviews).

³³ This estimate is based on Lighting Global (2016) citing that 10% of affiliate products were being used for income-generating activities. With an estimated total of 2.4 million affiliated and 5.9 million non-affiliated devices being sold between 2014 and 2017 (Lighting Global 2018) and assuming devices are replaced every five years, the 10% usage rate was applied to both categories. It should be noted that this number contains considerable uncertainty due to the limited information on deployment and use of non-affiliate products.

³⁴ BBOXX is a UK-based company that designs, manufactures, distributes, and finances solar home systems.

interviewed as part of the study reported increased revenue, either from offering phone charging services or higher sales of products (Enea Consulting 2012).³⁵

4.6 Recommendations

Papua New Guinea possesses a high potential for renewable energy, including hydropower, solar, wind, biomass, and geothermal sources (GoPNG 2014; IRENA 2013; Lowy Institute 2017). However, numerous challenges have prevented this potential from being realized.

The spectrum of challenges ranges from technical and financial obstacles to fiscal and legislative impediments to the country's macro-economic situation and law enforcement, including:

- The financial costs of grid extension, accentuated by the country's rugged terrain and dispersed population (APERC 2017; IRENA 2013; Lowy Institute 2017; Samanta and Aiau 2015; Lighting Global 2016);
- The dismal state of the existing electricity grid (ADB 2015; APERC 2017; GoPNG 2016; Kuna and Zehner 2015; Lowy Institute 2017);
- Low disposable incomes (IFC 2017);
- Lack of skilled labor in the energy sector (APERC 2017);
- Lack of an enabling policy environment, including a national electricity tariff that does not cover generation and distribution costs, and a lack of incentives for renewable energy technologies, such as tax rebates for investment in renewable energies (IFC 2017; IRENA 2013; in-country interviews);
- Lack of macroeconomic policy certainty with an adverse impact on employment and investment (IMF 2017);
- A complex system of customary land tenure (APERC 2017; CIFOR 2011; IOM 2014; IRENA 2013; Samanta and Aiau 2015);
- Legislative and regulatory uncertainty (IRENA 2013);
- Institutions suffering from lack of interagency coordination and limited capacity and resources for planning and analysis, project development, and implementation (Adam Smith International 2018; IRENA 2013);
- Lack of a mature private sector and financial services for renewable energy (Lighting Global 2018; IRENA 2013);
- Lack of reliable data and surveys (Adam Smith International 2018; GoPNG 2016; IRENA 2013; UNDP 2017); and
- Vandalism and theft of renewable energy installations (IRENA 2013).

The following recommendations are meant to address these obstacles and provide suggestions to the Government of PNG on how to facilitate deployment of renewable energy. Given the extensive list of challenges, these recommendations are not exhaustive but provide advice on how to reduce several of the most severe hindrances.

³⁵ In contrast, a study of 483 households in Uganda using a d.Light solar home system found no statistically significant impact on the amount of time spent on income-generating activities (D.Light et al. 2015).

Strengthen the administration's capacity to collect, compile, verify, and disseminate data relevant for the energy sector.

There is a paucity of data regarding Papua New Guinea's energy sector. Basic information—such as Total Primary Energy Supply (TPES), Total Final Consumption (TFC) by sector, electricity generation capacity, and the electricity mix by fuel—are subject to substantial uncertainty. This uncertainty in basic data propagates through most analyses of the energy sector and puts the results of many assessments on weak foundations. The lack of timely and reliable data undermines any evaluation of specific policies, interventions, and projects and makes investments less attractive.

During in-country interviews, different departments admitted that collection of energy data is a challenge. There is no regulation for mandatory reporting in place. Data collected by authorities is not compiled, managed, and disseminated in a standardized way, leading to information being lost. Furthermore, particularly regarding demand data, interviews suggested that industry actors have reservations about sharing data.

It is recommended that the Department of Petroleum and Energy (DP&E) or the National Statistics Office be given a clear mandate and the resources to collect relevant data.³⁶ This includes provisions on data collection and ensuring consistent definitions as well as agreement on which data is collected, when it is collected, and by whom. For the electricity sector, this will likely require mandatory reporting of relevant data from PPL, independent power producers, and industrial auto-producers. For the oil and gas sector, data reporting should be made mandatory for producers, importers, exporters, and retailers, in addition to or coordinated with customs and tax data. Finally, the relevant government agency needs to set up a system to compile, review, and disseminate the data.

Currently, the Department of Energy and Petroleum lacks the capacity and resources to collect relevant data. In-country interviews suggested that the government is increasingly recognizing that data collection is necessary in order to make informed policy decisions. It acknowledges the need for increasing technical capacities and recruiting skilled staff to improve data gathering. To some extent, it also appears to recognize the need for assistance in this area (GoPNG 2016; in-country interviews). Therefore, the GoPNG should actively seek support from statistics agencies of other countries, the UN Statics Division, or the International Energy Agency. Both IEA and UNSD have published manuals that support national governments in collecting energy data (IEA 2005; UN 2016) while statistics offices from third countries would be able to share practices on collecting, compiling, and disseminating data.

The following examples illustrate the extent to which data is missing for the energy sector and the implications this has for analysis and the development of policies and projects. First, there is insufficient data to build an energy balance for PNG, reflecting Total Primary Energy Supply (TPES) by fuel and Total Final Consumption (TFC) by sector and accounting for electricity transformation. Existing TPES figures are generally inconsistent and often do not account for the use of biomass. With more than 85% of PNG's population living in rural areas without access to electricity, the use of fuelwood for cooking, lighting, and heating likely accounts for a large share of energy supply but is completely absent from most estimates.³⁷ IRENA (2013) estimates that traditional biomass accounted for over half of the country's energy consumption in 2010. The few other existing estimates date as far back as the early 1990s (compare Duncan 2011).

³⁶ Responsibility for data collection could also be given to the National Energy Authority, envisioned in the National Energy Policy, if and when it is established.

³⁷ In addition, certain electricity and process heat is produced from biomass wastes within the palm oil industry, at sugar mills, and in the wood processing industry (IRENA 2013).

Beyond neglecting a considerable source of energy supply and demand, TPES and TFC estimates vary widely (compare APERC 2016; DPE and DP&E 2017; IRENA 2013; GoPNG 2016). Furthermore, the National Energy Policy 2017–2027 cites two different breakdowns for TPES. While the document is relatively consistent regarding biomass, indicated with 37% and 39%, respectively, other figures completely lack consistency. The document states that oil and gas account for 51% of supply in 2015 but also refers to oil alone accounting for 57% in 2011. Similarly, hydropower (7%) and geothermal (3%) are indicated to represent 10% of supply in 2015 while hydropower, natural gas, and geothermal are also cited as amounting to 6% of supply in 2011 (DPE and DP&E 2017). These inconsistencies cannot be explained alone by the four-year time gap between the different datasets.

A lack of or inconsistency in such essential data prevents any reliable analysis of supply and demand, as well as the assessment of trends and calculation of GHG emissions, and undermines the development of appropriate interventions. It renders technical analysis, such as APERC (2016) demand projections, largely pointless.

Second, data on electricity generation capacity and electricity mix is either incomplete or inconsistent and generally lacks reference years. ADB (2015) and Kuna and Zehner (2015) cite about 580 MW of generation capacity for 2010 while APERC (2016) refers to 792 MW in 2013. While there is some uncertainty around additional generation capacity being commissioned during the period 2010–2013, there is no evidence that new power plants increased the country's capacity by more than a third within those three years. The most striking example is, again, the National Energy Policy, which refers to both 580 MW and 797 MW (DPE and DP&E 2017).

The lack of reliable capacity data is compounded by the absence of consumption data. No transmission, distribution, or consumer metering data is available. Prepay meters are widely used but not checked, with prepaid receipts acting as the metric.³⁸ Electricity losses are subject to considerable uncertainty, and it is unclear to what extent these losses are caused by technical reasons or are the results of theft and tampering with meters. Load estimations are unreliable due to the use of generation meters with low accuracy and frequent load shedding (Adam Smith International 2018).

Finally, a lack of reliable data also undermines the analysis of Papua New Guinea's potential for exploitation of renewable energy sources. There are few recent studies, some of which are of questionable quality. Systematic assessments are scarce and often outdated. According to IRENA (2013), the renewable energy potential was assessed by the University of Papua New Guinea (UPNG), the University of Technology (Unitech), and the energy and forestry departments between the early 1980s and mid-1990s, with limited research since then.

For example, data on hydropower potential is very limited and potential sites need to be validated. Estimates on capacity potentials range from 4,200 MW (IRENA 2013) to as high as 15,000 MW (APERC 2017).³⁹ IRENA (2013) cites potential output from hydropower at approximately 37 TWh per year while GoPNG (2016) indicates nearly five times the amount with 175 TWh.⁴⁰

³⁸ PNG Power's (PPL) initiative of setting up advanced metering infrastructure (AMI) of 9,000 metering units during the course of 2019 can help to address the lack of end-user data. While, initially, the advanced metering infrastructure focuses on commercial customers, it is envisioned to expand toward residential customers.

³⁹ While IRENA (2013) explicitly indicates that its figures do not include the potential for micro- and mini-hydro, no such qualification is made in APERC 2017.

⁴⁰ The 175 TWh assumedly refers to a period of one year, though no reference period is given in the document.

Similarly, while there are 55 known areas of surface geothermal activity in Papua New Guinea, detailed information on most prospects is sparse, with reconnaissance chemical surveys mostly dating back to the 1960s and 1970s and geophysical surveys only known to have been undertaken at the site of the Lihir mine (McCoy-West et al. 2011). Hairai (2004) estimated a potential generation capacity of 3,000 to 4,000 MW from geothermal power. Without further reconnaissance surveys, determining the existing potential for exploitation and economic viability at specific sites is not possible.

Data on whether and where wind conditions are suitable for electricity generation is limited. Currently, a World Bank-funded wind resource mapping study is being conducted. Final results are pending, but interim results indicate a number of areas that might be suitable for the installation of wind turbines based on their comparatively high wind speeds (World Bank 2015a; see *Box 2. Wind Power in Papua New Guinea* in this report).

Designate areas for off-grid electrification, given the high costs of extending the grid to remote areas.

Off-grid electrification based on renewable sources offers a viable alternative to provide basic electricity services in areas where grid extension is expensive or physically difficult (APERC 2017; Lighting Global 2018; IRENA 2017b; IRENA 2017e; OECD/IEA 2014; Samanta and Aiau 2015).

It is recommended to prioritize the deployment of renewable energy in off-grid areas rather than focus on grid-connected projects. In the context of Papua New Guinea, many of the potential benefits associated with renewables appear more likely to occur in areas without access to the grid and at a considerably lower cost. The reasons behind this assessment are the severe challenges that grid extension faces, such as the state of the current grid, the country's rugged terrain, the lack of legislative and regulatory certainty, cost overruns, and slow government systems, evidenced by a long history of planned utility-scale projects not materializing.

Move beyond an assumption 'the grid is the answer'. As off-grid solutions improve in cost and reliability, the area for which grid extensions make sense is shrinking. For PNG, this area now ends much closer to the current electricity network than often thought. Outside urban areas, it is likely that most people currently off the grid should remain off the grid.

(ANZ 2015)

There is no single national electricity grid in Papua New Guinea. Instead, there are three separate main networks and a number of smaller local grids. The main networks consist of (1) the Port Moresby Grid, which is the largest by peak demand and capacity but geographically compact; (2) the Ramu Grid, with the second largest capacity but the geographically most extended network; and (3) the Gazelle Grid, the third largest network supplying parts of East New Britain Province. All three grids rely on a combination of hydro and thermal (mostly diesel and fuel oil-based) electricity generation (Adam Smith International 2018; APERC 2017; Kuna and Zehner 2015; Lowy Institute 2017; in-country interviews).

In addition, there are several local systems, although figures about their exact numbers vary.⁴¹ They include 14 isolated grids operated by PNG Power (PPL), as well as large auto-producers, such as mines

⁴¹ The Lowy Institute (2017) reports that 150–200 so-called "C" centers were established in the 1980s but that very few of them remain operational. Adam Smith International (2018) mentions "30 Isolated Large Generators and mini-grid[s] (or 'C' Centres)" while APERC (2017) mentions "14 independent

and agricultural processing plants, who in some cases provide electricity to local populations (Adam Smith International 2018; Kuna and Zehner 2015; Lowy Institute 2017; in-country interviews).

The main networks were predominantly built in the late 1960s and early 1970s, prior to PNG's independence in 1975. While there has been limited geographical expansion of the three grids, electricity loads have grown since, with future demand growth expected to put further stress on the systems (GoPNG 2016).⁴² The existing electricity system suffers from insufficient generation capacity, aging generation equipment coupled with obsolete spare parts and lack of maintenance, transmission and distribution networks working at their capacity limits or being overloaded, and high transmission

Being connected to the network has little relevance when supply is unreliable. Most of the time it is off.

(In-country interview)

and distribution losses, among others (ADB 2015a; Kuna and Zehner 2015; Lowy Institute 2017). System losses are estimated to amount to 20% to nearly 30%.⁴³ Furthermore, local distribution networks are very limited. Living within the vicinity of the network does not translate into having access to electricity. Similarly, a household having a grid connection does not

translate into receiving reliable services. Outside larger population centers, outages can last for weeks (in-country interviews). Major investments will be required to overhaul the existing system. Until then, it is recommended to not add considerable amounts of intermittent renewables to an already overburdened system.

There is a strong focus on extending the existing grids in Papua New Guinea, with little consideration being given to off-grid solutions (in-country interviews). However, extending an electricity network that faces as many challenges as the grids in Papua New Guinea will be very costly, raising the question of how households will be able to afford reliable supply. In addition, as evidenced in numerous countries, grid reliability is considerably more challenging in dispersed rural areas than in urban centers (Lighting Global 2018). Therefore, extending the network in Papua New Guinea is bound to increase the existing problems, without prior modernization of the current grid.

You have to cut through mountains, cross rivers and swamps to extend the grid to the majority of the population.

(In-country interview)

Due to Papua New Guinea's dispersed population and rugged terrain, extending the grid is both technically challenging and financially costly (Kaur and Segal 2017; Lowy Institute 2017). The IEA estimates that the levelized cost of grid-supplied electricity increases more than fourfold when power lines have to be extended by three kilometers to reach a community (OECD/IEA 2014). Already, electricity in PNG is comparatively expensive due to the high proportion of diesel and fuel oil-based generation (Kuna and Zehner 2015). Costly grid expansion will result in an increase in electricity prices, cause further financial struggles for PPL, be a drain on public budgets, or a combination of all three. In

There is no business case for extending the grid to many rural areas.

(In-country interview)

addition, maintenance of an extended grid will always be a challenge. Lightning, wind, rain, and rapidly growing vegetation take a constant toll on transmission lines (Fridriksson 1995).⁴⁴

provincial systems (stand-alone systems)." In-country interviews confirmed 14 mini-grids operated by PPL. No confirmation could be obtained regarding the number of auto-producers.

⁴² Demand growth for electricity is estimated to exceed 5% per year (ADB 2015a; Lowy Institute 2017).

⁴³ IRENA (2013) reports losses of 20% based on PPL data for 2012. KEMA (2012) reports system losses of 29% for 2011. In-country interviews suggested that total losses amount to more than 25%.

⁴⁴ The problem is exacerbated by landowners being reluctant to allow trees to be cut (Fridriksson 1995).

Furthermore, experience and projections for the African continent show that population growth is often outpacing extension of the grid. According to the IEA, despite grid expansion, the absolute number of people living without access to the grid will continue to rise in many countries (OECD/IEA 2014). While no such projections exist for Papua New Guinea, given the country's strong population growth, the trend is likely to be comparable.⁴⁵

There is no demarcation between areas where grid extension is feasible and areas that have to be supplied through off-grid solutions. However, in-country interviews suggested that approximately 30% of the population could be covered by extending the existing networks while 10% of the population is unlikely to ever be connected to the grid. This leaves considerable uncertainty about how the majority of the population will gain access to electricity.

A 2017 report by the Columbia University's Earth Institute and Economic Consulting Associates, prepared in the context of the development of the National Electrification Rollout Plan (NEROP), is more optimistic about the prospects of grid extension. It concludes that grid electrification is the least-cost option for approximately three quarters of the population that currently lacks electricity access. However, despite its favorable view on grid extension, the report acknowledges that at least 20% of the country's population will have to rely on off-grid solutions for electrification. It explicitly states, "Mini-grid and off-grid/solar systems are likely to play a role in PNG due to the highly distributed population, rough terrain, and other challenges to grid extension." This conclusion is based on a number of important observations (The Earth Institute and Economic Consulting Associates 2017):

1. Connection to the grid tends to be the least-cost option for households with high demand for electricity, as lower operating costs associated with grid-supplied electricity outweigh the costs of comparatively expensive but long-lived transmission and distribution lines;
2. Solar home systems often represent the least-cost option for households with low electricity demand, with their comparatively low initial costs and comparatively high operating costs (due to battery replacement, primarily); and
3. Mini-grids appear most relevant for areas with intermediate electricity demand since they involve moderate investment in generation and transmission but have comparatively high operating costs.

The report estimates the total cost of achieving 70% electrification by 2030 at approximately USD 1.8 billion. This amount includes both grid costs and the cost of off-grid solutions. The average cost for grid connection per household amounts to USD 1,475. The cost per household for mini-grid access, with the same service standard as grid-connected homes, is more than 20% cheaper at approximately USD 1,160 (The Earth Institute and Economic Consulting Associates 2017).⁴⁶

⁴⁵ In the period from 2000 to 2017, Papua New Guinea's population is estimated to have grown by an average annual rate of 2.3%, from about 5.6 million to 8.3 million (World Bank 2018c). UN (2017) projects the country's population to grow by an annual rate of nearly 2% for the next decade. IFC (2017) supports this assessment. In-country interviews suggested that population growth might be significantly higher than indicated by official statistics, with the country's total population possibly being considerably higher than 10 million people.

⁴⁶ The costs for grid extensions are based on assumed cost reductions for materials, labor, and other costs in the range of 20–40%. Under a "high cost" scenario, based on a selection of recent PPL-implemented electrification projects, total costs double, from USD 1.8 billion to USD 3.6 billion. Under that scenario, the average cost per household connected to the grid increases from about USD 1,600 to USD 3,100 (The Earth Institute and Economic Consulting Associates 2017). The anticipated cost reductions seem unlikely to materialize. In-country interviews confirmed that most projects in Papua

The report explains that grid connections would be cheapest for households that require improved connections⁴⁷ and for households located within a range of approximately 1 km of the existing grid infrastructure that are currently not connected. Taken together, these households represent less than 20% of the population. A far larger group of households, representing approximately 80% of the population, lives beyond a range of 1 km from the existing grid. According to the analysis, providing this group with access to electricity can be achieved through either extending the grid or through off-grid electrification, at comparable costs (table 5; The Earth Institute and Economic Consulting Associates 2017).

Connection costs above USD 1,000 per household, coupled with a low ability and willingness of residential customers to pay, questions whether investment costs could ever be recovered. Furthermore, many households might not have the need for electricity services at the same standard as grid-connected homes (see figure 13 SE4All electricity access tiers).

New Guinea experience considerable cost overruns, as all major equipment needs to be imported due to high local construction costs and as a result of deficient transport infrastructure. During in-country interviews, experts estimated that construction costs were two to three times higher compared to Southeast Asia. For example, during its rural grid extension program, the New Zealand High Commission experienced the continual inflation of its cost estimates, with a 10–20% increase in material costs per year. Furthermore, the assessment does not consider land use as a major (cost) factor (in-country interviews).

Moreover, extending the grid requires additions to the country's hydropower generation capacity and high voltage transmission lines, which will make lower-cost electricity widely available. The authors claim such assumptions to be realistic, based on discussions with DP&E and PPL (The Earth Institute and Economic Consulting Associates 2017). However, given the state of the current electricity grid, delays and cost overruns common for large infrastructure projects in Papua New Guinea, and slow pace of grid extension in the past, it is questionable how realistic the effective implementation of such major upgrades to both generation capacity and transmission and distribution infrastructure are.

Finally, the report notes that the estimate for mini-grid access varies considerably, depending on the capacity of the mini-grid and the fuel used for electricity generation, such as solar home systems, diesel-based mini-grids, hybrid systems, etc. (The Earth Institute and Economic Consulting Associates 2017). However, costs for mini-grids are estimated based on the assumption that off-grid electricity will be largely supplied by diesel gensets in the foreseeable future—by far the most expensive option (ANZ 2015). The report does not explore solar household systems as an option.

⁴⁷ These are "households who have grid access, either as PPL customers or as 'consumers' who use power but do not pay or are not properly metered or accounted for by the utility" (The Earth Institute and Economic Consulting Associates 2017).

Table 5. System results and costs for 100% electricity access by 2030

Results of spatial analysis	Grid access (2016)		Cost estimates for 100% Electricity Access by 2013			
	Access situation	Share of population	Recommended technology	Capex per household (in USD)	Total capex (in million USD)	
Within range of < 1km of existing grid	Customers with grid access and PPL account	6%	19%	EasyPay meters for existing customers	260	22
	Consumers with grid access with/without PPL account	6%		Improved connections and EasyPay meters for consumers	450	39
	No grid access	7%		Grid intensification (low voltage line and connection)	990	272
Beyond range of 1km of existing grid	No grid access	81%	Grid extension (medium and low voltage lines and connection)	1,680	2,200	
			Off-grid and mini-grid	1,160	660	
Total		100%		1,370	3,200	

Source: Adapted from The Earth Institute and Economic Consulting Associates 2017

In contrast to the favorable view taken during the preparation of the NEROP, other assessments are much more critical regarding the role of grid extension to provide electricity access. For example, ANZ (2015) regards grid extension as a feasible option only for “urban and rural population centers that fall within the economic limits of the existing major grids” (Ramu and Port Moresby). Disconnected provincial towns, remote villages, agricultural processing centers, and remote sites hosting extractive industries would all be served by off-grid solutions, including local mini-grids and stand-alone options of different sizes. For example, according to the assessment, for villages located farther than 5 km from the grid and having less than 2,000 inhabitants, all off-grid options (including diesel as the highest-cost option) are more cost-efficient than grid extension (ANZ 2015).

Large parts of the country might never get grid access.

(In-country interview)

Beyond the technical and financial obstacles, numerous utility-scale projects have suffered from delays or failure due to slow government systems,⁴⁸ a complex customary system of land tenure, a shortage of skilled labor, and cost overruns (Adam Smith International 2018; IHA 2018; IRENA 2013; GEF, UNDP, and SPREP 2009; World Bank 2018d; in-country interviews). Construction of major electricity infrastructure requires effective coordination between government authorities, private companies, and investors (OECD/IEA 2014)—a condition that seems hardly met in Papua New Guinea.

There is considerable uncertainty in existing policies and regulation. There are contradictions within and between policies, with the National Energy Policy being a prominent example. Where regulations exist, it is unclear whether and how they are implemented. For example, there is limited information on whether a specific provision has been approved or merely exists as a draft. Furthermore, for many utility-scale projects, a number of laws and regulations apply that are, however, not necessarily consistent with one another.⁴⁹

Finally, estimates suggest that more than 90% of Papua New Guinea's land area is customarily or communally owned, either by individuals or under some form of clan ownership. Land use for power projects is a significant barrier to both constructing new power plants and extending the grid. Formalizing customary landownership requires the establishment of an incorporated land group (ILG). However, the process of setting up an ILG is complex and lengthy, due to lack of documentation and competing claims. The formal establishment of landownership can take up to five years, with insufficient capacity in place to update records. Transferring ownership or land use rights is an equally complex process that is fraught with risks of misconduct (APREC 2017; CIFOR 2011; IOM 2014; IRENA 2013; GEF, UNDP, and SPREP 2009; in-country interviews). Insufficient consultations with landowners and local communities are a major cause for project delay, and lack of consensus can lead to infrastructure being built where it is not needed or not being built at all (in-country interviews).

I have never seen an ILG that works well.

(In-country interview)

Off-grid electrification has become increasingly relevant over the past decade. For example, Lighting Global (2018) estimates that, in 2017, off-grid solar provided basic electricity services to over 360 million people worldwide. This number is estimated to more than double to approximately 740 million people by 2022. Since 2010, the off-grid solar market has evolved and expanded substantially. It evolved from a single category of lighting products and a limited geographical presence to catering to a wide range of consumer needs (e.g., communication, cooling, entertainment, refrigeration) on a global scale. Lighting Global (2016) estimates that about 7 million households will be using solar-powered fans, and 15 million households will have a solar-powered TV by 2020. Two distinct business models (cash-based versus Pay-As-You-Go) have become firmly established. Both private investors and development institutions have been committing significant finance to the sector in recent years (Lighting Global 2018). This clearly demonstrates that off-grid electrification is a viable alternative to grid expansion and a global trend that Papua New Guinea should not forgo.

Papua New Guinea has a long history of off-grid electrification. However, most of the existing infrastructure is based on fossil fuels. For example, diesel generators for self-generation and back-up generation are widely used in the country (ADB 2015a; in-country interviews). Particularly in rural areas,

⁴⁸ Examples include changes in priorities due to internal changes in management, delays regarding co-financing commitments, overlap in responsibility between authorities, disconnect between national and provincial/district governments, a slow procurement system, and limited experience with competitive tenders in the electricity sector (in-country interviews).

⁴⁹ For further details, see *Introduce consistent legislation and provide regulatory certainty* in this report.

people rely on lighting supplied by candles, kerosene lamps, and battery-powered flashlights (Lighting Global 2016). Nevertheless, there are relevant examples of electricity from off-grid renewables in PNG. For example, while exact numbers are not available, estimates suggest that there are thousands of solar home lighting systems. Furthermore, PNG Telecom has hundreds of solar sites to support its network. In addition, over the past three decades, hundreds of solar systems were installed in hospitals and schools (IRENA 2013). While poor system design, lack of maintenance, and theft are a constant concern, these obstacles are likely easier to address than the many challenges related to grid expansion.

Focus on solar to expand off-grid electrification, with solar home systems showing clear advantages compared to mini-grids.

Given the obstacles for utility-scale projects and grid extension, off-grid electrification based on renewable sources offers a viable alternative to provide basic electricity services to rural communities (APEREC 2017; Lighting Global 2018; IRENA 2017e. Samanta and Aiau 2015). In Papua New Guinea, among the different fuels and technologies, solar household devices are deemed the most suitable option to provide basic electricity services while avoiding most of the existing obstacles.

Solar energy is estimated to be among the sources with the largest potential in PNG, with 1300–2500 hours of sunshine per year (4.5–8 hours per day) and an average irradiation of 400–800 W/m². There have been few reliable and systematic assessments of solar irradiation in the country. Radiation at a particular site cannot be easily estimated using satellite data, due to PNG's mountainous terrain and cloud cover, which causes solar radiation reaching the surface to vary considerably between locations (IRENA 2013; GoPNG 2014). In-country interviews suggest that solar PV is most relevant in coastal regions but less suited for the highlands, where cloud coverage is generally high.⁵⁰

Most villages located in the rural areas of Papua New Guinea have little or no access to electricity. Instead, local populations rely on other forms of energy, such as candles and kerosene for lighting and biomass (fuelwood) for cooking. Where solar radiation is sufficient, solar-powered standalone systems and mini-grids can deliver a wider range of services (kerosene, biomass) or provide a similar range of applications at a lower price (diesel).

Papua New Guinea has a growing domestic market for such systems, with an estimated 10–20 solar companies currently operating in the country. According to in-country interviews, many of the technical challenges have been largely resolved with improvements in system design and wiring. However, other challenges remain. In particular, grid-connected solar systems do not represent a feasible option currently. While financially compelling—10–15% cheaper than the current electricity tariff—there is no regulation in place regarding feeding electricity into the grid. There are no feed-in tariffs or net metering,⁵¹ both of which reduce economic viability. As a result, the few existing systems cannot be commissioned due to lack of approval from PNG Power (PPL), the country's utility and technical regulator (in-country interviews).

Adding intermittent electricity supply from renewables to current networks is seen as both technically and commercially challenging for PPL. To address these challenges, a 2-MW solar rooftop pilot project

⁵⁰ According to APERC (2017), the GoPNG has set an aspirational target of establishing 50 MW of solar-installed capacity by 2022 and 100 MW by 2050. However, this target could not be confirmed during in-country interviews.

⁵¹ According to in-country interviews, ICCG is currently developing advice for the GoPNG regarding the establishment of feed-in tariffs. GGGI was unable to obtain details on the content or status of this advice.

is being set up in Port Moresby with the aim to test the technology, its impact on the system, and potential consequences for the utility's business (in-country interviews). Until results from the pilot are available and the necessary regulation is in place, autonomous mini-grids and stand-alone systems of varying sizes are the only relevant options for solar equipment.

In theory, solar mini-grids represent a relevant option for replacing diesel in the existing subsidized mini-grids. However, past experiences in PNG provide a cautionary tale against the deployment of solar-powered mini-grids. In-country interviews highlighted several challenges, such as obtaining buy-in from local stakeholders and questions of ownership, agreeing with landowners on installing panels, operating and maintaining the infrastructure, and providing affordable services while recovering costs.

First, interviewees repeatedly mentioned that rural communities need to be given ownership of mini-grids. The community has to be a stakeholder instead of just a user. Buy-in is needed from the entire community and likely also neighboring communities for a system to be deployed successfully (in-country interviews).

Second, for larger systems, land is required for setting up panels. Establishing ownership and finding consensus on land use is a lengthy process. It can also increase costs when landowners expect compensation. While this might be avoided when panels and other equipment are placed on public land near schools, hospitals, and government buildings, such public land might not always be available or of sufficient size to host the needed capacity (in-country interviews).

Third, mini-grids require a 240-V system, which in return requires trained electricians and engineers to set up and maintain the system. Experience has shown that, without proper maintenance, systems break down and locals dismantle the infrastructure to use or sell components. However, there is a lack of skilled electricians in rural areas, where salaries are generally low and mines and extractive industries offer considerably more attractive earnings (in-country interviews).

Finally, financial sustainability of mini-grids is seen as a challenge, as the current tariff level is insufficient to recover costs and potential consumers are often unable to afford covering the actual costs. As was pointed out during several in-country interviews, many consumers cannot even afford to cover the operational and maintenance costs, not to speak of repaying upfront investments. Costs are driven by the need for local technicians, transportation, a lack of standardized equipment, and limited experience of properly managing off-grid solar systems (in-country interviews). Ultimately, insufficient revenue will most likely translate into mini-grids requiring an open-ended subsidy or systems failing due to lack of funding to maintain the infrastructure.

The current PPL tariff is 0.69 kina per kWh (USD 0.20 per kWh) compared to 5 kina per kWh (USD 1.50 per kWh) for solar mini-grids to merely cover operational and maintenance costs.

(In-country interview)

As a result, solar mini-grids were widely seen as an option for towns, hospitals, schools, and administrative buildings, with trained technicians for operation and maintenance onsite and spare parts readily available.

Once introduced in an area, particularly the uptake of solar lights—replacing kerosene—is high.

(In-country interview)

There is a growing market for solar household systems in Papua New Guinea, though little recent information on uptake and sales is available. Given the country's low electrification rate, the potential market is considerable. However, while systems are cost-competitive when considering the entire life cycle, comparatively high upfront costs remain an issue.

Existing applications for solar energy can be found both in urban and rural areas. Applications include lighting, cell phone charging, and water heating as well as solar drying of copra, cocoa, and coffee, particularly by smallholders. Standalone photovoltaic systems range from individual lanterns to pico products (1–2 lights) to larger household packages (several lights, phone charging, in some cases TV) and community lighting (APERC 2017; IRENA 2013; in-country interviews). 12-V appliances—such as LEDs, radios, and TVs—have become more efficient, but refrigeration and air conditioners still require much larger systems with more panels.

Our bestseller is a package including three lights, a battery, and a phone charging station.

(In-country interview)

In-country interviews pointed out several advantages of solar household systems compared to larger mini-grid designs. First, stand-alone systems have a clear price advantage, being approximately four times cheaper on a per kWh basis. Second, household systems are considerably easier to operate and require little

maintenance with no need for a trained electrician. Finally, they were regarded as less prone to vandalism and theft compared to larger systems.

Managing customer expectations might be a challenge for off-grid electrification, particularly for solar household systems. If households expect a full-range service of lighting and multiple appliances, including a TV, refrigerator, and air conditioner, their aspirations will be disappointed.⁵² However, in-country interviews suggest that expectations are largely dependent on location and income. The more remotely customers are located, the lower their ability to pay and the lower their service expectations, with expectations being limited to lighting and communication in large parts of the country (in-country interviews).

Box 2. Wind power in Papua New Guinea

APERC (2017) assumes that the construction of stand-alone off-grid wind turbines is a suitable alternative to electrify remote communities. They are considered technically simpler and circumvent some of the obstacles that grid-connected wind parks would face, such as landownership issues. However, currently, there is no utility-scale wind park in Papua New Guinea and no available information regarding any stand-alone off-grid installations. Both PPL and independent power producers (IPP) have no experience in constructing and operating wind turbines. Skilled labor is lacking. All of this makes it difficult to attract any private sector financing.

Data on whether and where wind conditions are suitable for electricity generation in PNG is limited. Currently, a World Bank-funded wind resource mapping study is being conducted. Final results are pending, but two interim reports on mesoscale modeling (World Bank 2015a) and site identification (World Bank 2015b) are available. The mesoscale modeling indicates a number of areas that might be suitable for the installation of wind turbines based on their comparatively high wind speeds.⁵³ These include the Highlands, Dura Island, the region southward and eastward of Port Moresby, the

⁵² However, the same challenge exists for extending the grid since current supply for many households is limited to basic services (in-country interviews).

⁵³ The results were obtained using the Weather Research and Forecasting (WRF) model, driven by Climate Forecast System Reanalysis (CFSR) data at a resolution of 5x5 km. Results are based on a 10-year simulation, covering the years 2004 to 2013. The model output consists of more than 43,000 individual data points with information on climatology, wind speed, wind power density, etc. Each point

Box 2. Wind power in Papua New Guinea (continued)

central spine of New Britain and some coastal areas around the island, Umboi Island, and the island chain from Bougainville Island to Latangai Island and Manus (World Bank 2015a; World Bank 2015b; figure 19).

However, the assessment emphasizes that the results are preliminary and that local verification of model results is crucial. First, local measurements are necessary to determine the accuracy of the modeling results, configure the model, and obtain a sound understanding of the uncertainty associated with the results. A final wind atlas for Papua New Guinea is envisioned to be developed based on an improved configuration of the model and relevant uncertainty estimates. Second, the authors also emphasize that the areas listed above were chosen from a wind climate perspective. However, many other factors need to be considered—such as land ownership, accessibility, security, etc.—to determine suitable locations (World Bank 2015a). Given the high costs, data collection is limited to three locations of the 10 initially identified sites, with results due in 2019 (in-country interviews).

Figure 19. Potential areas for wind power infrastructure and selected measurement sites



Source: World Bank 2015a

can be used in further micro-scale modeling to define winds over a prospective wind farm site (World Bank 2015a).

Biomass from agriculture residue and geothermal energy are suitable to supply individual industrial sites. Their role for expanding access to electricity for private households is limited.

Larger scale renewable energy infrastructure appears to be most feasible when associated with mining and agricultural processing. Many of the relevant companies are already auto-producers as a result of their remote location and the unreliable electricity system (ADB 2015a; IRENA 2013; Lowy Institute 2017). Both technical experience and regulations exist in Papua New Guinea for such sites, though currently, most auto-producers rely on diesel generators.⁵⁴ In this context, biomass and geothermal energy are regarded as the most viable options while large-scale hydropower is rather cautioned against.⁵⁵ Adoption of renewable energy solutions (particularly geothermal in the mining sector and biogas in agriculture processing) can have an even larger impact when combined with energy efficiency measures (IRENA 2017a).

Biomass

Biomass is considered to be a viable option, in combination with wood and agricultural processing, when feedstocks are readily available and cost-competitive. For example, in agricultural processing, residues from palm oil, coconut oil, cocoa, and coffee can replace diesel for electricity generation (ANZ 2015; in-country interviews). However, use of these alternatives ultimately depends on their costs and potential earnings compared to diesel prices. ANZ (2015) estimates that in Papua New Guinea, electricity generation from biomass is approximately 30% cheaper compared to using a diesel generator.

In-country interviews confirmed that there is a considerable number of biomass installations and pilot projects in Papua New Guinea. However, there is no consolidated overview. With a few exceptions, data on current use of residue for electricity generation in processing businesses is either not available or outdated. For example, in the 1990s, about 80 gasifiers were used in the copra, cocoa, coffee, and tea industries consuming biomass waste. However, there is no information on current numbers (APERC 2017; IRENA 2013; in-country interviews).

The potential for using residue in the wood processing industry is uncertain. The amount of residue produced and available for energy use is unknown. Raw logs appear to account for most of the wood export volume and value, with few finished wood products being manufactured in Papua New Guinea itself (PWC and PNG FIA 2006). However, employment statistics for the sector indicate that there might be a considerable amount of processing in the country (PWC and PNG FIA 2006), and according to IRENA (2013), there are almost 20 major wood-processing facilities in the country.⁵⁶

⁵⁴ Notable exceptions are the Lihir mine using geothermal power, a 58 MW hydropower plant at the Ok Tedi Mining Limited mines, as well as New Britain Palm Oil's two biogas digesters.

⁵⁵ During in-country interviews, GGGI was informed about a World Bank study covering the Port Moresby and Ramu grids and concluding that biomass and geothermal are not least-cost options, with other technologies being more cost-effective. However, the study is not publicly available, so that the methodology and assumptions could not be assessed. The study's focus on grid connected electricity generation suggests that these results are not in contradiction to this report.

⁵⁶ GGGI was unable to obtain relevant data. During in-country interviews, it was pointed out that data is difficult to obtain as companies likely consider such information as sensitive due to the situation of illegal logging in Papua New Guinea.

More recently, New Britain Palm Oil Ltd. commissioned two biogas digester facilities—in Mosa and in Kumbango—both using palm oil mill effluent to produce electricity (New Britain Palm Oil Limited 2017; TÜV Rheinland 2011).⁵⁷ There have been other recent attempts for electricity generation from biomass, including charcoal (unsuccessful due to erratic supply) and obtaining biodiesel from waste cooking oil, papaya seed oil (failed), and coconut oil (in-country interviews).

The planned 30-MW biomass power plant in the Markham Valley in Morobe Province is an example of a large-scale project that is not directly associated with a specific industry site. The power plant is supposed to feed electricity into the Ramu Grid to support regional supply (PNG Biomass 2019). As a feedstock, the plant would rely on approximately 16,000 hectares of associated plantations of eucalypt (PNG Biomass 2017). In-country interviews confirmed that the plant is cost competitive, with generation costs being somewhat higher than estimated costs for the anticipated Ramu 2 run-off river hydro plant but only about half the generation costs of using diesel. However, despite favorable economics, construction of the plant has experienced considerable delays.⁵⁸

The project is the result of a competitive tender for an electricity plant in Morobe. Biomass was deemed the most suitable option due to a number of factors, including (in-country interviews):

- Local supply of feedstock that allows for decoupling fuel supply from exchange risk and external market risks,
- Land availability in the Markham Valley to grow feedstocks,
- Concentration of 30–40% of PNG’s population within 20 km of the Ramu Grid (that the plant would be connected to),
- Positive impact on rural employment as the project creates mostly semi-skilled and non-skilled jobs (unlike other technologies), and
- Guaranteed local revenue and associated social benefits.

However, while biomass is generally regarded as a viable option to supply local industrial sites with electricity, particularly agricultural processing such as palm oil, circumstances in the Markham Valley are, to some extent, unique to allow for a larger-scale plant. Unlike in the case of the PNG Biomass plant, land availability in proximity to demand centers is usually a severe issue. With a capacity of 30 MW, the plant is cost-competitive. However, at capacities closer to 100 MW, hydro and gas-fired plants are more cost-effective on a kWh basis (in-country interviews).

Geothermal energy

Papua New Guinea has considerable geothermal potential. There are 55 known areas of surface geothermal activity in the country, particularly on the island of New Britain, with at least seven geothermal prospects and the D’Entrecasteaux Islands with 12 known geothermal areas. Despite the large potential, exploitation to date has been limited, mainly due to lack of an appropriate regulatory framework (McCoy-West et al. 2011; GoPNG 2014; in-country interviews).

⁵⁷ Further biogas facilities at the company’s Kapiura, Numondo, and Waraston mills are being explored (New Britain Palm Oil Limited 2017).

⁵⁸ All necessary approvals are confirmed to be in place, including a power purchase agreement being signed in 2015 and approved by the National Executive Council and ICCC approval for a commercial tariff being obtained in 2017. However, the project reportedly hinges on the GoPNG signing off on a security package required for the project to obtain concessional funding in order to deliver the tariff discounts desired by PNG Power. Potential lenders include ADB, EFIC, the European Union, and IFC (in-country interviews).

Given the isolated locations of geothermal resources—remote from larger population centers—and the high upfront costs for exploration and drilling, geothermal energy appears to be most suitable for supporting mining and other industrial activities.

It is less suited for supplying population centers with electricity (in-country interviews). This assessment is supported by the fact that many of the geothermal areas are located near metal deposits and (potential) sites for mineral exploitation, such as gold and copper (McCoy-West et al. 2011; GoPNG 2014).

Given its remote location and high upfront investment costs, geothermal energy is most relevant for the mining sector but less relevant as a source of supply for population centers.

(In-country interview)

Currently, most of the mining operations in Papua New Guinea rely on electricity generated from diesel and heavy fuel oil (in-country interviews). The only recorded geothermal plant is the Lihir Gold Mine in New Ireland Province, where a 6-MW backpressure plant was commissioned in 2003, and in 2007, power generation was expanded to a nameplate capacity of 56 MW.^{59, 60} It demonstrates the considerable potential for cost savings, when fossil fuels are replaced by suitable renewables. Until 2003, about two thirds of the mine's required electricity were produced from thermal generation (mainly fuel oil), with the remaining third coming from hydro. When operating at full capacity, the geothermal plant displaced electricity generation from fuel oil, with cost savings amounting to approximately USD 2 million per year (Booth and Bixley 2011; McCoy-West et al. 2011).

Hydropower

While Papua New Guinea has a large potential for hydropower, and hydropower plays an important role in the country's electricity mix (IRENA 2013; GoPNG 2014), large-scale hydropower projects are viewed with caution. The obstacles for such large-scale electricity infrastructure are considerable—particularly the condition of the existing electricity grid and questions of land ownership—and past hydropower projects have experienced considerable cost overruns or failed entirely (in-country interviews; see table 6). In addition, currently, hydropower is used for supplying the baseload in the grid. However, there are concerns that this setup is vulnerable to severe outages when electricity output from hydropower plants is affected during the dry season (lack of water) and by heavy rainfalls (clogging of water intake).⁶¹

⁵⁹ The plant experienced reduction in capacity as some wells had to be shut down due to mining operations moving into the area. Information on current capacity varies, putting it between 5 MW and 17 MW (in-country interviews).

⁶⁰ There is a proposal for a 5-MW pilot project in the western part of New Britain Province. Beyond generating electricity, the aim of the project is for the relevant authorities to gain experience, support the development of necessary regulation, and assess the capacity needs within the administration. The project aims to receive GCF funding but has yet to identify an accredited entity in order to access funds (in-country interviews).

⁶¹ There is disagreement to what extent electricity generation from hydropower is affected during the dry season and by heavy rainfalls. PNG Biomass (2017) mentions the experience of the Ramu-1 power project, where by August 2015, after two months of dry weather, water levels at the dam had suffered a five-meter drop. During in-country interviews, it was mentioned that the most recent example of hydropower being affected during the dry season occurred in 2017, leading to power rationing in Port Moresby. However, other interviewees regarded these episodes as exceptions and were confident that supply from hydropower was reliable, independent of weather and climatic conditions.

Finally, large-scale hydropower plants—including run-of-the-river plants, though to a lesser degree⁶²—can have significant and unavoidable negative environmental and social impacts. These are related to the flooding of land in the impoundment zone upstream of a dam and changes to water flows and water levels downstream from a dam. Impacts include forced land acquisition and population displacement; changes in river regimens (which can affect fish, plants, and wildlife), and flooding of land and wildlife habitats (through the creation of reservoirs). While the nature and severity of such impacts are highly site-specific and tend to vary in scale according to the size and type of the project, large-scale plants generally have an environmentally disruptive impact.

Table 6. Status of recent hydropower projects

Name	Generation capacity	Status
Karimui	1800 MW	Construction was expected to begin in 2017 and estimated to be completed by 2023. Information on the current status of the project is not available.
Ramu 2	180 MW	Construction has been delayed.
Naoro-Brown	80 MW	Preparation of the Naoro-Brown project commenced in 2012. An environmental and social impact study was scheduled for the end of 2018. No information on status of a planned tendering process is available.
Edevu	50 MW	The Edevu project was launched in February 2017, with expected commissioning delayed from 2018 to 2020.

Source: IHA 2018; PNG Power 2018; The National 2018

In contrast, small-scale hydropower systems represent a feasible alternative as they avoid many of the issues mentioned above. In addition, there appears to be some experience in the country with small-scale hydroelectricity, although details on the current state of many systems is scarce (IRENA 2013; Lowy Institute 2017). Small-scale hydropower has been commissioned by the GoPNG, church missions, NGOs, and community organizations. Admitting considerable uncertainty around its numbers, IRENA (2013) reports that between 1960 and 2004, approximately 200 small and micro systems were installed in rural Papua New Guinea, suggesting that up to a quarter of these plants might still be operational.

Kaur and Segal (2016) argue that combining small-scale hydro power with a natural gas-fired generator set represents the most cost-effective solution to meet the requirements of a small town of 5,000 people

⁶² Run-of-river hydropower plants harness energy for electricity generation mainly from the available water flow of the river. While these plants may include short-term storage or “pondage,” allowing for some short-term flexibility on the scale of hours or days, their output is usually subject to substantial seasonal and yearly variations (IEA 2018).

with an estimated peak demand of 290 kW.⁶³ In such a hybrid system, the natural gas-fueled generator absorbs the seasonal variability in hydropower. According to their estimates, combining hydro, a natural gas generator set, a solar PV system, and a battery represents a cleaner option, though at about twice the cost of electricity. If natural gas was replaced with biogas, both options would be even cleaner. However, the assessment does not consider specific project sites, nor does it reflect the political, legal, and economic aspects that play into the deployment of such systems.

Table 7 provides an overview of the different options for additional electricity generation capacity in Papua New Guinea. The options are divided into large grid-connected and small off-grid systems and compared across four categories, including how reliably they can provide electricity, the financial costs associated with them, their environmental impact, and to what extent they are aligned with existing policies. Generally, utility-scale systems provide more reliable supply but come at much higher overall financial costs.⁶⁴ The reliability of hydropower is estimated to be moderate due to the impact of insufficient water flows during the dry season and potential clogging of water intake during heavy rainfalls. The financial cost of off-grid diesel generators is estimated to be high, due to high expenses on fuel. Electricity from renewable sources generally scores favorably regarding their environmental impact and alignment with Papua New Guinea’s long-term policies. The environmental impact of large-scale hydropower is considered as less favorable due to the negative impacts described above. Off-grid renewables are generally intermittent but have clear advantages regarding their financial costs and environmental impact.

Table 7. Systematic comparison of electricity generation options

Fuel	Availability of electricity generation	Financial costs (capital costs, operational costs)	Environmental impact (including GHG emissions)	Alignment with Vision 2050
Utility-scale systems				
Coal	high	high	high	low
Diesel/fuel oil	high	very high	high	low
Natural gas	high	high	moderate	low
Large hydro	moderate	high	moderate/high	high
Geothermal	high	high	low	high
Biomass	high	moderate	low	high
Small-scale off-grid systems				
Off-grid solar	moderate	low	low	high
Small hydro	moderate	moderate	low	High
Diesel	high	high	high	Low

Source: GGGI

⁶³ Hydro generation is assumed to consist of a 75kW “run-of-the-river” type plant (i.e., generation is subject to seasonal rivers flows with no or a limited amount of water storage). The natural gas generator set is assumed to have a total capacity of 320 kW.

⁶⁴ This assessment explicitly refers to total investment and operational costs—not relative costs per kWh.

Support a larger role for the private sector, particularly in off-grid electrification.

Given the ambitious plans of increasing both electricity access and the share of renewables in Papua New Guinea's electricity mix (DNPM 2010; GoPNG 2009a; GoPNG 2016), private companies should be allowed to play a larger role in the electricity sector. Particularly off-grid electrification would benefit from a stronger private sector.

Regarding the electricity network, additional generation capacity, grid extension, and upgrades will require billions of dollars in investment. PNG Power is not in a position to shoulder these amounts (Adam Smith International 2018; Lowy Institute 2017). Therefore, independent power producers will need to play a larger role (APERC 2017). Establishment of the Independent Consumer and Competition Commission (ICCC) through the ICCC Act 2002 and adoption of the 2014 Third Party Access Code and the Electricity Code were steps toward that direction.

However, private sector participation in the electricity sector is largely limited to the role of auto-producers at isolated industrial sites, particularly to support mining and other extractive operations as well as agricultural processing. While electricity generation is open to competition, PPL has a monopoly on the transmission, distribution, and sale of electricity to retail customers (GoPNG 2009b). There are cases where independent power producers feed electricity into the networks owned by PNG Power under power purchase agreements, but their number is very limited (ADB 2015a; APERC 2017; Kuna and Zehner 2015; Lowy Institute 2017).

We haven't yet had overwhelming success in private sector engagement.

(In-country interview)

While numerous policies state the goal of increasing competition, unbundling of the electricity sector is not addressed.⁶⁵ Among others, introducing competition in the retail market is prevented by a uniform electricity tariff for customers within a particular category, regardless of location. This uniform tariff obligates PPL to subsidize electricity in diesel-powered mini-grids with revenues from the profitable three main grids. It is regarded as a means to provide "affordable prices for consumers in higher cost areas of investment" under the Community Service Obligation (GoPNG 2009b). In-country interviews confirmed that the current setup with cross-subsidies between different locations prevents competition

⁶⁵ For example, the National Energy Policy and the National Strategy for Responsible Sustainable Development explicitly ask for introducing stronger competition in the electricity sector (DPE and DP&E 2017; DNPM 2014).

The National Strategy for Responsible Sustainable Development states:

Restructuring of the sector by separating generation, transmission and distribution services can have a significant effect on electric power technologies, costs, prices, institutions, and regulatory frameworks, and can create more space for renewable and clean energy in the national energy mix. Similarly, deregulating power generation and taking the step towards wholesale power markets can allow IPPs to compensate for biases that traditional utility monopolies may have against renewable. Opening the generation sector to IPPs can also favor green and decentralized private sector-led solutions to energy access, since connecting isolated rural communities to the grid is often costlier than off-grid investments.

[emphasis added by author] (DNPM 2014). While this is factually correct, it does not amount to any commitment to unbundle the electricity sector.

The Electricity Industry Policy is somewhat ambiguous on competition, largely limiting it to electricity generation and, even in that area, only under certain conditions (GoPNG 2009b).

in the electricity retail market. However, without the existing obligation on PPL to subsidize local grids, either considerably higher tariffs would be needed to recover costs or these loss-making grids would be shut down.⁶⁶

In Papua New Guinea—as in many other countries—the dominant thinking revolves around electrification driven by centralized government planning. While numerous policies and strategies ask for a more active role of the private sector, in practice, some of the provisions and goals (often stipulated in the same documents) prevent a more active engagement.⁶⁷ For example, the National Energy Policy stipulates that, regarding the development of renewable energy, projects “up to 10 MW [are] reserved for state investment including National Government, Provincial Government and LLG and landowners” and “beyond 10 MW the state has the option to participate ranging from 20 - 40 percent” (DPE and DP&E 2017).

There is an inherent tension between the following two aspects: (1) reliable services, competition and adequate investment and (2) increased electricity access and affordable tariffs. This tension is not exclusive to Papua New Guinea; it is a reality in most countries—low and high income (OECD/IEA 2018; European Parliament 2017). However, this tension is barely recognized and much less addressed in PNG. For example, the country’s National Energy Policy stresses both the “deplorable state” of the country’s electricity infrastructure and the need to provide affordable prices to consumers (DPE and DP&E 2017). It treats the two as if they can be easily aligned, with little recognition that building reliable infrastructure comes at considerable costs and that companies need to recover those costs in order to maintain the system and make investments to extend it.⁶⁸ The policy asks electricity companies to minimize costs but extend the grid to rural customers. It encourages competition in the electricity sector but adheres to a system of strictly regulated tariffs (DPE and DP&E 2017).⁶⁹

Ambiguity toward the private sector is not limited to policy documents in Papua New Guinea. For example, APERC (2017) suggested for the GoPNG to design pilot projects for off-grid solar lighting in rural areas and develop a sustainable financial model. Such recommendations miss the points that any such projects have generally failed in the past (Adam Smith International 2018; IRENA 2013) and that the private sector already plays a role in off-grid electrification that should be supported, instead of

Competition is critical. It improves quality and lowers the price for consumers.

(In-country interview)

intervening in the market with the risk of creating severe distortions (APERC 2017; IRENA 2013; in-country interviews).

Therefore, it is recommended for the GoPNG to somewhat move away from centralized

planning and implementation by the national government and instead provide greater flexibility for the private sector. While this might be too politically controversial for grid-connected infrastructure, putting

⁶⁶ For a more detailed discussion of this subject, see *Reform the electricity tariff system, moving away from a uniform tariff. Strengthen the independent regulator.* in this report.

⁶⁷ See for example, DNPM (2014); DPE and DP&E (2017).

⁶⁸ The National Energy Policy does recognize that “there is an inherent inability to recover costs on the provision of electricity to rural areas in PNG broadly.” However, this “inherent inability” is neither addressed sufficiently—provisions under “community service obligation” contain considerable ambiguity—nor is it limited to rural areas.

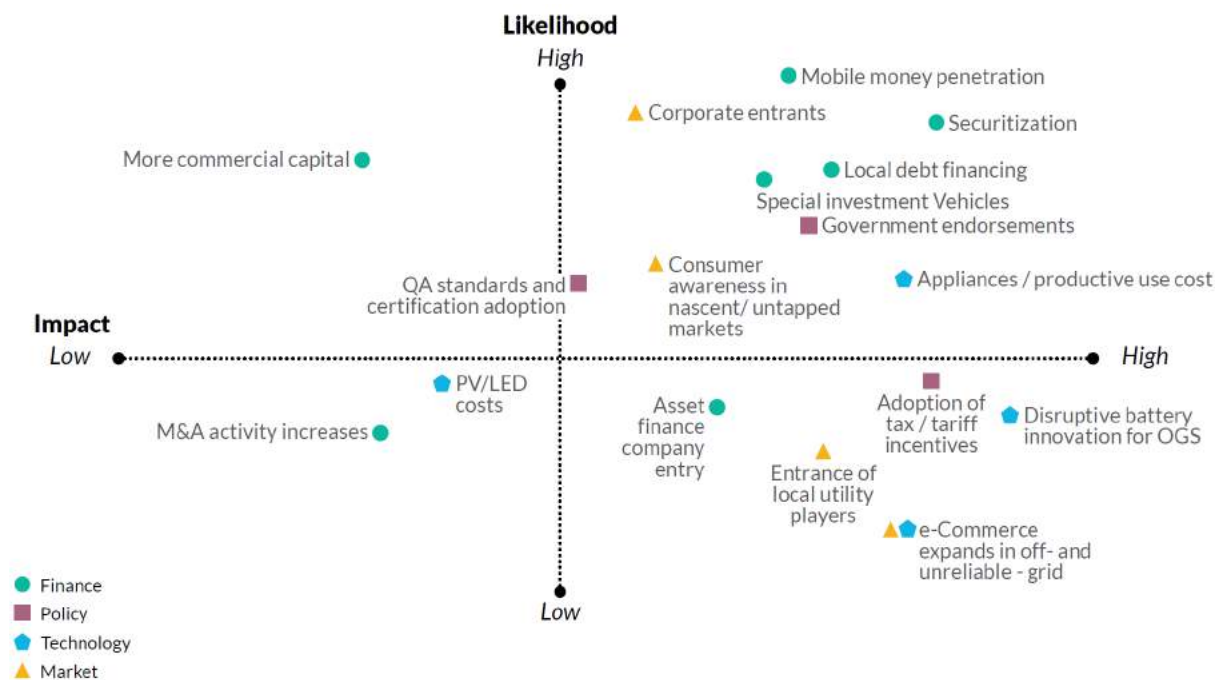
⁶⁹ Papua New Guinea’s uniform electricity tariff is repeatedly cited as discouraging private sector involvement in rural electrification (APERC 2017; IRENA 2013; Lowy Institute 2017). The Electricity Industry Policy allows for some flexibility for tariffs in areas beyond 10 km of the existing main grids, though the exact details on this provision are opaque (GoPNG 2009b). It is also questionable how effective the approach is, as it has not resulted in any measurable progress in electrifying rural areas.

in place conditions that enable more private sector initiatives in the off-grid sector is seen as feasible and can contribute substantially to achieving the government’s ambitious goals.

For example, in several African countries, the private sector has been instrumental in deploying and demonstrating the feasibility of distributed solar energy systems. Mobile network providers can play a crucial role in this respect. In Nigeria, the solar startup company Lumos Global has partnered with the country’s largest mobile provider to install solar power systems in over 50,000 homes, clinics, schools, and businesses, benefiting more than 250,000 people and creating 450 jobs. This joint-venture aims for installing 10 million systems by 2022 (UNEP 2017).

A conducive policy environment can play a critical role in stimulating such activity. Lighting Global (2018) ranks policy—together with finance—among the aspects that have the highest impact on facilitating private sector engagement for the successful deployment of off-grid solar infrastructure (Figure 20).

Figure 20. Relative ranking of catalysts for off-grid solar deployment



Source: Adapted from Lighting Global 2018

Note: The distribution catalysts along the dimensions of likelihood and impact are based on a subjective expert ranking considering a time horizon of five years.




Facilitate access to finance for private sector players.

There are a number of macro-economic risks that companies active in the renewable energy market face in Papua New Guinea—just like any other company operating in the country. Uncertainty around the country’s macro-economic policies, difficulties in obtaining foreign exchange, lack of contract enforcement and insolvency resolution, corruption, inefficient government bureaucracy, and obtaining permits all represent challenges to private businesses in PNG and make it harder for them to access

finance at affordable costs (IMF 2017). While strengthening policy coherence and regulatory certainty are challenges that, even in the best of circumstances, will take time, the GoPNG can undertake several simpler (and quicker) measures in order to support the private sector in deploying renewable energy.

Access to finance is one of the most important barriers for a more active role of private businesses in Papua New Guinea’s renewable energy sector, particularly regarding off-grid electrification. Access to finance has proven to be a challenge for both companies and clients. Figure 21 shows three types of financing for off-grid solar solutions where Lighting Global (2016) has identified gaps between supply and demand.

Figure 21. Capital requirements in the off-grid solar sector

DEBT		EQUITY
<p><small>*SHORTER TENORS*</small></p> <p>WORKING CAPITAL </p> <p> PURPOSE Financing the supply and distribution chain, including inventory.</p> <p> RECIPIENTS Mainly for companies doing cash sales or selling PAYGO products to distributors.</p> <p> PROBLEMS * Tight payment terms from suppliers. * Limited access to and high cost for bank loans and credit lines due to early stage nature of the business. * Exposure to foreign exchange risk.</p>	<p><small>*LONGER TENORS*</small></p> <p>CONSUMER FINANCING CAPITAL </p> <p> PURPOSE Funding payment plans for end-consumers.</p> <p> RECIPIENTS Mainly for companies selling PAYGO systems to end-consumers.</p> <p> PROBLEMS * Leads to high leverage if kept on balance sheet. * Lenders require historical track records which are not yet available. * Exposure to foreign exchange risk.</p>	<p>SEED AND EARLY STAGE EQUITY OR GRANT </p> <p> PURPOSE R&D, business planning, testing, piloting and market entry.</p> <p> RECIPIENTS New and unproven start-ups with very little track record.</p> <p> PROBLEMS * Impact investors and donors prefer companies with an initial track record but cannot offer tickets large enough for these firms.</p>

Source: Adapted from Lighting Global 2016

Mobilizing the very limited public funds to accelerate deployment of renewable energy is regarded as unrealistic. The GoPNG is often unable to deliver on its commitments for co-funding electricity infrastructure. Without commitments being reflected in budget plans and endorsed at all levels, co-funding is notoriously unreliable. Attaining such buy-in is time-consuming and regularly leads to delays in projects (in-country interviews). Given strained public budgets and strong clientelism in the country, this is unlikely to change during the foreseeable future. Therefore, it is recommended to instead focus on creating conditions that make private sector investment more attractive.

Regarding the existing off-grid solar market, there are two financing models. First, either the customers fully own the equipment and pay for it upfront or, second, customers lease the equipment and pay a monthly fee. To date, leasing models have been unsuccessful in Papua New Guinea (See Box 3. *Pay-as-you-go can play a crucial role for the deployment of off-grid renewables, but it faces severe challenges in Papua New Guinea*). In practice, private businesses are the most prominent customer for the independent systems as they have the financial means to afford them while donor funding is often required for households to afford larger home systems (in-country interviews).

Independent of what specific financing model is chosen, price and financing/business models will depend on location and need to take into account different customer segments. In-country interviews

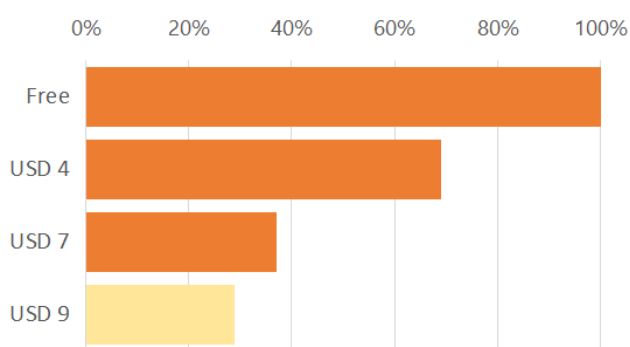
confirmed that the farther households are located from the existing grid, the lower their ability to pay. They highlighted the need for subsidies, with the amounts to be covered by subsidies increasing the farther afield households are located (in-country interviews).

Where income is available, existing solar household systems are already affordable. For example, communities near mines and agricultural centers producing cash crops would likely require no financial support. Also, where there is productive and business use, payback periods for solar kits in PNG are extremely short. For example, when used for phone charging businesses, payback periods are estimated to amount to less than a month (in-country interviews).

However, cash-starved rural communities with limited productive use are not in a position to afford the existing systems at market prices. While solar household systems are cost-competitive over their life cycle, the comparatively high upfront costs remain an issue. Given high costs of transportation and setting up new distribution points in Papua New Guinea, costs are unlikely to fall considerably.

Field research covering a sample of 1,401 households in Kenya confirmed that consumers responded strongly to price differences. Less than 30% of the households who received the offer to buy a solar light at the market price of USD 9 chose to purchase one. The share increased to 37% for households who were offered a reduced price of USD 7. It reached nearly 70% when prices dropped to USD 4 (Figure 22; Rom, Günther, Harrison 2017).

Figure 22. Take-up ration at different prices



Source: Rom, Günther and Harrison (2017)

In this context, it is important to note that few experts advocate a return to the indiscriminate financial support that beset the industry in its infancy. For example, Lighting Global (2018) cautions against the market distortions and counterproductive longer-term effects that generous incentive schemes tend to have. Nevertheless, it is also widely recognized that a substantial share of potential customers of off-grid renewable equipment live in remote areas and are highly cash-strapped (Lighting Global 2016; Lighting Global 2018; IRENA 2013). Therefore, support mechanisms, such as vouchers and discounts, are regarded as useful tools to support these consumers (Lighting Global 2018).

Past projects have been most successful in communities where there is an understanding that electricity has a value.

(In-country interview)

At the same time, past experience in Papua New Guinea has shown the importance of attaching a cost to the equipment in order to avoid creating a mentality among customers that electricity is for free. When systems were provided free of any charge, people often re-

sold them.⁷⁰ Attaching a cost to the equipment, while making it affordable, will require some innovative ideas. In-country interviews suggested bartering as an option or attaching non-monetary requirements to installing the equipment, such as vaccinations, WASH trainings, etc.⁷¹

⁷⁰ Similarly, systems should not simply be handed out or sold at a discount but be properly installed. Once customers experience the benefits, they are much less likely to dismantle or re-sell the equipment.

⁷¹ According to UNICEF (2016), "WASH is the collective term for Water, Sanitation and Hygiene. Due to their interdependent nature, these three core issues are grouped together to represent a growing sector. While each a separate field of work, each is dependent on the presence of the other. For example,

Currently, provisions on government financial support for renewable energy are very vague and of a largely declaratory nature. For example, the National Energy Policy only mentions “provisions of incentives for renewable energy projects so as to reduce the reliance on expensive petroleum based energy in the long term.” The policy does not provide any specific examples on what these incentives might entail (DPE and DP&E 2017).

Measures such as consumer education campaigns, financial de-risking through loan guarantees and foreign exchange facilities, and simplifying licensing procedures are regarded as effective means to promote private sector activity (IRENA 2013; Lighting Global 2016; in-country interviews). In addition, in-country interviews suggested that introducing a tax discount for investment and higher peak electricity pricing during daytime would support the industry. Furthermore, the establishment of an accredited entity was seen as crucial for the solar industry and provincial governments to be able to access GCF funding for renewable energy projects. Finally, government loan guarantees or credit enhancements can play a decisive role in attracting private capital and donor lending. However, the track record of the GoPNG is not favorable regarding these tools (in-country interviews).

Contrary to experiences in other countries, in Papua New Guinea, the general service tax (GST) and import fees on renewable energy-related equipment do not represent a severe burden.⁷² With a GST rate for renewable energy equipment at 10% and no import fees, reducing or entirely removing the tax would not substantially reduce end-user costs, stimulate demand, increase the competitiveness of those technologies, or encourage greater private sector activity.

Box 3. Pay-as-you-go can play a crucial role for the deployment of off-grid renewables, but it faces severe challenges in Papua New Guinea.

Off-grid renewable energy solutions are cost competitive with conventional technologies, such as kerosene or battery torches. However, relatively large upfront costs remain an important barrier for potential customers. Therefore, a number of companies have introduced a service model designated as “pay-as-you-go” (PAYGO). This service has proven to be an important instrument for customer finance (Lighting Global 2016).

PAYGO (also PAYG) refers to a service model that allows customers to pay for their product via embedded consumer financing. PAYGO systems include a variety of technologies, payment rules, ownership arrangements, and financing modalities. Their two common defining features are that they (1) allow the end-user to pay for the equipment (mostly solar home systems and multi-light pico devices) in small installments instead of a lump sum payment and (2) allow for the service provider to disable the system remotely if a payment is overdue.⁷³ Payments are usually made via mobile

without toilets, water sources become contaminated; without clean water, basic hygiene practices are not possible.”

⁷² This finding is contrary to some of the existing literature. For example, IRENA (2013) identified high value added tax (VAT) and import tariffs as a severe obstacle. Papua New Guinea’s general service tax is comparable to the VAT in other countries. Similarly, the 2012 Geothermal Energy Policy (not adopted) mentions import duty exemptions for extraction equipment as a support measure (DMPGM 2012).

⁷³ While the business model of offering a service combining an off-grid solar kit and a loan has existed for more than two decades, it required manual credit checks and agents to physically collect fees. This report defines PAYGO as a service based on a technology that enables remote activation or shut down of the equipment. PAYGO companies offer a large variety of products, ranging from simple solar lanterns to solar systems of more than 200 W.

Box 3. Pay-as-you-go can play a crucial role for the deployment of off-grid renewables, but it faces severe challenges in Papua New Guinea (continued).

money transfer, though there are alternative methods, such as scratch cards, cash payments, or mobile phone credit (Lighting Global 2018; Lighting Global 2016; UNEP 2017).

Pay-as-you-go has received much praise for driving the off-grid solar systems market (see Lighting Global 2018; Lighting Global 2016; UNEP 2017). By reducing upfront costs and shifting toward installments, PAYGO allows consumers to gain access to systems they could otherwise not afford. PAYGO also shifts the risk that the equipment will not function or that the manufacturer will not honor the warranty from the consumer to distributor (Lighting Global 2016).

However, pay-as-you-go is not without challenges. There are a number of requirements for it to work, including the availability of mobile money services, access to finance, and a conducive business environment—none of which is a given in Papua New Guinea.

First, PAYGO is most successful in countries with strong mobile money ecosystems, particularly in sub-Saharan Africa and a smaller presence in India and Southeast Asia (Lighting Global 2018; Lighting Global 2016).⁷⁴ In large parts of Papua New Guinea, reliable mobile connection and banking services are lacking.

Second, while PAYGO offers a viable approach to customer finance, PAYGO companies themselves need access to finance. These companies need external finance due to the relatively long lead times required to establish their business model.⁷⁵ Companies also need working capital to finance inventories and distribution. Companies relying on PAYGO attract multiple times the amount of investment that companies selling the same products for cash are able to secure. Nevertheless, access to finance for companies remains one of the major burdens for the off-grid renewables industry (Lighting Global 2016).⁷⁶

In Papua New Guinea, current business models require full payment of the equipment upfront or a payment subsidy provided by an individual development partner. There is little experience with pay-as-you-go in the country and the few trials that have been undertaken have failed so far, due to either lack of willingness or ability of customers to pay. While technically feasible in main population centers, it remains very risky for companies as long as potential customers cannibalize systems and sell components (in-country interviews).

⁷⁴ In this context, telecom operators have emerged as important partners for businesses relying on PAYGO. Both sides profit from this arrangement. PAYGO companies can rely on telecom companies' data networks for mobile money systems and use their physical presence in rural areas as a distribution channel, selling equipment out of their stores. Telecom companies profit through increased use of their services in rural areas (Lighting Global 2016; UNEP 2017).

⁷⁵ Companies often require several years to build the necessary operational capacity to efficiently distribute and maintain thousands of systems. Testing local preferences and dealing with slow public administrations further delay the process.

⁷⁶ The lack of historical data makes it difficult for private lenders to assess the risk associated with PAYGO companies. The necessary information on customer payment needs to cover the time period for companies to make a profit. For example, a PAYGO company that offers an 18-month payment cycle to its customers needs to stay in business for a year and a half to collect the data required by lenders. Since PAYGO companies often adjust their business model during the first years in business, repayment rates from later customer cohorts are likely higher than earlier cohorts, increasing the time to have a realistic risk assessment further (Lighting Global 2016).

Strengthen quality control by applying global standards to off-grid renewables equipment sold in Papua New Guinea.

Quality standards for renewable energy equipment are most relevant for (off-grid) solar household systems.⁷⁷ Enforcing quality standards for solar equipment entering the national market would prevent the adoption of substandard equipment. In turn, this would help to minimize the risk of negative consumer perception as failure of cheap equipment undermines the industries reputation—particularly when experiences are so bad that consumers return to previous stopgap technologies instead of purchasing new solar equipment once their first purchase ceases functioning (Lighting Global 2016; Lighting Global 2018; in-country interviews).

There is a large range of products, but generally, people go for the cheapest option. However, cheap products tend to fail, undermining the reputation of the industry.

(In-country interview)

Quality standards are particularly relevant in markets that have a large share of open market component-based solar systems, such as Papua New Guinea (Lighting Global 2018, in-country interviews).⁷⁸ Open market component-based systems offer a number of advantages to consumers. Among others, buying and assembling individual components is often

cheaper on a per watt basis than purchasing quality plug-and-play solar home systems. Furthermore, piecemeal purchases are inherently more flexible. They can be tailored and adapted to changing household needs or available income (Lighting Global 2018).

However, without vetting of suppliers, open market component-based systems tend to have high failure rates, as is the case in Papua New Guinea. Furthermore, quality and safety are compromised when consumers assemble components of mismatched capacity or do not include a control box when compiling their systems. These systems typically do not provide the benefits of servicing, warranty protection, and financing of pico or plug-and-play devices (Lighting Global 2018; in-country interviews).

⁷⁷ There are three main types of off-grid solar systems: (1) Pico solar devices, (2) plug-and-play solar home systems (PnP SHS), and (3) component-based systems. First, pico systems include lanterns and simple multi-light systems (and may enable mobile charging) below an 11-W maximum capacity (Wp). These enable partial or full Tier-1 electricity access to a household. Second, plug-and-play solar home systems comprise a SHS kit of more than 11 Wp including compatible appliances. They are typically able to power several lights, as well as energy-efficient appliances, enabling full Tier 1 or higher electricity access for a household. Third, component-based systems refer to devices in which components (i.e., PV module, battery, lights, inverter, wiring, etc.) are compiled independently. These devices are typically solar home systems (>11 Wp) but can be smaller (Lighting Global 2018). Component-based systems can be distinguished as (1) institutional sales of non-affiliated products and (2) open market equipment. Institutional sales refer to systems that are assembled from and distributed with the support of government subsidy programs, such as Bangladesh's IDCOL or India's National Solar Mission. Open market component-based systems refer to equipment that customers purchase from local markets and assemble themselves or through a retailer (Lighting Global 2018).

⁷⁸ There is little information on the market share of open market component-based systems. Some estimates suggest that their share in Papua New Guinea might be similar to Myanmar, at about 60% (Lighting Global 2018).

Currently, there are no quality standards for solar equipment entering Papua New Guinea (in-country interviews). Setting up local testing facilities appears unrealistic and risks damaging local markets.⁷⁹ Instead of local testing, it is recommended to either follow a global certification scheme (such as Lighting Global) or make membership in Papua New Guinea’s Solar Association a requirement to sell solar products. Both options would oblige sellers to adhere to a code of conduct, either using certified equipment from affiliated companies or vetting manufacturers themselves. For example, as a result of intensive investment to build the market for quality-verified and prepackaged pico devices and plug-and-play solar home systems, the market share of component-based systems in Kenya dropped from about 70–80% in 2010 to 1–4% in 2017 (Lighting Global 2018).

There was consensus during in-country interviews that the main obstacle will be enforcing quality standards. Preventing substandard equipment from entering the country was regarded as a serious challenge for the country’s customs authority. Funding for customs inspections and enforcement would be needed. However, if funding was available, interviewees agreed that it would be considerably more effective to strengthen customs control than to set up a system for in-country testing of equipment (in-country interviews).

Certified products will likely never be able to compete with the low prices of component-based systems. Therefore, in-country interviews pointed out that initiatives on quality control should be accompanied by information campaigns focused on a simple message: while quality products require a higher price, these products ultimately save money because they last much longer. It was suggested that such awareness raising can be done most effectively and at limited costs through short and pointed messages via social media.⁸⁰

Quality products will never be able to match prices of component-based systems.

(In-country interview)

Introduce consistent legislation and provide regulatory certainty.

All relevant ministries and the country’s development plans highlight the importance of renewable energy for Papua New Guinea and recognize the need for private sector participation. Vision 2050 has set the ambitious goal of achieving 100% electricity generation from renewable sources by 2050 (GoPNG 2009a). The National Strategy for Responsible Sustainable Development, the National Energy Policy 2017–2027, Papua New Guinea’s Intended National Contributions, and other policy documents reiterate this target.⁸¹

⁷⁹ Local quality rules can fragment markets and increase costs (Lighting Global 2016). Without coordination with established international standards and testing schemes, local quality standards can do considerable harm by creating unnecessary costs and barriers. Combined with poor implementation and enforcement, they can even be counterproductive, benefiting low-quality products that manage to avoid customs control. For example, in Ethiopia, mandated local testing of all products (including systems passing Lighting Global quality verification standards) with little testing capacity in the country led to already quality-verified products being held up in customs while a considerable share of non-affiliate products bypassed authorities (Lighting Global 2018).

⁸⁰ TV and radio were regarded as less effective means as the market is fragmented (in-country interviews).

⁸¹ See DNPM (2014); DPE and DP&E (2017); GoPNG (2014); and GoPNG (2016).

While targets are an important tool to signal political commitment and encourage investment (UNDP 2017), they are not sufficient in themselves. First, they have to be realistic. Second, in order to achieve them, goals need to be backed up by legislation and regulation that are effectively implemented and enforced.

The renewable energy industry has identified financial and political/regulatory risks as the most significant barriers for the deployment of renewable energy infrastructure (EIU 2011). Governments play a critical role in setting up a coherent and credible enabling environment, with policies that provide the incentives and support market signals for renewable energy (OECD/IEA and IRENA 2017; World Bank 2010). This includes the challenging task of balancing consumers' interest in affordable tariffs with the need to ensure sufficient and predictable commercial returns to attract private investment (Lowy Institute 2017).

While the Government of Papua New Guinea recognizes the need for private investment,⁸² so far, comparatively little has been done to create the necessary enabling conditions. The lack of a predictable and reliable regulatory environment for renewable energy undermines private sector activity in this area.

The economics of off-grid have become compelling, but policy setting has not caught up yet.

(In-country interview)

Therefore, it is recommended for the Government of Papua New Guinea to strengthen regulatory certainty in the electricity sector, particularly concerning off-grid electrification. This includes increasing policy and regulatory coherence, clarifying the roles and responsibilities among government institutions

relevant for renewable energy, strengthening the independent regulator, establishing incentives that are consistent with policy objectives, and creating a more flexible tariff system.⁸³

Regulatory uncertainty in Papua New Guinea is evidenced by the following three issues:

1. Necessary policies and legislation do not exist. This includes many instances where there is uncertainty about the current state of a specific policy, legislative act, or regulation. There are repeated cases where it is not clear whether provisions exist as a draft or have been approved by the government. When legislation is adopted, it is often uncertain to what extent it is being implemented by the relevant authorities.
2. There is considerable inconsistency between existing policies, legislation, and regulations. There are prominent examples in Papua New Guinea where existing provisions are contradictory.
3. There is a lack of existing policies and regulations being enforced. The lack of enforcement is a direct result of inconsistency within the existing legislation, coupled with unclear mandates and overlapping responsibilities between authorities as well as political interference.

These are symptoms of deeper governance challenges in Papua New Guinea, which are often complex and interlinked, including corruption, inefficient government bureaucracy, lack of security, paucity of basic infrastructure outside the main cities, and dearth of resources and qualified staff (IMF 2017).

⁸² For example, the National Strategy for Responsible Sustainable Development explicitly mentions among its eight policy instruments (5) the need for a "sound framework of fiscal, financial and legislative instruments" and (8) the need for "providing predictable policy signals to ensure that potential innovators and adopters of climate friendly technologies are not dissuaded from undertaking the necessary investments" (DNPM 2014).

⁸³ Strengthening the independent regulator, establishing incentives that are consistent with policy objectives, and creating a more flexible tariff system are discussed in a separate recommendation. See *Reform the electricity tariff system, moving away from a uniform tariff. Strengthen the independent regulator.* in this report.

Addressing them will require a long-term effort and strong political commitment at the highest levels of government. While it is well beyond the scope of this report to address these underlying challenges, the following sections offer recommendations on how to address some of the symptoms.

Necessary policy and legislation do not exist

First, there are several high-level strategic documents that cover renewable energy, including:

- Vision 2050,
- Development Strategic Plan 2010–30,
- National Strategy for Responsible Sustainable Development,
- National Climate Compatible Development Management Policy, and
- Climate Change Management Act.

These documents are largely aspirational and generally vague on how to support renewable energy. Some of them, such as the National Climate Compatible Development Management Policy (OCCD 2014), are of questionable quality and relevance.

There are also several central policies and plans that are relevant for the electricity sector. Often, they were drafted with the support of different development partners. There is no Renewable Energy Policy. Existing policies include:

- National Energy Policy (2017),
- Electricity Industry Policy (2011),
- Electricity Code (n.d),
- Third Party Access Code (2014),
- National Electrification Rollout Plan (2017),
- Independent Consumer and Competition Commission Act (2002), and
- Geothermal Energy Policy (2012).

However, the status of many of these plans and policies is either unclear or they are outdated and under revision. For example, there have been several drafts of a National Energy Policy. However, to date, none have been adopted and they have no formal status (in-country interviews).⁸⁴ The Electricity Industry Policy was adopted in 2011, opening electricity generation to competition (GoPNG 2009b). However, several of the provisions under this policy are currently not or have never been implemented. According to in-country interviews, the Electricity Industry Policy is currently under review. The National Electrification Rollout Plan exists in the form of a 2017 report by the Columbia University's Earth Institute and Economic Consulting Associates, prepared to inform the development of the National Electrification Rollout Plan (The Earth Institute and Economic Consulting Associates 2017). According to in-country interviews, the results of the study are being used as the basis to coordinate grid extension with off-grid solutions.⁸⁵

⁸⁴ Four distinct National Energy Policies have been identified for the period from 2010 to 2018, with likely more versions existing during that time frame. IRENA (2013) refers to a National Energy Policy drafted in 2011. Versions of the National Energy Policy 2016–2020 (DPE and DP&E 2015) and National Energy Policy 2017–2027 (DPE and DP&E 2017) were obtained by GGGI. A newspaper article from March 2018 refers to the National Energy Policy 2018–2028 (Tarawa 2018), but a copy could not be obtained by GGGI. During in-country interviews, the Department of Petroleum and Energy confirmed that the National Energy Policy 2018–2028 is identical to the National Energy Policy 2017–2027.

⁸⁵ This work is undertaken by a local consultant on behalf of DP&E (in-country interviews).

In addition, most of the existing strategies and plans appear to be focused on grid extension and provide little clarification on the government's vision for off-grid electricity. These plans do not critically evaluate the feasibility of the current target of expanding the grid to cover 70% of households by 2030, given the high investment costs. They also do not identify a role for off-grid technologies. The demarcation of grid and off-grid areas is at a very early stage.⁸⁶ While few details are known at this point, demarcating areas exclusively for off-grid development would help to minimize the risks of grid arrival to off-grid sites and enable companies, financiers, and consumers to make informed investment decisions.⁸⁷ For them, grid extension comes with considerable risk of affecting off-grid infrastructure, business plans, license regulations, and—in the worst case—rendering off-grid investments obsolete. Therefore, companies operating in the off-grid sector aim to align their strategies with government plans that pronounce a specific role for off-grid renewables (Lighting Global 2016). However, companies are unable to do so in the absence of clearly assigned roles for grid and off-grid electrification.

The Climate Change Management Act and the Paris Agreement Implementation Act were proud achievements, but at the moment, there is no regulation to support their implementation.

(In-country interview)

Furthermore, numerous plans and policies lack the necessary regulation to be implemented. Among others, regulation needs to be developed for the Climate Change Management Act, Paris Agreement Implementation Act, National Adaptation Plan, and National Energy Policy. For example, specific legislation adequately

addressing individual fuels and technologies is largely missing. The National Energy Policy calls for legislation and regulatory frameworks to be formulated, but the institutions for developing these provisions have yet to be created.⁸⁸

While there are frequent policy initiatives, electrification—particularly rural electrification—appears to remain ad hoc and uncoordinated, with individual projects often being implemented where donor finance is available. In the absence of a suitable regulatory framework, modalities for individual projects are often agreed on case by case (in-country interviews). This leads to both inconsistency and uncertainty, deterring potential investors. Finally, the uncertainty around existing policies and plans is also reflected in a gap between the institutional setup as it exists on paper and the actual distribution of responsibilities. Documents call for changes in institutional setup, which are often not or only partially implemented.⁸⁹

⁸⁶ While demarcation of grid/off-grid areas is at a very early stage, in-country interviews indicated that extension will likely start around the three profitable main grids and include unprofitable areas at a later stage.

⁸⁷ Given the state of uncertainty to what extent grid extension and off-grid solutions represent least-cost options, the entire territory of PNG would not need to be demarcated as one or the other. Instead, areas where uncertainty exists could be demarcated and assigned specific options once viability and costs become clearer based on experiences made in other locations (in-country interviews).

⁸⁸ The policy asks for a Geothermal Energy Policy, a Hydro Energy Policy, a Renewable Energy Policy (covering biomass and wind), and legislation for solar energy to be formulated by the proposed National Energy Authority under a newly created Ministry of Communication, Information, Technology, and Energy (DPE and DP&E 2017).

⁸⁹ Compare National Energy Policy 2017–2027 as a recent example.

Box 4. Geothermal policy as a quick win

The example of geothermal energy demonstrates how urgently suitable legislation and regulation is needed. The lack of adequate legislation and a regulatory framework is commonly regarded as the main reason for why no geothermal projects—beyond the Lihir mine—have materialized in Papua New Guinea (Kuna and Zehner 2015; in country interviews).⁹⁰ While several companies have undertaken reconnaissance, carried out exploration surveys, and in some cases even submitted license applications,⁹¹ progress hinges on a more appropriate legal framework. The Mineral Resources Authority (MRA) has put a moratorium on issuing licenses until the necessary regulations are in place (Kuna and Zehner 2015; in-country interviews).

The 2012 Geothermal Energy Policy (DMPGM 2012) is considered inappropriate for geothermal development. It is vague and, at times, contradictory. The policy defines geothermal energy as “a mineral for all purposes,” which allows it to be a subject of existing legislation.⁹² However, this definition hardly makes the Geothermal Policy suitable to fulfill its objective to “foster the potential development of geothermal resources in Papua New Guinea” (DMPGM 2012). The document contains no specific provisions for exploitation other than a vague reference to “international best practices” (DMPGM 2012), without any information on their nature or where they can be found. In-country interviews indicated that the policy was drafted without sufficient consultation as one reason for its deficiencies.

The Geothermal Policy needs to be in place as soon as possible. However, the political will to do so is lacking.

(In-country interview)

As a result, the Geothermal Policy has not been adopted. Jurisdiction over geothermal energy is contested between the Department of Petroleum and Energy and the Department of Mineral Policy and Geohazards Management. The existing Geothermal Policy is attached to the Mining Act, which itself is currently under revision. According to the Mining Act, policy and regulatory functions covering geothermal energy currently fall under the jurisdiction of the Department of Mineral Policy and Geohazards Management and the Mineral Resource Authority, respectively. However, the National Energy Policy (not approved) delegates the development of a Geothermal Energy Policy to the proposed National Energy Authority.

It is recommended to for the Government of Papua New Guinea to end the ambiguity regarding geothermal energy. For that purpose, the GoPNG should change the definition of geothermal energy and transfer authority to the Department of Petroleum and Energy (or the National Energy Authority once it has been established). This would be a comparatively simple measure, allowing for the creation of adequate regulation. Going forward, proper funding, resources, and qualified personal are needed to proceed on licensing and, ultimately, project development. However, unblocking the current impasse would be an important first step.

⁹⁰ In case of the Lihir mine, its geothermal power plant was developed using legislation under the Mining Act.

⁹¹ Companies include Geothermal Development Associates, KuTh Energy, and Reykjavik Geothermal (Kuna and Zehner 2015).

⁹² “Specific to its mode of operation in exploiting the geothermal energy, the mining tenement approval process, application, administration and regulation shall be applied” (DMPGM 2012).

Inconsistency between policies, legislation, and regulations

Second, unclear mandates and uncoordinated and ad-hoc development of policies lead to inconsistency between existing policies, legislation, and regulation. Such inconsistency creates uncertainty and undermines the aim to attract private sector investment. This is particularly important as individual projects are generally subject to numerous laws and provisions.⁹³

Three prominent examples highlighting existing inconsistencies and ambiguities are:

1. The target of achieving 100% electricity generation from renewable sources by 2050 (GoPNG 2009a);
2. The goal of 70% of households having access to electricity by 2030 (DNPM 2010) and how it aligns with the target of 100% electricity generation from renewables; and
3. The aim to deliver a reliable electricity supply, encourage competition, and attract private sector investment while increasing electricity access and supplying electricity at affordable prices.

First, there is no coherent plan toward achieving the goal of 100% electricity generation from renewable sources by 2050. It is laudable for the GoPNG to not commit to any single technology and let the market decide which renewable technologies are most suitable.⁹⁴ However, supporting all technologies—fossil and renewable—is in clear contradiction to the declared goal of achieving 100% electricity generation from renewable fuels. Such inconsistencies cannot only be found between different policies and plans but also exist within single documents. The National Energy Policy 2017–2027 is a prominent example, declaring its support for a wide range of renewables as well as natural gas and *clean* coal (DPE and DP&E 2017). In-country interviews pointed out that the goal of 100% renewables is politically contentious, with influential advocates of coal preventing a full commitment to renewables.

Second, there is also no coherent plan on how to achieve the target of 70% of households having access to electricity by 2030 (DNPM 2010). Currently, there is no consistent plan or timeline for grid extension. As a result, there is also no distinction between areas that will be connected to any of the existing electricity grids and areas for which off-grid solutions will be needed, undermining investment into off-grid renewables. Furthermore, the two goals—achieving 100% renewables and expanding electricity access to 70% of the population—do not represent a coherent mandate. The target of 70% access envisions relying on least-cost options for electrification. However, renewables do not necessarily represent the least-cost option. In particular, natural gas is regarded as cost competitive in Papua New Guinea (in-country interviews).⁹⁵

Finally, there is an inherent tension between increasing electricity access and providing reliable supply at affordable prices (see *Support a larger role for private sector, particularly in off-grid electrification* in this report). While this tension is not unique to Papua New Guinea (OECD/IEA 2018; European Parliament 2017), it is hardly acknowledged, much less addressed in PNG. Without recognition that reliable infrastructure comes at considerable costs and that companies need to recover those costs in order to maintain the system and make investments to extend it, the issue cannot be addressed successfully. For example, the country's uniform electricity tariff and the cap on tariffs that has been in place since 2013

⁹³ For example, geothermal energy projects are affected by at least nine existing acts and policies, including (1) the 2002 Electricity Industry Act, (2) 1992 Mining Act, (3) 1996 Land Act, (4) 1989 Physical Planning Act, (5) Independent Consumer and Competition Act, (6) Third Party Access Code, (7) Grid Code, (8) 2000 Environment Act, and (9) 1978 Conservation Areas Act (Kuna and Zehner 2015).

⁹⁴ The National Strategy for Responsible Sustainable Development mentions hydro, solar, wind, tide, geothermal, and biofuels replacing fossil fuels (DNPM 2014).

⁹⁵ Coal-fired power plants were regarded as less competitive and largely being promoted due to political agendas and economic interests of certain actors (in-country interviews).

promote affordability. However, at the same time, both measures undermine the financial health of the country's utility, PNG Power, and inhibit necessary investment to maintain and upgrade the existing networks.

Taking the 2012 Geothermal Energy Policy as an example, the document contains the same contradiction between encouraging cost recovery for investments and supplying electricity at affordable prices. It tasks the state to "[e]ncourage long term investment in geothermal power by ensuring commercial stability in electricity prices" and, at the same time, to ensure "[a]ffordable prices for electricity supplied by geothermal dependent on the supply and demand of geothermal energy power" (DMPGM 2012). Recognizing that these are, at least partially, contradicting mandates would be the first step in addressing them.

Lack of enforcement and political interference

Third, implementation and enforcement of existing regulations is weak. The Government of Papua New Guinea acknowledges this state of affairs. For example, the National Strategy for Responsible Sustainable Development explicitly recognizes the need to strengthen enforcement in order to increase investor confidence (DNPM 2014). However, the strategy does not include any means of how to improve enforcement, except in very broad terms.⁹⁶

Weak implementation and enforcement are a direct result of the lack of adequate legislation and inconsistencies between and within policies. This entails that goals are set (and occasionally revised), but the means to achieve these goals are often not being identified. For example, there are aspirations to build additional hydropower plants as well as to tap into the country's solar, wind, and biomass potentials. However, there is little detail on how to realize the existing potential.

Moreover, this is compounded by political interference; missing or unclear distribution of responsibilities between institutions; and a lack of resources, qualified staff, and budget within the administration (Adam Smith International 2018; IMF 2017; Lowy Institute 2017; The Earth Institute and Economic Consulting Associates 2017; in-country interviews).

A clear institutional setup can be a first step to promote implementation and enforcement. Based on successful and failed experiences of electrification attempts worldwide, the World Bank (2010) suggests that "[t]here is no evidence for the superiority of any specific institutional model for electrification." However, while there is no specific setup to guarantee success, clear roles and responsibilities should be assigned to individual authorities in order to reduce uncertainty and increase accountability. During in-country interviews, it was pointed out repeatedly that mandates between different institutions in Papua New Guinea are, at times, overlapping and contradictory, with coordination between departments, awareness of other departments' responsibilities, and consultative processes lacking. This finding is confirmed by various assessments (e.g., USAID and CCDA 2018).

Referring again to the example of the 2012 Geothermal Energy Policy, roles of relevant authorities are not clearly defined and/or overlapping. The document lists the following institutions as government agencies responsible for the development, planning, monitoring, and implementation of the policy (DMPGM 2012):

- Department of Mineral Policy and Geohazards Management (DMPGM),
- Mineral Resources Authority (MRA),

⁹⁶ The strategy mentions "prior and informed consent, polluter pays principle, and freedom of information" (DNPM 2014), without any explanation of how these measures support enforcement or would be enforced themselves.

- Mining Advisory Council (MAC),
- Independent Consumer and Competition Commission (ICCC), and
- PNG Power Limited (PPL).

The Mineral Resources Authority is declared “the overall implementing and regulating agency for the development of the geothermal energy resource.” However, the Independent Consumer and Competition Commission is also given regulatory authority as it “shall be responsible for regulating prices, service standards and in adjudicating disputes related to access codes and access arrangements” (DMPGM 2012). Furthermore, the Mining Advisory Council assesses applications by developers, instead of the regulator, while the Minister for Mining assesses the applications—again, instead of the regulator (DMPGM 2012). Finally, “the Mineral Resources Authority, the developer and the PNG Power Limited shall be responsible for formulating the power supply plan for the geothermal energy resources” (DMPGM 2012). It is unclear what that means in practice. While it might only refer to grid-connected infrastructure, it could also mean that, effectively, PPL is being given a veto on any geothermal projects. The reason behind this overlap of authority might be that relevant departments are either understaffed or lack technical capacity (IRENA 2013; The Earth Institute and Economic Consulting Associates 2017). However, in practice, such an arrangement undermines effective implementation and competition.

Deliberations during the development of the National Electrification Rollout Plan appear to confirm this analysis. They include the creation of a new agency to function as “the owner and licensed operator of all mini-grids.” It would fulfill the role of a procurement authority and asset manager, neither constructing nor operating the systems. Instead, all services would be contracted out to either the private sector or PPL (The Earth Institute and Economic Consulting Associates 2017). It is questionable whether creating yet another institution will alleviate any of the obstacles identified above (technical capacity, insufficient regulatory certainty, overlap of regulatory responsibilities). Since the authority is envisioned as a sister company to PPL, it is unclear how a competitive procurement process would be ensured.

In addition, the report admits that “the large scale and aggressive pace of NEROP suggest that technical capacity, staffing and financial resources will all need to be increased.” In particular, the capacity of the newly created agency “will largely need to be built from scratch” (The Earth Institute and Economic Consulting Associates 2017). Given the existing scarcity of qualified personnel, it is unclear if any level of technical assistance—as suggested in the report—can successfully address this gap.

Reform the electricity tariff system, moving away from a uniform tariff. Strengthen the independent regulator.

There is a large consensus that the uniform electricity tariff undermines both increasing electricity access in rural areas and the effective deployment of renewable energy solutions in Papua New Guinea (ADB 2015a; APERC 2017; IRENA 2013; OECD/IEA and IRENA 2017; Lowy Institute 2017; UNEP 2017). In PNG, power tariffs are set on a national basis. Retail prices depend on consumer size but are uniform within each consumer segment (PNG Power 2013; in-country interviews). The tariff neither reflects cost differences across location nor between different times of the day or different periods during the year. As a result, the existing tariff does not reflect local generation, transmission, and distribution costs.

The uniform tariff was established under the Community Service Obligation (CSO), obligating PNG Power to subsidize electricity prices in its loss-making, diesel-powered mini-grids with revenues from the profitable three main grids (GoPNG 2009b). In-country interviews confirmed that the current setup with cross-subsidies between different locations prevents competition in the electricity retail market.

However, without the existing obligation on PPL to subsidize local grids, considerably higher tariffs would be needed to recover costs or these loss-making grids would be shut down.

In practice, CSO has failed to catalyze rural electrification. Instead, the uniform electricity tariff serves as a disincentive for PPL and the private sector to make investments for increasing electricity access in rural areas and has led to chronic underfunding in the sector (ADB 2015a; ADB 2015c; APERC 2017; IRENA 2013; Lowy Institute 2017; The Earth Institute and Economic Consulting Associates 2017). It also discourages the deployment of renewable energy solutions in off-grid areas. While renewables are regarded as cost competitive with currently used diesel generators, their costs exceed the current retail tariffs. As a result, mini-grids supplied by renewable energy would make financial losses, although likely at a lower rate than current diesel-based generation.

Subsidies are an important policy tool, although they should be deployed cautiously. Given the existing dilemma of recovering costs while providing affordable access, there is no viable alternative to subsidizing off-grid electrification. However, ensuring affordability under a differentiated tariff structure will require changing the existing subsidies regime. The current system of internal cross-subsidies forced on PPL replaces an important policy decision: the mechanism and extent of subsidies to rural and other disadvantaged electricity users. While it is recommended for the GoPNG to deliberately make that decision, the government's track record regarding accountability of subsidies is mixed (ANZ 2015).

It is regarded as a step in the right direction that ICCC is currently undertaking a market review for options to move away from cross-financing. This is one requirement to allow for opening the retail market to competition and entails new options for local mini-grids (in-country interviews).⁹⁷

The adverse impact of the uniform tariff structure is aggravated by the GoPNG having put a freeze on tariffs since 2013. This political intervention goes against the provision that tariffs should be adjusted on a quarterly basis (ICCC 2013). Therefore, reforming the electricity tariff system will require strengthening the independence of the regulator and reducing the space for political interference in setting tariffs.

Officially, the Independent Consumer and Competition Commission has the role of technical and economic regulator in the electricity sector. However, ICCC suffers from a lack of technical capacity and underfunding, undermining its ability to carry out its mandate. Therefore, in practice, the function of technical regulation currently resides with PPL.⁹⁸ Independence of the ICCC is also undermined by its

This regulation [of a uniform tariff for customers within a particular category], however, suppresses the growth of the electricity sector in PNG by foreclosing investments that seek to charge the true cost on electricity commercially. The higher cost areas of investments, especially rural areas, have being effectively neglected the provision of the vital electricity service as the consequence of this. While the uniform tariff regulation of the Government may be to the benefit of the users of electricity services (in the form of avoided high prices) in commercially higher cost areas of investments in electricity supplies, it does not give the incentive to service providers, let alone the State-owned utility – PPL, to take up commercial investments in these areas.

(PNG Electricity Industry Policy, GoPNG 2009b)

⁹⁷ The commission is also looking into feed-in tariffs for grid-connected renewable energy systems.

⁹⁸ While PPL itself is a regulated entity and the arrangement raises question marks regarding fair competition, in-country interviews pointed out that there is currently no viable alternative except for PPL to play the role of technical regulator.

dependence on government finance. According to GEF, UNDP and SPREP (2009) fees paid by regulated entities only cover about 10% of the commission's budget, with the GoPNG providing the rest of the funding. Such financial dependence might reduce the ability of ICCC to resist political pressures and interference.

The National Energy Policy envisages that the function of technical regulator will move from PPL to the National Energy Authority (NEA), once it has been properly established (DPE and DP&E 2017, in-country interviews).⁹⁹ However, creating a new authority without addressing the shortcomings described above will not strengthen the regulator's independence. Rather, the National Energy Policy appears to maintain the status quo, with no provisions preventing political interventions and funding for the NEA being provided from government budgets, as well as licensing and regulation fees, which have already proven to be insufficient.

⁹⁹ More precisely, the National Energy Policy envisages the creation of the Energy Regulatory Commission (ENERCOM) as the regulator for the electricity sector. Together with the newly created National Energy Authority, ENERCOM is proposed to be part of a restructured Department of Petroleum and Energy. However, a number of provisions are inconsistent under the policy. It stipulates that ENERCOM should "be established as a separate entity to protect its mandate as a regulator for energy." However, the policy undercuts that provision by also declaring the NEA as responsible for "energy regulatory functions both technical as well as economic." Finally, the document suggests that ENERCOM will be initially housed under the NEA (DPE and DP&E 2017).



5. Agriculture and Forestry

5.1 Overview

Agriculture and forestry are essential sectors in Papua New Guinea. The country's forests are of global importance, covering more than two-thirds of PNG's land mass, and—together with forests in the neighboring Indonesian province of Papua—comprising the third largest tract of intact tropical forest in the world (Babon and Gowae 2013; UPNG 2015; GoPNG 2017a). As of 2017, approximately 85% of PNG's population of 8.3 million¹⁰⁰ lived in rural areas, with more than 80% of the population depending on subsistence farming and resource extraction from local forests for their livelihoods (Babon and Gowae 2013; UPNG 2015; Page et al. 2016; GoPNG 2017b).

In 2017, agriculture, forestry, and fisheries generated approximately 20% of Papua New Guinea's GDP and employed approximately 20% of the country's work force (BPNG 2019a; UNDP 2018). Over 3 million hectares of land are dedicated to smallholder farmers and family subsistence agriculture (UNDP 2018). Estimates suggest that, in 2006, informal incomes from subsistence agriculture were equivalent to USD 3.6 billion, amounting to approximately the same as the formal agricultural, forestry, and fisheries sectors' combined contribution to the economy (Anderson 2006; UNDP 2018).

Despite Papua New Guinea's rugged topography, rendering certain forested areas commercially inaccessible, agriculture- and forestry-related activities have a substantial impact on the country's environment, particularly in terms of forest cover. Between 2000 and 2015, over 250,000 hectares of land were deforested while close to 2.5 million hectares of forest land were degraded (figure 23). While there is considerable uncertainty, estimates suggest that, on average, between 13.5 and 30 Mt of CO₂

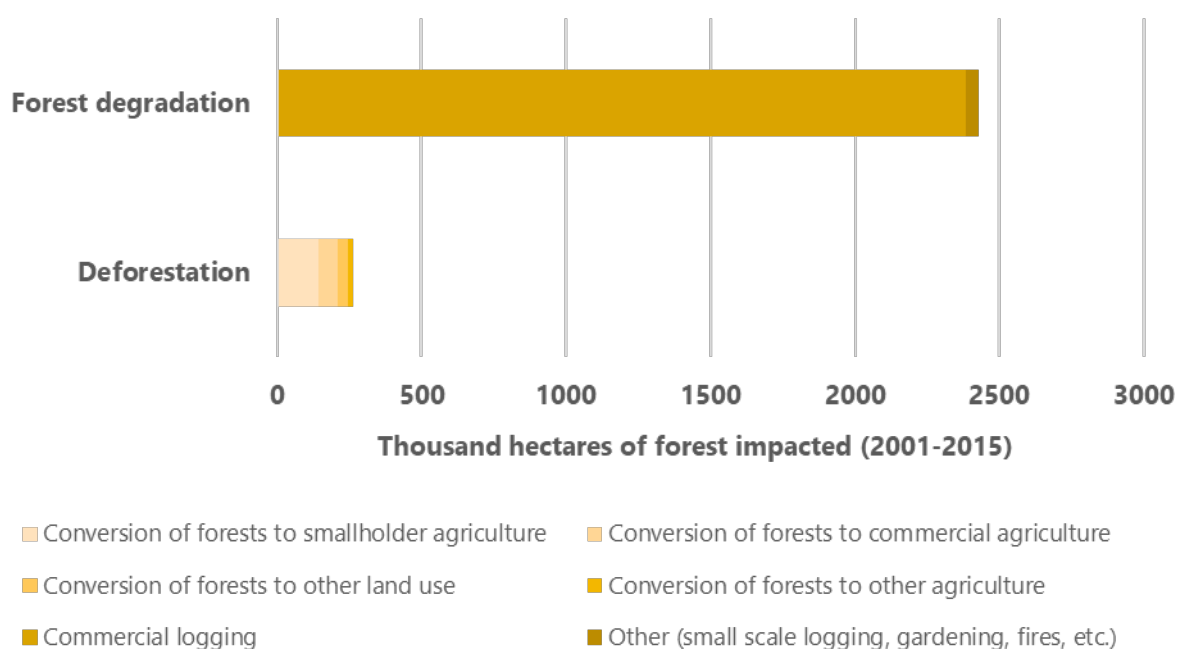
¹⁰⁰ The World Bank (2018c) estimates Papua New Guinea's population at approximately 8.3 million people as of 2017. In-country interviews suggested that the county's population might be significantly higher than indicated by official statistics, with the total population possibly amounting to more than 10 million people.

have been emitted annually as the result of deforestation and forest degradation, representing up to 70% of the country's total emissions (in-country interviews; GoPNG 2017b; UNDP 2018).

Commercial logging is estimated to account for 98% of forest degradation in Papua New Guinea and is often identified as the single largest source of emissions, with up to 24.3 Mt of CO₂ per year (GoPNG 2017b; UNDP 2018). As of 2015, subsistence farming was regarded as the lead cause of deforestation, due to the practice of shifting cultivation becoming increasingly unsustainable as a result of rapid population growth (Babon and Gowae 2013). Pressure on forestland is increasing in areas with higher population densities while deforestation caused by commercial plantations—notably oil palm plantations—is also rising.

A rapidly growing population¹⁰¹ and policies to expand commercial agriculture, along with plans to continue ineffective reduced-impact logging, are increasing the risk of further deforestation and forest degradation (Babon and Gowae 2013; UNDP 2018). For example, Papua New Guinea's Climate Compatible Development Strategy (2010–2030) stipulates the objective of expanding agricultural production of commercial plantations for palm oil, cocoa, coffee, and copra by 5–6% annually (OCCD 2010; Babon and Gowae 2013). This translates into considerable requirements for additional land.

Figure 23. Primary drivers of forest cover change in Papua New Guinea



Source: Adapted from GoPNG 2017b

¹⁰¹ Estimates suggest a population growth of 2–3% per year in Papua New Guinea (UN 2017; World Bank 2018c; in-country interviews).

5.2 Relevance of REDD+

While deforestation has considerable impacts on the local environment in Papua New Guinea, the country's forests are also of global significance. They represent the third largest tract of intact tropical forest and thereby one of the world's largest carbon storages. As a result, any decline in PNG's forest area has significant repercussions on global GHG emissions. Therefore, ongoing efforts toward sustainable forest management and more sustainable agricultural practices are addressed as part of Papua New Guinea's National REDD+ Strategy 2017–2027 (GoPNG 2017b).

REDD+ stands for "Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries." It is an international financing mechanism to support mitigating climate change through reducing net emissions of greenhouse gases related to forest cover loss. For that purpose, the program provides financial incentives to encourage more sustainable forest management practices in developing countries. Successful reductions in deforestation and forest degradation are rewarded in the form of results-based payments (GoPNG 2017b).

REDD+ was adopted under the United Nations Framework Convention on Climate Change (UNFCCC) (GoPNG 2017b). Papua New Guinea has been a major proponent of REDD+ since its conception, having introduced, jointly with Costa Rica, the concept of reducing emissions from deforestation at the UNFCCC 11th Conference of Parties (COP 11) in 2005. REDD+ is also included in Article 5 of the Paris Agreement and is an encouraged activity toward mitigating climate change (UNFCCC 2019).

A number of funding entities of REDD+ programs have been established, including UN-REDD and the Forest Carbon Partnership Facility (FCPF), which, along with other multilateral or bilateral agencies, support developing countries in establishing REDD+ activities (Corbera and Schroeder 2018; Cadman et al. 2017). REDD+ activities are present in 65 countries under the scope of UN-REDD and 47 countries with FCPF. Proponents of REDD+ regard it as an important financing mechanism for developing countries, with recent payments for reduced emissions in Brazil and agreements for future performance-based payments in Mozambique and the Democratic Republic of the Congo cited as evidence for the programs' potential (UNFCCC 2019; World Bank 2019).

REDD+ often involves a readiness phase, setting up relevant institutions and infrastructure to validate effective emissions reductions. This is followed by an implementation phase. During that phase, a country's REDD+ strategy is tested in selected areas and refined to be more effective, before being fully implemented and scaled up. If successful, measurement, reporting, and verification of GHG emissions from the forestry sector unlock the results-based payments for emission reductions. As of 2017, Papua New Guinea was in transition from the readiness phase to the implementation phase (GoPNG 2017b).

Countries are encouraged to engage in REDD+ through five types of activities that contribute to climate change mitigation (UNFCCC 2010):

1. Reducing emissions from deforestation,
2. Reducing emissions from forest degradation,
3. Conservation of forest carbon stocks,
4. Sustainable management of forests, and
5. Enhancement of forest carbon stock.

The initial focus of Papua New Guinea's REDD+ Strategy rests on three of these five activities: (1) reducing emissions from deforestation, (2) reducing emissions from forest degradation, and (3) enhancement of forest carbon stocks. Expanding the scope to the other two activities (conservation of forest carbon stocks and sustainable management of forests) will be considered as data availability and methodologies improve, particularly regarding the accuracy of measuring forest degradation through logging, as logging represents the largest source of emissions in PNG (GoPNG 2017b).

Furthermore, countries are requested to provide four components that are necessary for the effective implementation of REDD+ (UNFCCC 2010):

1. A national strategy or action plan;
2. A national forest reference emission level and/or forest reference level;
3. A robust and transparent national forest monitoring system; and
4. A safeguards information system.

PNG’s National Forest Monitoring System (NFMS) has been operational since 2016 while 2017 saw the submission of the country’s Forest Reference Level (FRL) and the publication of its National REDD+ Strategy (NRS) (GoPNG 2017a; GoPNG 2017b).

First, according to the UNFCCC, a national REDD+ strategy or action plan entails a structured approach to engage in REDD+ activities. A strategy should highlight the rationale for REDD+, its goals, and the actions to be taken to address forest cover loss and associated emissions (CCDA 2017a).

Papua New Guinea’s National REDD+ Strategy focusses on the three following areas to address forest cover loss:

1. Strengthen land use and development planning, through the development and application of indicators and improving coordination between national and subnational planning.
2. Strengthen environmental management, enforcement, and protection, through improved climate legislation and financing, forest and environmental management, and access to information and resources.
3. Enhance economic productivity and sustainable livelihoods, through the development of a sustainable commercial agricultural sector, improved food security, and increased productivity of smallholder farming.

The Government of Papua New Guinea will need to develop a REDD+ Finance and Investment Plan (FRIP) in order to identify specific activities to achieve the goals of the REDD+ strategy, including budgets and approaches to financing (GoPNG 2017b; FCPF 2018).

Figure 24. Timeline of REDD+ in Papua New Guinea



Source: GoPNG 2017b

Second, a national Forest Reference Level serves as a benchmark for assessing a country's performance in reducing emissions and increasing carbon sequestration as a result of REDD+ activities (GoPNG 2017a). The Government of Papua New Guinea submitted the country's Forest Reference Level to the UNFCCC in 2017 (FCPF 2018).

Third, a National Forest Monitoring System serves (1) to monitor national policies and measures toward REDD+ and (2) to measure, report, and verify GHG emissions and removals in the forest sector (GoPNG 2017a). PNG's National Forest Monitoring System has been officially operational since 2016.¹⁰² A National Forest Inventory is currently under development and will be integrated into the National Forest Monitoring System once it has been concluded.

Finally, a Safeguards Information System (SIS) is necessary to verify whether or not application of the Cancun REDD+ Safeguards in Papua New Guinea is in line with guidance provided by the UNFCCC. These safeguards comprise—among others—measures to prevent and mitigate undue harm to vulnerable people and ecosystems as the result of REDD+ activities (CCDA 2017b; GoPNG 2017b). While a scoping exercise on REDD+ safeguards was conducted in 2015, to date, a Safeguards Information System has not been established in Papua New Guinea (CCDA 2017b; GoPNG 2017b).

Box 5. Criticism toward REDD+

Although regarded as a cost-effective strategy to reduce emissions from forestry-related activities and included as a core element in the Nationally Determined Contributions (NDC) of many highly forested countries under the Paris Agreement, REDD+ has come under criticism for a number of different concerns (Corbera and Schroeder 2018). These concerns notably relate to the top-down, institutional approach of REDD+, which—if lacking in good governance, interagency coordination, and transparency—can render REDD+ less successful in mitigating climate change (Cadman et al. 2017). Similarly, weak governance, vested economic interests, and political patronage accentuate the risk of intensifying inequalities in access to forest and land resources. This can particularly affect the rights of indigenous communities whose subsistence and livelihoods are dependent on forests (Corbera and Schroeder 2018; Fujisaki et al. 2016). There is a wide spectrum of challenges, including lack of local capacity, misalignment of policies, inadequate tenure arrangements, and unfavorable political economies. These challenges can lead to social conflicts, limited gains in well-being for local populations, and insufficient sharing of benefits, ultimately undermining the legitimacy of REDD+ initiatives (Fujisaki et al. 2016; Cadman et al. 2017; Corbera and Schroeder 2018).

Concerns are also raised with regard to the accuracy of estimated reductions of GHG emission as a result of REDD+. For example, Nomura et al. (2019) note that different forest definitions—in terms of minimum closed canopy area, whether or not certain plantations are included in definitions, and minimum mapping units—have a significant impact on forest cover reporting. As a result, they suggest that forest cover and forest cover change may have been underestimated in Papua New Guinea's official Forest Reference Level. The FRL reports 36.2 million hectares of forest area in 2000 and 100,00 hectares of forest cover loss between 2000 and 2010 while the authors estimate a 2000 forest cover of 43.9 million hectares and a net loss of 280,000 hectares by 2010 (Nomura et al. 2019). Such uncertainties and inaccuracies entail the risk of undermining the credibility of measuring and assessing emission reductions, thus challenging the legitimacy of carbon payments (Nomura et al. 2019).

¹⁰² The National Forest Monitoring System can be accessed under <http://png-nfms.org/portal/>.

Box 5. Criticism toward REDD+ (continued)

A study involving participants in REDD+ activities conducted in 2010 and 2015 showed that respondents deemed the quality of governance in REDD+ as very important while they were concerned about capacity gaps and a lack of resources (Cadman et al. 2017). Fujisaki et al. (2016) found that early REDD+ efforts in Papua New Guinea did not sufficiently involve stakeholders at different levels of decision-making, notably indigenous communities and civil society. They further highlighted that, in 2013, different ministerial agencies and non-state actors had only a consultative function in REDD+ management bodies and institutional arrangements.

As REDD+ moves from its readiness to its implementation phase in Papua New Guinea, strengthening good governance and addressing the limited coordination between different government branches and across different administrative levels is essential. For decades, Papua New Guinea's forestry sector has been the subject of allegations of poor governance and corruption, resulting in illegal and unsustainable logging practices. Lack of transparency and accountability, bribery, non-compliance with regulations, violations of landowner rights, and political lobbying to influence decision-making are all symptoms that have plagued the sector (Babon 2011).

The main actors behind this state of affairs have occasionally been described as an "unholy alliance" of foreign logging companies, corrupt politicians, and willful public servants. While the country's forest laws have been generally regarded as strict, the government either lacked the capacity or the willingness (or both) to enforce these laws. Failures were reported across all ranks of government, from senior politicians to local departmental officers. Powerful vested interests and client-patron relationships have often protected illegal activities from investigation and thwarted attempts at reforming the sector. For example, political pressure is thought to have played an important role for granting illicit Clearance Authorities and Special Agricultural Business Leases (Babon 2011). While recent reports appear to indicate improvement in this regard, it is essential to strengthen anti-corruption efforts to allow for successful sustainable forest management and agricultural practices.

5.3 Recommendations

Strengthen the administration's capacity to collect, monitor, and verify agriculture and forestry data.

Reliable data on agriculture and forestry in Papua New Guinea is challenging to obtain. Due to various constraints, data and statistics on land use, forest cover, forest cover change, and drivers of deforestation are often inconsistent or incomplete. Until recently, Papua New Guinea did not have a reliable national forest monitoring system or inventory. A Forest Inventory Mapping System (FIMS) was developed in the mid-1990s but was considered as unreliable and outdated (Michalak et al. 2002; UPNG 2008; PNGFA 2010; FoE Japan, and GEF 2011).

Instead, UPNG (2008)—a study measuring forest cover change in PNG during 1972–2002 using high-resolution wall-to-wall imagery—was widely regarded as the most useful estimate of forest cover

change and the drivers behind deforestation and forest degradation in Papua New Guinea. The GoPNG and other actors, such as academia and NGOs, utilized estimates from that study—for example, for preparing many of its climate change and REDD+ policy documents—despite its findings being outdated and debates over the validity of its estimates (Filer 2009; Shearman et al. 2010; Babon and Gowae 2013).¹⁰³

Since then, considerable efforts have been made to improve forest monitoring while research has continued to obtain more updated information, notably through the implementation of a national REDD+ program. As a result, a National Forest Monitoring System web portal is now in place, and a National Forest Inventory is currently under development (GoPNG 2017a). Despite these efforts, considerable uncertainty regarding forest data remains.

The extent of uncertainty is exemplified by the considerable discrepancies between recent estimates of forest cover change from 2000 to 2015 (table 8). UPNG (2015) estimates that in 2014, 71% of Papua New Guinea’s land area was covered by some form of forest, with rainforests covering 60% of total land area. This differs from the estimates submitted by the GoPNG to the UNFCCC in its Forest Reference Level and cited in the REDD+ Strategy, suggesting that in 2015, more than 77% of the country’s total land area was forested (GoPNG 2017a; GoPNG 2017b). Meanwhile, FAO estimates forest land cover at approximately 74% of PNG’s land area (FAO 2019a). These differences amount to hundreds of thousands of hectares of forest.

Table 8. Estimates of forest cover and forest cover loss

Source	Period	Total forest cover estimate	Total deforestation over period	Mean annual deforestation rate
UPNG 2015	2002–2014	71%	-1.3%	0.11%
GoPNG 2017a	2000–2015	77.8%	-0.7%	0.05%
FAO 2019a	2000–2015	74.1%	-0.1%	0.01%

Source: Compiled by GGGI

Similarly, estimates for the deforestation rates differ between these sources. While UPNG (2015) estimates that 1.3% of forest land was deforested over the period 2002–2014, or 0.11% per year on average, GoPNG (2017a) reports 0.7% of total forest cover loss between 2000–2015. FAO records hardly any noticeable change over these periods with a total forest loss of 0.1% (FAO 2019a).

These differences may be, in part, the result of different total land area estimates. UPNG (2015) estimates Papua New Guinea’s land area at 46.1 million hectares while GoPNG (2017a) established it at 46.9 million hectares. In addition, forest cover estimates based on different land cover models and different satellite imagery provide different results, as evident from discrepancies between two remote-sensing models reported by FAO (2019b). MODIS suggested a total of 40.5 million hectares of tree-covered areas in 2012 while CCI-LC estimated an area of 39 million hectares for the same year, a difference of close to

¹⁰³ Contentious issues included the estimate of initial forest cover in 1972 and the rate and nature of forest regeneration following logging and clearing for subsistence agriculture (Filer 2009; Shearman et al. 2010; Babon and Gowae 2013).

4%. These discrepancies highlight that available data comes with considerable uncertainty, with little confirmation of these estimates through measurements at representative sampling sites.

Another reason behind discrepancies between estimates are the different forest definitions used by these studies. FAO defines forest as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, or trees able to reach these thresholds in situ (FAO 2019a). The GoPNG uses a similar but slightly different definition, with forests being defined as land spanning more than 1 hectare, with trees higher than 3 meters and a canopy cover of more than 10% (GoPNG 2017a). Finally, UPNG (2015) defines forests as closed canopy rainforests. This last definition does not include woody scrub and gardens nor timber plantations, which are mapped as separate classes to allow expansion of garden areas to be accurately measured and only the clearance of rainforest to be mapped as deforestation (UPNG 2015).

These differences highlight the difficulty to accurately and consistently assess forest cover and forest cover change in Papua New Guinea. The country's challenging topography poses a severe obstacle to data collection and monitoring. While PNG's lowlands are comparatively easier to access, a large share of forests is located in the rugged terrain of the country's extensive highlands. Due to the inaccessibility of certain areas, field validation is not always possible to confirm the accuracy of information collected through remote sensing (GoPNG 2017a). However, relying largely on remote-sensing comes with severe limitations as a result of inherent biases present within land cover models and the different but often coarse spatial resolution of satellite imagery (Pérez-Hoyos et al. 2017). Therefore, the limited accessibility complicates establishing a reliable forest inventory and monitoring of land use activities.

However, topography alone does not explain the situation. The lack of reliable data is also the result of the very limited capacity of the Government of Papua New Guinea to collect data in the agriculture and forestry sectors. This is, in part, due to the lack of human, technical, and financial resources to conduct and manage such evaluations to the extent needed at the provincial level (GoPNG 2014). In addition, repeated cases of corruption and misconduct, as well as a lack of good governance and accountability, have further hindered effective monitoring (Babon and Gowae 2013).

This lack of reliable data leads to significant uncertainty in any larger scale analysis and assessment undertaken in the agriculture and forestry sectors. With basic information regarding forest cover and forest cover change lacking, assessing more complex issues, such as forest regeneration following logging and clearing for subsistence agriculture, becomes largely impossible. Similarly, data on land ownership and land concessions is unreliable, making it difficult to verify and assess whether it accurately reflects actual land use changes. In return, the paucity of reliable analysis impedes the development of relevant policies to address the issues faced within these sectors. Finally, the absence of reliable data also prevents monitoring the impact and evaluating the effectiveness of policies and other interventions.

In effect, the issue of data availability and accessibility is transversal and is a major note of concern for many of the other recommendations within this chapter. Increasing the quality and quantity of data on agriculture and forestry would significantly improve the capacity of stakeholders to take the most appropriate actions toward supporting the efforts for sustainable land use management in Papua New Guinea.

Therefore, it is recommended to strengthen the administration's capacity to collect data and monitor land use activities. For that purpose, the mandate of relevant agencies needs to be reinforced by establishing clear provisions on data collection, including definitions and agreement on what data is to be collected, how it is collected, by whom, and at what frequency. The collected data should be stored within a system that is accessible across different branches of the administration in order to avoid duplication of efforts and inconsistencies. It is also suggested to make the information available to the public in order to increase transparency and facilitate external analysis.

In this context, it is suggested for the GoPNG to seek support from foreign statistics or other offices mandated to collect data and develop monitoring systems for land use. Countries in the Asia-Pacific region, such as Palau or Myanmar, or within Latin America generally possess robust capacities in terms of forest monitoring, inventory, and/or carbon stock reporting (Romijn et al. 2015). Support from international agencies working on land use management is also regarded as valuable. Ongoing efforts as part of the implementation of REDD+ in Papua New Guinea are an encouraging step in this direction. It is imperative that these activities be implemented effectively and their findings be made available for wider applications, as lack of data has severe implications beyond REDD+ activities.

First, lack of reliable data undermines efforts toward forest conservation efforts. Uncertainty around the size and composition of Papua New Guinea’s forests renders the accuracy of classification for their usage uncertain. Due to different definitions and classifications, comparison between sources is not straightforward yet suggests considerable discrepancies. As previously mentioned, estimates for the country’s total forest area show significant differences, ranging from 32.6 (UPNG 2015) to 35.9 million hectares (GoPNG 2017a). Furthermore, assessments of the expanse of different forest types differ. Table 9 illustrates the discrepancies based on the example of two forest types that are common to both studies.

Table 9. Estimated shares of different forest types

Forest type	UPNG (2015)	GoPNG (2017a)
Swamp forest	10.4%	6.8%
Mangrove	1.8%	0.8%

Source: Compiled by GGGI

Note: Values are given as share of forest according to the sources’ own definitions and figures.

Meanwhile, scrub is considered as a separate type of forest by the GoPNG but not by UPNG (2015). In addition, estimates by both sources show marked discrepancies, with 2.2 million hectares for GoPNG (2017a) and 5.1 million hectares for UPNG (2015). These differences in diversity and prevalence of forest types induce large uncertainties for conservation efforts in Papua New Guinea.

In this context, the government’s efforts toward establishing a national forest monitoring system and forest inventory are a first positive step. This is evidenced by Romijn et al. (2015), suggesting that the government’s capacity, in terms of monitoring and inventory capacities, improved from “intermediate” to “good” between 2010 and 2015, despite remaining below other countries in the region, such as Indonesia and Malaysia.

The National Forest Inventory was initiated in 2015–2016. One of the major objectives of the inventory is to estimate the above-ground biomass per unit of area of every forest type, disaggregated by its level of anthropogenic disturbance. This initiative will facilitate the calculation of emissions related to deforestation and degradation. The inventory is expected to be complete and available later in 2019 or 2020 (GoPNG 2017a). Once published, the inventory should help to reduce the uncertainty about fundamental forest data in Papua New Guinea. However, it is important to ensure that the information is shared across departments and made available publicly and that the inventory is updated in regular intervals.

Second, the lack of reliable forest coverage data also contributes to unsustainable logging practices and deforestation due to the overestimation of annual allowable cuts. The overestimation of permitted cuts is a result of overestimating the amount of timber contained within land concessions (UPNG 2015). Furthermore, lack of field data impedes the verification of land use activities. For example, such monitoring is needed to ensure that a concession actually results in the agreed agricultural development and does not merely become a logging enterprise.

Therefore, it is recommended for the Government of Papua New Guinea to obligate logging and commercial agriculture corporations to report on their activities according to more stringent standards than currently in use. Mandatory reporting should include the amount of exports to validate the quantities of harvested wood. It should also include detailed information regarding tree replanting or agricultural development activities to ensure compliance with the terms of leases. Mandatory reporting should be accompanied by independent verification through unannounced field audits. Furthermore, it is recommended for the administration to strengthen its checks on companies' track records, regarding past compliance with sustainable practices, and sanction companies with unfavorable records.

Third, collecting data on property rights is challenging due to the land tenure system in Papua New Guinea. The country officially recognizes customary land tenure in its constitution, where land can be attributed to an individual or group of individuals—most of the time, a clan. However, this traditional and decentralized practice is often undocumented and leads to challenges when attempting to identify landowners (Chand 2017). In-country interviews confirmed that the formal establishment of landownership is a complex and lengthy process, due to lack of documentation and competing claims. Transferring ownership or land use rights is equally complex and fraught with risks of misconduct.

The paucity of information concerning land tenure is evidenced by the uncertainty regarding the actual share of land under customary ownership. Numerous reports cite the figure of 97% of Papua New Guinea's land area as being under customary land tenure (Pat 2003; PNGFA 2009; Page et al. 2017; Scudder, Herbohn, and Baynes 2018). This figure is also cited at times by local stakeholders, despite the growing evidence that considerable amounts of land have been removed from customary ownership (Filer 2014). This has occurred, most notably, through Special Agricultural Business Leases (SABL), issued until 2011 but still in effect. Under these leases, 5.1 million hectares—corresponding to more than 10% of Papua New Guinea's land area—were attributed to mostly foreign corporations for long-term leases of usually 99 years, for the intended purpose of agricultural development (Filer 2014; UPNG 2015). The current uncertainty of who owns the land is such that Papua New Guinea's REDD+ Strategy now refers to only over 90% of the country's land area being under customary land ownership (GoPNG 2017b).

The lack of data transparency is further evidenced by the difficulty to identify the nominated developer in certain lease agreements, with the Government of Papua New Guinea often being unaware of transactions that occurred after the lease had been granted (Nelson et al. 2014). While the intended purpose of the SABLs was agricultural development, logging is the most frequent—if not only—activity on much of the land that falls under these leases (Nelson et al. 2014; UPNG 2015; Chand 2017). The lack of data and appropriate monitoring can lead to serious environmental and social impacts, including deforestation, forest degradation, and unfulfilled agreements of agricultural development and income generation (Filer 2011; Filer 2012; UPNG 2015; Dalsgaard and Pedersen 2015; Roberts 2019). Therefore, it is recommended to continue efforts to reform the system of customary land ownership, so that property and land use rights can be codified in formal registries.

Fourth, reliable data on forestry and land use activities is also essential to strengthen the GoPNG's reporting of greenhouse gas emissions. Papua New Guinea's forests are of global importance, covering more than two-thirds of the country's land mass, and—together with forests in the neighboring Indonesian province of Papua—comprising the third largest tract of intact tropical forest in the world (Babon and Gowae 2013). Emissions from land use play a prominent role in Papua New Guinea's GHG inventory. Estimates consistently suggest that land use contributes more than half the country's total

emissions. However, the lack of reliable data on forest cover and forest cover change are a source of considerable uncertainty in those estimates.

According to PNG’s Second National Communication to the UNFCCC, the agriculture sector was responsible for 1.9 Mt of CO₂ emissions while land use change and forestry accounted for 9.9 Mt, corresponding to more than 80% of total CO₂ emissions in the country in 2008 (GoPNG 2014). In-country interviews provided the figures of 0.8 Mt for agriculture and 13.6 Mt for forestry and other land use, representing close to 55% of total emissions. Despite the large discrepancy, these estimates represent a significant improvement in comparison to PNG’s First National Communication, where a total of only 1.5 Mt of CO₂ emissions were reported. However, the more recent estimates continue to include considerable gaps, such as some emissions from the energy sector being unavailable and therefore absent in the Second National Communication (GoPNG 2014).

Capacity to monitor greenhouse gas emissions from land use and deforestation is limited. As experienced in many low- and low-middle income countries, there are significant challenges regarding the establishment of a rigorous monitoring, reporting, and verification (MRV) system in Papua New Guinea, requiring investments in human and technical capacity (Babon 2011; Babon and Gowae 2013).

Data on forest biomass and carbon stocks is limited due to the low capacity of the GoPNG to report and monitor them (Romijn et al. 2015). For example, there is no country-specific data for carbon stocks in non-forest land. Carbon stocks after deforestation are considered zero in Papua New Guinea’s Forest Reference Level due to lack of reliable data for estimating carbon accumulation in regrowth (GoPNG 2017a). A combination of studies and the IPCC guidelines are being used to determine approximate emission factors to assess carbon stocks, but more reliable data is required to properly estimate the emission reduction potential of forestry activities (Bryan et al. 2010; Fox et al. 2010; Babon and Gowae 2013; GoPNG 2017a). The National Forest Inventory intends to address this current data gap and make a significant improvement to collect and share this data.

Table 10. Average total biomass of rainforests according to various studies

Source	Forest type	Disturbance level	Average total biomass (t/ha)
Bryan et al. 2010	Rainforest	Unlogged	358
Fox et al. 2010	Tropical rainforest	Primary	223
UPNG 2015	Rainforest (specific to Kamula Doso site)	Unlogged	372
Bryan et al. 2010	Rainforest	Logged	146
Fox et al. 2010	Tropical rainforest	Logged	161
UPNG 2015	Rainforest (specific to Kamula Doso site)	Logged	252

Source: Compiled by GGGI

Currently available studies show the high variability in estimates on the examples of average total biomass in unlogged or logged rainforests (table 10). The differences can have severe implications—for

example, when attempting to estimate the quantity of embedded CO₂ in above- and below-ground biomass—and highlight the need for more reliable data.

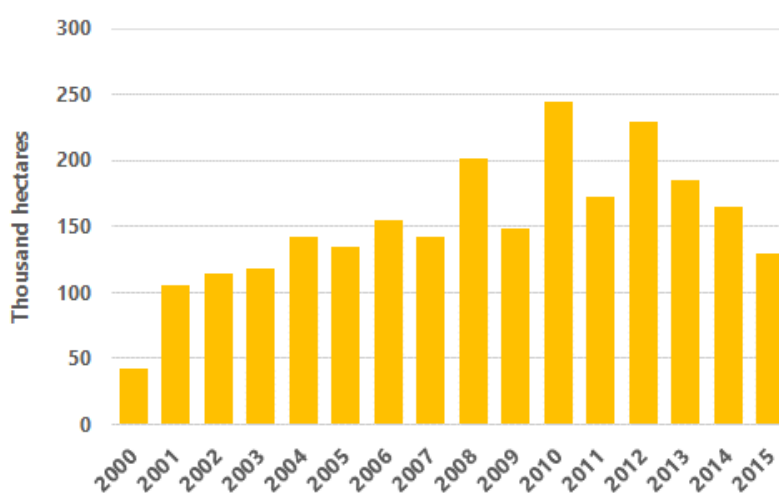
Papua New Guinea is one of the main proponents of the REDD+ program¹⁰⁴ as a way to address climate change and reduce greenhouse gas emissions. The program—initiated in collaboration with UNDP, UNEP, FAO, and other development partners—is currently transitioning from the readiness phase to the implementation phase, testing different approaches through pilot projects to refine the strategy and establishing a REDD+ Finance and Investment Plan to appropriately fund REDD+ activities (GoPNG 2017b). Improvements in data quality are recognized as essential for the effective implementation of the country’s REDD+ program and are highlighted as one of the main issues to be addressed (GoPNG 2017a; GoPNG 2017b). In this regard, the country’s National REDD+ Strategy not only serves to mitigate climate change through improved forest management but also as an approach to sustainable and responsible development, aiming to support low-emission economic growth, rural livelihoods, biodiversity conservation, and ecosystem services (GoPNG 2017b).

It is noted that this recommendation is already—at least partially—being followed by the GoPNG, and there are expectations for the GoPNG to strengthen its data monitoring capacities in the upcoming years, which will improve data reliability and consistency.

Enforce and monitor compliance with regulation on commercial logging and adherence to internationally recognized certification schemes.

Commercial logging is the leading cause of forest degradation in Papua New Guinea, responsible for an estimated 98% of nearly 2.5 million hectares of degraded forests between 2001 and 2015 (GoPNG 2017a). This represents ten times more land than the area affected by deforestation. Estimates further suggest that commercial logging has resulted in 5.4 million hectares of forest having been degraded since the 1970s, representing the equivalent of 25 million tons of CO₂ emissions (GoPNG 2017a; GoPNG 2017b). The extent of degradation is, in large part, a result of the land concessions granted in recent years under lease arrangements that have enabled logging companies to clear forests (Figure 25). With 8.6 million hectares still under logging concessions and a further 8.4 million hectares identified as potential concession areas, this trend is expected to continue if no corrective action is taken to address the issue (GoPNG 2017b).

Figure 25. Area of degraded forest by year in Papua New Guinea



Source: GoPNG 2017b

¹⁰⁴ See *Relevance of REDD+* in this report for an overview of and critical response to Papua New Guinea’s REDD+ program.

Commercial logging in Papua New Guinea takes the form of selective logging, formalized in the reduced impact logging (RIL) principles of the PNG Logging Code of Practice, where only sellable species of trees of sufficient size are logged (UPNG 2015).¹⁰⁵ Nonetheless, the process of selective logging contributes considerably to forest degradation through the loss of biomass from harvested timber, wood used for logging infrastructure, wastage from felled trees, damage to neighboring trees, and clearance to build access roads (UPNG 2015). Forest degradation also contributes to soil erosion and waterway siltation, gradual deforestation, and CO₂ emissions (UPNG 2015).

Logging is meant to take place only in specific land concessions given to developers. However, logging also occurs outside of such areas (UPNG 2015). Regulation officially restricts repeated timber harvesting to a 35-year cycle, to allow for the regeneration of an area. However, UPNG (2015) reports of areas where re-harvesting has taken place within 15 years of the beginning of logging operations, considerably increasing the risk of deforestation.

By 2014, there were nearly 300 logging concessions in Papua New Guinea, covering 14.9 million hectares. Of these concessions, 228 were active between 1972 and 2014 (UPNG 2015). Most of these concessions are located in accessible lowland areas, which are subject to higher logging rates than other areas in the country, with 72 of the active 228 concessions having logged over 80% of their commercially accessible forest area (UPNG 2015). As a result, logging is the main driver of deforestation in lowland areas (Babon and Gowae 2013).

The main product of commercial logging in Papua New Guinea is unprocessed round logs from natural forests for export, representing more than a fifth of the world's tropical hardwood log exports since 2001 (Scudder, Baynes, and Herbohn 2019). The market is dominated by a Malaysian company exporting to China to meet the country's large demand for timber (UPNG 2015; Filer 2012; GoPNG 2017a). It is expected that the demand for timber will continue to grow, leading to a continued increase in timber harvesting volumes in PNG. This assumption is further supported by the state of logging concessions, with 8.6 million hectares of forest land already being under logging concessions but not yet having been exploited and an additional 8.4 million hectares having been identified by the GoPNG as commercially accessible (GoPNG 2017a; GoPNG 2017b; UNDP 2018).

The main reason behind the recent increase in logging exports is a change in regulation on granting land concessions. Land tenure in Papua New Guinea is characterized by customary land ownership. As such, approximately 90% of all land in PNG is owned by local landowners, although most of it is undocumented (GoPNG 2017b; Chand 2017). Since 1991, an increasing number of logging concessions have been granted through Forest Management Agreements (FMAs), obtained through a process considered as complex by companies and foreign investors (ITTO 2007). The process involves around 30 steps that were beyond the capacity for the PNG Forest Authority to manage, impeding the agency from fulfilling its mandate of overseeing such logging concessions (Babon and Gowae 2013; Nelson et al. 2014).

In response to this situation, further land reforms were passed in 2003 and 2007, creating Forest Clearance Authorities (FCAs). The aim was to facilitate access to land for corporations to invest in agricultural development by avoiding safeguards and sustainable management provisions under the Forestry Act (GoPNG 2017a). These reforms made it easier for companies to obtain Special Agricultural Business Leases (SABLs), which are land concessions given on a lease-lease-back arrangement of up to 99 years. SABLs allowed the state to lease customary land from local landowners and then lease the land back to incorporated landowner groups or to foreign investors, who were to use the revenues from timber harvesting to subsidize agricultural development projects (Dalsgaard et al. 2015). Between 1979

¹⁰⁵ Under the PNG Logging Code of Practice, "sufficient size" is defined as tree trunks of 50 cm in diameter at breast height (UPNG 2015).

and 2003, less than 150,000 hectares of customary land were leased under SABLs, mainly for the purpose of oil palm plantations (Filer 2012; Babon and Gowae 2013). However, from 2004 to 2011, 5.1 million hectares were granted through SABLs, highlighting the substantial impact of the 2003 and 2007 reforms.

Although intended for agricultural development, most active SABLs were awarded to companies with little experience or interest in agricultural development. Under the pretext of agricultural development, activities under many such leases have been limited to logging (Babon and Gowae 2013; Filer 2012; Nelson et al. 2014). The extent is such that logging activities in SABLs accounted for 25% of all timber exports in PNG in 2015 (GoPNG 2017b). In addition, many of the leases were granted without the required "free, prior and informed consent" of the relevant landowners (Filer 2012; Laurance et al. 2012; Babon and Gowae 2013).

In response to concerns over the legality of awarding these concessions, a commission of inquiry was mandated to investigate the issue, and a moratorium on new SABLs was established in 2011. However, the moratorium did not affect logging activities in existing SABLs. In 2017, former prime minister of Papua New Guinea, Peter O'Neill, stated that all SABLs had been canceled, yet uncertainty remains as to the future development of these areas.

It is recommended for PNG authorities to transcribe customary land rights formally into land use registries and update them regularly (Laurance et al. 2012). This would provide clarity on land ownership, avoid overlapping concessions or ownership claims from multiple stakeholders, and reduce related disputes (Babon and Gowae 2013; Gabriel et al. 2017). It would also ensure that all relevant landowners are involved in discussions regarding the possible development of future logging concessions. Two laws passed in 2009 regarding the establishment of incorporated land groups and clan land use agreements (CLUAs) were initially lauded for addressing the issues related to customary land rights (Babon and Gowae 2013; Chand 2017). However, their implementation proved to be costly and require strong coordination and good faith from all parties, which are severe obstacles in PNG (Baynes, Herbohn, and Unsworth 2017).

It is suggested for the GoPNG to review and consolidate the laws and amendments passed since the 1990s to clarify and confirm customary land rights as well as to set standards for awarding concessions and their development (GoPNG 2017b). Such a review should also reassess the distribution of timber resource rents between landowners, the GoPNG, and the logging industry. Between 2007 and 2017, landowners received 6.1% of timber royalties while the share for GoPNG and the logging industry was 42.3% and 51.6%, respectively (Scudder, Baynes, and Herbohn 2019). This could be done by calculating timber royalties based on market value and including wider public participation to determine a more equitable distribution of timber harvest revenues between the different actors (Scudder, Baynes, and Herbohn 2019).

It is further recommended to conduct an independent and comprehensive inventory of all forestland concessions and related regulatory instruments and provisions. Such a review should address inconsistencies between intended activities (such as logging or agricultural development) and observed activities. It should also include provisions for conducting regular audits and reporting to ensure compliance to agreed lease arrangements and the delivery of environmental and social benefits. Any new regulation should ensure that communities affected by a specific project have access to independent arbitration. Deviations from the intended activity should be noted and provisions should be made to address them, such as the suspension or termination of concessions that were acquired illegally or implemented abusively, due to the absence of adequate stakeholder consent or the lack of agricultural development under SABLs. Concessions that have so far not seen any activity should also be reviewed according to the track record of the company in question, noting whether it has any prior experience in sustainable timber harvesting.

Finally, it is recommended that the Government of Papua New Guinea strengthen sustainable timber harvesting practices through applying international certification schemes. Forest certification is an

important non-state regulatory tool. It is “a process through which transnational networks of diverse actors set and enforce standards for the management of forests around the world” (Meidinger 2003). Certification, then, acts as a condition for importing countries and businesses that demand sustainable production and guaranteed provenance. The Forest Stewardship Council (FSC), the Programme for the Endorsement of Forest Certification (PEFC), and the International Tropical Timber Organization (ITTO) are organizations with developed and widely endorsed forest certification schemes.

During the 1990s, attempts to promote small-scale sustainable forest management using certification under the FSC failed once donor funding ran out. Moreover, landowners were unable to meet the demand from buyers and adhere to the FSC principles (Scudder, Herbohn, and Baynes 2018). A larger scale, nation-wide attempt, as initiated through the REDD+ scheme, may be a more effective method to sustain such certification standards.

National and private certification schemes should be viewed with caution. The degree to which such certification schemes encourage sustainable forest management differ, as each has its own standards (Durst et al. 2006, Global Forest Atlas 2018). For example, a number of nationally certified forests, such as those under the Malaysian Timber Certification Scheme (MTCS), have been criticized for unclear environmental and social protection standards. The MTCS and Lembaga Ekolabel Indonesia have emphasized reduced impact logging techniques, possibly at the expense of social factors (Global Forest Atlas 2018). Asian timber importers, like China, South Korea, and Japan, are generally less environmentally sensitive than those in Europe or North America, and thus standards for producers of such markets are lower. There are no known examples of successful private sector certification schemes, primarily due to the cost of implementation and monitoring, as well as lack of international endorsement, limiting access to international markets that demand sustainable management of forests.

Internationally recognized and endorsed forest certification is a key element to accessing high-value timber export markets and accessing global carbon funds through the REDD+ scheme. Certification also provides the foundation for the Forest Law Enforcement, Governance and Trade Voluntary Partnership Agreement (FLEGT VPA) with the European Union. While REDD+ focuses on land use planning and tenure allocations, FLEGT focuses on implementation and economic incentives to drive a viable and sustainable timber industry. Combined, the programs introduce opportunities for improved governance, forest laws and regulations, transparency, and technical and rights-based approaches to sustainable forest management, monitoring, and reporting systems (Forest Trends 2015).

Enforce and monitor compliance with regulation on commercial agriculture concessions and adherence to internationally recognized sustainability certification schemes.

Commercial agriculture directly contributes to deforestation by converting forest land into cropland. Between 2001 and 2015, commercial agriculture was responsible for up to 30% of deforestation in Papua New Guinea, corresponding to approximately 75,000 hectares (GoPNG 2017a). Prior to 2000, commercial agriculture was only a minor driver of deforestation. However, since then, it has been continuously growing and is expected to further increase in the upcoming years due to the planned expansion of agricultural plantations envisioned in the National Agriculture Development Plan (Babon and Gowae 2013; UNDP 2018). In addition, Papua New Guinea became a member of China’s Belt and Road Initiative in 2018, with plans to launch agriculture and road projects (Global Witness 2018).

In Papua New Guinea, commercial agriculture is focused mostly on oil palm plantations, coffee, and cocoa for exportation. Palm oil surpassed coffee as the country’s most important agricultural export in

2000 (Babon and Gowae 2013). Expansion of commercial agriculture plantations was limited before the early 2000s, with coffee and cocoa production focused on the renewing of stock and improvement of growing techniques. Oil palm plantations were somewhat limited in their expansion due to high costs in comparison to neighboring Indonesia and Malaysia (Babon and Gowae 2013). In response, the two dominating palm oil firms in Papua New Guinea sought to enter higher value niche markets for their production by obtaining international certification through complying with the Roundtable on Sustainable Palm Oil (RSPO) standards (Babon and Gowae 2013; FCPF 2016). This has proven to be successful as 93% of PNG’s palm oil production was sustainably certified in 2014, representing the highest percentage in the world and comprising the world’s third largest area of certified plantations (FCPF 2016). This commitment had the effect of limiting conversion of primary forest areas due to oil palm plantations (GoPNG 2017a).

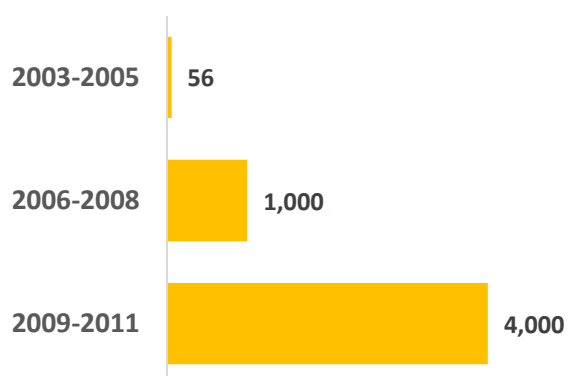
Similar to commercial logging, recent land reforms have led to an increase in commercial agriculture, notably of oil palm plantations. Although the 5.1 million hectares of land concessions granted through Special Agricultural Business Leases (SABLs) were intended for commercial-scale agricultural development, especially oil palm, most active concessions are limited to logging activities (Babon and Gowae 2013; Nelson et al. 2014). Only a handful of concessions led to the development of oil palm plantations. Around 150,000 hectares were allocated to oil palm plantations prior to the land reforms in 2004. Since then, an additional 200,000 hectares have been developed or are currently under development through SABLs (FCPF 2016; UNDP 2018).

While limited, this expansion is marked by new market entrants that have little to no prior experience in oil palm plantations (Nelson et al. 2014). PNG’s historical track record of certified oil palm production and the country’s valuable market position might be threatened if new market entrants rely on unsustainable practices for establishing plantations, such as clearing forests with a high conservation value (Filer 2012; Babon and Gowae 2013; FCPF 2016).

Coffee and cocoa plantations, together, cover approximately 350,000 hectares, comparable to the total area used for oil palm plantations (FCPF 2016; UNDP 2018). Agriculture represents an important economic sector and source of income in PNG (GoPNG 2017a). In total, agriculture, forestry, and fisheries represent about a fifth of Papua New Guinea’s gross domestic product (BPNG 2019a). Altogether, coffee, cocoa, and palm oil exports amounted to approximately kina 2 billion (USD 600 million) in 2017, accounting for two thirds of the country’s total agricultural exports (BPNG 2019b). Commercial agriculture is also an important source of income in PNG. Over 30,000 local farmers are involved in oil palm plantations, and over 60,000 households are supported by the coffee or cocoa industry (FCPF 2016; GoPNG 2017a).

The commercial agriculture sector is expected to grow further. The national agricultural development policy envisions allocating a substantial area of land to commercial plantations, with the total area envisioned to nearly increase threefold by 2030 (OCCD 2010; Babon and Gowae 2013; UNDP 2018). The expansion of oil palm plantations in PNG is also expected to increase with a growing international

Figure 26. Area granted to private companies through Special Agricultural Business Leases (in thousand hectares)



Source: Filer 2012

Note: Figures include total area granted to private companies through SABLs. Disaggregated numbers including only oil palm are not available.

demand and more stringent regulation in Indonesian and Malaysian production (GoPNG 2017a). This development significantly increases the risk of future deforestation, notably as new market entrants are not currently obliged to produce according to international certification standards. Although deforestation due to oil palm production is unlikely to reach the extent recorded in Indonesia or Malaysia, due to its relatively higher costs, it is still expected to become the most important cause of forest cover change in Papua New Guinea in the short to medium term (Babon and Gowae 2013; FCPF 2016).

In line with the recommendation on commercial logging, it is suggested that the Government of PNG transcribe customary land rights formally into land use registries and update them regularly (Laurance et al. 2012). This would provide clarity on land ownership, avoid overlapping concessions or ownership claims from multiple stakeholders, and reduce related disputes (Babon and Gowae 2013; Gabriel et al. 2017). This would also ensure that all relevant landowners are involved in discussions regarding the possible development of future agricultural concessions. Two laws passed in 2009 regarding the establishment of incorporated landowner groups and clan land use agreements (CLUAs) were initially lauded for addressing the issues related to customary land rights (Babon and Gowae 2013; Chand 2017). However, their implementation proved to be costly and to require strong coordination and good faith from all parties, which are severe obstacles in PNG (Baynes, Herbohn, and Unsworth 2017). It is suggested for the GoPNG to review and consolidate the laws and amendments passed since the 1990s to clarify and confirm customary land rights as well as to set standards for awarding concessions and their development (GoPNG 2017b). Such a review should also reassess the distribution of resource rents between landowners, the GoPNG, and the agriculture industry.

Also following proposals for commercial logging, it is further recommended to conduct an independent and comprehensive inventory of all land concessions and related regulatory instruments and provisions. Such a review should address inconsistencies between intended activities (such as logging or agricultural development) and observed activities. It should also include provisions for conducting regular audits and reporting to ensure compliance with agreed lease arrangements and the delivery of environmental and social benefits. Any new regulation should ensure that communities affected by a specific project have access to independent arbitration. Deviations from the intended activity should be noted and provisions should be made to address them, such as the suspension or termination of concessions that were acquired illegally or implemented abusively, due to the absence of adequate stakeholder consent or the lack of agricultural development under SABLs. Concessions that have not seen any activity to date should also be reviewed according to the track record of the company in question, noting whether it has any prior experience in sustainable agricultural development practices.

Finally, it is recommended for the Government of Papua New Guinea to continue its efforts to support sustainable agricultural practices through adherence to international certification schemes for its agricultural commodities, in line with both its historic approach toward the palm oil industry and the country's REDD+ Strategy. Similar to sustainable timber certification, agricultural certification acts as a condition for importing countries and businesses that demand sustainable production and guaranteed provenance. Demand for internationally recognized certification is increasing as companies accounting for 90% of the global palm oil trade have committed to zero deforestation in their supply chain policies while fair trade and environmental standards in coffee and cocoa are becoming increasingly important (FCPF 2016). While PNG's palm oil industry has historically focused on complying with RSPO standards, there is a notable risk that the development of uncertified palm oil on recently granted land concessions destined for new export markets, such as China and India, would not only damage the reputation of the country's oil palm industry but could also lead to large areas being managed unsustainably and ultimately being deforested (FCPF 2016).

As suggested in Papua New Guinea's REDD+ Strategy, learning from different initiatives can provide valuable insight into how to develop strategies to ensure sustainable production standards, notably from the coffee and cocoa sectors with their Productive Partnership for Agriculture Programme (PPAP).

The PPAP is a World Bank-funded project that aims to improve the livelihoods of the country's 60,000 coffee and cocoa farmers by increasing productivity within existing plantations through strengthening extension services (FCPF 2016). It is suggested to extend this approach to the palm oil sector. This should include establishing a multi-stakeholder dialogue similar to the Indonesia Palm Oil Platform (FCPF 2016). This platform should develop a national action plan to advance sustainable palm oil production, work toward coherent institutional and regulatory frameworks, and build on PNG's existing sustainably certified plantations and their partnerships with communities and landowners (FCPF 2016; GoPNG 2017b). Meanwhile, the expansion of certification would help to maintain high environmental and sustainability standards and improve access of Papua New Guinean products to premium markets (FCPF 2016).

Strengthen extension services, providing support to smallholder farmers to adopt sustainable agricultural practices.

Subsistence agriculture is the leading cause of deforestation and second largest driver of forest-related GHG emissions in Papua New Guinea (GoPNG 2017b; UNDP 2018). Close to 90% (over 200,000 hectares) of deforestation between 2000 and 2015 is the result of converting forestland to cropland, of which approximately two thirds are due to subsistence farming (GoPNG 2017a; UPNG 2015; Babon and Gowae 2013).

This level of deforestation is caused by the practice of shifting cultivation, which is the predominant form of subsistence agriculture in PNG (GoPNG 2017a). Deforestation from subsistence agriculture is exacerbated by the rapid population growth in Papua New Guinea, estimated at an annual rate of 2–3% (Babon and Gowae 2013; GoPNG 2017b). This growth, coupled with an increasing demand for food and additional cash income, is driving an increase in the clearing of land for family subsistence agriculture (Babon and Gowae 2013; GoPNG 2017b). The most significantly deforested areas are those affected by internal migration of communities either in search of employment or displaced due to mining, infrastructure, urbanization or other infrastructure developments (GoPNG 2017b).

The traditional system of shifting cultivation is characterized by farmers clearing patches of forests, commonly through the practice of slash-and-burn. This provides land for the development of a food garden, comprising a variety of food crops and intended mostly for domestic use or to be sold at local markets.¹⁰⁶ Once crop production declines, the garden is fallowed for a period of time for the soil and forest to regenerate while a new garden is grown elsewhere. At low population densities, gardens are located far apart, and time periods are sufficient for soil and forest to recover after cultivation (Babon and Gowae 2013; Alepa et al. 2016).

However, population growth leads to the intensification of subsistence agriculture in PNG, as access to land becomes more competitive and challenging (Babon and Gowae 2013; Alepa et al. 2016). As a result, land is used more frequently, reducing fallow periods or extending cultivation periods. With increasing population density, the practice of shifting cultivation leads to net deforestation as there is insufficient time for forests and soils to recover (Alepa et al. 2016). In turn, decreasing soil fertility results in increased land degradation and, ultimately, in declining food production (Bourke and Harwood 2009). In addition, intensification of land use causes carbon and sulfur emissions to rise, from the slashing and burning of fallowed biomass (Alepa et al. 2016). Finally, different assessments agree that the expansion of

¹⁰⁶ More recently, many farmers have been transitioning from mere subsistence agriculture to growing cash crops (Scudder, Herbohn, and Baynes 2019).

subsistence agriculture is likely to be concentrated in already degraded forest areas and along transport routes near urban areas, accentuating local hotspots of deforestation and social tensions (GoPNG 2017b; UNDP 2018).

Agricultural techniques have not improved in response to the detrimental impacts of intensified land use caused by subsistence agriculture, affecting the livelihoods of a large share of the country's population. The necessary adaptation is lacking due to significant gaps in the provision of extension services to communities, notably as a result of capacity and institutional constraints within the country's agriculture sector (GoPNG 2017b).

It is recommended for the Government of Papua New Guinea to strengthen extension services, providing support to communities to adopt sustainable agricultural practices. Notably, this should include approaches to increase resilience toward natural hazards, pests, and diseases, as suggested in Papua New Guinea's National REDD+ Strategy (GoPNG 2017b). Sustainable agricultural practices aim to maximize the use of natural processes and ecosystems, reduce excessive use of external inorganic inputs, enhance the diversity of production, tailor production intensity to the capacity of the landscape, and use a mix of traditional and new technologies (IFAD 2012).

These measures are often referred to as sustainable intensification or climate-smart agriculture practices. Sustainable intensification refers to any agricultural process that can increase yields without causing adverse environmental impacts and without the conversion of additional non-agricultural land (Pretty and Bharucha 2014). Similarly, climate-smart agriculture is a concept that aims at (1) sustainably increasing productivity and yields without compromising the functional integrity of the ecosystem services on which agriculture depends, (2) strengthening the resilience of communities to adapt to climate change and reducing vulnerability, and (3) reducing GHG emissions (Kaczan, Arslan, and Lipper 2013; IFAD 2012).

Such an agricultural modernization will require increasing public expenditures on extension services and agricultural research in areas, such as the introduction of adapted seeds and crops resistant to drought, heat, pests, and diseases (IFAD 2012). An appropriate system of crop rotation, low-tillage, and application of manure as fertilizer can improve soil structure and fertility (IFAD 2012; Pretty and Bharucha 2014). These approaches are diverse, and their application requires expertise. When introduced, it is important to consider existing local knowledge, innovations, and seed varieties already accessible to farmers. Accounting for these conditions will help scale up and strengthen the deployment of such modern practices (IFAD 2012). Improving practices of subsistence agriculture has the potential to deliver significant co-benefits, including reducing deforestation and forest degradation, curbing carbon emissions, increasing food security, and contributing to poverty alleviation (Babon and Gowae 2013).

As noted in the country's Climate Compatible Development Strategy (CCDS), implementing change in agricultural practices of subsistence farming is challenging, particularly due to a lack of capacity to disseminate knowledge, seeds, and technology in Papua New Guinea (OCCD 2010; Babon and Gowae 2013). As a result of these challenges, the CCDS and early REDD+ debates largely ignored opportunities for reducing deforestation and GHG emissions from subsistence agriculture (Babon and Gowae 2013). However, given its considerable environmental impact and its fundamental role to sustain the livelihoods of large parts of the population, subsistence farming needs to be addressed.

It is laudable that the country's REDD+ Strategy acknowledges the impact of agricultural practices associated with subsistence farming. In line with this report, the strategy recommends strengthening extension services to support communities in developing and managing their land to secure rural livelihoods while protecting natural assets. The strategy highlights that cooperation between national, provincial, and local government agencies will be required to improve extension services (GoPNG 2017b).

Further research is necessary to identify the most appropriate sustainable agricultural practices and opportunities for reducing emissions as the result of smallholder agriculture. For example, the motivations behind crop diversity choices of subsistence farmers need to be considered, as those can vary from socioeconomic benefits or status to environmental risk management (Nordhagen, Pascual, and Drucker 2017). In this context, several studies observed the importance for new techniques and inputs to provide material benefits to smallholder farmers, who often welcome ecological experimentation as long as the discovery of fundamental ecological principles pays better than growing cash crops for the nearest market (Babon and Gowae 2013; UPNG 2015).

Support sustainable fuelwood production and the use of improved cookstoves.

Fuelwood is a major source of energy used in Papua New Guinea. Although official data on fuelwood use is available, these estimates have not evolved significantly in the past years, and their reliability is questionable.¹⁰⁷ IRENA (2013) estimated that traditional biomass accounted for over half of the country's energy consumption in 2010, but figures vary significantly between sources (see APERC 2016; Department of Public Enterprises, and Department of Petroleum and Energy 2017; IRENA 2013a; GoPNG 2016). The National Energy Policy 2017–2027 cites two different values regarding biomass, indicated at 37% and 39%, respectively, but provides no reference year for these values, and data for other fuels is inconsistent (Department of Petroleum and Energy 2017). A study conducted in 2008–2009 determined that 85% of the surveyed population had used fuelwood within the previous year (Nuberg 2015).^{108, 109} Nuberg (2015) further estimates that approximately 1.8m³ of fuelwood is used annually per person, which would place PNG as the second highest user of fuelwood in South and Southeast Asia, after Bhutan, according to UN (2019).¹¹⁰

In Papua New Guinea, fuelwood is used both in rural and urban areas, even when alternatives are present. Fuelwood is the most common source of energy used by villagers for cooking while it is also used for heating in the highlands due to low nighttime temperatures (Bourke and Harwood 2009). Often, fuelwood is harvested as a result of agroforestry or garden fallows as well as in the form of deadwood

¹⁰⁷ UN (2019) provides estimates of fuelwood consumption by households for most countries from the United Nations Statistics Division, including for PNG, citing 5,493 m³ of fuelwood consumed per year by households in 2017, down from 5,509 m³ in 1990.

¹⁰⁸ Nuberg (2015) developed a set of three questionnaire surveys that were conducted over two periods (October–December 2008 and March–May 2009), in the National Capital District around Port Moresby, the city of Lae and its hinterland, the city of Mt. Hagen and the rural areas of Mt. Hagen District of the Western Highlands Province, Chuave District in Chimhu, and Henganofi District in the Eastern Highlands. The survey included 2,673 domestic urban users of fuelwood, 1,321 domestic rural users, and 157 fuelwood vendors. The fuelwood use of 36 urban and rural households was monitored over a two-week period and semi-structured interviews were conducted with 66 commercial and industrial users of fuelwood.

¹⁰⁹ This value seemingly stems from one of the only studies specifically collecting information regarding fuelwood, as it is referenced in PNG's REDD+ Forest Reference Level submission to the UNFCCC in 2017 (GoPNG 2017a).

¹¹⁰ While Nuberg (2015) estimates a use of 1.8m³ per person per year, UN (2019) suggests 0.69m³ per person in 2015.

collected from other non-forested areas (Nuberg 2015; Ojha et al. 2016). In rural lowland villages, most firewood comes from trees cleared during shifting cultivation (Bourke and Harwood 2009). Therefore, Nuberg (2015), as well as Page et al. (2016), suggests that the collection of fuelwood often does not involve a cash exchange and implies little-to-no impact on primary or secondary forests.

However, a considerable share of Papua New Guinea's population also reportedly purchases fuelwood, which is sold in many urban and some rural markets, particularly in the highlands but also near major lowland urban centers (Bourke and Harwood 2009). Prices are highly variable depending on the area (Nuberg 2015). Nuberg (2015) estimates that 10% of the rural and 3% of the urban population sell fuelwood as a part-time means of income. Despite the relative abundance of freely available fuelwood in many areas, estimates suggest that sales of fuelwood generated kina 5 million of income for rural villagers (Bourke and Harwood 2009).

Many of those using or purchasing fuelwood use it to generate income themselves, namely as a fuel source for selling food products. A large majority of this activity takes place informally, as there is no specific national policy on fuelwood harvesting or use, nor does the PNG Forest Authority have the capacity to monitor fuelwood plantings. The only type of regulation that seems to exist is initiated by local governments or landowners (Nuberg 2015).

Fuelwood consumption contributes to local deforestation, leads to competition for resources among users in densely populated areas, and is a major cause for indoor air pollution in Papua New Guinea.

Although fuelwood harvesting is not the leading factor of deforestation in Papua New Guinea, it is an issue that is gradually becoming more severe due to population growth and the informal economy that characterizes fuelwood use. Fuelwood is already scarce in some lowland rural locations and, given the increasing population pressure and ongoing urbanization, demand for fuelwood is likely to continue to increase (Bourke and Harwood 2009). It is estimated that approximately 50% of the population has already experienced conflict relating to the increasing competition for fuelwood collection, especially near urban areas (Nuberg 2015). This trend is likely to continue and to cause environmental pressure, such as on mangroves near Port Moresby, as well as localized deforestation, exemplified by the barren hills in the more densely populated areas in the country's highlands region (Nuberg 2015; GoPNG 2017a). Fuelwood-specific planting is already common practice in PNG and has been sporadically promoted in certain areas (Nuberg 2015; Bourke and Harwood 2009). However, most of it is conducted in an unplanned manner, either scattered or in a linear configuration, and not at a scale sufficient to sustain small fuelwood businesses (Nuberg et al. 2015).

In addition to deforestation, fuelwood use is a common source of indoor air pollution, which is known to increase the risk of respiratory diseases and other health issues. Worldwide, indoor air pollution causes the deaths of an estimated 2.6 to 4.4 million people every year (IRENA 2017b; Lighting Global 2016). This is particularly relevant in Papua New Guinea, where lung and respiratory diseases figure among the most prominent causes of death, with chronic obstructive pulmonary disease (COPD) being ranked third, lower respiratory infection fourth, and asthma ranked sixth (IHME 2018a). The Institute for Health Metrics (2018a) sees air pollution as the most important environmental and occupational risk driving death and disability in the country, being ranked among the top five risk factors for the past ten years. Indoor air pollution is estimated to have caused more than 10,000 premature deaths and more than 400,000 disability-adjusted life years (DALYs) in Papua New Guinea (IHME 2018b). The high number of premature deaths due to indoor air pollution mostly affect women and children in rural areas where health care facilities and services are almost nonexistent.

Due to these conditions and trends, there is a strong need to encourage sustainable fuelwood harvesting, which would also provide an opportunity to generate income, particularly for the country's rural population (Nuberg et al. 2015; Bourke and Harwood 2009). Therefore, it is recommended for the GoPNG to encourage private investment in sustainable fuelwood production and harvesting. Any such provisions should be developed in concert with several government departments as fuelwood

encompasses a range of different aspects, including environmental and natural resource management and energy supply as well as social and economic considerations.

Given the obstacles of enforcing regulation in Papua New Guinea, it is recommended for the government to focus on creating an enabling environment to encourage formalized private sector activity while setting conditions to ensure the sustainable harvesting of fuelwood (Nuberg 2015). For example, the establishment of short-rotation coppicing fuelwood production could be supported as a way to harvest fuelwood in an efficient and sustainable manner (Nuberg et al. 2015).¹¹¹ Market entry is a challenge due to the omnipresence of the informal economy. Therefore, it is paramount to demonstrate to the concerned population that a more formalized fuelwood supply chain entails considerable economic and environmental benefits (Page et al. 2016; GGGI 2018). The existing practice of smallholder farmers maintaining woodlots shows the potential benefits, including income generation, domestic timber use, and securing land ownership (Page et al. 2016). In addition to that, a more formal system would allow private sector players to apply for loans while credit guarantees could allow for microfinancing loans with less risk taken by potential investors (FAO 2013). Furthermore, sustainable harvesting would reduce resource stress in areas where fuelwood consumption contributes to local deforestation.

In addition to promoting sustainable fuelwood production, the introduction of improved cookstoves can reduce the adverse impacts of extensive fuelwood use. Nuberg (2015) observes that different types of cooking stoves are present in Papua New Guinea. However, the majority are open fireplaces, either outside (51%) or inside (34%) the household. The other main type of observed cooking stoves was drum ovens, often present in combination to open fireplaces. Although charcoal was promoted in the 1980s, it has had limited uptake and its use is currently limited in scale while no improved cookstoves were observed (Nuberg 2015).¹¹² While kerosene stoves are commonly used in urban areas, fuelwood still represents a considerable share of fuel consumption (Bourke and Harwood 2009). One of the reasons behind the predominance of fuelwood is the low costs compared to other options (Nuberg 2015; Nuberg et al. 2015). This implies that fuelwood is most likely to remain an important source of energy, as well as household income, for the near future (Nuberg 2015).

As such, it is recommended to reduce the adverse impacts of fuelwood use by encouraging the uptake of improved cookstoves.¹¹³ Improved cookstoves either use biomass more efficiently or replace it entirely by other fuels, such as liquid petroleum gas (LPG) and biogas (USAID and WINROCK 2017). Access to clean cooking technologies reduces local deforestation and associated soil erosion. It also reduces indoor air pollution as well as emissions of greenhouse gases and black carbon (USAID and WINROCK 2017; Werry 2005). With approximately 85–90% of Papua New Guinea's population using fuelwood for cooking, potential benefits are high when replacing the use of traditional cookstoves with improved cookstoves or fuelwood with cleaner cooking fuels (IRENA 2013a; Jeuland and Tan 2016).

¹¹¹ Short-rotation coppicing systems entail planting fast-growing tree species that are harvested within a period of two to five years with the aim to produce high biomass yields that can be used for energy purposes (Dimitriou and Rutz 2015).

¹¹² While Nuberg (2015) refers to "fuel-saving cookstoves," this analysis uses the terminology "improved cookstoves." Both terms are largely used synonymously within the literature, with fuel-savings being one of the aims of improved cookstoves (Urmee and Gyamfi 2014; Gebreegziabher et al. 2018).

¹¹³ The Clean Cooking Alliance defines improved cookstoves as "any technology that reduces [household air pollution (HAP)], regardless of the fuel that is used, and regardless of whether these actually produce measurable improvements in health. [The] term clean cookstove [is reserved] for a technology that is clean from a [HAP] perspective, e.g., LPG, electric, or very high efficiency biomass-burning stoves. Improved cookstoves can be characterized by the type of fuel being used (biomass or non-biomass) as well as their emissions, efficiency, and safety level" (Jeuland and Tan 2016).

First, improved cookstoves, in the form of improved fuel efficiency, burn fuelwood more efficiently, providing more energy per unit of fuel. A study in Ethiopia demonstrated fuelwood savings of almost 40% after replacing traditional three-stone fires with improved cookstoves (Dresen et al. 2014). The authors further concluded that if efficient cookstoves were adapted to local cooking habits, their adoption could contribute to forest conservation and reduce CO₂ emissions (Dresen et al. 2014).

Second, improved cookstoves also allow for a significant reduction in indoor air pollution by (1) reducing the quantity of harmful emissions as a result of more efficient fuel combustion or using cleaner fuels, (2) channeling emissions away from users using ventilation or a chimney, or (3) a combination of both. Traditional cookstoves emit a range of pollutants, such as fine particulate matter (black carbon, PM_{2.5}) and carbon monoxide (CO), which are damaging to health (Khushk et al. 2005; McCracken et al. 2007; Clougherty 2009). For example, residential sources, mainly from cookstoves, account for more than 25% of global black carbon emissions (Bond et al. 2004).

A systematic review of improved cookstoves confirmed that their installation significantly reduces indoor air pollution, although not to the point of meeting WHO air quality guidelines (Pope et al. 2017). Studies undertaken in Uganda and Mozambique suggest that clean cooking technology can provide considerable improvements in public health (URBANET 2017; UNEP 2017). While figures for Papua New Guinea are scarce, high levels of fuelwood use for cooking suggest a comparable potential for improved cookstoves in the country, with greater benefits for the health of women and girls (Clougherty 2009; Khushk, Fatmi, and Kadir 2005; UNEP 2011; McCracken et al. 2007).

When assessing the costs and benefits of improved cooking solutions, the choice of fuel and technology is decisive. Costs and benefits at the household level have to be distinguished from the larger social benefits.¹¹⁴ Looking at costs and benefits for private households indicates whether households are likely to adopt improved cooking technologies on their own and which factors are most important to determine whether households will perceive investing in improved cookstoves as beneficial to them. The social perspective evaluates the net benefits for society as a whole, by mitigating the negative externalities generated by use of traditional cookstoves (Jeuland and Tan 2016).

Private net benefits show large variations. Whether they are positive or negative depends on the extent of households using improved cookstoves, time savings, fuel costs for the chosen technology, and fuel efficiency. Including the social dimension, all technologies and fuel options become more attractive, showing higher net benefits. Nevertheless, due to the prominence of emissions savings in determining social benefits, they remain highly dependent on the choice of technology and fuel (Jeuland and Tan 2016). Cleaner fuels, including emission-free solar and low-emission LPG and ethanol, virtually eliminate emissions of harmful soot and other toxic gases (Global Alliance for Clean Cookstoves 2011) and should be encouraged. However, resorting to modern fuels is likely to be beyond the means of many households in Papua New Guinea, given the country's low income level (Werry 2005). Therefore, it is recommended that the decision of which specific fuel and technology is adopted be left to consumers. Their preferences will ultimately decide which option is successful and commercially viable.

To encourage uptake of improved cookstoves, the GoPNG should consider a targeted awareness-raising campaign highlighting their benefits as well as the establishment of a subsidy scheme. First, Werry (2005) and in-country interviews suggest that combining media coverage, including social media, and workshops specifically targeting women and different ethnic groups would increase acceptance and use of improved cookstoves. Second, similar to renewable energy solutions, mechanisms—such as vouchers,

¹¹⁴ Private costs refer to capital costs for cookstove, operation and maintenance costs, fuel costs, and learning and promotion program costs. Private benefits consist of saved fuel costs, improved health, and time savings. Social benefits refer to improved ecosystem services provided by forest; in particular, reduced carbon emissions (Jeuland and Tan 2016).

rebates, or targeted tax incentives—are regarded as useful tools to support cash-poor consumers (Lighting Global 2018). Independent of the specific modalities, price and financing models will need to take into account different customer segments and their ability to afford upfront costs. In-country interviews confirmed that the need for subsidies increases the more remotely households are located.

The Clean Cooking Alliance (CCA) is an initiative involving governments, companies, UN agencies, and nongovernmental organizations with the goal to create a thriving market for clean cookstoves and fuels. For that purpose, the initiative seeks to address the market barriers that currently impede the production, deployment, and use of clean cookstoves in developing countries. The alliance’s market-based approach is founded on three core objectives (CCA 2014):

- To strengthen supply through fostering innovation, providing capacity building, supporting financing, and developing an inclusive value chain;
- To enhance demand through raising awareness, improving accessibility, and increasing affordability; and
- To enable markets for cookstoves and establish rigorous testing protocols by engaging in relevant research, advocating relevant technologies, and supporting the development of policies.

Although the Clean Cooking Alliance does not currently work in Papua New Guinea, the organization’s approach could be replicated and tested in areas of Papua New Guinea that are most affected by the adverse impacts of fuelwood use.

6. Conclusion

Papua New Guinea is characterized by a dual economy. The country has an export-oriented extractive industry, producing oil, gold, copper, silver, and—more recently—natural gas (ADB 2017). As of 2017, this capital-intensive sector generated approximately 25% of GDP and 80% of the country's exports but only employs roughly 15% of the country's workforce (ADB 2017; IMF 2017; GoPNG 2014). Additionally, more than 80% of the country's population lives in rural areas with minimal services and infrastructure, mainly relying on subsistence agriculture (UNDP 2018; UNDP, UNEP and GEF 2018). In per capita terms, recent evidence suggests that growth in non-resource sectors has been slow. The average per capita growth rate between 1990 and 2015 in non-resource sectors (1.8%) trails that of the resource sector (5.6%) (IMF 2017).

Given these conditions, the Government of Papua New Guinea has set itself the goal of promoting economic growth and distributing the generated wealth more equally. The government aims to raise the living standards of the wider population while preserving the country's extensive natural assets. What is already a challenging task is rendered even more difficult by the pronounced impacts that climate change is having on the country. In this context, the government places a high priority on accessing climate finance to assist the country in mitigating its contribution to climate change and in adapting to the adverse impacts of climate change. This report is meant to provide valuable analysis to support the ongoing efforts toward that aim.

From the findings in this report a number of broader conclusions can be drawn regarding fundamental requirements for the government in order to achieve its aspirations.

First, it is recommended for the Government of Papua New Guinea to support a larger role for private sector initiatives by strengthening policy coherence and providing regulatory certainty. While this report refers specifically to the electricity sector, this recommendation is also viable for other sectors. A predictable policy and regulatory environment can play a critical role in stimulating economic activity. However, currently, there is considerable uncertainty in existing policies and regulation. There are contradictions within and between policies. Where regulation exists, it is often unclear whether and to what extent it is implemented. Unclear mandates of government and regulatory agencies, as well as uncoordinated and ad-hoc development of policies, all lead to inconsistency between existing policies, legislation, and regulation. Such inconsistency creates considerable uncertainty for businesses and works as a strong disincentive for private investment.

Second, it is recommended for the GoPNG to strengthen data collection as a fundamental requirement to design well-informed policies. In Papua New Guinea, there is considerable uncertainty in basic data that propagates through the analysis of numerous issues across different sectors. The lack of timely and reliable data puts the results of many assessments on weak foundations. In return, the paucity of reliable analysis impedes the development of relevant policies to address the issues faced within these sectors. Finally, the absence of reliable data also prevents monitoring the impact and evaluating the effectiveness of policies, projects, and other interventions.

Third, to achieve many of the benefits associated with the recommendations outlined in this report, it is imperative to strengthen efforts toward good governance and address the issue of corruption. Papua New Guinea faces severe governance challenges, which are often complex and interlinked, including corruption, inefficient government bureaucracy, lack of security, paucity of basic infrastructure outside the main cities, and a dearth of resources and qualified staff. Addressing these challenges will require a long-term effort and strong political commitment at the highest levels of government. While it is well beyond the scope of this report to address these underlying challenges, lack of progress in these areas will continue to undermine any development efforts. Corruption undermines economic development

by creating an environment where accountability is lacking, resources are wasted, and trust between and within different entities is low. In order to reduce corruption and strengthen good governance, clear roles and responsibilities should be assigned to individual authorities, reducing uncertainty and increasing accountability. In addition, the consistent enforcement of existing rules and regulation needs to be strengthened in order to create incentives for all relevant parties to comply.

Ultimately, there are ample opportunities for green growth in Papua New Guinea, supporting the country's efforts to mitigate its contribution to and adapt to the adverse impacts of climate change. The recommendations discussed in this report can support the Government of Papua New Guinea to achieve the goals identified in its Vision 2050 and Climate Change Management Act. Beyond that, the suggestions and analysis behind the recommendations can contribute to achieving the Sustainable Development Goals and delivering on the country's climate change commitments.

Papua New Guinea's Climate Change and Development Authority is meant to play a central role in achieving these goals and in implementing the recommendations outlined in this report. The authority can act as a coordinator between different government branches to foster a shared approach for sustainable development. In the areas under its auspices, it is in a strong position to strengthen regulatory certainty and enforcement to attract investment and promote conservation. Beyond attracting finance and technical support from development partners for specific initiatives, CCDA can engage with relevant actors—including producers, business federations, buyers, processors, and financial intermediaries—to explore how business opportunities can be aligned with conservation efforts and a more equitable distribution of wealth.

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Appendix

A1.1 Papua New Guinea: GGPA Workshop Report



Global
Green Growth
Institute

Green Growth Potential Assessment of Papua New Guinea

Workshop Report

August 2018





Green Growth Potential Assessment of Papua New Guinea Workshop Report

August 2018

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1. BACKGROUND

Papua New Guinea (PNG) is one of the most vulnerable countries to the adverse effects of climate change. Adapting to and mitigating the impacts of climate change remains a high priority for the government. Efforts in this direction are guided and supported by existing policies and strategies, such as the Vision 2050 Plan, the National Strategy for Responsible Sustainable Development for PNG, the PNG Climate Change (Management) Act, and the National Climate Compatible Development Management Policy.

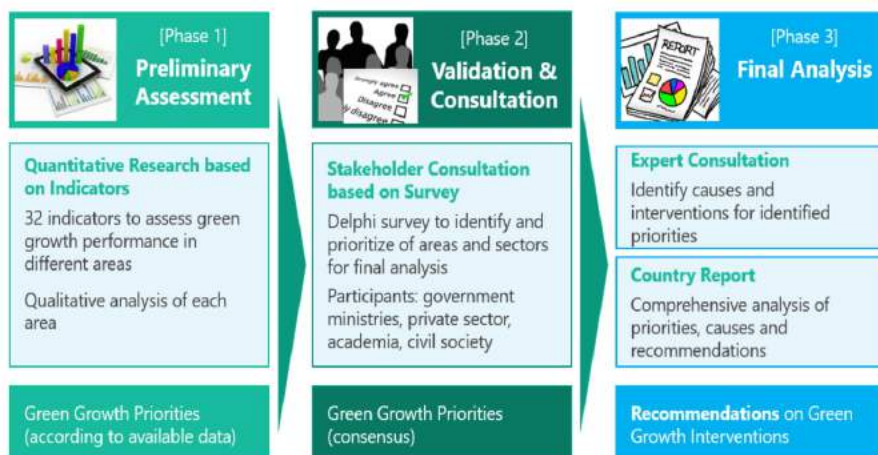
The government of Papua New Guinea places a high priority on accessing climate finance to assist the country in mitigating its contribution to climate change and adapt to the adverse impacts of climate change that are already occurring. Working closely with the Climate Change and Development Authority (CCDA) as well as the Department of Foreign Affairs (DFA), the Global Green Growth Institute (GGGI) is supporting the government in accessing funds from the Green Climate Fund through providing *Readiness and Preparatory Support*.

In this context, the Green Growth Potential Assessment (GGPA) is used to provide valuable analysis to strengthen the ongoing efforts. The

GGPA will identify interventions offering the greatest potential to mitigate PNG's contribution to climate change and to mitigate the adverse impacts of climate change in the country. The result of the assessment will be a set of recommendations addressing the identified priorities. Each recommendation will be underpinned by analysis based on existing research, case studies, and relevant examples from other countries, considering existing policies, strategies, plans and regulation.

The GGPA is a diagnostic tool, developed by GGGI, consisting of a combination of data analysis and stakeholder consultation in order to identify and prioritize a country's opportunities for green growth. In the context of Papua New Guinea, the methodology was adapted to identify priorities in relation to climate change. The GGPA process consists of the following three stages: (1) the preliminary assessment based on data analysis and literature review; (2) consultation with stakeholders to validate and/or revise the findings of the preliminary assessment; and (3) the final analysis covering the identified priorities and including the development of recommendations (Figure 1). This design aims to ensure that the assessment process is systematic, objective, and participatory.

Figure 1 Overview of the GGPA Process



2. WORKSHOP OBJECTIVES AND METHODOLOGY

An essential part of the GGPA is to gather input from a broad range of stakeholders through an interactive Delphi-based workshop. The workshop serves to validate and/or revise the initial findings of the preliminary assessment. Presenting the results of the data analysis, coupled with a systematic participatory process, is essential to ensure broad stakeholder consensus on priorities to address climate change. The consultation process also serves to compensate for any lack of relevant data and ensures the alignment of GGPA results with existing policies. This report summarizes the proceedings during the workshop and presents the results.

The GGPA consultation workshop was held on 26 July 2018 in Port Moresby with about 50 participants representing different departments and agencies of the Government of Papua New Guinea (GoPNG) as well as representatives from developing partners, academic institutions and the private sector (The list of the participants and the workshop agenda are provided in Appendix A2).

The workshop was organized by the Climate Change and Development Authority, in

collaboration with the Department of Foreign Affairs, and the Global Green Growth Institute.

A sequence of voting and discussion, based on the Delphi method and led by representatives of CCDA and GGGI, was used to identify priorities in respect to climate change in Papua New Guinea. For that purpose, participants were asked multiple times via an electronic survey to select priorities related to climate change. The choices were based on a list of preselected areas represented by the indicators used during the preliminary assessment. Each consultation round was informed by relevant results from the preliminary assessment. After each consultation round the results were shared with participants to inform the discussion. The survey system allowed participants to voice their opinion anonymously, while discussing the results after each consultation round allowed them to adjust their assessment based on additional information and feedback within the group, without interference of status, age, or sex of other participants.

The identified priorities serve as the basis for analysis leading up to the GGPA final report. As part of this analysis, GGGI will work with stakeholders to contextualize the analysis, considering existing research and plans, and consult with local experts to inform the analysis.

Figure 2 Plenary Session and Group Discussions During Consultation Workshop



3. WORKSHOP PROCEEDINGS AND RESULTS

3.1 Consultation

To identify green growth priorities, the workshop altered between presenting the results of the data analysis and asking participants for their feedback in several interactive survey rounds.

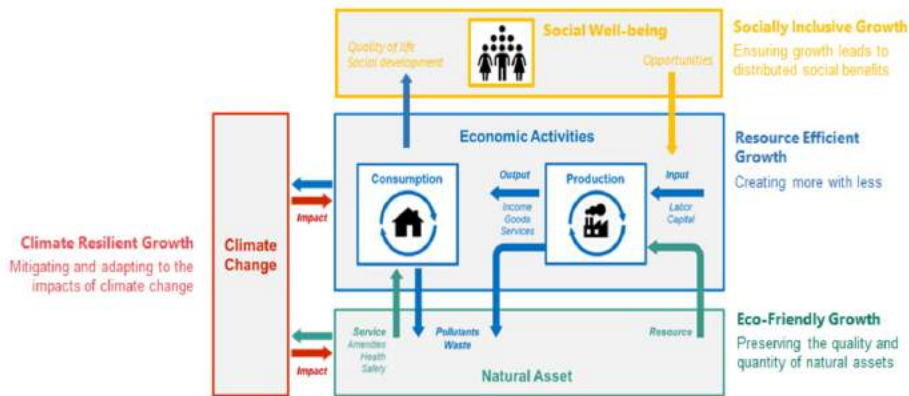
3.1.1 GGPA Methodology

Jan Stelter, GGGI Senior Analyst, introduced the assessment methodology, explaining that the GGPA is a diagnostic tool that combines data

analysis with stakeholder consultation to identify areas where mitigating climate change and/or addressing its adverse impact is most relevant. He briefly explained the assessment process and the workshop objectives.

In order to introduce the findings of the preliminary assessment, he explained that the preliminary analysis attempts to benchmark a country against its income group and selected regional peers based on 32 indicators. These indicators are grouped into four dimensions reflecting different aspects of climate change and its impacts. The four dimensions are (1) natural assets, (2) economic activities, (3) mitigation of and adaptation to climate change, and (4) social well-being (Figure 3).

Figure 3 Conceptual Framework for GGPA Indicators



3.1.2 Identification of Priorities

In order to identify priorities for addressing climate change in PNG, participants went through a series of consultation rounds. In each round, participants were asked to choose up to eight priorities out of a list of 32 areas. These consultation rounds were supported by an electronic survey system. Between each round, participants were provided with further information on the results of the preliminary assessment and provided their own insights into the relevant topics.

Prior to the first consultation round, PNG's performance on 32 indicators (representing the areas participants were asked to select from) was compared to regional peers (Timor-Leste, Fiji and Indonesia) as well as the group of the Lower Middle-Income Countries. A list of the indicators with details on their definition and sources is provided in Appendix A1.

Prior to the second and third consultation rounds, the plenary discussion focused on the areas that participants had prioritized during the previous round. Each area was introduced by providing additional context and more

detailed information from the preliminary assessment in order to stimulate the discussion. Participants identified three priority areas for climate change in Papua New Guinea (Figure 5).

These areas are:

- Agricultural productivity,
- Vulnerability to climate change, and
- Renewable energy.

The identified priorities remained remarkably stable between multiple survey rounds. The three top priorities increased their share in votes over the course of the workshop, with agricultural productivity (+10%), vulnerability to climate change (+8%), and renewable energy (+18%). While experience in slight decline in total votes, the share of votes given to forest cover remained largely unchanged. This is the result of two participants less participating in the final survey round compared to the first survey round. Given the small gap in votes between these four areas, forest cover should

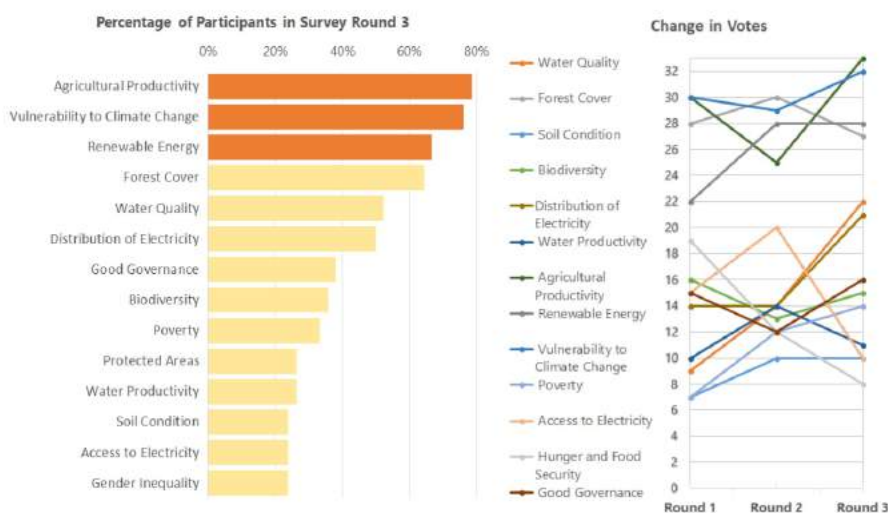
also be considered as a priority for climate change in Papua New Guinea.

These results reflect high consensus among participants that the selected areas reflect indeed priorities for climate change mitigation and adaptation.

It is noteworthy that both, water quality (+32%) and distribution of electricity (+18%) experienced considerable gains in the number of participants who saw them as priorities. Furthermore, the number of participants considering the costs of climate change as a priority increased by nearly 20%. While far from being among the top priorities, it is closely related to concerns about the countries vulnerability to the adverse impacts of climate change.

Finally, throughout the workshop, more than a third of the participants regarded good governance as an important aspect of addressing climate change.

Figure 4 Priority Areas Identified by Participants



3.1.3 Break-Out Group Discussions

After lunch, participants were divided into three breakout groups. Each of these groups was led by an experienced facilitator from CCDA. All three groups were asked to complete the two following tasks:

1. Based on the priorities proposed by the plenary, please discuss whether or not you agree with the three highest priorities for addressing climate change in Papua New Guinea.
2. Please select three issues that are related to each of the priorities that your group agreed on.

Figure 5 Workshop Discussions



The results of the group discussions confirmed the results of the plenary session. All three groups agreed that agricultural productivity, vulnerability to climate change, and renewable energy represent the highest priorities in order to address the adverse impacts of climate change.

- Agricultural productivity was selected by participants, due to the high importance of agriculture for rural livelihoods, food security, and Papua New Guinea's economy.
- Renewable energy was regarded as an opportunity to increase electrification, particularly in rural areas with off-grid solutions and stand-alone systems. Participants emphasized the high potential for renewable energy in PNG, given the country's abundant renewable energy resources,
- Vulnerability to climate change was identified as a priority, due to the country's high exposure to climate change (including droughts, landslides, sea level rise, soil erosion, floods, and change in weather patterns), and the economy's sensitivity to the adverse impacts of climate change, given its dependence on sectors that experience considerable impacts from climate change such as fisheries and agriculture. Furthermore, participants saw the need to strengthen the country's adaptive capacity.
- Participants consistently mentioned financial resources, technical capacity and technology, as well as good governance as critical enablers for progress in the identified priorities.

Identifying issues that are most related (in the context of PNG) to the priorities mainly served to further narrow down and provide guidance for aspects that the analysis needs to cover. For that purpose, participants were provided with a list of 14 suggestions for relevant issues. They were given the choice to either choose from this preselected list or define their own list of issues. In a final plenary survey round, participants were asked to select relevant issues for all three priorities taking into account any additional suggestions made by the three groups (Table 1).

More details on the selected priorities are provided in Chapter 3.2 'Interpreting the

Results', while the results of individual breakout groups are presented in Appendix A3.

Table 1 Selected Growth Priorities and Related Issues by Number of Participants

Related Issues \ Priority	Agricultural Productivity	Vulnerability to Climate Change	Renewable Energy
Infrastructure, transportation, ¹ equipment ²	24	20	16
Financial resource and access to finance	28	32	27
Technical capacity and technology	19	20	21
Market access and competition	21	2	8
Affordability and subsidies	9	5	14
Information and data management ³	9	33	7
Private sector and services	9	5	20
Governance and institutions	10	9	6
Policy and regulation	2	4	25
Monitoring and enforcement ⁴	3	19	12
Land tenure	17	-	14
Disaster risk management	-	22	-
Awareness	-	18	-

*Highlighted cells suggest priority and issue are strongly related, with half or more participants regarding them as related.

¹ For agricultural productivity, infrastructure and transportation.

² For vulnerability to climate change, infrastructure and equipment.

³ For vulnerability to climate change, data collection and dissemination.

⁴ For vulnerability to climate change, planning and monitoring.

3.2 Interpreting the Results

For the interpretation of the workshop results, it is important to look beyond the top three priorities that participants identified. Two points are important to consider in this respect: First, some of the areas are closely interrelated, Second, some of the areas are of a cross-cutting nature, involving multiple areas and sectors.

Agricultural Productivity

Participants agreed that agricultural productivity is a priority when addressing the adverse impact of climate change. Agriculture is central to rural livelihoods due to the high share of subsistence agriculture in Papua New Guinea, supporting about 80% of the population. Furthermore, the agriculture sector is an important pillar of the country's economy, accounting for 30% of the country's GDP and more than 10% of export earnings.

Given the high impact of agricultural activities on forests in Papua New Guinea, one cannot be considered without the other. The importance of both sectors is reflected in participants' choices, with agricultural productivity being seen as a priority by four out of five participants and forest cover by two out of three participants. Similarly, given the important ecosystem services that forests provide to the agricultural sector, water quality (52%) and soil conditions (24%) will need to be considered in the analysis where relevant.

In this context, participants pointed to the challenges of accessing markets, from logistics and transportation to institutions and marketing. They also highlighted the important role played by the agricultural sector regarding food security and social inclusiveness.

The GGPA analysis will look into interventions for increasing agricultural productivity while reducing its role as a main driver for deforestation. The use of affordable technologies, changes in agricultural practices, improvement of extension services, as well as opportunities to enhance market access and commercialization will play a prominent role.

Furthermore, the analysis will look at the strong link between improving agricultural productivity and other aspects of rural development that were highlighted during the workshop, such as electricity access.

Renewable Energy

More than two thirds of all participants regarded renewable energy as a priority. They explicitly pointed out that renewable energy should play an important role in improving access to electricity. Participants saw renewable energy as an important source of electricity supply, both for grid and off-grid systems. Participants saw small and micro hydro projects as the primary source for renewable energy, with natural gas playing an important role as a bridge technology over the medium term.

Participants agreed that there is a high potential for renewable energy in PNG. However, they also pointed out that renewable energy resources are specific to individual sites and locations. In this context, they regarded access and dissemination of data as crucial to efficiently tap into the existing potential.

Renewable energy was commonly regarded as an opportunity to increase electrification in rural areas, both for household electrification and productive use. Productive use of renewable energy was seen as a potential means to increase agricultural productivity, for example, by powering water pumps, support irrigation systems, allow for proper storage and cooling. Renewable energy was also regarded as a source of economic growth, allowing for more processing and other value-adding activities in rural areas.

Participants regarded access to finance, the development of mechanisms to promote investment in renewables together with strengthening existing regulation, as well as access to equipment and technology as crucial enablers for the deployment of renewable energy. Furthermore, the question of landownership might play a crucial role as well.

Finally, in the context of reliable electricity supply, several participants highlighted the importance of reducing technical losses as well as theft.

The final analysis will consider these aspects when discussing renewable energy.

Vulnerability to Climate Change

Participants agreed that vulnerability to climate change represents a cross cutting challenge, affecting numerous areas and sectors in Papua New Guinea.

The country faces considerable exposure to climate change, including droughts, landslide, sea level rise, soil erosion, floods, and change in weather patterns. At the same time, given the importance of agriculture and fisheries, the

country's economy is sensitive to the adverse impacts of climate change. Finally, participants saw the need to strengthen the country's adaptive capacity.

Accessing finance, collecting and disseminating relevant data, as well as developing technical capacity within PNG were seen among others as requirements to reduce the adverse impact of climate change. Similar to other priorities, participants also saw the need to strengthen institutional capacities, from mainstreaming climate change consideration into different development plans at the national, provincial and district level to improving the country's disaster risk management.

The final analysis will discuss climate change and its impacts on Papua New Guinea, highlighting the various ways in which the country is affected. A focus will be laid on the impact of climate change in the two areas highlighted above, i.e. agriculture (and forestry) and energy.

4. PHASE 3: FINAL ANALYSIS

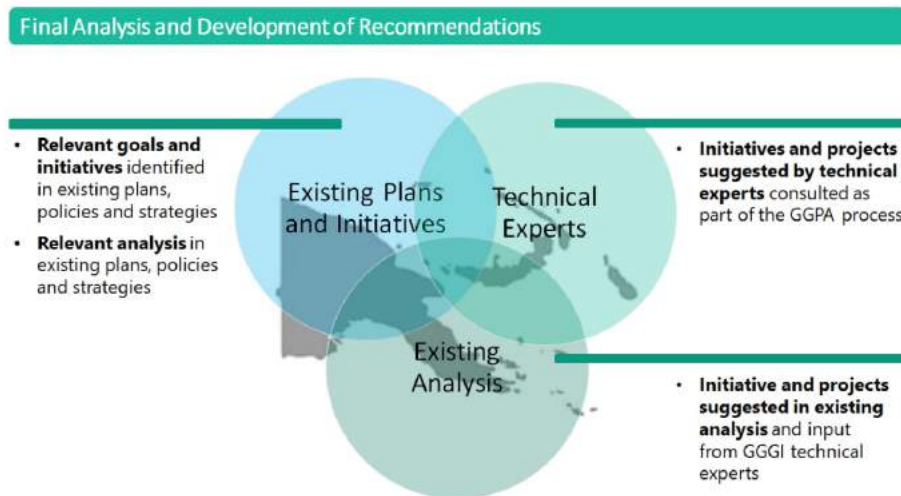
The final analysis will focus on the identified priorities as outlined above (see 3.2 Interpreting the Results), but it will not be limited to them. Where necessary it will consider aspects that are closely related to these priorities as suggested during the consultation workshop or as identified as part of the research.

The final analysis will be based on three principal sources of information. First, the report will consider relevant goals and initiatives identified in existing sectoral and cross-sectoral plans, policies, and strategies, as well as draw from relevant analysis included in

any of these documents. Second, a series of interviews with technical experts in Papua New Guinea will be conducted to inform the analysis. GGGI together with CCDA will identify relevant experts from ministries, the private sector, academia, and development partners. Third, the assessment will draw on existing analysis in the form of research papers, case studies, project evaluations, sector assessments, etc. In addition, GGGI technical experts will provide input.

The GGPA report will propose specific initiatives and interventions based on the assessment, each underpinned by a solid rationale based on empirical evidence.

Figure 6 Schematic of Analytical Framework for GGPA Final Report



A1.2 GGPA Indicators

Theme	Indicator	Unit	Description	Source
Natural Assets	Baseline Water Stress Index	0 – 5 (higher score = greater competition among users)	Ratio of total annual water withdrawals (municipal, industrial, and agricultural) to total renewable supply and the values are normalized from 0 to 5. http://www.wri.org/sites/default/files/aqueduct_country_rankings_010914.pdf	WRI
	Disability-adjusted life years (DALYs) due to unsafe water source	Life Years	DALYs are also defined as years of healthy life lost. The definition of unsafe water source considers the share of households with access to different water sources and reported use of household water treatment methods). Unsafe water sources refer to water from limited, unimproved, and surface water sources without any treatment. A limited water source refers to drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing. An unimproved water source refers to drinking water from an unprotected dug well or unprotected spring. Surface water refers to drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal. Data is available for a single year. http://ghdx.healthdata.org/gbd-results-tool	GHDx
	Changes in Forest Cover	Annual change in total forest cover (%)	Annual percent change in forest cover between 2005 and 2015 (Definition of forest: Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use). http://faostat3.fao.org/download/R/RL/E	FAO
	Population-Weighted Exposure to PM _{2.5}	µg / m ³	Three-year average exposure to PM _{2.5} , particles of less than 2.5 micrometers in diameter. https://epi.envirocenter.yale.edu/epi-downloads	EPI
	Trends in Soil Health Index	0 – 50 (higher score = better soil condition)	Measures the physical part related to loss of soil mass and structure; and the long-term chemical well-being of the soil in terms of nutrients and absence of toxicities built up. http://www.fao.org/nr/lada/index.php?option=com_docman&task=doc_download&gid=773&lang=en	FAO
	Share of threatened species	% of Total Species	Number of animal species and plant species in each IUCN Red List Category by country. http://cmsdocs.s3.amazonaws.com/keydocuments/Categories_and_Criteria_en_web%2Bcover%2Bbckcover.pdf	IUCN
	Fish Stocks	% of overexploited species in total catch	Fish Stocks measures the percentage of a country's total catch – within its exclusive economic zone - that is comprised of species that are overexploited or collapsed, weighted by the quality of fish catch data. https://epi.envirocenter.yale.edu/epi-downloads	EPI
	Protected Areas	% of important terrestrial biodiversity sites covered by protected areas	This indicator shows temporal trends in the mean percentage of each important site for terrestrial biodiversity (i.e., those that contribute significantly to the global persistence of biodiversity) that is covered by designated protected areas. https://sustainabledevelopment.un.org/sdg15	UNEP-WCMC, IUCN

Efficient Use of Resources	Energy Intensity	MJ per USD constant 2011 PPP GDP	An indication of how much energy is used to produce one unit of economic output. It is the ratio between energy supply and GDP measured at purchasing power parity. Lower value indicates that less energy is used to produce one unit of output. (GDP: 2011 USD PPP) http://data.worldbank.org/indicator/EG.EGY.PRIM.PP.KD	WB
	Transmission and Distribution Losses	% of output	Losses in transmission between sources of supply and points of distribution and in the distribution to consumers, including pilferage. http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS	
	Water Productivity	USD/m ³ per year	Indication of the efficiency by which a country uses its water resources. Calculated as GDP (2010 USD) in constant prices divided by the annual freshwater withdrawal. http://data.worldbank.org/indicator/ER.GDP.FWTL.M3.KD	WB
	Agriculture Productivity	International Dollar /km ² per Year	Ratio between agricultural production and total area of arable land under permanent crops, and under permanent pastures. Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures. http://faostat3.fao.org/download/Q/QV/E (gross production value constant 2004-2006) http://data.worldbank.org/indicator/AG.LND.AGRI.K2 (for further description of agricultural land)	FAO, WB
	Labor Productivity	Thousand USD, constant 2010	GDP per worker of labor force (ages 15 and older who meet the ILO definition of the economically active population). http://www.ilo.org/global/statistics-and-databases/research-and-databases/kilm/lang--en/index.htm Indicator: Output per worker (GDP constant 2005 USD)	ILO
	Busses per 1,000 people	Number	Number of busses divided by total population.	IRF
	Share of Population Covered by a 2G Mobile Network	% of population	The percentage of inhabitants living within range of a mobile-cellular signal, irrespective of whether or not they are mobile phone subscribers or users. This is calculated by dividing the number of inhabitants within range of a mobile-cellular signal by the total population and multiplying by 100.	ITU
	Share of Population with Access to Improved Sanitation	% of population	Sanitation services refer to the management of excreta from the facilities used by individuals, through emptying and transport of excreta for treatment and eventual discharge or reuse. https://washdata.org/data#!/table?geo0=region&geo1=sdg	WHO, UNICEF
	Municipal Solid Waste Generation Intensity	kg of waste / unit GDP	Municipal waste is defined as the waste mainly produced by households, including also similar waste generated from sources such as commerce, offices and public institutions. The amount of municipal waste generated consists of waste collected by or on behalf of municipal authorities and disposed of through the waste management system. The indicator is the ratio between GDP (constant 2010 USD) and municipal solid waste generated. http://www.atlas.d-waste.com/ (for municipal solid waste generation) http://data.worldbank.org/indicator/NY.GDP.MKTP.KD (for GDP)	Dwaste, WB

Risk and Resilience	CO ₂ Emission per GDP	kg CO ₂ . per unit GDP (USD)	Amount of carbon dioxide emissions (those stemming from the burning of fossil fuels and the manufacture of cement) per unit of gross domestic production (GDP: constant 2010 USD). http://data.worldbank.org/indicator/NY.GDP.MKTP.KD (for GDP) http://data.worldbank.org/indicator/EN.ATM.CO2E.KT (for CO ₂)	WB
	CO ₂ Emission Trend	Annual growth rate (%)	Annual growth rate in national emissions of CO ₂ over the latest five years available. http://data.worldbank.org/indicator/EN.ATM.CO2E.KT	
	Carbon Stock in Living Biomass	Annual growth rate (%) between 2005 and 2015	Annual changes in carbon stock, which is a quantity of carbon contained in a reservoir or system of living forest biomass which has the capacity to accumulate or release carbon. http://www.fao.org/3/a-i4808e.pdf	FAO
	Renewable Energy	% of total electricity output	Annual changes in carbon stock, which is a quantity of carbon contained in a reservoir or system of living forest biomass which has the capacity to accumulate or release carbon. http://www.fao.org/3/a-i4808e.pdf	FAO
	Fossil Fuel Subsidies	Price gap in USD	The IEA estimates subsidies to fossil fuels that are consumed directly by end-users or consumed as inputs to electricity generation. https://www.iea.org/statistics/resources/energysubsidies	IEA
	Vulnerability to Climate Change	0 – 100 (higher score = higher vulnerability)	Propensity or predisposition of human societies to be negatively impacted by climate hazards ND-GAIN assesses the vulnerability of a country by considering six life-supporting sectors: food, water, health, ecosystem services, human habitat and infrastructure. Each sector is in turn represented by six indicators that represent three cross-cutting components: the exposure of the sector to climate-related or climate-exacerbated hazards; the sensitivity of that sector to the impacts of the hazard and the adaptive capacity of the sector to cope or adapt to these impacts. https://gain.nd.edu/assets/254377/nd_gain_technical_document_2015.pdf	ND-GAIN
	Climate Risk Index	lower score = higher risk	The Global Climate Risk Index 2018 analyses to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.). https://germanwatch.org/en/download/20432.pdf	Germanwatch
Social Inclusion	Poverty Headcount Ratio at \$1.90 a day (2011 PPP)	% of population	The percentage of the population living on less than USD1.90 per day. http://data.worldbank.org/indicator/SI.POV.DDAY	WB
	Access to Electricity	% of population	Proportion of population with access to electricity is the percentage of population with access to electricity. https://data.worldbank.org/indicator/eg.elc.accs.zs	WB
	Proportion of Stunted Children under Age of 5 Years	% of population	The percentage of population below minimum level of dietary energy consumption (also referred to as prevalence of undernourishment). It shows the percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously. http://data.worldbank.org/indicator/SN.ITK.DEFC.ZS	WB

Social Inclusion	Healthy Life Expectancy at birth	Years	Average number of years that a person can expect to live in "full health" by taking into account years lived in less than full health due to disease and/or injury. Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. http://apps.who.int/gho/data/node.main.HALE?lang=en	WHO, WB
	Net completion rate for primary education	% of relevant age group	1) Primary Completion Rate is defined as the number of new entrants (enrollments minus repeaters) in the last grade of primary education, regardless of age, divided by the population at the entrance age for the last grade of primary education. Data limitations preclude adjusting for students who drop out during the final year of primary education. https://data.worldbank.org/indicator/SE.PRM.CMPT.ZS	WB
	GINI Index	0 – 100 (higher score = higher inequality)	The GINI index measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. http://data.worldbank.org/indicator/SI.POV.GINI	WB
	Gender Inequality Index (GII)	0 – 1 (higher score = higher inequality)	The GII measures gender inequalities in three important aspects of human development — reproductive health, measured by maternal mortality ratio and adolescent birth rates; empowerment, measured by proportion of parliamentary seats occupied by females and proportion of adult females and males aged 25 years and older with at least some secondary education; and economic status, expressed as labor market participation and measured by labor force participation rate of female and male populations aged 15 years and older. http://hdr.undp.org/en/composite/GII	UNDP
	Corruption Perception Index (CPI)	1-100 (higher scores = lower levels of corruption)	The CPI scores and ranks countries/territories based on how corrupt a country's public sector is perceived to be. It is a composite index, a combination of surveys and assessments of corruption, collected by a variety of reputable institutions. https://www.transparency.org/news/feature/corruption_perceptions_index_2017	TI
	Ease of Doing Business Rank	0 – 190 (higher rank = better business environment)	A high ease of doing business ranking means the regulatory environment is more conducive to the starting and operation of a local firm. The rankings are determined by sorting the aggregate distance to frontier scores on 10 topics, each consisting of several indicators, giving equal weight to each topic. http://www.doingbusiness.org/Rankings	WB

About the Global Green Growth Institute

The Global Green Growth Institute was founded to support and promote a model of economic growth known as "green growth," which targets key aspects of economic performance such as poverty reduction, job creation, social inclusion, and environmental sustainability.

Headquartered in Seoul, Republic of Korea, GGGI also has representation in a number of partner countries.

Member Countries: Australia, Cambodia, Costa Rica, Denmark, Ethiopia, Fiji, Guyana, Hungary, Indonesia, Jordan, Kiribati, Republic of Korea, Mexico, Mongolia, Norway, Papua New Guinea, Paraguay, Philippines, Qatar, Rwanda, Senegal, Thailand, United Arab Emirates, United Kingdom, Vanuatu, Vietnam

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