Climate-Resilient Green Growth in New Ireland Province

February 2021

Photo credits GGGI.

Global Green Growth Institute
Jeongdong Building 19F
21-15 Jeongdong-gil
Jung-gu, Seoul 04518
Republic of Korea

Climate-Resilient Green Growth in New Ireland Province

February 2021

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

°C	degrees Celsius
2G	second generation mobile phone network standard (narrowband)
3G	third generation mobile phone network standard
ADB	Asian Development Bank
AFOLU	agriculture, forestry, and other land use
ANU	Australian National University
BoM	Australian Bureau of Meteorology
CCDA	Climate Change and Development Authority
CFE-DM	Center for Excellence in Disaster Management and Humanitarian Assistance
CIF	Climate Investment Fund
CIFOR	Center for International Forestry Research
cm	centimeter
CRGG	Climate Resilient Green Growth (Project)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
GDP	gross domestic product
GEF	Global Environment Facility
GGGI	Global Green Growth Institute
GHG	greenhouse gas
GoPNG	Government of Papua New Guinea
GSMA	Groupe Speciale Mobile Association
ha	hectare
HLPE	High Level Panel of Experts on Food Security and Nutrition
IBRD	International Bank for Reconstruction and Development
ICF	Inner City Fund
ICRC	International Committee of the Red Cross
IDMC	Internal Displacement Monitoring Centre
IEA	International Energy Agency
IMF	International Monetary Fund
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ITTO	International Tropical Timber Organization
ITU	International Telecommunication Union
kg	kilogram
km	kilometer
kt	kilotonne
LLG	local-level government

m	meter
mm	millimeter
MW	megawatt
ND-GAIN	Notre Dame Global Adaptation Initiative
NFA	National Forest Authority
NIP	New Ireland Province
NIPA	New Ireland Provincial Administration
NOAA	National Oceanic and Atmospheric Administration
NRC	Norwegian Refugee Council
NSO	National Statistics Office
OECD	Organisation for Economic Co-operation and Development
PEFC	Programme for the Endorsement of Forest Certification
PES	payment for ecosystem services
PGK	Papua New Guinea Kina
REDD+	Reducing emissions from deforestation and forest degradation
RSPO	Roundtable on Sustainable Palm Oil
SABL	Special Agricultural Business Lease
SE4All	Sustainable Energy for All
SPREP	Secretariat of the Pacific Regional Environment Programme
t	tonne
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
WASH	water, sanitation, and hygiene
WCS	Wildlife Conservation Society
WHO	World Health Organization
WWAP	World Water Assessment Programme

LIST OF CHEMICAL SYMBOLS

Ca^{2+}	calcium ion
$CaCO^{3}$	aragonite
CH_4	methane
CO_2	carbon dioxide
CO_3^{2-}	carbonate ion
H^+	hydrogen ion
H_2CO_3	carbonic acid
HCO_3^-	bicarbonate ion
N_2O	nitrous oxide

Executive summary

The Climate Resilient Green Growth (CRGG) assessment shows that New Ireland Province is exposed to the adverse impacts of climate change, as evidenced in a rise in temperature and potential changes in rainfall. At the same time, the province's population and economy are very sensitive to these phenomena, given their dependence on sectors that experience considerable impacts from climate change—particularly agriculture and fishing. Finally, low income levels and a lack of essential infrastructure such as transportation, health, electricity, water, and sanitation also mean their capacity to adapt to the adverse impacts of climate change is limited.

The CRGG assessment shows that there are ample opportunities for fostering climate-resilient green growth in New Ireland Province. Based on available data and research, and consultation with local stakeholders, the assessment identifies three priority areas for the province to enhance its resilience towards the adverse impacts of climate change:

- Agriculture;
- Water; and
- Fishing.

For each priority area, the assessment identifies several interventions that could help strengthen resilience against climate change.

Agriculture

Given the dominance of smallholder farming, interventions to strengthen resilience against climate change in the agriculture sector will have to focus on improving productivity without shifting to large-scale industrial farming, as this would undermine the livelihoods of smallholder farmers and cause major environmental damage. This requires more research into climate-resilient crops and agricultural techniques—including options for intercropping and agroforestry—that are suitable for specific locations in New Ireland Province. Furthermore, improving water management will be important for reducing the impact of droughts. For example, improving water storage and micro-irrigation systems could make smallholder farmers more resilient. Successfully disseminating such climate-resilient agricultural practices requires systematic improvements in extension services, and implementing these requires improved access to formal finance. Finally, deforestation reduces agricultural productivity and exacerbates the impact of climate change on agriculture. Adhering to internationally recognized sustainable logging practices and piloting initiatives to reduce emissions from deforestation and forest degradation (REDD+) at community level are two options for conserving forests in New Ireland Province.

Water

The assessment discusses two aspects of water supply that are likely to be affected by climate change: accessibility of drinking water and sanitation. Improving access to—and the quality of—drinking water and sanitation will require strengthening the enabling environment, putting in place the necessary infrastructure, and ensuring maintenance of that infrastructure. Strengthening the enabling environment includes articulating targets, priorities and approaches; establishing clear roles and responsibilities among the government agencies involved in the sector; creating adequate planning and decision-making mechanisms; allocating available government funds; and setting up budget mechanisms for allocating and tracking expenditure. Relevant infrastructure includes boreholes, rainwater harvesting systems, storage facilities, handwashing facilities, and pit latrines. Schools and healthcare facilities have been identified as a potential priority for such infrastructure. Finally, a lack of maintenance and availability of qualified technicians and managers are among the main reasons for systems failing. Therefore, simple systems that require minimum maintenance are generally preferable and the installation of new systems should be accompanied by an arrangement to ensure their maintenance.

Fishing

Fish and other marine species are a crucial protein source and fishing represents an important economic activity in the province. However, fish stocks in Papua New Guinean waters are declining, triggering concerns that coastal communities will face increasing food scarcity during the coming decades. Coupled with the adverse impacts of climate change, population growth, more destructive fishing methods, high returns on particular species such as sea cucumbers, and habitat degradation from agriculture, logging, and mining activities all contribute to declining fish stocks. However, options for directly reducing the adverse impacts of climate change on fisheries are limited. Therefore, interventions should focus on reducing stress from other factors—particularly human activity—on the marine environment to strengthen its resilience towards climate change.

It is recommended that interventions focus on the sustainable exploitation of marine resources in coastal waters. Establishing community-driven, locally managed marine protected areas is identified as a promising means for encouraging sustainable marine resource use. Furthermore, mangroves serve as nursery grounds and habitats for many marine species. Therefore, the conservation of mangrove forests through payment for ecosystem services can also play a crucial role. Aquaculture is considered to represent another option for reducing pressure on marine resources while creating income-earning opportunities for coastal communities. Finally, local authorities, supported by donor funding and external technical expertise, should investigate whether tourism can present an alternative to fishing as a source of income.

Acknowledgements

This publication was prepared by the Global Green Growth Institute (GGGI). This publication is part of the Climate Resilient Green Growth (CRGG) project funded by the Australian government's Department of Foreign Affairs and Trade.

The CRGG Assessment was made possible thanks to close collaboration between the Climate Change and Development Authority (CCDA), the New Ireland Provincial Administration and the assessment team. The assessment could not have been successfully conducted without the support and co-operation provided by the New Ireland Provincial Administration, notably:

Lamiller Pawut, OBE	New Ireland Provincial Administrator
Gideon Bogosia	Director, Division of Agriculture, Livestock, Fisheries, Forestry and Climate Change (Department of Primary Industries)
Barbra Makapa	Acting Manageress, Division of Agriculture and Livestock (Department of Primary Industries)
Stanley Paulus	Manager, Provincial Climate Change Office (Department of Primary Industries)
Emmanuel Tamba	Manager, Division of Provincial Fisheries and Marine Resources (Department of Primary Industries)
Amanda Toaligur	Executive Officer, Chief of Chiefs Office, Provincial Tourism Authority

It also benefited greatly from the input and guidance gathered from a consultation workshop and a series of expert interviews.

Jan Stelter, Senior Analyst (GGGI), was responsible for carrying out the CRGG assessment in New Ireland Province and drafting of this report. Sharon Tubal, Provincial Officer (GGGI) and Feelgeun Song, Modelling Officer (GGGI), supported the assessment by gathering relevant literature, conducting stakeholder interviews and being responsible for the logistics of the consultation workshop.

The work also benefited from the expertise of GGGI colleagues, particularly:

Achala Abeysinghe	Country Representative (Papua New Guinea)
Nathalie Andre	Specialist (Sanitation)
Hohit Seyoum Gebreegziabher	Project Officer (Papua New Guinea)
Juan Jose Robalino	Senior Associate (Sustainable Landscapes)

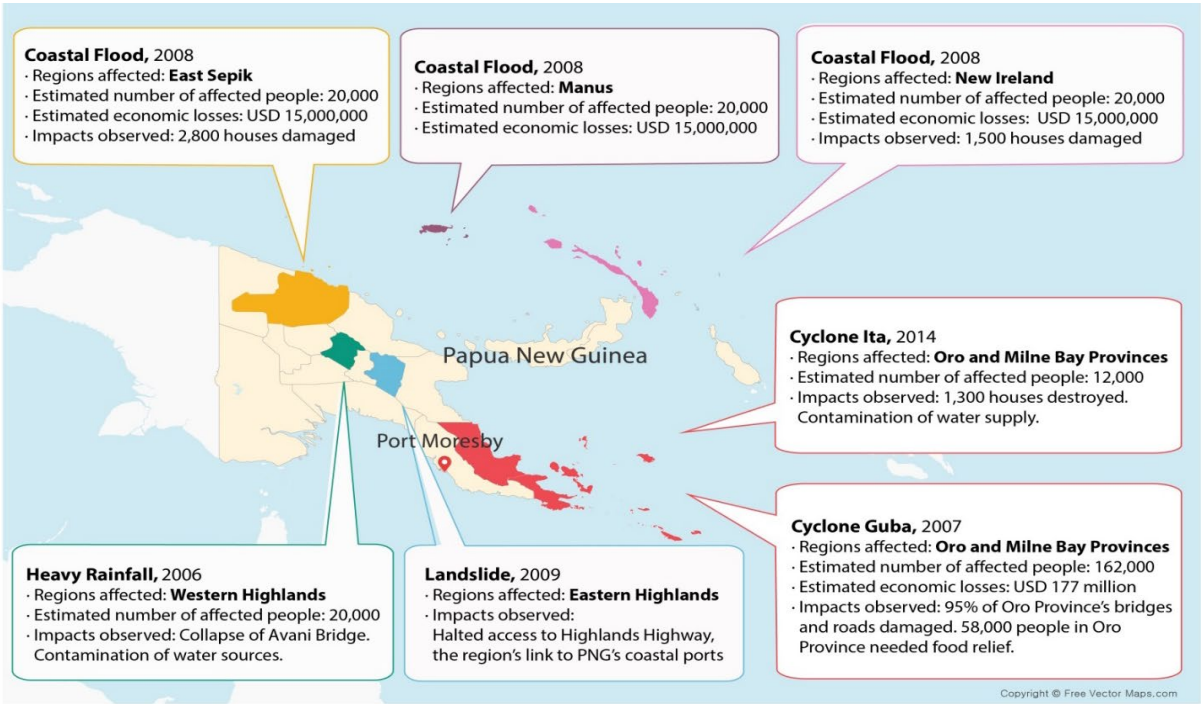
Assistance on design and layout was provided by Sujeung Hong. Editorial support from Lucy Southwood is also gratefully acknowledged.

Background

Papua New Guinea is highly exposed to climate change, as evidenced in higher temperatures and sea levels, changes in rainfall, increased ocean acidity, and less frequent but more intense droughts and cyclones (BoM and CSIRO 2014; ADB 2013b). At the same time, the country's population and economy are very sensitive to these phenomena, given their dependence on sectors that experience considerable impacts from climate change, such as fisheries and agriculture. Finally, their ability to cope with the adverse impacts of climate change is also compromised by the country's lack of essential transport, health, electricity, water, and sanitation infrastructure (GGGI 2019b; Figure 1).

The government of Papua New Guinea has recognized climate change as one of the country's greatest challenges. Environmental sustainability and adaptation to the adverse impacts of climate change represent one of the key pillars of its Vision 2050. Specifically, the document recognizes the challenges that climate change poses to food security and public health (GoPNG 2009).

Figure 1. 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

The Climate Resilient Green Growth (CRGG) project aims to address these challenges by strengthening Papua New Guinea's capacity to mitigate its contribution to climate change and adapt to the adverse impacts of climate change by: (1) supporting the preparation of provincial development plans and budgets; (2) designing relevant projects and interventions; and (3) establishing and operationalizing a financial mechanism for long-term financing of such projects.

To achieve these goals, it is pertinent to determine what climate resilience means in Papua New Guinea at the outset of the project. For that purpose, this assessment uses a transparent and evidence-based methodology to identify priorities for enhancing resilience towards the adverse impacts of climate change and relevant interventions to address these priorities.

Given the country's geographical, economic, and cultural diversity, a provincial approach is regarded as more advantageous than a centralized option. As such, the CRGG project was piloted in three provinces: Enga, Milne Bay, and New Ireland.

This report presents the results of the CRGG assessment of New Ireland Province. It describes the priorities for enhancing resilience towards the adverse impacts of climate change in the province and how these priorities have been identified. Finally, it proposes a set of interventions for coping with the adverse impacts for priority.

Ultimately, the aim is for the New Ireland Provincial Administration to incorporate the identified priorities into its development plans and budgets. Furthermore, the findings of the assessment will contribute to developing relevant interventions under Component 2 of the CRGG project (Figure 2).

Figure 2. CRGG project overview

Component 1: Provincial CRGG planning	Component 2: CRGG project preparation	Component 3: Enabling financing for CRGG
Output 1.1: Workplans for provincial CRGG mainstreaming Output 1.2: Provincial CRGG assessments Output 1.3: Mainstreaming of CRGG priorities into provincial development plans and budgets and identification of projects Output 1.4: Replication plan to roll out CRGG planning in additional provinces	Output 2.1: Selection of provincial CRGG priorities for further development Output 2.2: Workplans and budgets for CRGG project preparation Output 2.3: CRGG project designs and funding proposals Output 2.4: Replication plan to roll out project preparation in additional provinces	Output 3.1: Identification of barriers to accessing finance for CRGG Output 3.2: Tailored solutions to address the identified barriers Output 3.3: Implementation of solutions to reduce barriers to accessing finance for CRGG Output 3.4: Medium-term investment strategy for CRGG financing

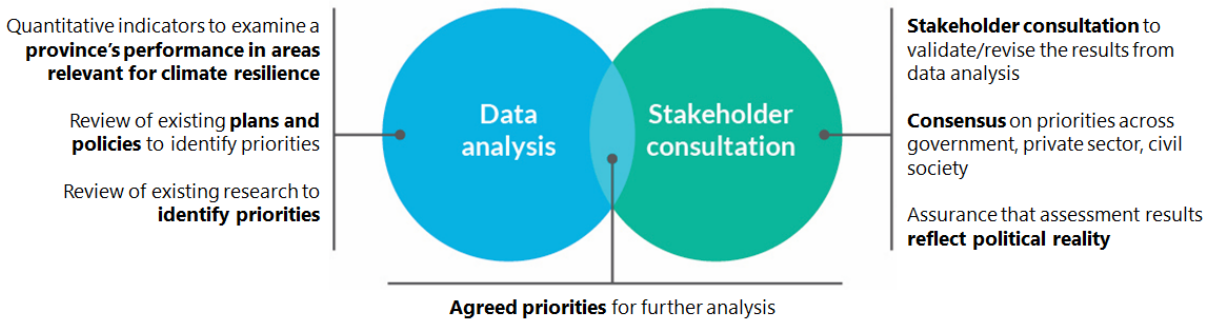
Source: GGGI

Methodology

Climate resilience is a broad concept, encompassing not only different economic sectors but also different levels of intervention. Furthermore, what climate resilience means in individual provinces and how it can be translated into specific actions depends on a wide range of factors. These include a province's economic structure, geography, endowment with natural assets, and social characteristics. Given the broad nature of the concept, there is a need to define what climate-resilient green growth means in a specific province's context by identifying and systematically assessing related priorities.

For that purpose, Global Green Growth Institute (GGGI) has developed the CRGG Assessment Methodology, which combines data analysis and stakeholder consultation (Figure 3). The methodology permits the evaluation and prioritization of a province's challenges resulting from the adverse impacts of climate change. It also helps identify opportunities for mitigating a province's contribution to—and strengthening its resilience towards—climate change.

Figure 3. Conceptual schematic of the CRGG Assessment Methodology



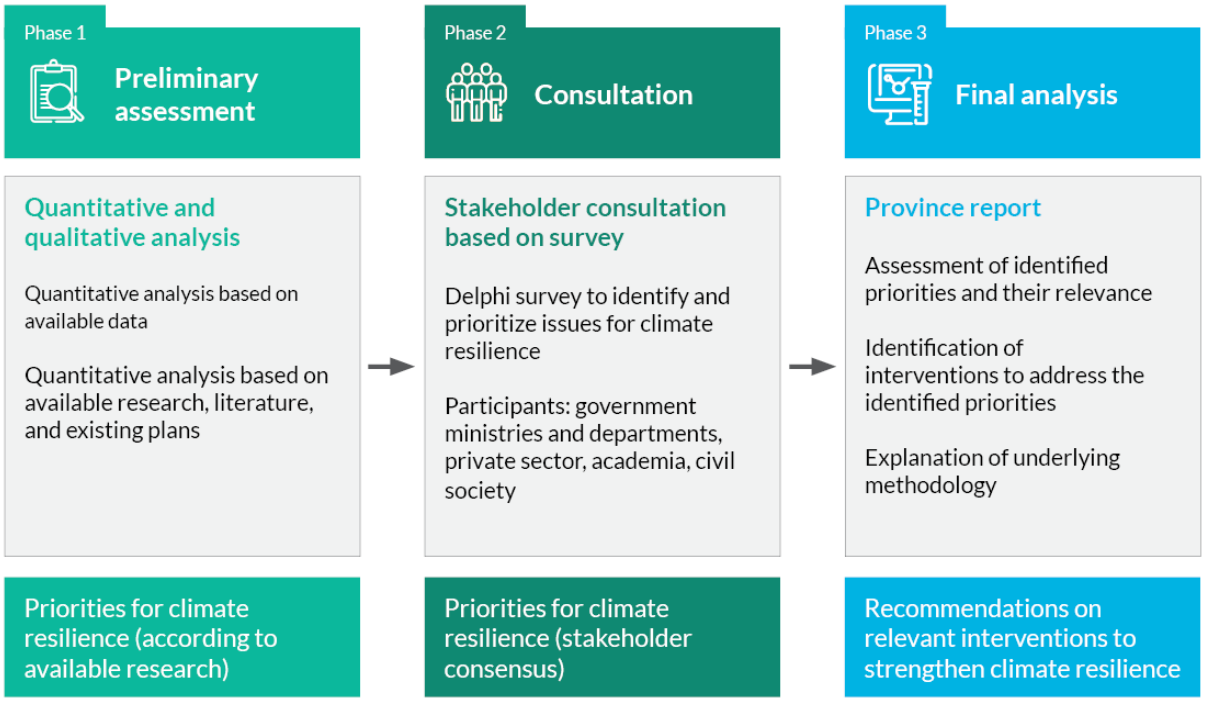
Source: GGGI

The CRGG assessment consists of the following three phases:

1. A preliminary assessment based on data analysis and literature review;
2. Consultation with stakeholders to validate, revise and add granularity to the findings of the preliminary assessment; and
3. A final analysis covering the identified priorities and including the development of recommendations to address these priorities (Figure 4).

This design aims to ensure that the assessment process is systematic, objective, and participatory.

Figure 4. Overview of the CRGG process



Source: GGGI

2.1 PRELIMINARY ASSESSMENT

The preliminary assessment serves as a starting point for identifying the priorities for climate-resilient green growth, considering the selected province's socioeconomic characteristics, geography, and climatic conditions. It relies on two principal aspects:

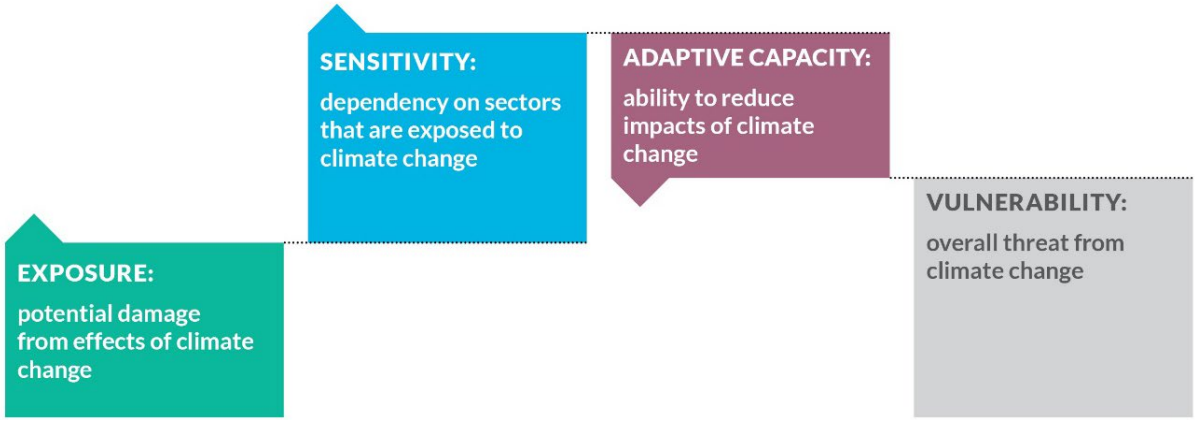
1. Understanding the relevant sources of greenhouse (GHG) gas emissions to mitigate the province's contribution to climate change; and
2. Evaluating a province's vulnerability to climate change to strengthen its resilience.

First, to determine the potential for mitigation and possible options for reducing GHG emissions, the assessment identifies relevant sources of GHG emissions and trends. Key indicators include a province's total GHG emissions, carbon intensity, carbon stock and potential for carbon sequestration, per capita emissions, and a sectoral breakdown of emissions. Depending on data availability, the preliminary assessment is designed to consider the two most important greenhouse gases, namely carbon dioxide (CO_2) and methane (CH_4).[1] Furthermore, to assess a province's potential for mitigating its contribution to climate change, the preliminary assessment considers its total primary energy supply, electricity mix, and the population's access to clean fuels and technologies for cooking.

Second, to systematically assess a province's vulnerability to the adverse impacts of climate change, the preliminary assessment distinguishes between three aspects of vulnerability, namely exposure, sensitivity, and adaptive capacity (Figure 5). This disaggregation is largely based on the Notre Dame Global Adaptation Initiative (ND-GAIN) Index (Chen et al. 2015).

[1] In 2010, global GHG emissions consisted of: 65% CO_2 from fossil fuel combustion and industrial processes; 11% CO_2 from forestry and other land use; 16% CH_4; 6.2% N_2O; and 2% fluorinated gases (IPCC 2014).

Figure 5. Conceptual framework for assessing vulnerability



Source: GGGI

A province is regarded as exposed to climate change when it is subject to major changes in extreme climate events and weather patterns. Relevant phenomena to be considered under exposure include: rise in temperature, changes in rainfall, occurrence of drought, rise in sea level, increase in ocean acidity, and occurrence of cyclones. A province is considered as sensitive to this exposure when its economy and population rely on sectors that are susceptible to climate change-related phenomena, such as agriculture and fisheries.

A province also has adaptive capacity, which is defined as its ability to reduce the adverse impacts of climate change, despite its level of exposure and sensitivity. Measuring adaptive capacity considers a province's poverty rates, access to electricity, reliability of transportation network, and access to and quality of health services, among others. Exposure and sensitivity increase a province's overall vulnerability to climate change, whereas adaptive capacity reduces its overall vulnerability. As part of the analysis, the assessment aims to identify means to reduce vulnerability by increasing a province's adaptive capacity.

2.2 CONSULTATION

As part of the CRGG assessment, stakeholders are given a leading role in determining the scope and content of the final analysis. Their input is essential for identifying priorities and developing recommendations that consider local conditions. Stakeholders include representatives from government, academic institutions, the private sector, civil society, and development partners.

While stakeholder engagement occurs throughout the entire assessment process, there is a concerted effort to systematically gather feedback from a broad range of constituents through an interactive workshop following the preliminary assessment. This workshop brings together 30–60 participants. Given the importance of stakeholder input for shaping the assessment, this systematic participatory process is essential to ensure broad consensus on priorities and potential remedies that are to be addressed in the final analysis.

There is a large spectrum of weighting and prioritization techniques in the context of multi-criteria decision-making methods.[2] There is no objective or correct way to determine priorities or assign weights. A methodology's suitability depends on the multi-criteria problem it is meant to solve and purpose for which it is employed (Ananda and Herath 2009; Roszkowska 2013; Zardari et al. 2015). Therefore, a methodology's characteristics—its transparency, its complexity of calculating results, and the costs

[2] Popular techniques include pairwise comparisons as the basis for the analytic hierarchy process, the budget allocation method, trade-off weighting method, rank ordering centroid, and the Delphi method (OECD and the Joint Research Centre of the European Commission 2008; Zardari et al. 2015).

involved—are, in many cases, just as important as technical soundness. There are several frequently used methodologies for assigning weights to different options, and each has its advantages and disadvantages when considering transparency, complexity, technical soundness, cost and so on (OECD and the Joint Research Centre of the European Commission 2008; Zardari et al. 2015).

As part of the CRGG assessment, stakeholder consultation relies on the Delphi method to identify priorities. The Delphi method is a systematic, interactive, and multiple-stage survey methodology that relies on a panel of experts. It was originally developed to systematically gather expert opinions and evaluate events and trends, based on consent or dissent among participants (Okoli and Pawlowski 2004; Turoff and Linstone 1975; Vorgrimler 2003). Of all the available weighting methodologies, the Delphi method was the best match for the basic requirements of the CRGG assessment, which include:

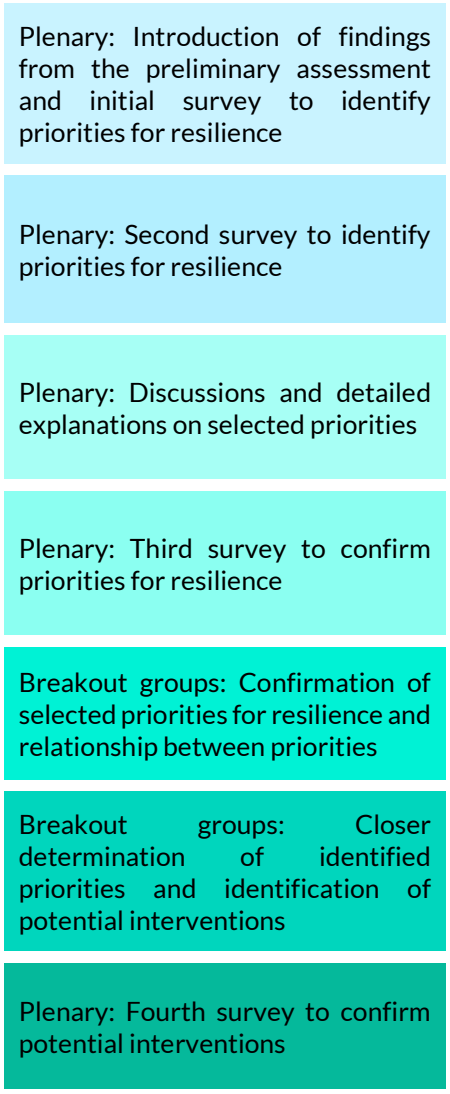
- Engaging stakeholders and reflecting their opinions in the identified priorities;
- Being simple, transparent, and easy for participants to understand;
- Sharing results among all participants instantaneously;
- Providing immediate feedback and repetition of the survey; and
- Requiring the least time possible.

The consultation workshop takes participants through the following steps (Figure 6). First, it introduces the results of the preliminary assessment separately for the three categories of climate resilience—exposure, sensitivity, and adaptive capacity (see Section 2.1). At this stage, participants are asked for their initial feedback on the preliminary assessment results and select three priorities for each category. Second, there is another round of feedback in which participants can select up to nine priorities across all three categories. Third, the plenary discusses the selected priorities and any prominent results from the preliminary assessment. This discussion is supported by presenting the audience with a more detailed analysis covering the selected areas. Participants are then asked for a third time to select nine priorities to confirm or revise the earlier results.[3]

In the second part of the workshop, participants are divided into smaller breakout groups to consolidate the results of the plenary survey, define the identified priorities more closely, and suggest remedies to address these priorities. Past experiences have shown that participants appreciate this interactive session of small group discussions, while the results provide additional insights to determine the direction of the final analysis.

To guide the discussions, breakout groups are given two specific tasks. First, they are asked to verify whether their group agrees with the priorities selected by the plenary, choosing alternative priorities if they do not agree. In addition, they are asked to identify possible relationships between the selected priorities across the three categories (exposure, sensitivity, and adaptive capacity). Second, each group is asked to identify possible remedies and interventions. For that purpose, participants are given a list of possible interventions and asked to identify relevant measures to strengthen resilience for each of the relationships that they have selected in the first task. The list of choices is based on the results of the preliminary

Figure 6. The consultation process



Source: GGGI

[3] Three consultation rounds have proven to be sufficient to build consensus around priorities (GGGI 2019a).

assessment, a literature review, and input from GGGI thematic experts. Beyond these preselected options, participants are encouraged to suggest further measures.

Appendix D contains a detailed overview of the two tasks given to the breakout groups and the preselected set of options.

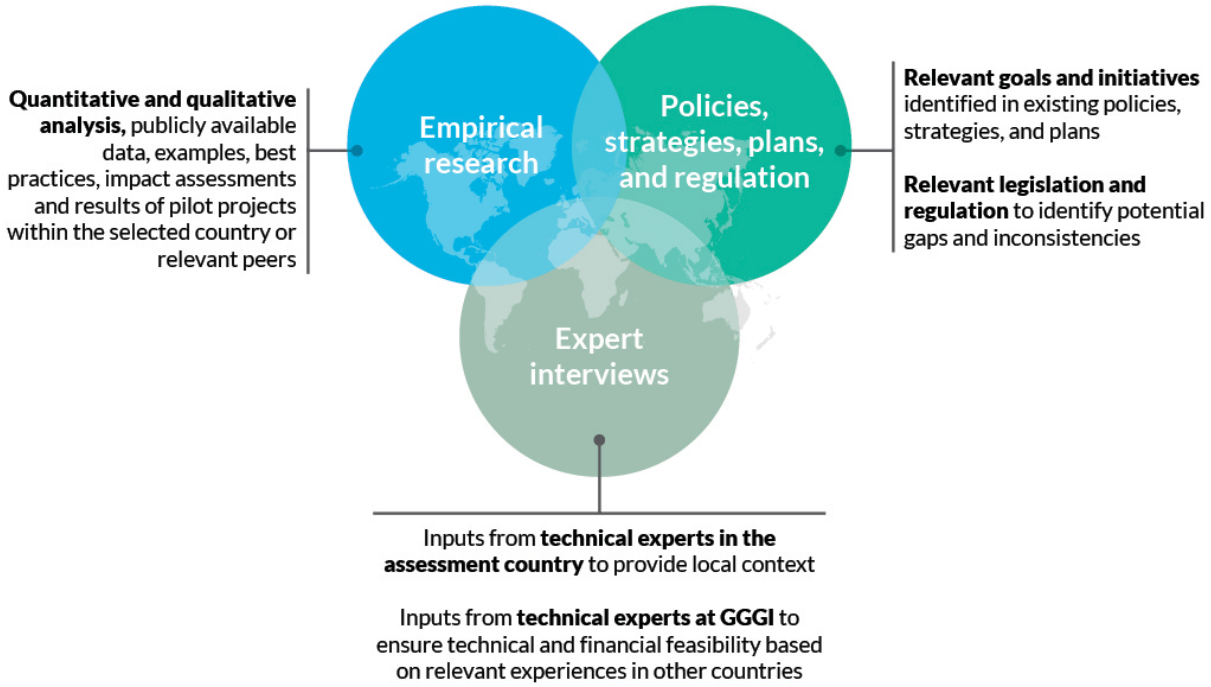
2.3 FINAL ANALYSIS

Building on the results of the consultation workshop, the final analysis identifies specific opportunities and barriers to climate-resilient green growth for each of the selected priorities. This analysis is built around a set of recommendations, ranging from changes in policy, to strengthening regulation and enforcement to identifying technical interventions and specific projects.

Recommendations are developed based on three kinds of input (Figure 7):

- Empirical research: The recommendations are informed by quantitative and qualitative analysis drawn from existing research and based on publicly available datasets. Furthermore, they rest on inference from examples, best practices, impact assessments, and results of pilot projects within the selected province, country, or relevant peers.
- Policies, strategies, plans, and regulations: The current policy and regulatory framework is reviewed considering existing policy, legislation, regulation, and institutional arrangements. This allows for the identification of relevant goals and initiatives and determination of potential gaps, inconsistencies, or obstacles within the current legislative, regulatory, and institutional setup.
- Expert interviews: A crucial input to developing the recommendations is a series of interviews with technical experts in the province from government, academia, the private sector, and civil society, who are consulted on specific issues within their area of expertise. These interviews serve multiple purposes. They address any gaps that remain after reviewing the literature, legislation, and regulation; clarify issues where the information gathered from documents is ambiguous; verify the recommendations that the assessment team is proposing; provide further context; and reflect the most recent developments that might not yet be available in written documents. In addition to local experts, technical experts from within GGGI provide their input to ensure that important aspects and trade-offs have not been overlooked, verify that recommendations are technically feasible and cost effective, and share relevant experiences from other countries.

Figure 7. Schematic of inputs to the final analysis



Source: GGGI

Preliminary assessment

The preliminary analysis served as a starting point for defining what climate-resilient green growth means in New Ireland Province, identifying relevant priorities and possible remedies. For that purpose, it considers the province's contribution to mitigating climate change and its capacity to cope with the adverse impacts of climate change.

To assess New Ireland Province's options for mitigation, the preliminary assessment relied on understanding the relevant sources of greenhouse gas emissions. To evaluate its vulnerability to climate change and identify means to strengthen its resilience, the preliminary assessment considered three elements: the province's exposure to climate change-related phenomena, the province dependence on economic activities that are susceptible to these phenomena, and the province's adaptive capacity to cope with the adverse impacts of climate change.

3.1 MITIGATION

To assess the potential for mitigation and possible remedies to reduce greenhouse gas emissions, the assessment first identified relevant sources of GHG emissions and trends. Given the paucity of available data and considerable uncertainty regarding its reliability, the assessment of mitigation options had to rely on estimates. GHG emission data is only available at a national—not provincial—level; and even these national-level estimates and their sectoral breakdown are only indicative.

As a result, the preliminary assessment focused on identifying relevant sources of GHG emissions and potential mitigation options. The assessment did not consider other indicators—such as carbon intensity, emissions per capita, existing carbon stocks, or the potential for carbon sequestration—as any such estimates would have been compromised by the low quality of available data (see Box 1).

Total national GHG emissions are comparatively low. Given the large extent of the country's forests, it can be deduced with reasonable certainty that the country is a net carbon sink (GoPNG 2014). Papua New Guinea's forests cover more than two-thirds of its land mass, and together with forests in the neighboring Indonesian province of Papua, comprise the third largest tract of intact tropical forest in the world (Babon and Gowae 2013). As a result, they represent one of the world's largest carbon storages.

There are two principal sources of GHG emissions in Papua New Guinea. First, the energy sector—including all activities that involve fossil fuel combustion (IPCC 2006)—accounts for an estimated 45% of the country's total CO_2 emissions. Second, agriculture, forestry, and other land use (AFOLU) account for approximately 55% of total CO_2 emissions (Table 1).

Table 1. Estimated CO_2 emissions by sector (kilotonnes)

Source	Energy	Industrial processes and product use	Agriculture, forestry, and other land use	Waste
GoPNG 2014	2,436 kt	61 kt	11,754 kt	0 kt
GoPNG 2018	11,806 kt	35 kt	14,370 kt	0 kt

Source: GGGI

Available information on economic activity and energy use also indicates that these two sectors are responsible for most of New Ireland Province's GHG emissions. First, between 2002 and 2014, 7.5% of

the province's forest area was deforested or logged, putting the province among those with the highest deforestation rates in the country (Bryan and Shearman 2015). Second, in the energy sector, electricity generation and transport are considered to be the principal activities responsible for GHG emissions. The mining sector accounts for more than 80% of electricity generation capacity in the province (ADB 2009; in-county interviews) and has been identified as the dominant source of GHG emissions from fossil fuel combustion. Vehicle ownership rates are low (NSO and ICF 2019) and, a result, transport only accounts for a small share of GHG emissions.

Efforts to reduce GHG emissions should focus on the AFOLU sector. Low electricity access and motorization rates limit the potential of reducing GHG emissions from the energy sector. However, should access increase, generating electricity from renewable sources, public transportation and energy efficiency measures will become relevant interventions to cap any increase in emissions from both activities. The Lihir Gold Mine represents an insightful example for using renewable energy to support mining operations. It commissioned a 6-megawatt (MW) geothermal backpressure plant in 2003, and expanded power generation to a capacity of 56 MW in 2007 (Booth and Bixley 2005; McCoy-West et al. 2011). However, the plant's capacity was reduced when it had to shut down some wells after moving mining operations into the area. Information on current capacity varies, putting it between 5 and 17 MW (in-country interviews).

Box 1. Data availability

The level and sectoral breakdown of GHG emissions in Papua New Guinea was estimated based on data published in the government's second national communication to the United Nations Framework Convention on Climate Change (UNFCCC) and more recent estimates made available to GGGI by the Climate Change and Development Authority (CCDA). To simplify the assessment, the estimates only include CO_2 emissions, as they represent over 95% of the country's GHG emissions (GoPNG 2014; GoPNG 2018). Although the combination of these two sources provides a more accurate sectoral breakdown of the country's GHG emissions, the estimates remain largely indicative. Their reliability is highly uncertain, and the available data does not allow analyzing trends or making projections.

First, the assessment used CCDA figures for GHG emissions from the energy sector, as Papua New Guinea's nationally determined contribution highlights that emissions from the energy sector are most likely underreported in the second national communication (GoPNG 2016).

Second, GHG emissions from AFOLU are subject to considerable uncertainty (GoPNG 2017b; UNDP 2018) because data and statistics on land use, forest cover, forest cover change, and drivers of deforestation are often inconsistent or incomplete. The extent of uncertainty is exemplified by the considerable discrepancies between recent estimates of forest cover and deforestation rates from 2000 to 2015 (Table 2).

Table 2. Estimates of forest cover and forest cover loss

Source	Period	Total forest cover estimate	Total deforestation over period	Mean annual deforestation rate
Bryan and Shearman 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

Third, given the country's comparatively low level of total GHG emissions and the large extent of its forests, it can be deduced with reasonable certainty that Papua New Guinea is a net carbon sink (GoPNG

2014). However, estimates for the amount of carbon stored in the country's forests and sequestered each year suffer from a paucity of information. For example, there is no country-specific data for carbon stocks in non-forest land. Due to the lack of reliable data for estimating carbon accumulation in regrowth, Papua New Guinea's Forest Reference Level considers the country's carbon stocks after deforestation to be zero (GoPNG 2017a). This assessment uses a combination of studies and the IPCC guidelines to determine approximate factors to gauge carbon sequestration, but more reliable data is required to increase the accuracy of those estimates (Bryan et al. 2010; Fox et al. 2010; Babon and Gowae 2013; GoPNG 2017a).

Available studies show the high variability in estimates using the examples of average total biomass in unlogged or logged rainforests (Table 3). Such differences can have severe implications—for example, when attempting to estimate the quantity of embedded CO_2 in above- and below-ground biomass—and highlight the need for more reliable data. The National Forest Inventory intends to address this data gap and make a significant improvement to collect and share this data (in-country interviews).

Table 3. Average total biomass of rainforests, according to various studies (tonnes per hectare)

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

Source: Compiled by GGGI

Beyond the paucity of data about GHG emissions and carbon sequestration, numerous other important indicators are either unavailable or unreliable for Papua New Guinea as a whole and New Ireland Province specifically. For example, there is considerable uncertainty about the country's population size. According to the 2011 census, the national population more than doubled between 1980 and 2011, to 7.3 million, and annual population growth increased from an estimated 2.2% in 1980 to approximately 3.1% in 2011 (NSO 2011). More recent estimates suggest a total population of 8.8 million people in 2019 (World Bank 2020b), with the annual growth rate declining from 2.4% in 2008 to 2.0% in 2019 (World Bank 2020c). However, in-country interviews suggested that population growth might be significantly higher than indicated by official statistics, and that total population might be considerably higher than 10 million.

3.2 VULNERABILITY

To systematically assess New Ireland Province's vulnerability to the adverse impacts of climate change, the preliminary assessment distinguished between three aspects of vulnerability: exposure, sensitivity, and adaptive capacity (Figure 5).

3.2.1 Exposure

Exposure to climate change refers to the extent to which the economy and population are subject to major changes in climate and weather patterns. Relevant phenomena for assessing a province's exposure include: rise in temperature, changes in rainfall, occurrence of drought, rise in sea level, increase in ocean acidity, and occurrence of cyclones. Of these six phenomena, the assessment found that only three were relevant for New Ireland Province: increase in temperature, rise in sea level, and increase in ocean acidity. There is a high confidence that these phenomena are closely related to climate change and that they occur in New Ireland. In contrast, while changes in rainfall and drought occur in New Ireland Province, there is low confidence that they are related to climate change. Finally, there is only a low to medium confidence that climate change affects the occurrence of cyclones, and they do not affect New Ireland Province directly (Table 4).

Table 4. Phenomena related to climate change and their impact in New Ireland Province

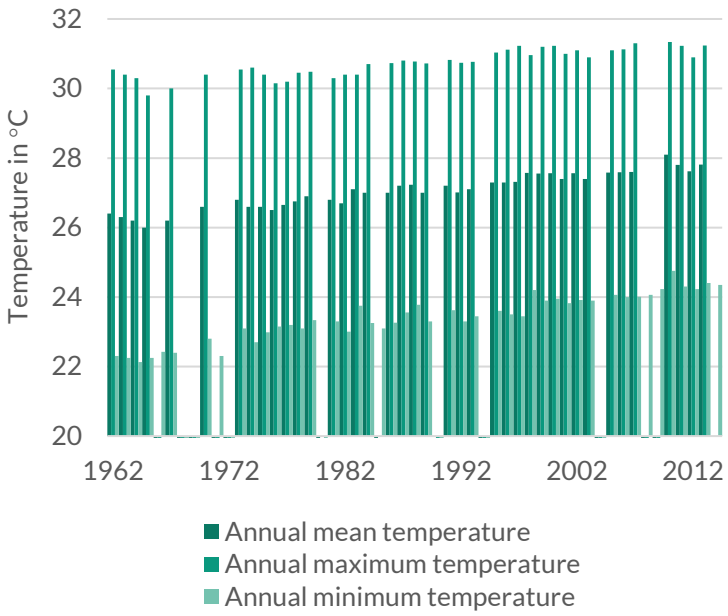
Phenomenon	Confidence	Potential impacts
Rise in temperatures	Very high	Decreased yield and quality of agricultural crops Reduced fish catch and increased degradation of coral reefs Increase in vector-borne and respiratory diseases
Rise in sea level	Very high	Increase in coastal flooding, decrease in agricultural productivity, and damage to infrastructure Contamination of drinking water Degradation of coral reefs
Increase in ocean acidity	Very high	Degradation of coral reefs Reduced productivity of coastal fisheries
Change in rainfall	Low	Damage to infrastructure Decrease in agricultural productivity Degradation of coral reefs Increase in vector- and water-borne diseases
Occurrence of droughts	Low	Decrease in agricultural productivity Reduced access to drinking water and reduced food security
Occurrence of cyclones	Medium	Destruction of infrastructure Decrease in agricultural productivity Reduced fish catch and increased degradation of coral reefs

Source: GGGI

Rise in temperature

Temperatures in Papua New Guinea have increased during the 20th century and mean monthly air temperature is projected to increase by 0.9°C by 2030 (BOM and CSIRO 2011; Allen and Bourke 2009). Historical records for New Ireland show that annual air temperatures at the provincial capital Kavieng have been increasing since 1962; and that the increase in minimum air temperature is more pronounced than the increase in maximum air temperature (BoM and CSIRO 2016; Allen and Bourke 2009; Figure 8). Temperatures are projected to continue to increase, with estimates suggesting a warming of 0.4–1°C by 2030 and 1.1–1.9°C by 2050 under a business-as-usual emissions scenario (D'Haeyer et al. 2017).

Figure 8. Historical annual temperatures in Kavieng, New Ireland Province



Source: BoM and CSIRO 2016

Increasing temperatures are expected to particularly affect agriculture, fish catch, and public health. First, increasing temperatures can lead to lower yield and crop quality due to decreased photosynthesis, higher water stress, and increased exposure to pests and diseases (GEF, UNDP and SPREP 2009; Jaramillo et al. 2011; Kudela 2009; Moretti et al. 2010). For example, sweet potato is one of the most important food crops in New Ireland Province. Tuber formation in sweet potato is significantly reduced at temperatures above 34°C. Maximum temperatures in New Ireland are projected to reach this threshold, with the risk of considerably reducing sweet potato yield (Allen and Bourke 2009; Hay et al. 2003).

Table 5. Trends in malaria incidence, rainfall, and temperature in Papua New Guinea (1996–2008)

Location	Average increase per year			
	Incidence	Rainfall	Minimum temperature	Maximum temperature
Western Province	-3.1%	-1.4%	+0.1%	+0.0%
Port Moresby City (national capital)	-6.1%	+0.4%	+0.1%	-0.1%
Eastern Highlands Province	+4.8%	+3.2%	+0.3%	+0.1%
East Sepik Province	-0.5%	-1.7%	+0.1%	+0.1%
Madang Province	+0.5%	-0.3%	+0.3%	+0.1%

Source: Park et al. 2016

Second, sea surface temperatures are projected to increase, leading to reduced fish catch. Both oceanic fish and coastal fish are projected to be affected. Oceanic fish, such as tuna, are likely to relocate beyond Papua New Guinean waters, while coastal fish stocks will deplete due to loss of habitat—as thermal stress

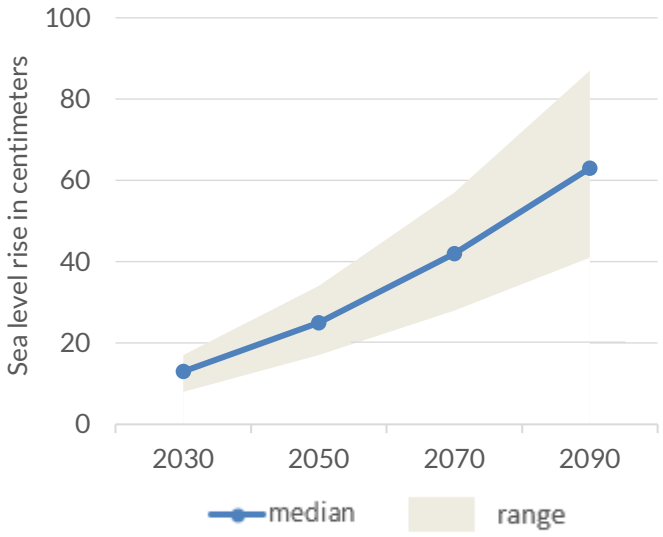
causes coral bleaching and reef degradation—and food, with the decline in phytoplankton and food web organisms (Bell et al. 2011; Drew, Amatangelo, and Hufbauer 2015; Leisz 2009). The loss of marine biodiversity will likely directly affect New Ireland Province, where fish is a crucial protein source and fishing is an important economic activity (Bell et al. 2009; Oxford Business Group 2018).

Finally, temperature can play an important role in malaria transmission, influencing mosquito abundance, development, biting rate, and survival (Park et al. 2016; Table 5). Okuneye, Eikenberry and Gumel (2019) expect the impact of higher temperatures to be considerable in areas with marginal malaria potential, but limited in areas where malaria is already endemic. Although there are no dedicated studies for the impact of higher temperatures on malaria incidence in New Ireland Province, with a reported 240 malaria incidences per 1,000 people in 2016, it is among the provinces with the highest malaria incidence in the country (GoPNG 2017c). Therefore, it is assumed that higher temperatures would have a moderate impact on malaria incidences.

Rise in sea level

Sea levels in Papua New Guinean waters are projected to rise under all emissions scenarios, with an estimated rise of 7–17cm by 2030, 7–34cm by 2050, and 41–87cm by 2100 (BoM and CSIRO 2014; World Bank 2020a; Figure 9). Sea level rise refers to the average relative sea level over a sufficiently extended period to average out transients, such as waves and tides (BoM and CSIRO 2014). Rising sea levels can lead to coastal flooding, salinization, and land erosion (CFE-DM 2016; Connell 2015; Ganpat and Isaac 2014). Estimates suggest that the impacts associated with rising sea levels might affect up to 30% of Papua New Guinea's population (NRC and IDMC 2013). New Ireland will be particularly affected, as most parts of the province are low and most communities are located close to the coast, making them intrinsically susceptible to coastal flooding and seawater intrusion (D'Haeyer et al. 2017).

Figure 9. Projected sea level rise in Papua New Guinea (2030–2090)



Source: World Bank 2020a

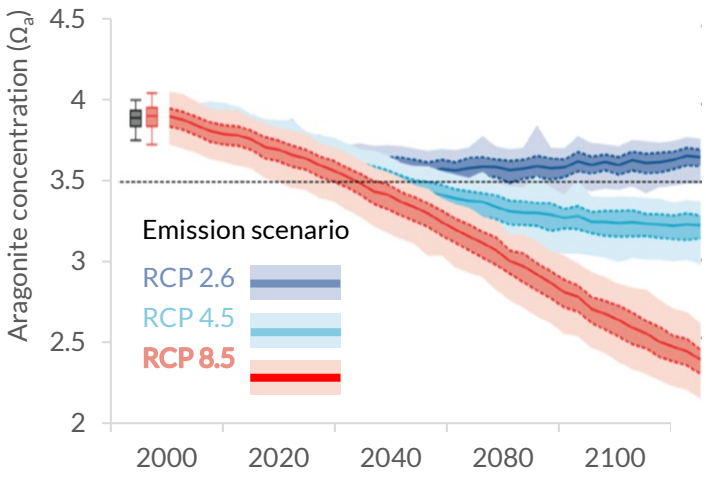
First, agriculture will likely be one of the sectors most affected by inundation, salinization, and erosion of farmlands, particularly during storm surges. Sea water flooding often has a long-lasting effect on soil salinity and suitability for plant growth. Over the longer term, sea level rise is likely to change water quality parameters and contaminate groundwater reserves (Ganpat and Isaac 2014; D'Haeyer et al. 2017).

Second, sea level rise also has an impact on the marine environment, as many nursery grounds for commercially important fish and shellfish are located in the shallow reefs and within mangrove forests near the coast (CIF 2012). Mangrove forests, which offer protection from storms, are projected to decrease by up to 60% by 2100 under a high emissions scenario (Bell et al. 2011). Furthermore, the growth rates of coral reefs may not be able to keep up with the rapid rise in sea levels (Perry et al. 2018).

Increase in ocean acidity

Higher CO_2 concentrations in the atmosphere cause more CO_2 to be absorbed by the world's oceans. As more CO_2 dissolves in the sea, it forms carbonic acid (H_2CO_3), which breaks into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). A higher concentration of hydrogen ions translates into a decrease in ocean pH level. [4] This process is commonly known as ocean acidification.

Figure 10. Projected decrease in aragonite saturation in Papua New Guinean waters



Source: BoM and CSIRO 2011

Note: RCP=representative concentration pathways, scenarios for different greenhouse gas concentration trajectories, several of which were used in the Fifth IPCC Assessment as a basis for the climate projections.

Ocean acidification has a negative impact on marine organisms that build skeletons and shells. These organisms rely on aragonite ($CaCO^3$) to build their skeletons and shells. Aragonite is formed from calcium and carbonate ions (Ca^{2+} and CO_3^{2-}), both of which are naturally dissolved in sea water. Both calcium and hydrogen ions tend to bond with carbonate ions, but hydrogen has a greater attraction to carbonate than calcium. As a result, higher concentrations of hydrogen ions lead to lower aragonite levels. When a hydrogen and carbonate ion bond, they form a bicarbonate ion (HCO_3^-). Many corals and other organisms are unable to extract carbonate ions, which they need to build their skeletons and shells, from bicarbonate (NOAA 2020; Smithsonian Institution 2018).

By 2000, aragonite concentrations in Papua New Guinean waters had declined to 3.8–4.0Ω_a.[5] They are projected to continue declining, reaching levels below 3.5Ω_a by 2030, which is often regarded as a critical threshold (BoM and CSIRO 2011; Figure 10). Corals and crustaceans use aragonite to build and maintain their skeletons. Decreases in ocean pH and aragonite saturation levels would increase the fragility of these organisms and reduce their ability to recover from disturbance, such as storm surges and attacks from other marine organisms. Even if organisms are able to build their shells and skeletons in more acidic water, they may have to spend more energy in the process, taking away resources from other activities like reproduction. If hydrogen ion (H^+) concentration reaches a level where there are insufficient molecules for them to bond with, they can even begin breaking existing calcium carbonate molecules apart, dissolving shells that already exist (NOAA 2020; Smithsonian Institution 2018). When atmospheric concentrations of CO_2 are higher than 450 parts per million, aragonite concentration could fall to levels that make it impossible for corals to sustain building their skeletons, resulting in the erosion of coral reefs (Bell et al. 2011). This would have severe impacts on fisheries, food security, coastal protection, and tourism as corals provide a habitat for many other marine organisms (CFE-DM 2016; Johnson, Bell, and Gupta 2015).

[4] The pH level reflects the hydrogen ion concentration, with higher amounts of hydrogen ions translating to higher acidity and a lower pH value (NOAA 2020).

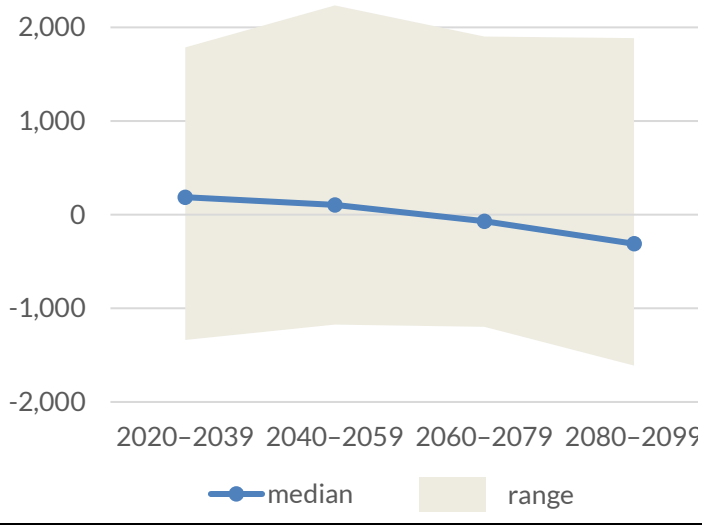
[5] The unit used to measure aragonite saturation is represented by the Greek letter omega (Ω).

Change in rainfall

There is considerable uncertainty about precipitation trends in New Ireland Province, as variability in rainfall trends over the years and complexity of rainfall patterns makes forecasting difficult. While historical trends show a decrease in rainfall, many projections suggest an increase in average annual rainfall in the short to medium-term (Allen and Bourke 2009; BoM and CSIRO 2011). However, other estimates suggest a decrease in annual rainfall over the longer term (World Bank 2020a; Figure 11).

An increase in rainfall would particularly affect agriculture, transportation and other infrastructure, fisheries, and public health.

Figure 11. Projected change in annual rainfall in New Ireland Province



Source: World Bank 2020a

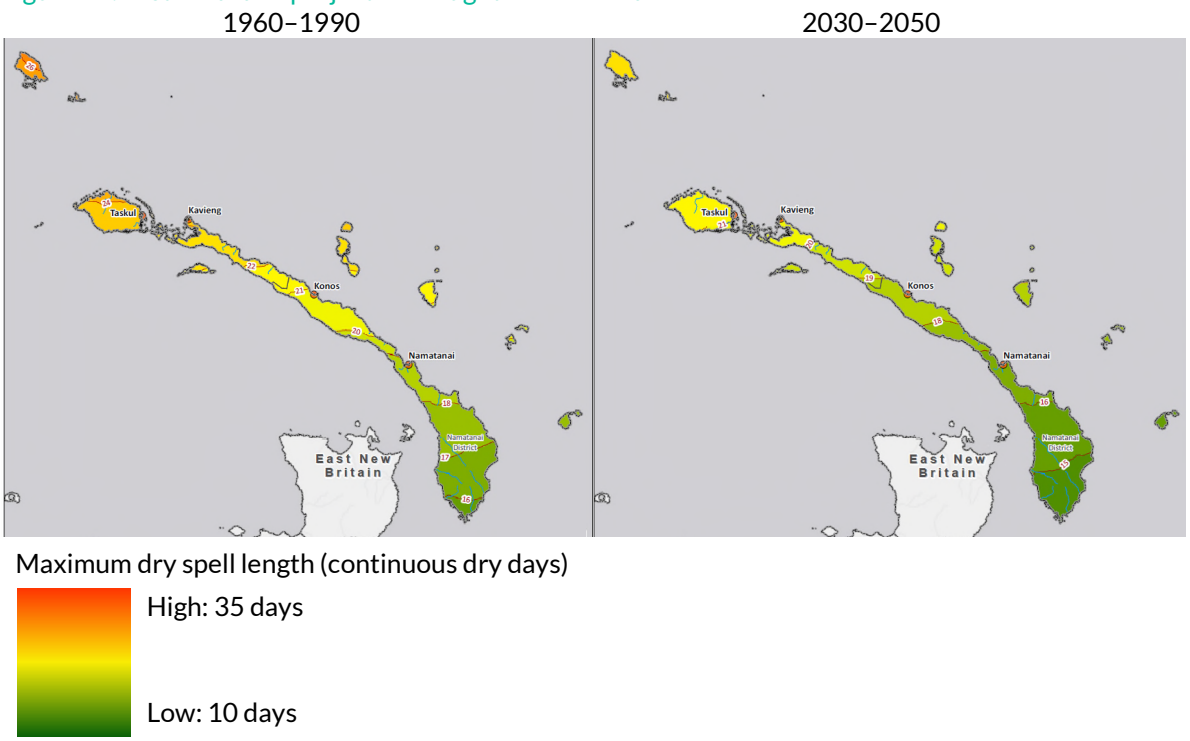
Occurrence of drought

Projections suggest that New Ireland Province will be affected by fewer drought episodes in the short- to medium-term. The number of continuous dry days experienced in the province is projected to slightly decrease from 16–26 days in 1960–1990 to 15–22 days in 2030–2050 (Figure 12). Vulnerability to drought is projected to remain generally higher in the northern part of the province than in the south, with risks to agriculture, particularly taro, coconut, and cacao. However, as with changes in rainfall, these projections are subject to considerable uncertainty. In particular, the number of continuous dry days is an imperfect indicator of drought frequency (D'Haeyer et al. 2017).

Other projections suggest a possible increase in the intensity of droughts in years impacted by the El Niño Southern Oscillation (ENSO) phenomenon.[6] El Niño years are generally drier, whereas La Niña years tend to experience higher precipitation levels (BoM and CSIRO 2014). However, while ENSO is a major variable in projecting future climate, the relationship between the phenomenon and climate change is subject to debate. In particular, the difficulty in predicting the ENSO phenomenon has implications for the level of uncertainty in climate projections for droughts (BoM and CSIRO 2014).

[6] 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).

Figure 12. Historical and projected drought in New Ireland Province



Source: D'Haeyer et al. 2017

Occurrence of cyclones

Tropical cyclones are weather systems with wind speeds of more than 34 knots and pressure below 985 hectopascals. Cyclone routes are located south of New Ireland, so the province is only subjected to marginal impacts, such as high winds, which present a low risk of damage to crops, infrastructure, and the marine ecosystem. Projections suggest no change in cyclone routes (BoM 2020; D'Haeyer et al. 2017).

3.2.2 Sensitivity

Sensitivity to climate change refers to the extent to which the economy and population rely on sectors and activities that are susceptible to climate change-related phenomena. To assess the province's sensitivity, the preliminary assessment considered the following sectors and activities: agriculture, forestry, fishing, mining, transportation, electricity supply, and water supply and sanitation.

Like Papua New Guinea in general, New Ireland Province is characterized by a dual economy. The export-oriented extractive industry provides a large share of gross domestic product (GDP), while more than 80% of the country's population lives in rural areas with minimal services and infrastructure, mainly relying on subsistence agriculture (ADB 2021; IMF 2017; UNDP, UNEP, and GEF 2018). As a result, the province's agriculture and fishing sectors show a particularly high sensitivity to climate change. In addition, the province's weak infrastructure—including electricity, transportation, and water and sanitation—is regarded as susceptible to the adverse impacts of climate change (Table 6).

Table 6. Sectors affected by climate change

Sector	Relevance	Sensitivity to climate change
Agriculture	High share of population engaged in subsistence agriculture Sale of agricultural commodities is the most significant source of income for the rural population	Adverse impacts of climate change likely to further increase existing agricultural pressure
Forestry	Commercial logging is an important contributor to the local economy Commercial logging provides infrastructure in rural areas	Forestry sector not considered susceptible to the adverse impacts of climate change, but amplifies the adverse impacts of climate change
Fishing	Fish represents an alternative source of protein and an important source of income	Considerable impact of climate change on oceanic and costal fish stocks
Mining	Mining is a major contributor to the local economy and a major employer	Commercial mining operations largely unaffected by climate change Small-scale mining considered susceptible to climate change
Transportation	Access to road transportation and vehicle ownership rates are low Maritime transport is of high importance	Low quality of road infrastructure likely to be susceptible to negative impacts of climate change
Electricity supply	Low electricity access rate	Electricity supply not considered susceptible to adverse impacts of climate change as electricity generation relies largely on diesel generators
Water supply and sanitation	Access to protected drinking water sources and improved sanitation is limited, particularly in rural areas	Unprotected water sources and unimproved sanitation can be affected by climate change, causing health hazards

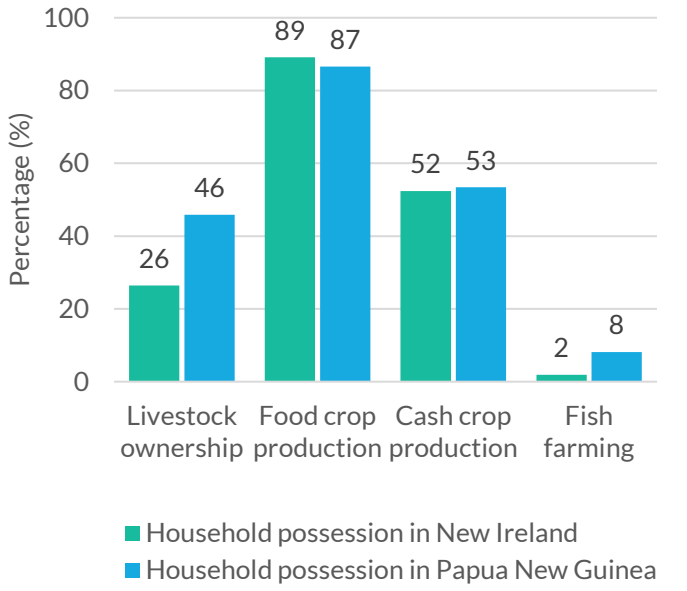
Source: GGGI

Agriculture

New Ireland Province's economy is dominated by subsistence farming. An estimated 90% of households are engaged in growing food crops, vegetables and root crops—including cassava, sweet potato, yam, corn, pumpkin, beans, pitpit and aibika—and approximately half of all households are engaged in producing cash crops such as coconut, cocoa and oil palm (NSO and ICF 2019; Figure 13).

Commercial agriculture—including cocoa, coconut/copra, rubber, and livestock—has experienced a gradual decline over the past two decades. The Provincial Administration has set goals for the remaining major commercial ventures—which include oil palm and coconut plantations—to increase agricultural processing and value-adding activities in the province (NIPA 2012).

Figure 13. Livestock ownership, food and cash crop production and fish farming at household level



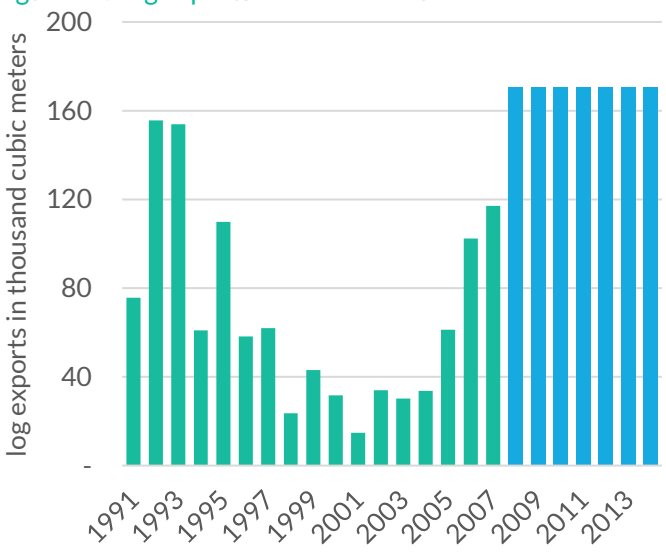
Source: NSO and ICF 2019

Forestry

Commercial forestry has experienced a decline in New Ireland Province, but the sector continues to play an important role in the province's economy, creating formal employment in rural areas (NIPA 2012). Until a decade ago, New Ireland Province accounted for approximately 5% of Papua New Guinea's total log exports (Allen and Bourke 2009; Figure 14). Furthermore, the logging industry provides much-needed infrastructure in the province, particularly roads and bridges (NIPA 2012).

Logging activities—which are conducted in natural forests with little plantation forestry or reforestation (NIPA 2012)—are the principal driver of New Ireland's forest cover loss. By 2014, an estimated 50% of the province's rainforest area had been logged in 2014 (Bryan and Shearman 2015). While the forestry sector is not directly affected by climate change, logging activities amplify the impact of climate change by reducing the essential ecosystem services forests provide.

Figure 14. Log exports from New Ireland Province



Source: Bryan and Shearman 2015; NFA 2015

Fishing

Fish represents an important protein source in Papua New Guinea's coastal regions, where each person consumes an estimated 48kg of fish a year (Friedman et al. 2008). Estimates suggest that half of New Ireland's households are engaged in fishing as a food source; approximately 40% of the fish they catch is eaten locally (Table 7). Fishing also represents an important source of income, with 5–10% of households engaged in fishing for income generation; approximately 60% of fish caught by local communities is sold (Booth, Nagombi, and Boslogo 2019; D'Haeyer et al. 2017). However, the relevance and output of commercial fishing in New Ireland has declined over the past decades (NIPA 2012), and fish farming is in its early stages of development (NIPA 2019).

Table 7. Share of households engaged in fishing

	Households engaged	Households engaged for income
Kavieng	45%	10%
Namatanai	50%	5%

Source: D'Haeyer, et al. 2017

Mining

Mining in New Ireland Province includes both large-scale and artisanal ventures. Two commercial gold mines are operational in the province: the Lihir mine, one of the country's largest, and the Simberi mine, which has a considerably smaller output. Both are major contributors to the local economy and large employers. There is small-scale mining on Lihir, Simberi and Tabar Islands (NIPA 2012).

Climate change is considered unlikely to have a major direct impact on mining. Changes in the frequency and intensity of storms can impact mining operations, but they are not a concern in New Ireland Province (NSWG n.d.). Generally, small-scale mining is expected to be more impacted by climate change than commercial mining operations (Sharma et al. 2013).

Transportation

With little information available on the relevance of maritime and air transport, low ownership rates and low passenger numbers, the assessment focused on road transport, which, according to the New Ireland Department of Works (2019), accounts for 80% of freight and passenger demand.

The quality of the road network is generally low and susceptible to adverse impacts of climate change, particularly heavy rainfall¸ which causes flooding and erodes road foundations. However, these impacts are somewhat limited by the population's low access to road transport. An estimated 50% of the province's population lives beyond 15km distance of a national road (Bourke and Harwood 2009), and only 6% of the population owns a car, truck or motorcycle (NSO and ICF 2019; Table 8).

Table 8. Vehicle ownership in New Ireland Province

	Bicycle	Motorcycle	Car/truck	Boat with motor
New Ireland total	21%	1%	5%	10%
New Ireland urban	35%	3%	21%	12%
New Ireland rural	18%	0%	2%	9%

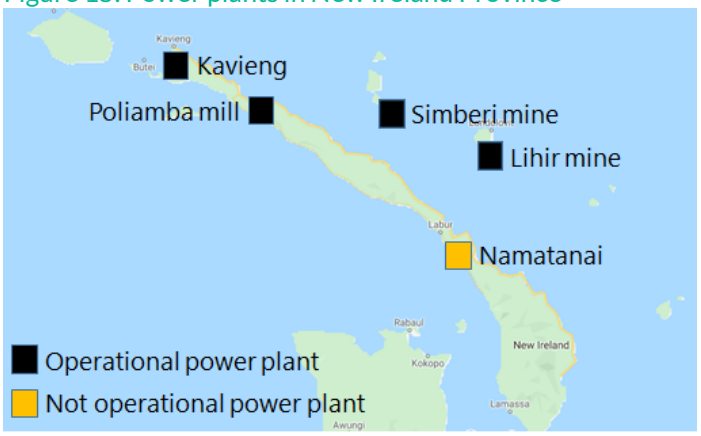
Source: NSO and ICF 2019

Given the province's geography, maritime transport is of high importance. Small boat travel allows for improved access and interconnectivity, but fuel costs are a severe constraint on the population's ability to travel. While weather conditions make small boat travel dangerous during parts of the year (Allen and Bourke 2009), the extent to which climate change will affect maritime transport is uncertain.

Electricity supply

Due to the paucity of information on off-grid systems, the assessment of the sensitivity of New Ireland Province's electricity supply focused on utility-scale electricity generation. The province's electricity mix consists of diesel and heavy fuel oil, geothermal, and biomass. There are several local networks and auto-producers of different sizes. Local networks include Kavieng, which is supplied by a 3–4 MW diesel-fired power plant, and a 0.2 MW hydropower plant at Namatanai, which is not operational. Auto-producers include the Lihir mine, with a 55 MW combined system of diesel and geothermal energy to generate electricity; the Simberi mine, with a 10 MW heavy fuel oil plant; and the New Britain Palm Oil Limited Mill at Poliamba, with a combined biomass and diesel-fueled system (Figure 15).

Figure 15. Power plants in New Ireland Province



Source: GGGI

Of these systems, only the non-operational hydropower plant is considered directly susceptible to the negative impacts of climate change. In addition, if climate change were to cause increased electricity outages, the share of affected population would be comparatively low, given the low access rates. Survey data from NSO and ICF (2019) suggests that only approximately 14% of the province's population has access to electricity. This is reflected in equally low appliance ownership: only approximately a fifth of households own a radio and less than 15% own a television, refrigerator, or computer (NSO and ICF 2019).

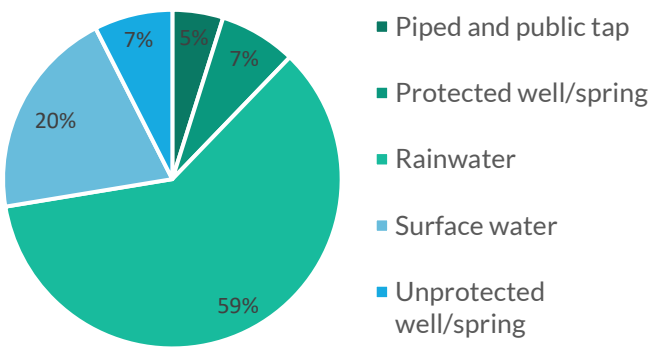
Water supply and sanitation

To evaluate the sensitivity of water supply and sanitation, the assessment considered the population's access to protected drinking water sources and improved sanitation facilities.

Prolonged rainfall, flooding and increase in droughts can affect unprotected water sources and unimproved sanitation, causing health hazards (IOM 2016b). Particularly in rural areas, water supply and sanitation are considered susceptible to the negative impacts of climate change.

Approximately one-third of the rural population relies on unprotected

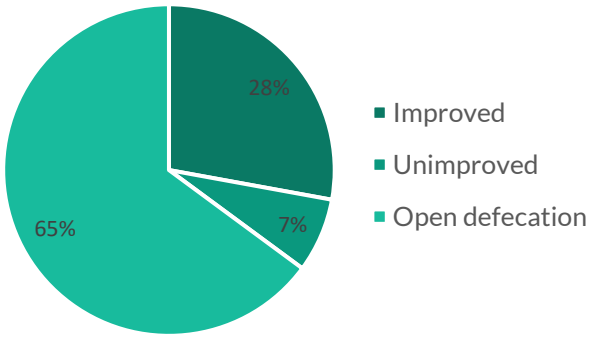
Figure 16. Source of drinking water in New Ireland Province



Source: NSO and ICF 2019

sources of drinking water. Rainwater serves as the main source for drinking water in both urban and rural areas (NSO and ICF 2019; Figure 16). While rainwater is considered a protected source of drinking water, access to rainwater is susceptible to episodes of drought, independently of whether or not these are related to climate change. Only an estimated quarter of the population has access to improved sanitation facilities (Figure 17). While these are common in urban areas, where approximately two-thirds of the population have access, an estimated 80% of the rural population relies on unimproved sanitation and open defecation (NSO and ICF 2019).

Figure 17. Sanitation facilities in New Ireland Province



Source: NSO and ICF 2019

3.2.3 Adaptive capacity

Adaptive capacity refers to the extent to which the population is able to cope with the adverse impacts of climate change, despite levels of exposure and sensitivity. To assess New Ireland's adaptive capacity, the assessment considered the following features: poverty rates; access to electricity, access to water and sanitation; reliability of the transport network; access to and usage of information and communication technologies; access to and quality of health services, education and labor skills; and deforestation as a proxy for ecosystem services.

Reflective of Papua New Guinea in general, a high share of New Ireland Province's population lives in rural areas with minimal services and infrastructure (ADB 2021; IMF 2017; UNDP, UNEP, and GEF 2018). Poverty, limited access to and low quality of services are the defining features for the province's capacity to cope with the adverse impacts of climate change. As a result, interventions should focus on reducing poverty and improving services to strengthen the population's resilience to climate change (Table 9).

Table 9. Adaptive capacity in New Ireland Province

Feature	Relevance	Status
Poverty	Poverty is a defining feature for adaptive capacity as many means of adaptation require at least some financial investment	Large share of population dependent on subsistence farming Limited opportunities for cash income
Access to electricity	Access to electricity is fundamental for development and the availability of other services, and income-generating activities	Low access to electricity
Access to water	Water is an essential substance for all living organisms, delivering nutrients and oxygen and discharging metabolic wastes Water sustains plant life, which is a food source and provides important ecosystem services	Somewhat limited access to protected drinking water sources in rural areas Agriculture largely rainfed with limited deployment of irrigation

Transportation	Reliable transportation network increases the ability to adapt to the adverse impacts of climate change	Limited access to and low quality of road network Important role of marine transport constrained by limited capacity, fuel costs, and aging equipment
Information and communication	Mobile phone services to communicate and access information are important for overcoming infrastructure and service barriers and strengthening adaptive capacity	Mobile phone connectivity dependent on location and expensive Limited access to formal finance
Health service	Climate change can have severe impacts on health, particularly when combined with poor health infrastructure and weak health systems	Limited access to and low quality of health services
Education and labor skills	Level of education is a critical determinant for an individual's income and skill levels across the workforce as a defining feature for economic development	Low completion rates for all levels of education Labor skills focused on agriculture
Deforestation	Forest resources play an important economic role Forests provide essential ecosystem services	Comparatively high rate of deforestation

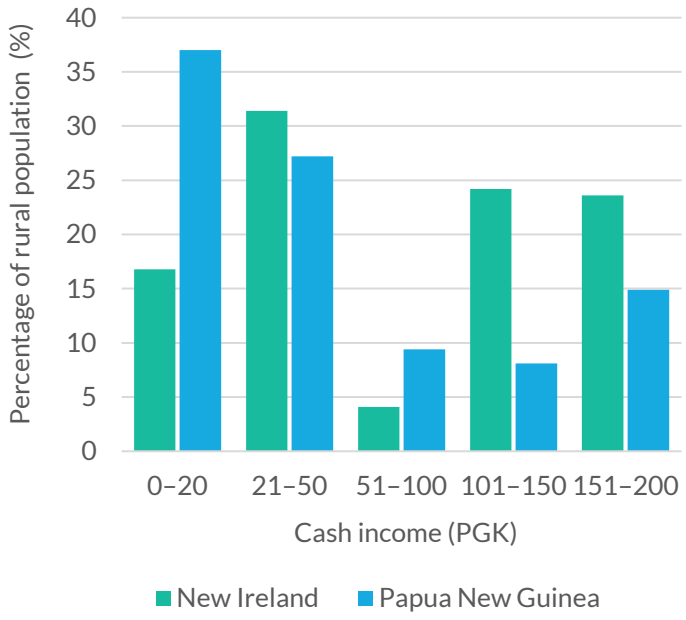
Source: GGGI

Poverty

Within the context of the CRGG assessment, poverty relates to material wealth and cash income. Many means of adaptation require some level of financial investment. Therefore, poverty severely reduces adaptive capacity. As such, any increase in opportunities for earning cash income would strengthen the population's resilience to the adverse impacts of climate change.

New Ireland Province is characterized by a dual economy. The majority of the population depends on subsistence farming, while mining accounts for a large share of GDP and provides pockets of high income for a limited number of people (ADB 2021; IMF 2017; UNDP, UNEP, and GEF 2018). Cash incomes in the far north are comparatively higher than in the south of the main island and on the

Figure 18. Estimated annual cash income for rural population (1990–1995)



Source: Bourke et al. 2009

island groups. A considerable share of people on Lihir Island receive cash wages and royalties from gold mining operations (D'Haeyer et al. 2017).

Recent data for income levels in New Ireland Province are not available. As a result, the preliminary assessment had to rely on estimates dating back to the mid-1990s (Figure 18). However, given the decline in commercial agriculture and forestry, it is assumed that income levels have not increased considerably since then. Average annual cash income was less than PGK200 per person (Bourke and Harwood 2009).

Access to electricity

Access to electricity—which is fundamental for economic development and availability of numerous other services, such as lighting, use of appliances, and communication—is limited. Only an estimated 15% of New Ireland Province's population have access to electricity (NSO and ICF 2019) and the service is often unreliable.

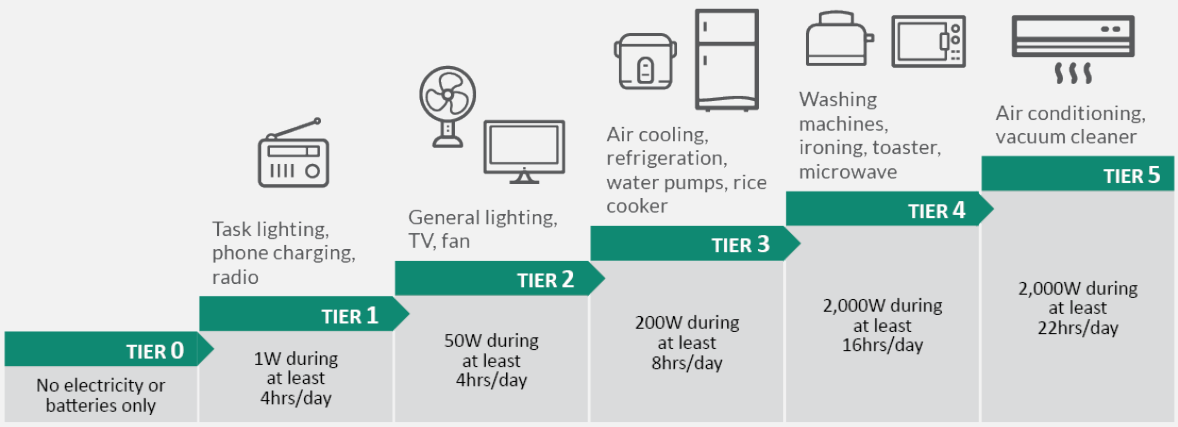
Electrification can play an essential part in strengthening adaptive capacity in New Ireland Province. In particular, the preliminary assessment identified off-grid electrification as an opportunity to increase adaptive capacity by improving water pumping and irrigation, storage, drying, and refrigeration (IRENA 2016).

However, it important not to regard access to electricity as a binary measure—that is, whether a household has access to electricity or not. Quantity, reliability, and affordability are also decisive criteria when assessing access to electricity and considering possible interventions (see Box 2). For example, demand and affordability are crucial factors for determining whether or not off-grid systems are a suitable source of supply.

Box 2. Defining access to electricity

There is no universally agreed-on 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 (that is, a household either has or does not have access). The measure is insufficient to capture issues such as quantity, quality, adequacy, and affordability of the service. Nor does it capture progress in electrification through off-grid solutions. However, a lack of data often confines the analysis to the binary metric, particularly in developing countries where access is an issue (SE4All 2013; Lighting Global 2016; Lighting Global 2018).

Figure 19. SE4All's Multi-Tier Framework for Electricity Access



Source: Adapted from Lighting Global 2016

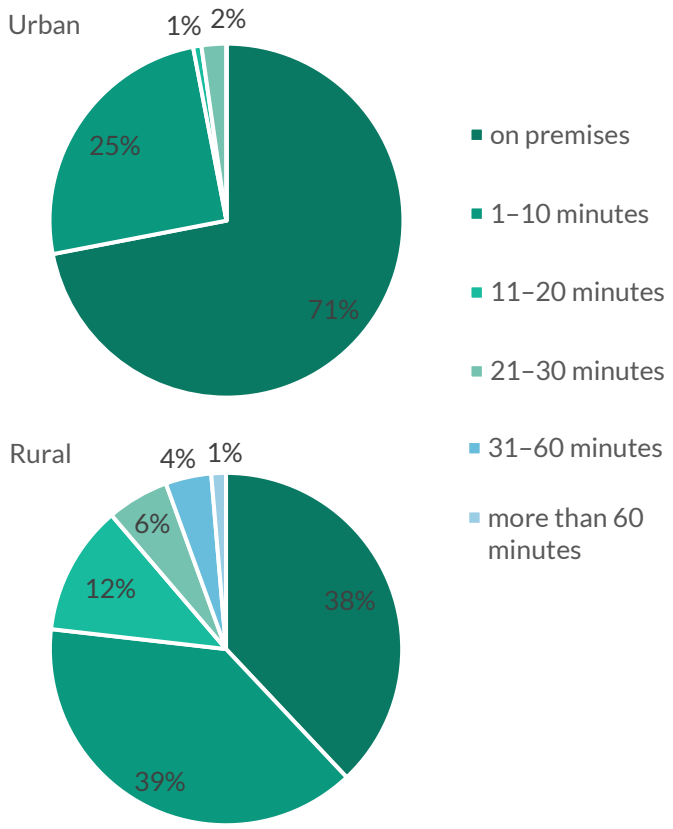
A more accurate metric would measure the degree of access to electricity along various dimensions. Recent efforts to move to more granular metrics include the International Energy Agency's (IEA) Energy Access Outlook 2017, which covers renewable off- or mini-grid connections that have sufficient capacity to provide a minimum of energy services for several lights, phone charging, and a radio (IEA 2017a; IEA 2017b).[7] The UN's Sustainable Energy for All (SE4All) Multi-Tier Framework for Measuring Electricity Access seeks to capture 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 framework distinguishes between six tiers of electricity access (Figure 19; SE4All 2013).

Access to water

The preliminary assessment considered access to drinking water and the availability of water for economic activities, principally agriculture. Water is an essential substance for all living organisms, delivering nutrients and oxygen and discharging metabolic wastes (Popkin, D'Anci, and Rosenberg 2010; WWAP 2012). It also sustains plant life, which in turn provides essential ecosystem services and serves as a food source (Cosgrove and Rijsberman 2000; FAO 2019b; UN Water n.d.). Therefore, access to water represents a defining feature for assessing adaptive capacity.

In New Ireland Province, a comparatively low share of the population has no immediate access to drinking water. In urban areas, only 3% of the population requires more than 10 minutes to access a drinking water source. In rural areas, this share increases to approximately a quarter of the population (Figure 20). The most common sources of drinking water are rainwater (60%) and—particularly in rural areas—surface water (20%) (NSO and ICF 2019; Figure 16).

Figure 20. Time to reach a drinking water source



Source: NSO and ICF 2019

Agriculture plays a dominant role in New Ireland Province, and is largely rainfed. While soils in New Ireland Province have historically experienced only comparatively infrequent and minimal water deficits (Allen and Bourke 2009), droughts are perceived as a severe risk factor for agricultural output and food security (in-country interviews). In that context, water storage and irrigation systems are important means for improving access to water and increase adaptive capacity.

[7] For the full definition, see IEA 2017b.

Transportation

A reliable transportation network increases the ability to adapt to the adverse impacts of climate change, as it allows for the movement of goods and people.

The quality of the road network in New Ireland Province is regarded as moderate to low, with non-national roads being in particularly poor condition (New Ireland Department of Works 2019; Table 10). Furthermore, accessibility is limited by geography and lack of infrastructure, with approximately half of the province's population living more than 15km away from a national road (Bourke and Harwood 2009).

Given the province's geography, maritime transport plays an important role in the movement of people and goods. However, the general paucity of data on freight and passenger sea transport prevents its assessment.

Improved road access, quality of road network, and conditions for maritime transport would strengthen adaptive capacity, reducing disruption experienced during extreme weather events in the short term, and allowing for increased access to services and markets in the longer term.

Table 10. Road conditions in New Ireland Province

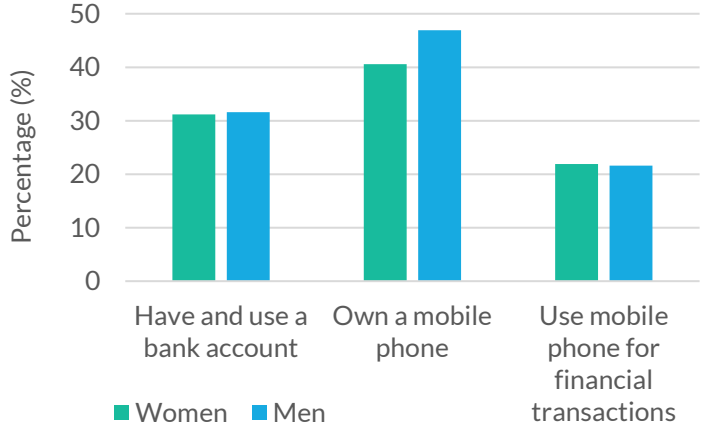
Road name	Total length (km)	Road condition		
		Good	Fair	Poor
Boluminski Highway	338	97%	4%	0%
Kaut Road	25	0%	100%	0%
Lelet Road	21	0%	100%	0%
West Coast Road	198	6%	55%	40%
Lihir Ring Road	93	20%	0%	80%
National Institutional	11	5%	13%	83%
Total	**686**	**52%**	**25%**	**24%**

Source: New Ireland Department of Works 2019

Information and communication

In the preliminary assessment, 'access to mobile phone network' served as a proxy to evaluate the availability and use of modern means of information and communication. Over the past decade, the possibility of using mobile phone services to communicate and access information has become an important means for overcoming basic infrastructure and service barriers. In that context, access to mobile phone network can be regarded as a means to strengthen adaptive capacity. For example, farmers and vendors can use mobile phones to determine prices and sell

Figure 21. Mobile phone ownership and access to finance in New Ireland Province



Source: NSO and ICF 2019

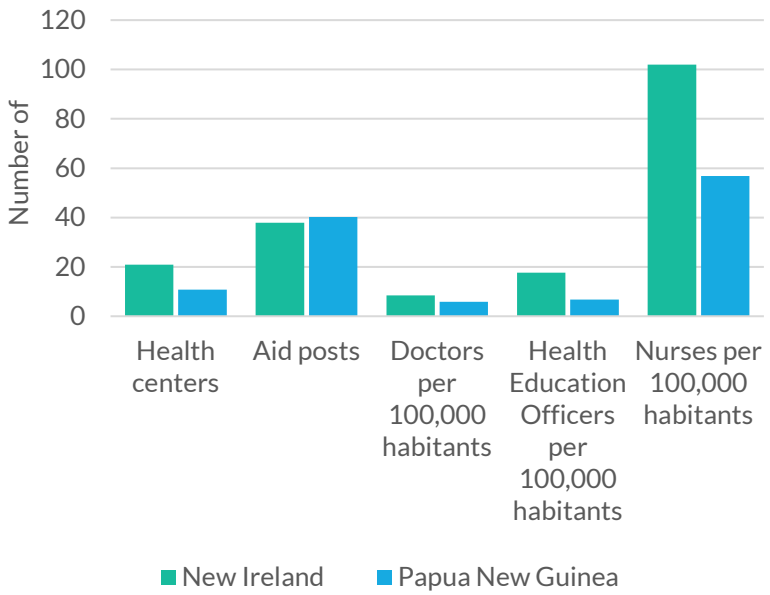
their goods, among other uses (Baumüller 2015; GSMA 2019; Trendov, Varas, and Zeng 2019). At the same time, mobile money transfer has become an important means to facilitate financial transactions (GSMA 2019; Jack and Suri 2011), particularly in countries where physical access to banks or other financial institutions is limited. Mobile technology is also helping to tackle limitations in many other sectors, including health, education, water, and sanitation (GSMA 2019; USAID 2014).[8]

In Papua New Guinea, mobile coverage has expanded from less than 3% of the population in 2006 to approximately 90% in 2019 (De Rosbo 2020). However, service outages are common, while bandwidth is limited, and affordability is an issue (ITU 2017). In New Ireland Province, rural districts are mostly limited to 2G, with 3G only available in urban areas and industrial sites (in-country interviews). Furthermore, while more than two-fifths of the population own a mobile phone, only around one-fifth use their phones for financial transactions (NSO and ICF 2019, Figure 21).

Health service

The preliminary assessment considered health infrastructure and quality of health services as important determinants for adaptive capacity (Figure 22). Climate change can have severe impacts on health, particularly when combined with poor health infrastructure and weak health systems (WHO 2013; WHO 2009).

Figure 22. Health service indictors for New Ireland Province



Source: NSO and ICF 2019

For example, climate change-related phenomena—such as rising temperatures and changes in precipitation—can cause increases in vector- and waterborne diseases (Park et al. 2016). According to WHO (2002), health patterns usually show disadvantages for the poor, who tend to die earlier and are subject to higher levels of morbidity. Given the comparatively high poverty rate in New Ireland Province—and Papua New Guinea in general—health services can play an important role in strengthening adaptive capacity.

Estimates suggest that half of Papua New Guinea's population relies exclusively on traditional herbal medicine, and has no access to modern medicine or healthcare facilities (Rai, Matainaho and Barrows 2015). Available data shows that access to and quality of health services in New Ireland province is limited, particularly in rural areas. Health services generally suffer from a lack of financial resources, qualified personnel, medical equipment, and supplies, with two-thirds of health facilities lacking transport and fridge (NIPA 2012). This weakens the population's resilience towards the adverse impacts of climate change.

[8] While many of the available studies assessing the relevance of using mobile phone services were conducted in sub-Saharan Africa, their findings are considered relevant for Papua New Guinea, given the similar socioeconomic and geographical conditions.

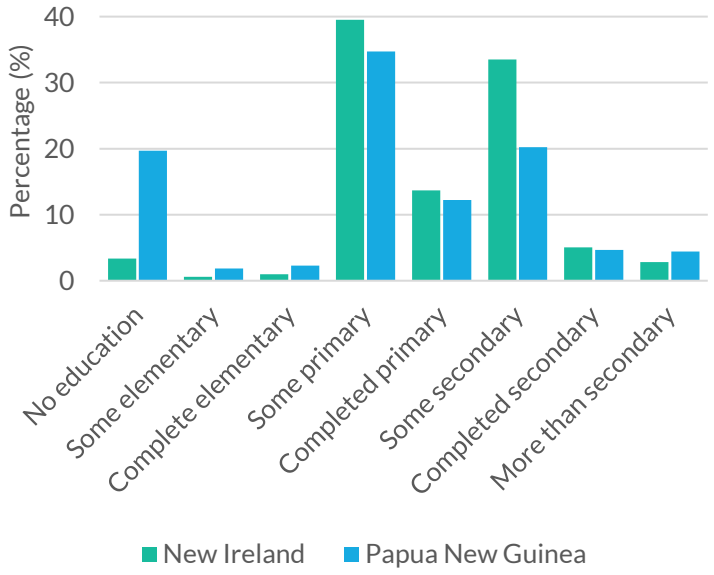
Education and labor skills

Education and labor skills are important features determining a population's ability to cope with the adverse impacts of climate change. Level of education is a critical determinant for income on an individual level, while skill levels across the workforce are a defining feature for a country's level of economic development (UNESCO 2004).

Completion rates—used as a measure for education—are low for all levels of education in New Ireland Province (NSO and ICF 2019). While the share of people in New Ireland with no education is considerably lower than the average for Papua New Guinea, more than half of the province's population has not progressed beyond primary education (Figure 23). Approximately 5% of the population has completed secondary education and less than 3% has progressed beyond secondary education. It should be noted that differences in completion rates between the province's women and men appear to be marginal (NSO and ICF 2019).

Labor skills in New Ireland Province are concentrated in sales and services, and agriculture (Figure 24). It is noteworthy that, in agriculture, there is no substantial difference between genders, with approximately a quarter of both women and men working in the sector. However, an estimated 45% of all women work in sales and services, compared to 20% of all men. In the unskilled manual labor sector, men make up the bulk of workforce (NSO and ICF 2019).

Figure 23. Share of population by level of education



Source: NSO and ICF 2019

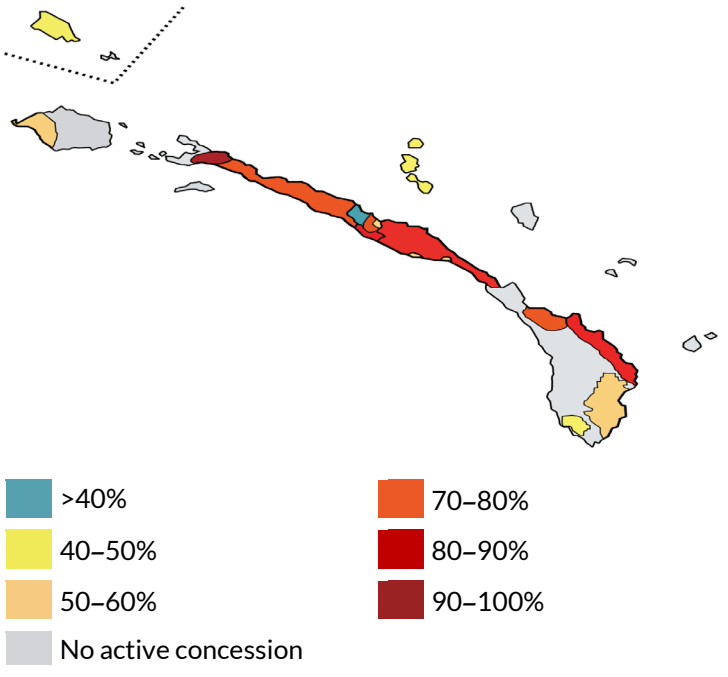
Figure 24. Share of population by occupation

Source: NSO and ICF 2019

Deforestation

Forests represent a crucial resource for coping with the adverse impacts of climate change. They provide essential ecosystem services, including carbon sequestration and storage, nitrogen fixation, increased soil carbon, protection against soil erosion, improved water quality and regulation, and refuge for biodiversity and edible pollinators (HLPE 2017; Mattews et al. 2000; UNECE n.d.). Furthermore, forests play an important economic role in sustaining the livelihoods of rural populations (Dawson et al. 2014; World Bank 2008) and provide essential fuelwood to meet households' energy needs (NSO and ICF 2019).

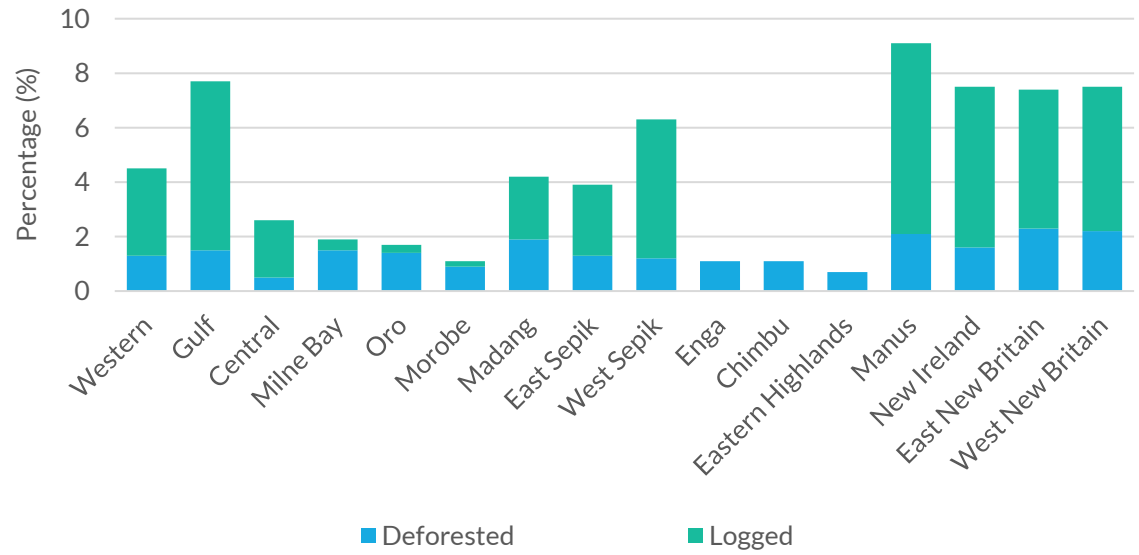
Figure 25. Share of accessible forest logged by 2014



Source: Bryan and Shearman 2015

By 2014, almost half of New Ireland Province's rainforest area had been logged (Figure 25). From 2002 to 2014, forest cover decreased due to commercial logging (5.9%), agricultural activities and bush fires (1.6%). The magnitude of deforestation and logging in the province puts New Ireland among those with the country's highest forest cover loss (Bryan and Shearman 2015; Figure 26)

Figure 26. Share of forest area deforested and logged (2002–2014), by province



Source: Bryan and Shearman 2015

Consultation

Gathering input from a broad range of stakeholders through an interactive Delphi survey-based workshop was an essential part of the CRGG assessment. The workshop served to identify priorities for climate resilience and relevant interventions in the specific context of New Ireland Province. Coupled with presenting the results of the preliminary analysis, this systematic participatory process helped ensure broad stakeholder consensus around priorities and interventions. The consultation process also helped compensate for any lack of relevant data and ensure the assessment results were aligned with existing provincial policies. This chapter summarizes the workshop proceedings and presents its results.

The CRGG consultation workshop, held in Kavieng on 7 October 2020, brought together approximately 25 participants, representing different departments and agencies of the New Ireland Provincial Administration and representatives of civil society and the private sector (Figure 27). The participants list and workshop agenda are provided in Appendices A and B of this report.

The workshop was organized by the New Ireland Provincial Administration (NIPA), the CCDA, and the Australian Department of Foreign Affairs and Trade, in collaboration with GGGI.

Figure 27. Plenary session during the consultation workshop

Source: GGGI

4.1 PRIORITIES FOR CLIMATE RESILIENT GREEN GROWTH

To identify priorities for climate-resilient green growth in New Ireland Province, workshop participants took part in a series of interactive consultation rounds. Based on the Delphi method, these followed a sequence of presenting the results of the preliminary assessment, discussion, and survey. In each round, participants were asked to choose up to nine priorities from a set of 24 possible choices (Table 11). The 24 options were based on a list of preselected categories across the three aspects of vulnerability considered in the preliminary assessment: exposure, sensitivity, and adaptive capacity.

Table 11. Survey choices to identify priorities for climate-resilient green growth

Exposure		Sensitivity		Adaptive capacity	
1	Rise in temperatures	8	Agriculture	16	Poverty
2	Change in rainfall	9	Forestry	17	Access to electricity
3	Occurrence of droughts	10	Fishing	18	Access to water
4	Rise in sea Level	11	Mining	19	Transportation
5	Increase in ocean acidity	12	Transportation	20	Information and communication
6	Occurrence of cyclones	13	Electricity supply	21	Health service
7	Other	14	Water supply and sanitation	22	Education and labor skills
		15	Other	23	Deforestation
				24	Other

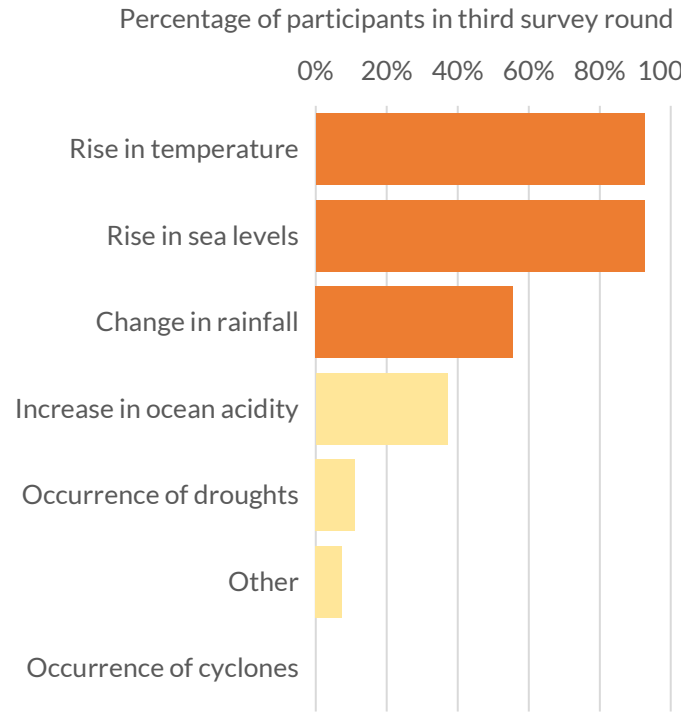
Source: GGGI

Between each consultation round, participants received further information based on the results of the preliminary assessment and provided their own insights into the topics. Before the first consultation round, the key findings from the preliminary assessment were presented regarding New Ireland Province's exposure, sensitivity, and capacity to adapt to the adverse impacts of climate change. The plenary discussions before the second and third consultation rounds focused on the aspects that participants had prioritized during the previous round.

Each aspect was introduced by providing additional context and more detailed information from the preliminary assessment to stimulate the discussion.

The consultation rounds were supported by an electronic survey system, allowing participants to voice their opinion anonymously. Discussing the results after each round allowed them to adjust their assessment based on additional information and feedback within the group.

Figure 28. Priorities for exposure identified by participants



Source: GGGI

Participants identified the following priorities for climate-resilient green growth in New Ireland Province:

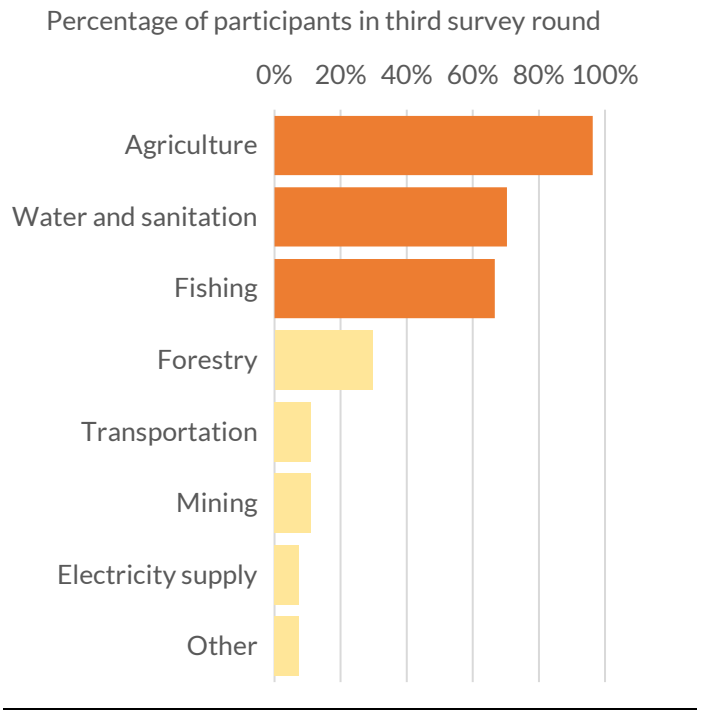
- For exposure, rise in temperature and rise in sea levels as the most prominent climate change-related phenomena, followed by change in rainfall (Figure 28);
- For sensitivity, agriculture, water and sanitation, and fishing as the sectors and activities most susceptible to the adverse impacts of climate change (Figure 29); and
- For adaptive capacity, information and communication, education and labor skills, access to water and sanitation, and poverty as the defining features for coping with the adverse impacts of climate change (Figure 30).

Although the identified priorities remained largely stable between the multiple survey rounds, the share of participants who agreed with the selected priorities increased throughout the workshop. The most noteworthy changes in participants' feedback concerned the priorities they selected for sensitivity and adaptive capacity.

Participants identified agriculture as by far the most susceptible sector to the adverse impacts of climate change (sensitivity). The share regarding agriculture as impacted by climate change increased from 80% in the first round to more than 95% in the last. Similarly, the share of participants who identified poverty as an important aspect of adaptive capacity increased from approximately 40 to 50% between the first and third survey rounds.

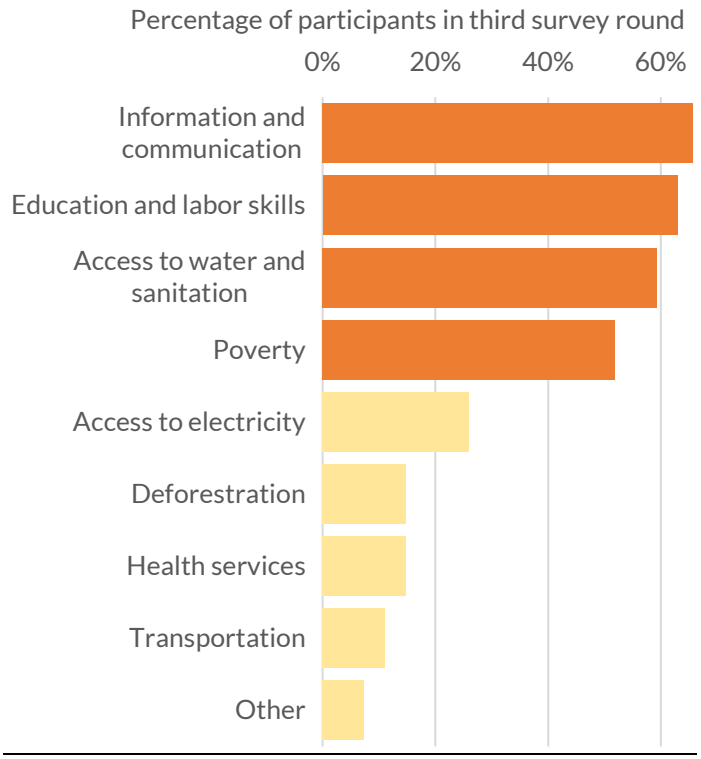
Appendix C provides a detailed overview of the changes in survey results between consultation rounds.

Figure 29. Priorities for sensitivity identified by participants



Source: GGGI

Figure 30. Priorities for adaptive capacity identified by participants



Source: GGGI

4.2 INTERVENTIONS TO STRENGTHEN CLIMATE-RESILIENT GREEN GROWTH

In the second part of the workshop, participants were divided into three breakout groups (Figure 31), each led by a local facilitator. All three groups were asked to complete the following tasks:

Figure 31. Workshop discussions

Source: GGGI

Task 1. Please discuss whether you agree with the priorities selected in the plenary. If you disagree, please indicate the priorities for your group. Please indicate any connections between the priorities across the three categories of exposure, sensitivity, and adaptive capacity.

Task 2. For each connection between the priorities that you have identified in task 1, please identify measures to strengthen resilience.

To identify measures to strengthen resilience towards the adverse impacts of climate change in the context of New Ireland Province, participants were provided with a list of 14 possible interventions. They could either choose from these options or define their own measures.

In summary, it is noteworthy that participants regarded information and communication as important aspects of strengthening adaptive capacity. They highlighted that, in their understanding, this would not only include communication infrastructure, but also education, training, and awareness. In that context, they regarded a lack of education and awareness as a source for numerous problems, and perceived training and skills as essential requirements for the design and implementation of reforms, projects, and so on.

Together with the findings of the preliminary assessment, the results of the workshop determined the scope and direction of the final analysis. The priorities selected during the consultation workshop were well aligned with and reinforced the priorities identified in the preliminary analysis. The strong consensus on these priorities across different stakeholders further underlined their relevance. The identified interventions provided additional granularity to guide the final analysis.

The principal results of the group discussions are summarized in Table 12 and presented in this chapter. More details on the modalities of the group discussions are provided in Appendix D, while the results of individual breakout groups are summarized in Appendix E.

Table 12. Suggested interventions, by sector

Sector	Agriculture		Fishing		Water	
Suggested interventions	Agroforestry	(3)	Planting/ rehabilitation of mangroves	(3)	Rainwater harvesting and storage	(2)
	Drought-resilient crops	(3)	Access to electricity	(2)	Decentralized wastewater treatment	(2)
	Intercropping	(3)	Early warning and weather forecasting	(2)	Coastal protection	(2)
	Financial services and financial literacy	(3)	Aquaculture	(1)	Financial services and financial literacy	(1)
	Forest conservation	(2)	Rehabilitation of jetties with proper anchorage	(1)	Relocation of population	(1)
	Hydroponics	(2)	Economic diversification	(1)		
	Economic diversification	(1)				
	Irrigation	(1)				

Source: GGGI

Note: The numbers in parentheses indicate how many groups identified an intervention for that sector.

4.2.1 Agriculture

All three groups highlighted the economic importance of the agriculture sector in New Ireland and identified agriculture as susceptible to the adverse impacts of climate change. The high importance of agriculture is in line with the results from the plenary discussion and preliminary assessment. Participants regarded rising temperatures as a concern for the sector, followed by drought—despite the limited evidence that climate change is related to the occurrence of droughts—and change in rainfall.

Participants regarded adapting existing agricultural practices as essential for making the sector more resilient to the adverse impacts of climate change. Suggested practices and techniques included agroforestry and forest conservations, introducing drought-resistant crops, intercropping, mixing crops and livestock, and establishing hydroponics. All three groups regarded improving formal financial services and financial literacy as important enablers for introducing new techniques and equipment.

4.2.2 Fishing

All three groups regarded fishing as susceptible to the adverse impacts of climate change. This perception matches the results of the preliminary assessment, which further showed that fishing is an important source of protein and income in New Ireland Province. In line with the preliminary assessment, the groups considered fishing to be affected by multiple climate change-related phenomena, including rising temperatures, change in rainfall, rising sea levels, and ocean acidification. Participants highlighted that fisheries are often overlooked when considering the adverse impacts of climate change, partly because the impacts are more obvious and immediate in the agriculture sector.

All three groups considered planting or rehabilitating mangroves—the nursery grounds of many marine species—as an important means to cope with the impacts of climate change. Furthermore, two of the three groups identified access to electricity as essential for improving storage and refrigeration, and for accessing relevant information, such as weather forecasts. One group thought aquaculture was a possible alternative to fishing.

4.2.3 Water

All three groups identified limited access to protected drinking water sources and improved sanitation as potential health hazards affected by change in rainfall and rising sea levels. There was general agreement among the groups that water supply and sanitation are both important for increasing resilience towards climate change.

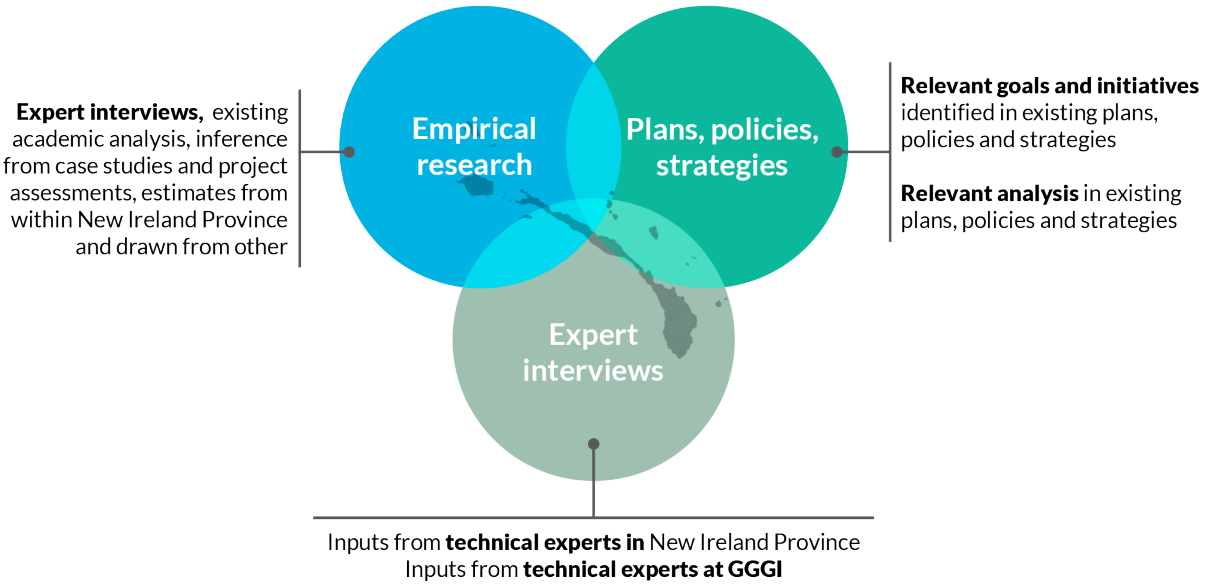
Participants identified a broad range of possible interventions to strengthen water supply, including rainwater harvesting and storage, coastal protection to prevent the salinization of water sources, and relocating populations away from atolls onto larger islands in response to salinization. To improve sanitation, two groups highlighted a need for drainage and decentralized wastewater treatment to avoid contamination of water sources from runoffs.

Final analysis

The final analysis aims to define what climate-resilient green growth means in New Ireland Province. For that purpose, it determines relevant elements of climate resilience and provides guidance on interventions to strengthen climate resilience for each of those elements. The identified priorities—as outlined in Chapter 4—serve as a starting point for the final analysis; but it is not limited to them. Where necessary, the final analysis also considers aspects that are closely related to these priorities, as suggested during the consultation workshop or identified as part of the preliminary assessment.

The final analysis is based on three principal sources of information (Figure 32). First, it draws 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 analysis and reflected in the recommendations. Second, the final analysis considers existing policies, strategies, plans, regulations, goals, and initiatives identified in these documents as well as any relevant analyses they contain. Finally, it is informed by technical experts within GGGI and feedback from technical experts in New Ireland Province, including representatives from government departments, the private sector, academia, and development partners.

Figure 32. Schematic of inputs for final analysis



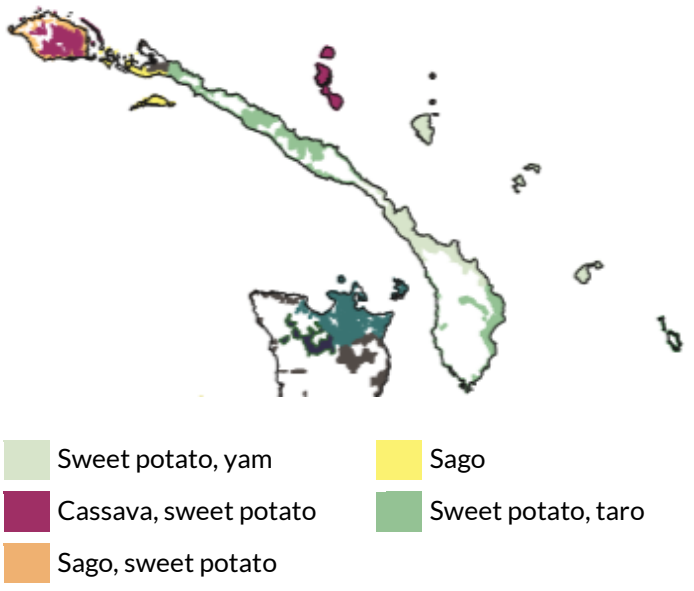
Source: GGGI

This chapter discusses the identified priorities, explaining their relevance for climate resilience and offering guidance on interventions and avenues to strengthen climate resilience.

5.1 AGRICULTURE

Agriculture is the dominant economic activity in New Ireland Province, where smallholder farmers produce mostly subsistence crops for household consumption, alongside some cash crops as a source of income. Estimates suggest that approximately 80–90% of the province's population are engaged in producing food crops. Smallholder farming is characterized by mixing different yield crops, including cassava, sweet potato, yam, corn, pumpkin, beans, pitpit and aibika (D'Haeyer et al. 2017; NSO and ICF 2019; Figure 33). Approximately half of all households engage in cash crop production, including coconut, cocoa, and oil palm (NSO and ICF 2019).

Figure 33. Distribution of most important staple food crops in New Ireland



Source: Allen and Bourke 2009

Large-scale commercial agriculture has experienced a gradual decline over the past two decades, affecting the production of cocoa, coconut/copra, rubber, and livestock. Major remaining commercial plantations include oil palm, cocoa, and copra, and there have been attempts to increase processing and value adding activities in the province (NIPA 2012). Only a small number of people on the southeast coast receive cash wages from work in cocoa and oil palm plantations, and cash incomes in the far north of the province are higher than those in the south of the main island and on the island groups (D'Haeyer et al. 2017; NSO and ICF 2019).

Approximately half of New Ireland Province's land area is used for agriculture, which is concentrated in the low-lying areas. Agricultural pressure is highest in Namatanai District, Boang Island, and Lihir Island, where land degradation and declining crop yields are evident (D'Haeyer et al. 2017). Agricultural

productivity is generally low as a direct result of the high share of smallholder farming (characterized by lack of inputs and modern technologies), a lack of extension services, and poor transport and marketing infrastructure (IMF 2017; UNDP, UNEP, and GEF 2018). The introduction of commercial oil palm plantations has created large areas of monoculture, which increases risk from extreme weather events, disease, and other hazards (Anderson 2006; D'Haeyer et al. 2017; Emori et al. 2005). Poor environmental practices in oil palm plantations and deforestation further increase agricultural pressures, although deforestation is driven more by uncontrolled logging than agricultural expansion (Bryan and Shearman 2015; D'Haeyer et al. 2017). Finally, population growth makes it necessary to either increase agricultural productivity or expand agricultural land. To date, New Ireland Province has experienced the latter. However, extending gardens into steeper hillsides increases the risk of erosion and landslides (Anderson 2006; D'Haeyer et al. 2017; Emori et al. 2005).

These pressures are exacerbated by the adverse impacts of climate change, such as rising temperatures and changes in rainfall patterns. Crops cultivated in New Ireland have shown limited tolerance to many of those impacts, which could cause lower yields and crop quality (D'Haeyer et al. 2017; Table 13). Negative effects are expected along the entire chain of production, affecting planting time, growing stages, harvest periods, and post-harvest crop storage (Ganpat 2014; GEF, UNDP and SPREP 2009; Jaramillo et al. 2011; Kudela 2009; Moretti et al. 2010; World Bank 2011).

Table 13. Estimated tolerance of selected crops to climatic hazards

	Inland flood (0.5–5m)	Rise in sea level (0.5–5m)	Increase in annual rainfall (>3,500mm)	Decrease in annual rainfall (0–500mm)	Drought (14–30 consecutive dry days)
Banana	moderate	intolerant	moderate	intolerant	intolerant
Cassava	intolerant	intolerant	moderate	tolerant	moderate
Coconut	intolerant	tolerant	moderate	intolerant	moderate
Corn	intolerant	intolerant	intolerant	intolerant	tolerant
Pumpkin	intolerant	intolerant	moderate	intolerant	moderate
Sago	moderate	intolerant	moderate	intolerant	moderate
Sweet potato	intolerant	intolerant	moderate	intolerant	intolerant
Taro	moderate	intolerant	moderate	intolerant	intolerant
Yam	intolerant	intolerant	tolerant	intolerant	tolerant

Source: D'Haeyer et al. 2017

While climate models suggest little change in rainfall levels for New Ireland Province, these projections are subject to considerable uncertainty (BoM and CSIRO 2014; D'Haeyer et al. 2017; World Bank 2020a). In general, the crop mix in the province is more susceptible to drier than wetter climatic conditions. While the topography of the province reduces the risk of flash floods and erosion from increased rainfall, deforestation levels increase their likelihood. Therefore, if rainfall levels were to increase, the risk of inland floods would also rise. Independently of its connection to climate change, many workshop participants and much of the literature mentioned drought as a high risk factor for agriculture. Despite being infrequent, droughts have a severe impact on crop yields and are often accompanied by pests, disease, and bushfires (D'Haeyer et al. 2017; in-country interviews).

Finally, with agriculture concentrated in the low-lying areas of New Ireland Province, sea level rise—leading to coastal flooding and salinization—is a concern (D'Haeyer et al. 2017). However, the evidence

of sea level rise affecting agriculture is mixed, and coastal erosion and freshwater contamination are recorded mostly on small islands and atolls and less so on the larger islands (Allen and Bourke 2009).

Under these conditions, the main challenge for the agriculture sector is improving productivity without shifting to large-scale industrial farming, which would undermine smallholder farmers and potentially cause major environmental damage. The traditional smallholder farming system has come under pressure from a combination of limited arable land, a growing population, expectations of higher living standards, and the adverse impacts of climate change.

Such a complex challenge will require a nuanced response that accounts for local conditions at specific locations. While formulating such targeted interventions goes beyond the scope of this assessment, it is possible to provide some guidance on potential interventions addressing the adverse impacts associated with climate change.

First, the traditional crop mix in New Ireland Province has proven to allow the population to cope with different hazards. Sago, for example, has historically replaced other crops as the main staple food during periods of droughts. However, if climate patterns and the frequency of hazardous events change, the relative importance between crops may also change. This is evident in the gradual decline in taro and rise in sweet potato and cassava being grown in many areas. It remains to be seen how the adverse impacts of climate change will alter the crop mix further. For example, longer dry spells are likely to increase the importance of cassava and sago, which have moderate tolerance of drought (Hanson et al. 2001; D'Haeyer et al. 2017; in-country interviews).

Strengthening the sector's resilience to climate change will require identifying the crops that cope best with the changing climatic conditions. In that context, it is also important to explore options for crop rotation, intercropping and agroforestry to find combinations of species that deliver the highest mutual benefits and productivity increases. There have been extensive research and breeding programs in Papua New Guinea to develop early-maturing and high-yielding sweet potato varieties with resistance to droughts and prevalent diseases, and acceptable culinary traits (Cuthbert et al. 2016; Kapal et al. 2003; Kapila et al. 2010; Wamala and Akanda 2010). However, relevant technologies and practices are not transferred to the provinces for local dissemination and distribution (Ivahupa 2001; in-country interviews).

Second, agricultural land in New Ireland Province is characterized by infrequent and slight water deficits. Regardless of whether or not the occurrence and intensity of drought is directly related to climate change, reducing its negative effects will benefit agricultural productivity and food security (D'Haeyer et al. 2017). In that context, large-scale irrigation systems are not considered suitable for farmers, due to their high upfront costs and the considerable technical and management skills required. Instead, water storage and micro-irrigation systems—potentially in combination with off-grid renewables—are the preferred option for strengthening smallholder farmers' resilience. Not only would this improve agricultural productivity, it could also increase access to electricity, drinking water, and improved sanitation facilities (Sitapai 2012).

Third, the successful dissemination of climate-resilient agricultural practices—such as drought-resistant crops, irrigation, and water storage—requires systematic improvement in extension services (ADB 2013a). For example, the World Bank (2014) estimates that disseminating advanced techniques with adequate timely support to farmers could improve yields of coffee in Papua New Guinea by 30–50%. A project involving smallholder farmers in Eastern Highlands and Morobe provinces also showed that improved agricultural support services increase agricultural productivity and smallholder incomes, and help make agricultural practices more sustainable. Given that provincial and district administrations play an important role in providing extension services, these results underline the importance of building the capacity of staff at those levels. In addition, the project demonstrated that including private service providers improves the flexibility and cost-effectiveness of extension services (ADB 2013a; Cuthbert et al. 2016; see also Sitapai 2012; Sitapai 2011). However, extension services in New Ireland Province will continue to be inadequate if funding remains insufficient and expertise is lacking (Liu, Oliver, and Woodford 2008; in-country interviews).

Fourth, deforestation has a negative impact on agricultural productivity and exacerbates the adverse impacts of climate change on agriculture. Forests provide many essential ecosystem services, including nitrogen fixation, increased soil carbon, protection against soil erosion, improved water quality, improved

water regulation, refuges for biodiversity, and hosts for edible pollinators (HLPE 2017; Mattews et al. 2000; UNECE n.d.). Furthermore, despite experiencing a decline in New Ireland Province, the commercial forestry sector continues to play an important role in the local economy, creating formal employment in rural areas and providing much-needed infrastructure (NIPA 2012). Finally, forests also play an essential role in providing fuelwood to meet households' energy needs (NSO and ICF 2019).

The magnitude of deforestation and logging puts New Ireland among the provinces with the highest forest cover loss in Papua New Guinea (7.5% from 2002 to 2014). It is surpassed only by Manus (9.1%) and Gulf (7.7%) Provinces. By 2014, almost half of New Ireland's rainforest area had been logged, with the decline in forest cover primarily driven by commercial logging, followed by agricultural activities and bush fires between 2002 and 2014 (Bryan and Shearman 2015).

There is little plantation forestry or reforestation in New Ireland Province, where logging activities are mainly conducted in natural forests (NIPA 2012). Therefore, forest conservation will require a reduction in either logging activity or the ecological impact of logging through the enforcement of international certification schemes. The Forest Stewardship Council, Programme for the Endorsement of Forest Certification, and International Tropical Timber Organization have all developed and widely endorsed forest certification schemes. Adhering to their sustainable logging practices could strengthen access to global markets for New Ireland timber (Cuthbert et al. 2016; GoPNG n.d.; Meidinger 2003).[9]

In addition, REDD+ could be another option for reducing deforestation in New Ireland Province, which at the end of 2020 had no planned REDD+ projects. There was one REDD+ related activity—the development of a forest inventory—but progress on this had been delayed (in-country interviews). As REDD+ in Papua New Guinea moves from its readiness to its implementation phase, there is an opportunity to develop a community-level pilot project in New Ireland Province to address issues that have been proven to hamper progress on a national scale, such as governance, monitoring, reporting and verification systems, and stakeholder participation (Babon 2011; Fisher et al. 2014; Leggett 2011; in-country interviews).

Certification and REDD+ activities both require coordination with national government. Establishing the legal framework to address questions of land rights and carbon tenure will likely have to be addressed at national level. But provincial (and local) authorities will also have a crucial role to play, granting land use rights, and monitoring and enforcing relevant laws and regulation (Cuthbert et al. 2016; GoPNG 2017b; Leggett 2011).

Finally, as with commercial logging, adhering to international certification schemes would allow commercial agriculture to contribute to environmental conservation, improve socioeconomic conditions for the workforce, and fetch higher prices. Papua New Guinea's palm oil industry has a track record of complying with standards set by the Roundtable on Sustainable Palm Oil (RSPO),[10] which has limited the conversion of primary forest areas into oil palm plantations. However, there is a notable risk that expanding production will undermine adherence to these standards, as existing legislation only covers companies that already operate in the country, so new market entrants are not obliged to comply with international certification standards (Babon and Gowae 2013; Cuthbert 2016; FCPF 2018; Filer 2012; GoPNG 2017a). In New Ireland Province, 10,720 hectares are dedicated to oil palm plantations. Of these, 7,910 hectares are large-scale commercial agriculture under Poliamba Ltd., and 2,810 hectares are planted by smallholders (in-country interviews). An assessment in 2012 concluded that Poliamba's operations comply with RSPO requirements (Allan 2012).

In that context, the provincial government's decision to put a moratorium on granting Special Agricultural Business Leases (SABLs) since 2010 is laudable. Between 2003 and 2010, six SABLs with a total area of more than 140,000 hectares were granted to private developers in New Ireland Province (Filer 2011; in-country interview). While SABLs were intended for commercial-scale agricultural development (mainly

[9] National and private certification schemes, however, should be viewed with caution. These encourage sustainable forest management to differing degrees, as each has its own standards (Durst et al. 2006; Global Forest Atlas 2018). Several nationally certified forests, such as those under the Malaysian Timber Certification Scheme, have been criticized for their unclear environmental and social protection standards (Global Forest Atlas 2018). Similar criticism has been directed towards Papua New Guinea's Logging Code of Practice (Bryan and Shearman 2015).
[10] For more information on the RSPO, please refer to https://www.rspo.org/

oil palm), in practice most active concessions are limited to logging activities (Babon and Gowae 2013; FCPF 2018; Nelson et al. 2014; UNDP 2018). It is recommended that the provincial government maintain that moratorium and follow guidance from international certification schemes when developing any future commercial agriculture initiatives. As with forestry, provincial and local-level authorities will play a crucial role in monitoring and enforcing certification schemes, laws, and regulation (Cuthbert et al. 2016).

5.2 WATER

Climate change has a potential impact of on rainfall levels and water availability. While sea level rise is assumed to have the most pronounced impact on water supply, changes in precipitation patterns can also affect drinking water and sanitation. However, medium- and long-term precipitation trends are subject to considerable uncertainty.

Sea levels in Papua New Guinean waters are projected to rise under all emissions scenarios (BoM and CSIRO 2014; World Bank 2020a). In New Ireland Province, the combination of sea level rise and storm surges is expected to cause more frequent flooding and the loss of wetlands. More frequent seawater intrusion can contaminate drinking water supplies contained in freshwater lenses, the impacts of which would be amplified by increasing demand for drinking water from a growing population (expert interviews).

Variability in rainfall trends over the years and the complexity of rainfall patterns in the province renders forecasting difficult, creating considerable uncertainty about precipitation trends in New Ireland. While historical trends show a decrease in rainfall, many projections suggest an increase in average annual rainfall in the short to medium-term (Allen and Bourke 2009; BoM and CSIRO 2011). Others suggest a continued decrease in annual rainfall over the longer term (World Bank 2020a).

As with changes in rainfall, occurrences of drought are also subject to considerable uncertainty. While some projections suggest that New Ireland Province will be affected by fewer drought episodes in the short- to medium-term, others forecast an increase in the intensity of droughts in years experiencing an ENSO event (compare D'Haeyer et al. 2017 and BoM and CSIRO 2014). Historically, New Ireland has been less impacted by drought than other Papua New Guinean provinces. For example, Allen and Bourke (1997) estimate that during the severe 1997 drought, less than 1% of the total affected population was located in New Ireland Province.

This section discusses two aspects of water supply that are likely to be affected by climate change: accessibility of drinking water and sanitation. The impact of climate change on water supply for agriculture is assessed in Section 5.1.

There is a strong consensus that Papua New Guinea has a shortage of safe water and improved sanitation facilities, with severe consequences for public health. Since 1990, access to safe drinking water and improved sanitation has been virtually stagnant. Contaminated water and poor sanitation continue to cause diarrhea and dysentery and are among the principal contributing factors to infant mortality in the country (ABD 2016; World Bank 2018). But the financing requirements for water and sanitation are

enormous. Reaching the government's 2030 target of 70% access to clean water and improved sanitation would require an estimated US$2 billion of investment between 2011 and 2030—more than two-thirds of this is for sanitation alone (World Bank 2018).

Like the rest of Papua New Guinea, New Ireland Province has an abundance of freshwater resources, and water withdrawal as a share of available renewable water resources is negligible (FAO 2012). However, seawater intrusion, prolonged rainfall, flooding and increased drought can all affect unprotected sources of drinking water, causing health hazards (IOM 2016a). Limited access to protected drinking water sources is particularly an issue in New Ireland Province's rural areas, where approximately one-third of the population relies on surface water and unprotected wells (NSO and ICF 2019).[11] Moreover, an estimated quarter of the rural population does not have access to drinking water at home, and approximately one in ten people require more than 20 minutes to access a drinking water source (NSO and ICF 2019).

Similarly, only an estimated quarter of the population has access to improved sanitation. While approximately two-thirds of the urban population have access to such facilities, four out of five people in rural areas have no access to improved sanitation. In those areas, pit latrines and septic tanks are often poorly constructed over water bodies—which are also drinking water sources—and open defecation is ubiquitous (ABD 2016; NSO and ICF 2019).

This assessment puts forwards several recommendations to improve access to safe drinking water and improved sanitation.

Papua New Guinea has a large but scattered rural population located in poorly accessible locations. Although some of the challenges in ensuring access to water, sanitation, and hygiene (WASH)[12] are the result of the country's geography, there is general agreement that the enabling environment for WASH needs to be strengthened. This includes articulating targets, priorities and approaches to water supply and sanitation, establishing clear roles and responsibilities between government agencies involved in the sector, creating adequate planning and decision-making mechanisms, and establishing budget mechanisms for allocating and tracking expenditures. Many, though not all, of these issues can be addressed at a subnational level (ABD 2016; Cooper 2019; GoPNG 2013; IBRD 2015; World Bank 2017).

First, there is an urgent need to establish clear roles and responsibilities between government agencies and create adequate planning and decision-making mechanisms. The National WaSH Policy established definitions and minimum standards, set targets for 2030, and defined organizational responsibilities (GoPNG 2015). But despite the laudable achievement of establishing a national legislative framework for the sector, the policy contains few concrete recommendations for actions. As a result, implementation has fallen short of its ambitious targets, and the mandates of different agencies and coordination between them remain weak (World Bank 2017). For example, the public utility Water PNG has a mandate to promote access to water and sanitation in rural areas, but focuses on urban areas (Brown, Nott, and Shaw 2015; IBRD 2015). The 2010–2020 National Health Plan designates the Department of Health as the agency responsible for planning and coordinating safe community water supplies and waste disposal (GoPNG 2010). However, the plan does not stipulate specific targets, and the department lacks the financial resources for implementation (ABD 2016; Brown, Nott, and Shaw 2015). As a result, nongovernmental organizations and international donor agencies continue to operate as the main service providers, largely operating in a vacuum, absent of government planning, investment, and monitoring (Brown, Nott, and Shaw 2015; Cooper 2019).

Second, the government of Papua New Guinea has traditionally made water and sanitation a low priority (ABD 2016; GoPNG 2013), as reflected in the low level of public funds allocated to the sector. For example, Members of Parliament have funds dedicated to district service improvement programs at their direct disposal. But, despite WASH being a provincial and local responsibility, these funds have largely not been used for WASH initiatives. And when government funds are allocated to water and sanitation, it is

[11] Protected sources of drinking water include: pipes into a dwelling or yard plot, pipes to a neighbor, public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs, rainwater, tanker trucks or carts with small tanks, and bottled water. Unprotected sources include unprotected dug wells, unprotected springs, surface water, and any other source not listed as a protected source (NSO and ICF 2019).
[12] For more information on the definition of WASH, see UNICEF (2016).

largely for urban initiatives. There is no government budget specifically allocated to rural projects (Brown, Nott, and Shaw 2015; Cooper 2019).

Third, planning and decision-making mechanisms for allocating financial resources to the sector at national and subnational levels remain unclear. Moreover, the national budgeting system does not distinguish fully between water and sanitation budgets, and budget monitoring and reporting are incomplete (World Bank 2017).

Fourth, the construction of boreholes, storage facilities, and particularly rainwater harvesting systems for schools and villages would improve drinking water quality and reduce distances to access water (ICRC 2017; IOM 2016b). In New Ireland Province, rainwater is the main drinking water source in both urban (85%) and rural (50%) areas (NSO and ICF 2019). Studies in other provinces support the use of rainwater harvesting as an improved source of drinking water (Horak et al. 2010). It is recommended that any systems or infrastructure be built on government-owned land in the vicinity of health facilities, schools, and churches to avoid conflict over land rights and ownership (IOM 2016b). Similarly, interventions to enhance access to improved sanitation could focus on schools and healthcare facilities. Less than half of the country's schools are equipped with handwashing facilities with soap and water.

Interventions at schools and health care facilities should include two elements. First, the relevant infrastructure—including rainwater collection systems, handwashing facilities, and basic pit latrines—needs to be installed and maintained. Second, it is important to ensure new infrastructure is accompanied by education and training on the safe treatment and storage of water as well as hygiene practices (IOM 2016b; UNICEF and WHO 2018; WaterAid 2013). The educational aspect is particularly important for changing behaviors beyond schools and health centers. Children who learn safe water, sanitation, and hygiene habits at school can reinforce positive behaviors at home and in their communities (UNICEF and WHO 2018). Surveys have shown that, once households are convinced of the value of sanitation, they invest in it and maintain it (World Bank 2017).

Finally, studies have shown that maintenance and the availability of qualified technicians and managers are key to well-functioning water supply and sanitation systems, particularly in rural areas. A lack of maintenance is the main reason for systems failing. Therefore, all new systems should be accompanied by provisions to ensure their maintenance (IBRD 2015; IOM 2016b; World Bank 2017). As far back as the 1980s, field reports showed that, the more sophisticated the systems are, the higher their failure rates over time. As a result, this assessment recommends focusing on simple systems that require minimum maintenance—such as handpumps and solar pumps—and abstracting water from surface water sources where possible (Baumann 2000; Wohlfahrt and Kukyuwat 1982; expert interview).

5.3 FISHING

Fish and other marine species are a crucial protein source in New Ireland Province, with estimates suggesting that people living in the Papua New Guinea's coastal regions consume up to 53kg of fish a year (ADB 2014; Bell et al. 2009; Friedman et al. 2008; Gillet 2009; Govan 2017). [13] And, although commercial fishing has experienced a decline over the past decades (NIPA 2012; Oxford Business Review 2018), fishing remains an important economic activity in the province (Tables 14 and 15). Fish farming is at an early stage of development (NIPA 2019).

Table 14. Fish caught in 13 communities in Kavieng District (2019)

Fish family	Total caught	Eaten	Sold
Surgeon	591	70%	30%
Trevally	368	34%	66%
Biddy	768	42%	58%
Emperor	1,724	33%	67%
Snapper	636	41%	49%
Mullet	836	38%	62%
Goatfish	506	33%	67%
Parrotfish	549	69%	31%
Grouper	209	72%	28%
Rabbit fish	2,347	35%	65%
Total	8,534	41%	59%

Source: Booth et al. 2019

Despite this prominent role as a food and income source, there is limited data on the catch, domestic sale, consumption, and export of marine resources. [14] Therefore, this assessment largely relies on inference from individual case studies conducted in New Ireland Province.

Fish stocks in Papua New Guinean waters are declining, triggering concerns that coastal communities in New Ireland Province will face increasing food scarcity in the coming decades. Population growth, more efficient (and more destructive) fishing methods, high returns on particular species such as sea

[13] Estimates for fish consumption in Papua New Guinea's coastal regions range from 5–53kg, highlighting the considerable uncertainty in available data (compare ADB 2014; Bell et al. 2009; Friedman et al. 2008; Gillet 2009; Govan 2017).
[14] Gillet (2009) provides a detailed discussion about gaps in available data and estimation methods.

cucumbers, and habitat degradation due to agriculture, logging, and mining—alongside the adverse impacts of climate change—are all contributing to this decline (ADB 2014; Booth, Nagombi and Boslogo 2019; Govan 2017). The combined impacts of climate change are projected to cause oceanic fish—particularly tuna—to relocate, and populations of coastal and demersal fish, and invertebrates, to decline due to habitat and food loss (Bell et al. 2011; Table 16).

Table 15. Share of households engaged in fishing

	Households engaged	Households engaged for income
Kavieng	47%	10%
Namatanai	51%	5%

Source: D'Haeyer, et al. 2017

Table 16. Projected changes in fisheries production in Papua New Guinea under different GHG emissions scenarios

Category	Projected change under different scenarios (%)			Climate change-related causes
	B1/A2 2035	B1 2100	A2 2100	
Skipjack tuna	3.1	-10.6	-30.2	Relocation to areas further east within the Pacific due to changes in temperature, currents, and food chains
Bigeye tuna	-4.5	-13	-27.9	Relocation to areas further east within the Pacific due to changes in temperature, currents, and food chains
Demersal fish	-3.5	-20	-35	Habitat loss and reduced recruitment due to increasing sea surface temperature and reduced currents
Nearshore pelagic fish	0	-10	-17.5	Reduced production of zooplankton in food webs for non-tuna species
Targeted invertebrates	-3.5	-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

Notes: Demersal fish are bottom-dwelling fish associated with coral reefs, mangroves, and seagrass; pelagic fish live in the pelagic zone of ocean or lake waters, which is neither close to the bottom nor near the shore.

Scenarios B1 and A2 represent low (B1) and high (A2) GHG emissions scenarios from the IPCC Fourth Assessment Report for 2035 and 2100. Under the B1 scenario, CO_2 concentrations in the atmosphere are projected to reach 400–450 parts per million by 2035, and 500–600 parts per million by 2100. Under the A2 scenario, the projections for 2035 are the same, but CO_2 concentrations increase to 750–800 parts per million by 2100.

Warmer sea surface temperatures are expected to affect oceanic and coastal fish species, as well as invertebrates (Bell et al. 2011; Drew, Amatangelo, and Hufbauer 2015). Economically, tuna is New Ireland Province's most significant fish resource. Although catch numbers disaggregated by province are not available, total catch for Papua New Guinea averages 150,000–200,000 million tonnes a year, which represents about 10% of the global catch (Oxford Business Group 2018). However, the country's tuna yield is expected to decrease, as skipjack and bigeye tuna populations relocate to areas further east within the Pacific due to changes in temperature, currents, and food chains (Bell et al. 2011). Stocks of demersal fish and non-tuna nearshore pelagic fish species—such as Spanish mackerel, rainbow runner, wahoo, and mahimahi or common dolphinfish—are also expected to decrease as higher temperatures lead to habitat loss, reduced recruitment, and reduced production of zooplankton in food webs (Bell et al. 2011). While

some species may be able to adapt to the temperature changes 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; Drew, Amatangelo, and Hufbauer 2015).

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 that are extremely vulnerable to coastal flooding and storm surges. Mangrove trees, which 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), while the growth rate of coral reefs—important habitats for the country's fish species—may not be able to keep up with the rise in sea level (Perry et al. 2018).

Higher concentrations of CO_2 in the atmosphere cause more CO_2 to be absorbed by the world's oceans, decreasing the pH and causing aragonite saturation levels to fall (see Section 3.2.1). This process is commonly referred to as ocean acidification (Bell et al. 2011). Aragonite concentrations in Papua New Guinean waters have declined from 4.5 Ω_a in the late 18th century to approximately 3.8–4.0 Ω_a in 2000. Ocean acidity is projected to continue increasing, with maximum aragonite concentration expected to fall below 3.5 Ω_a by 2030 (BoM and CSIRO 2011). Coral reefs and calcifying invertebrates—including molluscs, crustaceans, and echinoderms—are highly vulnerable to increases in ocean acidity, as they rely on aragonite to build their shells and skeletons (Bell et al. 2011; Ries, Cohen, and McCorkle 2009). Lower aragonite levels will likely weaken and degrade coral reefs, while calcifying invertebrates are expected to form thinner shells and show lower rates of growth and survival than they would under normal pH conditions (Bell et al. 2011; CME-Programme 2018; Gazeau et al. 2013; Shirayama and Thornton 2005; Watson et al. 2012).

Finally, higher amounts of rainfall and a rise in rainfall-induced floods increase turbidity and enrich nutrient levels in coastal waters. The resulting higher sediment and nutrient loads reduce photosynthesis in coastal reefs and create favorable conditions for epiphytic algae, which compete with corals, affecting coral growth and recovery after storm damages (Bell et al. 2011).

There are limited options for interventions to directly reduce the adverse impacts of climate change on fisheries. Therefore, interventions should focus on reducing stress from other factors—particularly human activity—on the marine environment to strengthen its resilience towards climate change.

First, this assessment recommends focusing the limited available resources on the sustainable exploitation of marine resources in coastal waters. The relocation of tuna populations due to changes in temperature, currents, and food chain can only be limited by reducing the expected increase in surface water temperatures. However, this issue has to be addressed at a global, not a national—and much less, provincial—level. In addition, while the Papua New Guinean authorities could establish stricter catch quotas for tuna in an effort to preserve populations, enforcing such provisions is considered virtually impossible. Estimates suggest that foreign vessels operating under access arrangements that allow them to fish in Papua New Guinean waters accounted for more than three-quarters of the tuna catch in 2010 (ADB 2014). The national government simply has insufficient resources to monitor foreign fishing vessels and enforce catch quotas in the country's waters.

Second, the development of coastal fisheries has not met expectations in the past due to several challenges to the effective and sustainable management of coastal fisheries. These include (Govan 2017):

- The complexity and diversity of coastal fisheries, ecosystems, and coastal communities;
- The logistics of managing geographically extended coastlines and near-shore marine areas;
- A lack of reliable data, feasibility assessments, and monitoring and evaluation for interventions, which has undermined decision making and reduced effectiveness;
- Limited alternatives for income generation and sustaining livelihoods in coastal communities;
- The paucity of suitable financing arrangements for developing small-to-medium-scale commercial activities;
- A lack of marketing and transport infrastructure to enable small-to-medium-scale commercial activities;
- Limited coordination within and between authorities and across levels of government;

- Public funding and services that are not adequately tied to desired outcomes; and
- Limited capacity at all levels of government.

The National Fisheries Authority's *Roadmap for Coastal Fisheries and Marine Aquaculture* was meant to address these challenges. However, inadequate funding, a lack of capacity, and allegations of misuse of funds mean that implementation of the roadmap is falling short of its ambitions (WCS n.d.; in-country interviews).

Establishing community-driven, locally managed marine protected areas (MPAs) is one promising option for implementing the ambitious strategy. The Wildlife Conservation Society (WCS) is currently running a program in 13 communities in New Ireland Province to establish MPAs and develop site-specific fisheries management plans, with rules and penalties decided by community members and enforced by community-elected marine management committees. The program aims to scale up coastal fisheries management measures to at least 80% of the communities in New Ireland Province (Booth, Nagombi, and Boslago 2019; Green et al. 2009; WCS n.d.).

Locally managed MPAs can address several causes of declining fish stocks, including overfishing of larger, more vulnerable reef fish species at infant and juvenile stages, and the use of spear guns. Increased spear gun use is causing declines in algal grazer populations—such as surgeonfish, rabbitfish, and parrotfish—potentially leading to a shift from coral-based habitats to algae-dominated systems. Initiatives such as a night-time spear gun ban could be a simple and pragmatic measure to manage their use and conserve the marine environment, but it requires support from the entire local community (Booth, Nagombi, and Boslogo 2019).

Third, conservation of mangroves can play a crucial role in managing sustainable coastal fisheries. As well as providing many coastal communities in New Ireland Province with protection from storm surges, timber for building, firewood, traditional medicines, and recreational opportunities, mangroves serve as nursery habitats for important coral reef fisheries and provide perennial habitats for other marine species, such as mud crabs and shellfish (ADB 2014; Waru and Frijlink n.d). One approach to conserving mangrove forests as vital ecosystems is through payment for ecosystem services (PES). The rationale behind PES schemes is that ecosystems provide essential services that can be valued in monetary terms, but users do not value these services unless they pay for them. Therefore, owners or custodians of these ecosystems should be remunerated for ensuring that the ecosystem in question retains the ability to provide its services. For example, mangrove forests serve as nurseries for juvenile shrimp. Under a PES scheme, the annual licensing fee that shrimp fishers pay could include a component that accounts for the nursery services mangroves provide. This share of the total fee can be used to pay mangrove forest owners as an incentive to ensure their sustainable management. Such PES schemes provide incentives for conservation without negatively impacting the government budget (ADB 2014).

Fourth, aquaculture represents another option for reducing pressure on marine resources while creating income-earning opportunities for coastal communities. There is little information on aquaculture in New Ireland Province. Findings from a 2007 study suggest that aquaculture was at an early stage in the province, with the main obstacles including a lack of knowledge about fish farming practices and technologies, and a lack of finance (Smith et al. 2007). The provincial authority's 2019 *Fisheries and Marine Resource Divisional Report* confirms that fish farming remains at an initial stage of development and farmers need regular visits from divisional staff to guide them in their pursuit of developing aquaculture (NIPA 2019).

Introducing sea cucumber mariculture is a promising opportunity, particularly when focusing on high-value species, such as sandfish.[15] Sea cucumbers are used in various cuisines and have medicinal value. *Bêche-de-mer*—the dried body wall of sea cucumber—used to be a valuable marine export commodity and important income-earning opportunity in New Ireland Province, with an estimated 2,000 people in the province having been directly involved in the industry. However, in October 2009, in response to overfishing, the National Fisheries Authority imposed a moratorium on sea cucumber fishery across the

[15] Mariculture is the farming of marine organisms for food and other products such as pharmaceuticals, food additives, jewelry (for example, cultured pearls), nutraceuticals, and cosmetics, either in the natural marine environment, or in land- or sea-based enclosures, such as cages, ponds, or raceways. Sea cucumber mariculture is known as holothuriculture (Phillips 2009).

country (Hair et al. 2019; NIPA 2012).[16] Instead of lifting the moratorium and replacing it with total allowable catch ceilings or export restrictions (Barclay, Fabinyi, and Kinch 2017), provincial authorities could launch a pilot project for farming sea cucumbers. Acknowledging that mariculture interventions have risks and that many externally supported projects fail (Barclay et al. 2016; von Essen et al. 2013), any pilot project should focus on identifying effective management practices, resolving technical issues, and addressing social barriers for communities to adopt sea cucumber mariculture (Hair et al. 2019).

Finally, the report recommends investigating how far tourism could present an alternative income source for coastal communities. While Papua New Guinea's tourism sector is fragmented and little data is available at provincial level, diving accounts for an estimated two-thirds of tourist arrivals (ADB 2014). Given its abundant marine resources, New Ireland Province has considerable potential for ecotourism and marine recreation—including snorkeling, scuba diving, kayaking, and surfing (NIPA 2012). However, only 15% of an estimated 5,000–7,000 registered annual visitors between 2014 and 2019 were tourists (PNG Tourism Promotion Authority 2020), and the province's tourism industry remains small. Obstacles for tourism include: a lack of transport infrastructure; insufficient quality accommodation to meet visitor demands; high cost of travel packages relative to other destinations; a lack of standards and quality control for tourism products and services; and a (perceived) lack of safety and security (NIPA 2012; Sumb 2020; in-country interviews).

[16] The fishery was reopened in 2017 for less than two months (Hair et al. 2019). Other sources claim that the moratorium was lifted entirely in 2017 and replaced by maximum fishing limits (total allowable catch) within certain timeframes and for specific species. Trade in undersized and broken up *bêche-de-mer* pieces is also banned (Polon 2004; in-country interviews). However, survey results from New Ireland Province suggest that fisheries do not adhere to total allowable catch quotas (Hair et al. 2018). Furthermore, there is insufficient data to determine total allowable catch quotas. As a result, the current closed season—scheduled from October 2020 to January 2021—remains in place in March 2021 (in-country interview).

Conclusion

The CRGG assessment shows that New Ireland Province is exposed to the adverse impacts of climate change, as evidenced in a rise in temperature and potential changes in rainfall. The province's population and economy are also very sensitive to these phenomena, given their dependence on sectors that experience considerable impacts from climate change—particularly agriculture and fishing. Finally, low income levels in the province, coupled with lack of essential transportation, health, electricity, water, and sanitation infrastructure means their capacity to adapt to the adverse impacts of climate change is limited.

Based on available data and research as well as consultation of local stakeholders, the assessment identifies agriculture, water, and fishing as three priority areas for New Ireland Province to enhance its resilience towards the adverse impacts of climate change. For each of these priorities, it outlines several possible interventions that could contribute to strengthening resilience in the province.

Agriculture: Given the dominance of smallholder farming, strengthening resilience against climate change in the agriculture sector should focus on improving productivity without shifting to large-scale industrial farming, which would take away smallholder farmers' livelihoods and cause major environmental damage. More research is required into climate-resilient crops and agricultural techniques—including options for intercropping and agroforestry—that are suitable for specific locations in New Ireland Province. Furthermore, improving water management will be important for strengthening resilience, as it reduces the impact of drought. For example, improving water storage and micro-irrigation systems could make smallholder farmers more resilient. Successfully disseminating such climate-resilient agricultural practices requires systematic improvements in extension services; successfully implementing them will require improved access to formal finance. Finally, deforestation has a negative impact on agricultural productivity and exacerbates the adverse impacts of climate change on agriculture. Adhering to internationally recognized sustainable logging practices and piloting REDD+ at the community level are two options for conserving forests in New Ireland Province.

Water: Access to and quality of drinking water and sanitation are both likely to be affected by climate change. Improving them will require strengthening the enabling environment, putting the necessary infrastructure in place, and ensuring maintenance of that infrastructure. To strengthen the enabling environment, it is recommended that the provincial administration articulate targets, priorities, and approaches, establish clear roles and responsibilities among the agencies involved in the WASH sector, create adequate planning and decision-making mechanisms, and set up budget mechanisms for allocating and tracking expenditure. Necessary investments in infrastructure include boreholes, rainwater harvesting systems, storage facilities, handwashing facilities, and pit latrines, with infrastructure in schools and healthcare facilities identified as a priority. Finally, the lack of maintenance and availability of qualified technicians and managers are among the principal reasons for systems failing. Therefore, simple systems that require minimum maintenance are generally preferable, and the installation of new systems should be accompanied by an arrangement to ensure their maintenance. Education and training in their use are also vital.

Fishing: Fish and other marine species are a crucial protein source and fishing represents an important economic activity in New Ireland Province. However, fish stocks in Papua New Guinean waters are declining, triggering concerns that coastal communities in the province will face increasing food scarcity in the coming decades. Population growth, more destructive fishing methods, high returns on particular species, and habitat degradation from agriculture, logging, and mining activities—coupled with the adverse impacts of climate change—are all contributing to declining fish stocks. With limited options for directly reducing the adverse impacts of climate change on fisheries, interventions should focus on reducing stress from human activity on the marine environment to strengthen its resilience towards climate change. Recommendations include: focusing the limited available resources on the sustainable exploitation of marine resources in coastal waters; establishing community-driven locally managed MPAs; establishing PES schemes to conserve mangrove forests; investing in aquaculture to reduce pressure on marine resources while creating income earning opportunities for coastal communities; and exploring the potential of tourism as an alternative income source.

References

ADB (Asian Development Bank), *Member Fact Sheet: Papua New Guinea,* 2021. https://www.adb.org/sites/default/files/publication/27788/png-2017.pdf

ADB, *Country Partnership Strategy for Papua New Guinea, 2016–2020. Sector Assessment (Summary): Water Supply and Other Urban Infrastructure and Services,* 2016. https://www.adb.org/sites/default/files/linked-documents/cps-png-2016-2020-ssa-04.pdf

ADB, *State of the Coral Triangle: Papua New Guinea*. Mandaluyong City, Philippines: Asian Development Bank. 2014.

ADB, *Papua New Guinea: Smallholder Support Services Pilot Project. Performance Evaluation Report,* 2013a. https://www.oecd.org/derec/adb/Papua-New-Guinea-Smallholder-Support-Project.pdf

ADB, *The Economics of Climate Change in the Pacific,* 2013b. https://www.adb.org/sites/default/files/publication/31136/economics-climate-change-pacific.pdf

ADB, *Papua New Guinea: Power Sector Development Plan. Technical Assistance Consultant's Report, Project Number: 40174*, 2009.

Allan, Thomas, *RSPO Certification Assessment: Poliamba Ltd, New Ireland Province, Papua New Guinea.* BSI Public Summary Report, 2012. https://www.rspo.org/sites/default/files/Poliamba_PUBLIC_SUMMARY_REPORTFINAL_150312-53.pdf

Allen, Bryant and R. Michael Bourke, "People, Land and Environment."In *Food and Agriculture in Papua New Guinea*, edited by R. Michael Bourke and Tracy Harwood, 28–127. Canberra: Australian National University (ANU) E Press, The Australian National University, 2009.

Allen, Bryant and R. Michael Bourke, *Report of an Assessment of the Impacts of Frost and Drought in Papua New Guinea.* Australian Agency for International Development, Port Moresby, 1997. https://www.researchgate.net/publication/291335887_Report_of_an_assessment_of_the_impacts_of_frost_and_drought_in_Papua_New_Guinea

Ananda, Jayanath and Gamini Herath, "A Critical Review of Multi-Criteria Decision Making Methods with Special Reference to Forest Management and Planning." *Ecological Economics* Vol. 68 no. 10 (August 2009): 2535–2548. https://doi.org/10.1016/j.ecolecon.2009.05.010

Anderson, Tim, *Oil Palm and Small Farmers in Papua New Guinea.* Report for the Centre for Environmental Law and Community Rights on the Economic Prospects for Small Farmers in PNG's Oil Palm Industry. University of Sydney, Australia, 2006. http://np-net.pbworks.com/f/Anderson+(2006)+Oil+palm+and+small+farmers+in+PNG,+CELCR.pdf

Babon, Andrea, *Snapshot of REDD+ in Papua New Guinea.* Center for International Forestry Research (CIFOR) info brief No. 40, August 2011. https://www.cifor.org/library/3443

Babon, Andrea, and Gae Yansom Gowae, *The Context of REDD+ in Papua New Guinea: Drivers, Agents and Institutions.* Bogor: CIFOR, 2013. https://www.cifor.org/library/4153/

Barclay, K., Kinch, J., Fabinyi, M., EDO, N.S.W., Waddell, S., Smith, G., Sharma, S., Kichawen, P., Foale, S., and Hamilton, R.H., *Interactive Governance Analysis of the Bêche-de-Mer 'Fish Chain' from Papua New Guinea to Asian Markets.* Report commissioned by the David and Lucile Packard Foundation. University of Technology, Sydney, 2016.

Barclay, Kate, Michael Fabinyi, and Jeff Kinch, "Governance and the Papua New Guinea beche-de-mer value chain." *SPC Beche-de-mer Information Bulletin*, Issue 37, March 2017, 3–8. https://png-data.sprep.org/system/files/BDM37_03_Barclay_0.pdf

Baumann, Erich, *Water Lifting. Series of Manuals on Drinking Water Supply,* Volume 7. St. Gallen, Switzerland: SKAT, Swiss Centre for Development Cooperation in Technology and Management, 2000. https://skat.ch/wp-content/uploads/2017/01/Handbook_V7.pdf

Baumüller, Heike, "Assessing the Role of Mobile Phones in Offering Price Information and Market Linkages: The Case of M-Farm in Kenya." *The Electronic Journal of Information Systems in Developing Countries* Vol. 68, no. 6 (2015): 1–16. https://ssrn.com/abstract=2595613

Bell, Johann D., Johanna E. Johnson, Alex S. Ganachaud, Peter C. Gehrke, Alistair J. Hobday, Ove Hoegh-Guldberg, Robert Le Borgne, Patrick Lehodey, Janice M. Lough, Tim Pickering, Morgan S. Pratchett, and Michelle Waycott, *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change: Summary for Pacific Island Countries and Territories.* Noumea: Secretariat of the Pacific Community, 2011. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers15-01/010063492.pdf

Bell, Johann D., Mecki Kronen, Aliti Vuniseaa, Warwick J. Nash, Gregory Keeble, Andreas Demmke, Scott Pontifex, and Serge Andréfouët, "Planning the Use of Fish for Food Security in the Pacific." *Marine Policy* 33 (2009): 64–76. https://doi.org/10.1016/j.marpol.2008.04.002

BoM (Australian Bureau of Meteorology), *Southern Hemisphere Tropical Cyclone Data Portal*, 2020. http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/history/tracks/

BoM and CSIRO (Commonwealth Scientific and Industrial Research Organisation), *State of the Climate* 2016, 2016. www.bom.gov.au/state-of-the-climate/

BoM and CSIRO, *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports. Chapter 11: Papua New Guinea.* Melbourne, Australia: Pacific-Australia Climate Change Science and Adaptation Planning Program Technical Report, BoM and CSIRO, 2014. https://www.pacificclimatechange.net/sites/default/files/documents/PACCSAP_CountryReports2014_Ch11PNG_WEB_140710.pdf

BoM and CSIRO, *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports. Chapter 11: Papua New Guinea*. Melbourne, Australia: Pacific-Australia Climate Change Science and Adaptation Planning Program Technical Report, BoM and CSIRO, 2011. https://www.pacificclimatechangescience.org/wp-content/uploads/2013/09/Papua-New-Guinea.pdf

Booth, J.R., Nagombi, E., and Boslogo, T., *Fisheries Catch-and-effort Report, Kavieng District, New Ireland Province, Papua New Guinea: January 2019 – July 2019.* Wildlife Conservation Society Report, Kavieng, New Ireland Province, Papua New Guinea, 2019.

Booth, Martin G., III, and Paul F. Bixley, "Geothermal Development in Papua New Guinea. A Country Update Report: 2000–2005." *Proceedings of World Geothermal Congress 2005*, Antalya, Turkey, April 24–29, 2005. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2005/0136.pdf

Bourke, R. Michael and Tracy Harwood (eds), *Food and Agriculture in Papua New Guinea.* ANU E Press, The Australian National University, Canberra, 2009. http://www.jstor.org/stable/j.ctt24h987

Brown, A., T. Nott, and D. Shaw, *WaterAid PNG Country Program Evaluation.* Final report, 2015.

Bryan, Jane and Phil Shearman, *The State of the Forests of Papua New Guinea 2014: Measuring Change Over the Period 2002–2014.* Port Moresby, Papua New Guinea: University of Papua New Guinea, 2015. https://png-data.sprep.org/dataset/state-forests-papua-new-guinea-2014/resource/c7336b31-fe0b-4ba9-bdf4-a8311e6836fa

Bryan, Jane, Phil Shearman, Julian Ash, and J. B. Kirkpatrick, "Estimating Rainforest Biomass Stocks and Carbon Loss from Deforestation and Degradation in Papua New Guinea 1972–2002: Best Estimates, Uncertainties and Research Needs." *Journal of Environmental Management* 91 (2010): 995–1001. https://doi.org/10.1016/j.jenvman.2009.12.006

CFE-DM (Center for Excellence in Disaster Management and Humanitarian Assistance), *Papua New Guinea Disaster Management Reference Handbook,* 2016. https://www.cfe-dmha.org/LinkClick.aspx?fileticket=Hcbz81c1u-4%3d&portalid=0

Chen, C, I. Noble, J. Hellmann, J. Coffee, M. Murillo, and N. Chawla, *University of Notre Dame Global Adaptation Index: Country Index Technical Report*, 2015. https://gain.nd.edu/assets/254377/nd_gain_technical_document_2015.pdf

CIF (Climate Investment Fund), *Strategic Program for Climate Resilience for Papua New Guinea*. Meeting of the PPCR Sub-Committee, Istanbul, Turkey, November 1, 2012. PPCR/SC.11/44, October 11, 2012. https://www.climateinvestmentfunds.org/sites/cif_enc/files/PPCR_4_PNG.pdf

CME-Programme (Commonwealth Marine Economies Programme), "Pacific Marine Climate Change Report Card: Effects of Climate Change on Fish and Shellfish Relevant to Pacific Islands, and the Coastal Fisheries they Support". In *Science Review* (2018): 74–98. https://reliefweb.int/sites/reliefweb.int/files/resources/6_Fish_and_Shellfish.pdf

Connell, John, "Vulnerable Islands: Climate Change, Tectonic Change, and Changing Livelihoods in the Western Pacific." *The Contemporary Pacific* 27(1) (2015): 1–36. https://doi.org/10.1353/cp.2015.0014

Cooper, R., *Political Economy of Papua New Guinea and the Water, Sanitation, and Hygiene Sector.* GSDRC Helpdesk Research Report. Birmingham, UK: GSDRC, University of Birmingham, 2019. https://gsdrc.org/publications/political-economy-of-papua-new-guinea-and-the-water-sanitation-and-hygiene-sector

Cosgrove, William and Frank Rijsberman, *World Water Vision: Making Water Everybody's Business*. London: Earthscan, 2000.

Cuthbert, R.J., G. Bush, M. Chapman, B. Ken, E. Neale, and N. Whitmore, *Analysis of National Circumstances in the Context of REDD+ and Identification of REDD+ Abatement Levers in Papua New Guinea.* Report produced by the Wildlife Conservation Society (Goroka, Papua New Guinea), for Papua New Guinea's UN-REDD National Programme, 2016.

Dawson, Ian K., Roger Leakey, Charles R. Clement, John C. Weber, Jonathan P. Cornelius, James M. Roshetko, Barbara Vinceti, Antoine Kalinganire, Zac Tchoundjeu, Eliot Masters and Ramni Jamnadass, "The Management of Tree Genetic Resources and the Livelihoods of Rural Communities in the Tropics: Non-Timber Forest Products, Smallholder Agroforestry Practices and Tree Commodity Crops." *Forest Ecology and Management* 333 (December 2014): 9–21. https://doi.org/10.1016/j.foreco.2014.01.021

De Rosbo, Sebastian, *Papua New Guinea—Telecoms, Mobile and Broadband—Statistics and Analyses.* Paul Budde Communication Pty Ltd, 2020. https://www.budde.com.au/Research/Papua-New-Guinea-Telecoms-Mobile-and-Broadband-Statistics-and-Analyses

D'Haeyer, Tom, Julie Deleu, Edith Maroy, Danitza Salazar, Georg Petersen, Charles Pendley, Michael Allen, Bonie Belonio, and Ethel Pirola Igoa, *Climate Risk, Vulnerability and Risk Assessment in the New Ireland Province in Papua New Guinea—Province and District Profile*. Antwerp, Belgium. 2017.

Drew, Joshua A., Kathryn L. Amatangelo, and Ruth A. Hufbauer, "Quantifying the Human Impacts on Papua New Guinea Reef Fish Communities across Space and Time." *PLOS ONE.* 10(10) (2015): e0140682. https://doi.org/10.1371/journal.pone.0140682

Durst, P. B., P. J. McKenzie, C. L. Brown, and S. Appanah, "Challenges Facing Certification and Eco-Labelling of Forest Products in Developing Countries." *International Forestry Review*, 8(2) (2006): 193–200. http://www.bioone.org/doi/abs/10.1505/ifor.8.2.193

Emori, Rebecca, Paul Hukuku, Kritoe Keleba, Dickson Mandenget, Steven Sangi, and Nancy Sullivan, *Welpam Woris: The Social Impact of Oil Palm in Oro Province.* Nancy Sullivan & Associates Ltd, 2005. https://www.academia.edu/4492658/Welpam_Woris_The_social_impact_of_oil_palm_in_Oro_Province

FAO (Food and Agriculture Organization of the United Nations), *FAOSTAT—Land Use Indicators*. Rome: FAO, 2019a. http://www.fao.org/faostat/en/#data/EL

FAO, *Land & Water—Water FAO*, 2019b. http://www.fao.org/land-water/water/en/

FAO, *Irrigation in Southern and Eastern Asia in Figures. AQUASTAT Survey 2011*. FAO Water Reports No. 37. Rome, Italy, 2012. http://www.fao.org/3/i2809e/i2809e.pdf

FCPF (Forest Carbon Partnership Facility), *REDD + Annual Country Progress Reporting, Papua New Guinea,* 2018.

Filer, Colin, "Why Green Grabs Don't Work in Papua New Guinea." *Journal of Peasant Studies*, Volume 39 (2012): 599–617. https://doi.org/10.1080/03066150.2012.665891

Filer, Colin, *The New Land Grab in Papua New Guinea: A Case Study from New Ireland Province.* Canberra: Australian National University, College of Asia and the Pacific, State Society and Governance in Melanesia Program (Discussion Paper 2011/2), 2011.
https://openresearch-repository.anu.edu.au/bitstream/1885/9879/1/Filer_NewLand2011.pdf

Fisher, Robert, Norlie Miskaram, Alfred Faitelli, John Herbohn, Jack Baynes, David Smorfitt, and Hartmut Holzknecht, "Challenges to Upscaling Community Ecoforestry and Community-based Reforestation in Papua New Guinea". In *Promoting Responsible Sustainable Development Through Science & Technology, the PNG Way.* Volume 2, edited by Victor Temple, David Mowbray, Prem P. Rai, Osia Gideon, Chalapan Kaluwin, and John Watmelik. Proceedings of the 6th Research Science and Technology & UPNG Science Conference, 17–25 (November 2015): 32–40, 2014.

Fox, Julian C., Cossey K. Yosi, Patrick Nimiago, Forova Oavika, Joe N. Pokana, Kunsey Lavong, and Rodney Kennan, "Assessment of Aboveground Carbon in Primary and Selectively Harvested Tropical Forest in Papua New Guinea." *Biotropica* 42(4) (2010): 410–419.
https://doi.org/10.1111/j.1744-7429.2009.00617.x

Friedman, Kim, Mechi Kronen, Silvia Pinca, Franck Magron, Pierre Boblin, Kalo Pakoa, Ribanataake Awiva, and Lindsay Chapman, *Papua New Guinea Country Report: Profiles and Results from Survey Work at Andra, Tsoilaunung, Sideia and Panapompom (June to November 2006).* Noumea: Secretariat of the Pacific Community, 2008.
https://www.spc.int/DigitalLibrary/Doc/FAME/Reports/PROCFish/PROCFish_2008_PNGReport.html

Ganpat, Wayne G. and Wendy-Ann P. Isaac, *Impacts of Climate Change on Food Security in Small Island Developing States*, 2014.
https://www.igi-global.com/book/impacts-climate-change-food-security/108332

Gazeau, Frédéric, Laura M. Parker, Steeve Comeau, Jean-Pieere Gattuso, Wayne A. O'Connor, Sophie Martin, Hans-Otto Pörtne, and Pauline M. Ross, "Impacts of ocean acidification on marine shelled molluscs." *Marine Biology* 160 (2013): 2207–2245. https://doi.org/10.1007/s00227-013-2219-3

GEF (Global Environment Facility), UNDP (United Nations Development Programme) and SPREP (Secretariat of the Pacific Regional Environment Programme), *Pacific Adaptation to Climate Change Papua New Guinea—Report of in Country Consultations*, 2009.
https://www.sprep.org/attachments/Climate_Change/PACC_Report_of_in-country_consultations_Papua_New_Guinea.pdf

GGGI, *Green Growth Potential Assessment—Methodology Report.* GGGI Technical Report No. 6. Seoul: GGGI, 2019a. https://gggi.org/site/assets/uploads/2020/01/GGPA-Methodology-Review.pdf

GGGI, *Green Growth Potential Assessment of Papua New Guinea*. Seoul: GGGI, 2019b. https://gggi.org/report/green-growth-potential-assessment-of-papua-new-guinea/

Gillet, Robert, *Fisheries in the Economies of the Pacific Island Countries and Territories*. Pacific Studies Series. Mandaluyong City, Philippines: ADB, 2009.

Global Forest Atlas, *Forest Certification,* Yale School of the Environment, 2018.
https://globalforestatlas.yale.edu/conservation/forest-certification

GoPNG (Government of Papua New Guinea*), Total CO2 Emissions in 2015*. Internal document, 2018.

GoPNG, *Papua New Guinea's National REDD+ Forest Reference Level.* Climate Change and Development Authority*,* 2017a*.*

GoPNG, *Papua New Guinea National REDD+ Strategy for the Period 2017–2027,* 2017b*.*

GoPNG, *Sector Performance Annual Review for 2016: National Health Plan 2011–2020*, 2017c.
https://www.health.gov.pg/pdf/SPAR_2016.pdf

GoPNG, *Intended Nationally Determined Contribution (INDC) Under the United Nations Framework Convention on Climate Change,* 2016.
https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Papua%20New%20Guinea%20First/PNG_INDC%20to%20the%20UNFCCC.pdf

GoPNG, *PNG National Water, Sanitation and Hygiene (WaSH) Policy 2015–2030.* Department of National Planning and Monitoring, 2015.
https://png-data.sprep.org/dataset/water-quality/resource/dd1716a5-f57d-4bda-9249-c30306ce998f

GoPNG, *Papua New Guinea Second National Communication Under the United Nations Framework Convention on Climate Change,* 2014. https://unfccc.int/resource/docs/natc/pngnc2.pdf

GoPNG, *Water Supply and Sanitation in Papua New Guinea – Turning Finance into Services for the Future. Service Delivery Assessment*, 2013.

GoPNG, *National Health Plan 2011–2020*. National Department of Health, Waigani NCD, Papua New Guinea, 2010.

GoPNG, *Papua New Guinea Vision 2050,* 2009.
http://actnowpng.org/sites/default/files/png%20version%202050.pdf

GoPNG, *PNG REDD+ Finance and Investment Plan*. Unpublished draft, undated.

GoPNG and UN Country Team in Papua New Guinea, *ENSO Impact Outlook: Papua New Guinea 2017/2018*, 2017. https://reliefweb.int/report/papua-new-guinea/enso-impact-outlook-papua-new-guinea-20172018

Govan, Hugh, *A Roadmap for Coastal Fisheries and Marine Aquaculture for Papua New Guinea: 2017–2026,* 2017. https://www.researchgate.net/publication/315783523

Green, Alison, Scott E. Smith, Geoff Lipsett-Moore, Craig Groves, Nate Peterson, Stu Sheppard, Paul Lokani, Richard Hamilton, Jeanine Almany, Joseph Aitsi, and Leo Bualia, "Designing a Resilient Network of Marine Protected Areas for Kimbe Bay, Papua New Guinea." *Oryx*, 43(4) (2009): 488–498. http://dx.doi.org/10.1017/S0030605309990342

GSMA (Groupe Speciale Mobile Association), *The Mobile Economy Sub-Saharan Africa 2019, 2019.*

Hair, Cathy, Simon Foale, Jeff Kinch, Sven Frijlink, Daniel Lindsay, and Paul C. Southgate, "Socioeconomic Impacts of a Sea Cucumber Fishery in Papua New Guinea: Is There an Opportunity for Mariculture?" *Ocean and Coastal Management*, 179 (2019).
https://doi.org/10.1016/j.ocecoaman.2019.104826

Hair, Cathy, Jeff Kinch, Terencehill Galiurea, Posolok Kanawi, Mathew Mwapweya, and Joshua Noiney, "Re-opening of the sea cucumber fishery in Papua New Guinea: A case study from the Tigak Islands in the New Ireland Province", *SPC Beche-de-mer Information Bulletin*, Issue 38, March 2018: 3-10.
https://png-data.sprep.org/system/files/Beech-de-mer%20in%202018.pdf

Hanson, L. W., Allen, B. J., Bourke, R. M. and McCarthy, T. J., *Papua New Guinea Rural Development Handbook.* The Australian National University, Canberra, 2001.
https://researchers.anu.edu.au/publications/47081

Hay, John E., Nobuo Mimura, John Campbell, Solomone Fifita, Kanayathu Koshy, Roger F. McLean, Taito Nakalevu, Patrick Nunn and Neil de Wet, *Climate Variability and Change and Sea-level Rise in the Pacific Islands: Region: A Resource Book for Policy and Decision Makers, Educators and Other Stakeholders,* 2003.
https://www.cakex.org/sites/default/files/Climate%20Variability%20and%20Change%20and%20Sea-level%20Rise.pdf

HLPE (High Level Panel of Experts on Food Security and Nutrition), *Sustainable Forestry for Food Security and Nutrition*. Rome: HLPE, 2017.

Horak, Helena M., Joshua S. Chynoweth, Ward P. Myers, Jennifer Davis, Scott Fendorf, and Alexandria B. Boehm, "Microbial and Metal Water Quality in Rain Catchments Compared with Traditional Drinking Water Sources in the East Sepik Province, Papua New Guinea." *Journal of Water and Health*, 8.1 (2010): 126–138. https://iwaponline.com/jwh/article-pdf/8/1/126/397371/126.pdf

IBRD (International Bank for Reconstruction and Development), *Water Supply and Sanitation in Papua New Guinea. Turning Finance into Services for the Future. Service Delivery Assessment,* 2015. https://www.wsp.org/sites/wsp/files/publications/WSP-PapuaNewGuinea-WSS-Turning-Finance-into-Service-for-the-Future.pdf

ICRC (International Committee of the Red Cross), *Papua New Guinea—Operational Highlights, January–December 2017.* ICRC Mission in Papua New Guinea, 2017.

IEA, *Energy Access Outlook 2017*. Paris: IEA, 2017a. https://www.iea.org/reports/energy-access-outlook-2017

IEA, *World Energy Outlook 2017: Methodology for Energy Access Analysis*. Paris: IEA, 2017b.

IMF (International Monetary Fund), *Papua New Guinea*. IMF Country Report No. 17/411. Washington DC: IMF, 2017. https://www.imf.org/en/Publications/CR/Issues/2017/12/29/Papua-New-Guinea-2017-Article-IV-Consultation-Press-Release-Staff-Report-and-Statement-by-45532

IOM (International Organisation for Migration), *Enhancing Climate-Resilient Agriculture and Water Supply in Drought-Affected Communities in Papua New Guinea,* 2016a.

IOM, *Papua New Guinea Drought: IOM Response and Recovery,* Situation Report, 25 January 2016. IOM Papua New Guinea, Disaster Management Unit, 2016b. https://www.iom.int/sites/default/files/situation_reports/file/IOM-Sitrep-6-PNG-Drought-Jan25-final.pdf

IOM, *Assessing the Evidence: Migration, Environment, and Climate Change in Papua New Guinea, 2015.* https://publications.iom.int/system/files/pdf/meclep_assessment_png.pdf

IPCC (Intercontinental Panel on Climate Change), *Climate Change 2014—Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report: Volume 1: Global and Sectoral Aspects*. Vol. 1. Cambridge: Cambridge University Press, 2014.

IPCC, *IPCC Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Programme. Japan: IGES, 2006. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

IRENA (International Renewable Energy Agency), *Renewable Energy Benefits. Decentralised Solutions in the Agri-food Chain,* 2016. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Decentralised_solutions_for_agrifood_chain_2016.pdf

ITU (International Telecommunication Union), *ITU Facts and Figures 2017*. Geneva: ITU, 2017.

Ivahupa, S. R., "PNG Disaster Management: 1997–98. Drought and Frost Impact Assessment—Methods Used and Experiences." In *Food Security for Papua New Guinea,* edited by R. M. Bourke, M. G. Allen, and J. G. Salisbury. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99, xviii + 892 (2001): 232–235. https://aciar.gov.au/publication/technical-publications/food-security-papua-new-guinea-proceedings-papua-new-guinea-food-and-nutrition-2000

Jack, William and Tavneet Suri, *Mobile Money: The Economics of M-PESA*, NBER Working Paper No. 1672, National Bureau of Economic Research, 2011. https://www.nber.org/papers/w16721.pdf

Jaramillo, Juliana, Eric Muchugu, Fernando E. Vega, Aaron Davis, Christian Borgemeister and Adenirin Chabi-Olaye, "Some Like It Hot: The Influence and Implications of Climate Change on Coffee Berry Borer (*Hypothenemus hampei*) and Coffee Production in East Africa." *PLOS ONE* Vol. 6, no. 9 (September 2011): e24528. https://doi.org/10.1371/journal.pone.0024528

Johnson, Johanna, Johann Bell, and Alex Sen Gupta, *Pacific Islands Ocean Acidification Vulnerability Assessment,* 2015. https://www.sprep.org/attachments/Publications/CC/ocean-acidification.pdf

Kapal, Debbie, Sergie Bang, Dave Askin and Bryant Allen, *Drought Response: On-Farm Coping Strategies*. National Agriculture Research Institute, Information Bulletin No.6, 2003. https://www.nari.org.pg/web/sites/default/files/pdf_files/drought_strategy.pdf

Kapila, R. K., B. Wera, M. Deros, R. P. Pawilnga, S. Ivahupa, G. Bagle, T. Okpul, and E. Guaf, "Potential of Newly Bred Sweet Potato Clones as Improved Cultivars Under Highland Conditions of Papua New Guinea I. Performance of Early Maturing Sweet Potato Clones." *Niugini Agrisaiens*, Vol. 2, no. 1 (January–December 2010): 30–38. Lae, Papua New Guinea: PNG University of Technology, Department of Agriculture. https://www.unitech.ac.pg/sites/default/files/Volume%202%202010.pdf

Kudela, Václav, "Potential Impact of Climate Change on Geographic Distribution of Plant Pathogenic Bacteria in Central Europe." *Plant Protection Science* 45 (2009): 527–532.

L'Heureux, Michelle, "What is the El Niño–Southern Oscillation (ENSO) in a nutshell?" ENSO blog, 2014. https://www.climate.gov/news-features/blogs/enso/what-el-ni%C3%B1o%E2%80%93southern-oscillation-enso-nutshell

Leggett, Matt, *The Status of REDD+ in Papua New Guinea. USAID Lowering Emissions in Asia's Forests (LEAF) Program,* 2011. https://png-data.sprep.org/system/files/StatusofREDDinPNG.pdf

Leisz, Stephen J., *Locations in Melanesia Most Vulnerable to Climate Change*. Bishop Museum, 2009. http://data.bishopmuseum.org/ccbm/Areas/Melanesia/Papers/MelanesiaClimateChangeVulnerability.pdf

Lighting Global, *Off-Grid Solar Market Trends Report 2018,* 2018. https://www.gogla.org/sites/default/files/resource_docs/2018_mtr_full_report_low-res_2018.01.15_final.pdf

Lighting Global, *Off-Grid Solar Market Trends Report 2016,* 2016. https://www.lightingglobal.org/wp-content/uploads/2016/03/20160301_OffGridSolarTrendsReport-1.pdf

Liu, Mathias, Allan Oliver, and Keith Woodford, *Livelihood Training in the Islands Region of Papua New Guinea: The Integrated Agricultural Training Program*. Paper presented at DEVNET Conference, Otago University New Zealand, 2008. http://researcharchive.lincoln.ac.nz/handle/10182/2122

Mattews, Emily, Richard Payne, Mark Rohweder and Siobhan Murray, *Pilot Analysis of Global Ecosystems: Forest Ecosystems*. Washington DC: WRI, 2000. http://pdf.wri.org/page_forests.pdf

McCoy-West, Alex, Sarah Milicich, Tony Robinson, Greg Bignall, and Colin C Harvey, "Geothermal Resources in the Pacific Islands: The Potential of Power Generation to Benefit Indigenous Communities." *Proceedings of Thirty-Sixth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 31–February 2,* 2011. https://www.researchgate.net/publication/229036839

Meidinger, Errol, "Forest Certification as a Global Civil Society Regulatory Institution." In *Social and Political Dimensions of Forest Certification*, edited by Errol Meidinger, Chris Elliott, and Gerhard Oesten, SUNY Buffalo Legal Studies Research Paper No. 2015–007, Law Legal Studies, University at Buffalo School of Law, 2003. https://digitalcommons.law.buffalo.edu/book_sections/188/

Moretti, C. L., L. M. Mattos, A. G. Calbo and S. A. Sargent, "Climate Changes and Potential Impacts on Postharvest Quality of Fruit and Vegetable Crops: A Review." *Food Research International,* 2010.

Nelson, Paul N., Jennifer Gabriel, Colin Filer, Murom Banabas, Jeffrey A. Sayer, George N. Curry, Gina Koczberski, and Oscar Venter, "Oil Palm and Deforestation in Papua New Guinea." *Conservation Letters* Volume 7 (2014): 188–195. https://10.1111/conl.12058

New Ireland Provincial Fisheries and Marine Division, *Fisheries and Marine Resource Divisional Report for 2019.* Kavieng, 2019.

New Ireland Department of Works, *Project Status Report No.11–2019*, December 2019.

NFA (National Forest Authority), *NIP Logging Export Report to the New Ireland Provincial Administration.* Kavieng, 2015.

NIPA (New Ireland Provincial Administration), *New Ireland Integrated Provincial Development Plan 2012–2015,* 2012.

NIPA, *Fisheries and Marine Resources Divisional Report for 2019.* Division of Fisheries and Marine Resources. Power Point presentation, 2019.

NOAA (National Oceanic and Atmospheric Administration), *El Niño/Southern Oscillation (ENSO) Technical Discussion,* n.d. https://www.ncdc.noaa.gov/teleconnections/enso/enso-tech.php

NOAA, *Ocean Acidification*, 2020. https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

NRC (Norwegian Refugee Council) and IDMC (Internal Displacement Monitoring Centre), *Global Overview 2012: People Internally Displaced by Conflict and Violence,* 2013. https://www.internal-displacement.org/publications/global-overview-2012-people-internally-displaced-by-conflict-and-violence

NSO (National Statistics Office), *Census 2011*, 2011. https://png-data.sprep.org/dataset/2011-census-report/resource/cfdd385b-d2a9-4fce-8a84-abcfcc96fdcc

NSO and ICF (Inner City Fund), *Papua New Guinea Demographic and Health Survey 2016–18*. Port Moresby, Papua New Guinea, and Rockville, Maryland, USA, 2019.

NSWG (New South Wales Government), *Projected Impacts of Climate Changes on Mining.* Department of Primary Industries, n.d. https://www.dpi.nsw.gov.au/content/research/topics/climate-change/mining

OECD (Organisation for Economic Co-operation and Development) and the Joint Research Centre of the European Commission, *Handbook on Constructing Composite Indicators: Methodology and User Guide,* 2008. http://www.oecd.org/sdd/42495745.pdf

Okoli, Chitu, and Suzanne D. Pawlowski, "The Delphi Method as a Research Tool: An Example, Design Considerations and Applications." *Information & Management* Vol. 42, no.1 (2004): 15–29.

Okuneye, Kamaldeen, Steffen Eikenberry, and Abba Gumel, "Weather-Driven Malaria Transmission Model with Gonotrophic and Sporogonic Cycles." *Journal of Biological Dynamics.* 13(3) (2019): 1–37. https://doi.org/10.1080/17513758.2019.1570363

Oxford Business Group, "Agriculture & Fisheries". In *The Report: Papua New Guinea 2018,* 2018. https://oxfordbusinessgroup.com/papua-new-guinea-2018/agriculture-fisheries

Papua New Guinea Tourism Promotion Authority, *Visitor Arrival Reports 2014–2019,* 2020. https://www.papuanewguinea.travel/visitor-arrival-reports

Park, Jae-Won, Hae-Kwan Cheong, Yasushi Honda, Mina Ha, Ho Kim, Joel Kolam, Kasis Inape and Ivo Mueller, "Time Trend of Malaria in Relation to Climate Variability in Papua New Guinea." *Environmental Health and Toxicology* Vol. 31 (February 2016). https://doi.org/10.5620/eht.e2016003

Perry, Chris T., Lorenzo Alvarez-Filip, Nicholas A. J. Graham, Peter J. Mumby, Shaun K. Wilson, Paul S. Kench, Derek P. Manzello, Kyle M. Morgan, Aimee B. A. Slangen, Damian P. Thomson, Fraser Januchowski-Hartley, Scott G. Smithers, Robert S. Steneck, Renee Carlton, Evan N. Edinger, Ian C. Enochs, Nuria Estrada-Saldívar, Michael D. E. Haywood, Graham Kolodziej, Gary N. Murphy, Esmeralda Pérez-Cervantes, Adam Suchley, Lauren Valentino, Robert Boenish, Margaret Wilson, and Chancey Macdonald, "Loss of Coral Reef Growth Capacity to Track Future Increases in Sea Level." *Nature* 558 (2018): 396–400. https://doi.org/10.1038/s41586-018-0194-z

Phillips, Michael, "Mariculture Overview". In *Encyclopedia of Ocean Sciences,* edited by John Steele. Second edition: 537–544, 2009. https://www.sciencedirect.com/science/article/pii/B9780123744739007529

Polon, Philip, "The Papua New Guinea national beche-de-mer fishery management plan." In *Advances in Sea Cucumber Aquaculture and Management,* edited by Chantal Conand, Steven Purcell, Sven Uthicke, Jean-François Hamel, and Annie Mercier. Food and Agriculture Organization of the United Nations, Rome, Italy, 2004. http://www.fao.org/3/y5501e/y5501e0p.htm#bm25

Popkin, Barry M, Kristen E. D'Anci and Irwin H. Rosenberg, "Water, Hydration, and Health." *Nutrition Reviews* Vol. 68(8) (2010): 439–458. https://doi.org/10.1111/j.1753-4887.2010.00304.x

Rai, Prem, Teatulohi Matainaho, and Louis Barrows, *Research and Development in Papua New Guinea Traditional Medicine*. Third International Conference and Exhibition on Traditional & Alternative Medicine, August 03–05, 2015, Birmingham, UK. 2015 https://d2cax41o7ahm5l.cloudfront.net/cs/speaker-ppts/prem-p-rai-university-of-papua-new-guinea-papuanew-guinea.pptx

Ries, Justin B., Anne L. Cohen, and Daniel C. McCorkle, "Marine Calcifiers Exhibit Mixed Responses to CO2-Induced Ocean Acidification." *Geology* 37 (2009): 1131–1134.

Roszkowska, Ewa, "Rank Ordering Criteria Weighting Methods—A Comparative Overview." *Optimum.Studia Ekonomiczne* Nr 5(35) (2013): 14–33. https://doi.org/10.15290/ose.2013.05.65.02

SE4ALL, *Global Tracking Framework,* 2013. http://documents.worldbank.org/curated/en/603241469672143906/pdf/778890GTF0full0report.pdf

Sharma, Vigya, Shashi van de Graaff, Barton Loechel and Daniel Franks, *Extractive Resource Development in a Changing Climate: Learning the Lessons From Extreme Weather Events in Queensland, Australia.* National Climate Change Adaptation Research Facility, Gold Coast, 2013.

Shirayama, Y., and H. Thornton, "Effect of Increased Atmospheric CO2 on Shallow Water Marine Benthos." *Journal of Geophysical Research: Oceans,* Vol 110(C9) (2005): C09S08. https://doi.org/10.1029/2004JC002618

Sitapai, E.C., *A Critical Analysis of Agriculture Extension Services in Papua New Guinea: Past, Present and Future*. CIMC National Agriculture Conference, May 2012. http://www.inapng.com/pdf_files/A%20Critical%20Analysis%20of%20Agriculture%20Extension%20Services%20in%20Papua%20New%20Guinea%2018%20July%202012.pdf

Sitapai, E.C., *Case study of Extension and Advisory Services in Papua New Guinea.* Nairobi, Kenya: International Conference on Innovations in Extension and Advisory Services, 15–18 November 2011. https://www.slideshare.net/ctaspace/sitapai-case-study-of-extension-and-advisory-services-in-papua-new-guinea

Smith, Paul T, Kine Mufuape, Kaupa Kia, and Micah Aranka, "Findings of the Survey of Fish Farms." In: *Aquaculture in Papua New Guinea: Status of Freshwater Fish Farming,* edited by Paul T Smith. Australian Centre for International Agricultural Research. ACIAR Monograph No. 125, 2007.

Smithsonian Institution, *Ocean Acidification*, 2018. https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification

Sumb, Allan, *Developing Papua New Guinea's Tourism Sector.* Working Paper 2020/3. Department of Pacific Affairs, The Australian National University, 2020. http://dpa.bellschool.anu.edu.au/sites/default/files/publications/attachments/2020-04/dpa_working_paper_20203_sumb.pdf

Trendov, Nikola M., Samuel Varas, and Meng Zeng, *Digital Technologies in Agriculture and Rural Areas.* Briefing Paper, FAO, 2019. http://www.fao.org/3/ca4887en/ca4887en.pdf

Turoff, Murray and Harold Linstone, *The Delphi Method: Techniques and Applications.* Boston: Addison-Wesley Educational Publishers Inc, 1975.

UN Water, *Water and Ecosystems*, United Nations, n.d. https://www.unwater.org/water-facts/ecosystems/

UNDP, *Landscape of Climate-Relevant Land-Use Finance in Papua New Guinea: A Review of Financial Flows Related to Land-Use Mitigation and Adaptation. United Nations Development Programme,* 2018. https://www.undp.org/content/dam/papua_new_guinea/docs/Projects/PNG%20FCPF%20REDD+%20Readiness/Landscape%20of%20Land-Use%20Finance%20in%20Papua%20New%20Guinea%20FINAL%20REPORT.pdf

UNDP, UNEP (United Nations Environment Programme), and GEF, *National Adaptation Plan Process in Focus: Lessons from Papua New Guinea,* 2018.

UNECE (United Nations Economic Commission for Europe), *Carbon Sinks and Sequestration,* n.d.

UNESCO (United Nations Educational, Scientific and Cultural Organisation), *EFA Global Monitoring Report 2005: Education for All—The Quality Imperative*. Paris: UNESCO, 2004. https://www.right-to-education.org/sites/right-to-education.org/files/resource-attachments/EFA_GMR_Quality_Imperative_2005_en.pdf

UNICEF (United Nations of Children's Fund), *About WASH,* 2016. https://www.unicef.org/wash/3942_3952.html

UNICEF and WHO (World Health Organization), *Drinking Water, Sanitation and Hygiene in Schools: Global Baseline Report 2018*. New York, 2018. https://data.unicef.org/resources/wash-in-schools/#

USAID (United States Agency for International Development), *Technical Brief: Use of Technology in the Ebola Response in West Africa,* 2014. https://www.msh.org/sites/msh.org/files/technology_and_ebola_response_in_west_africa_technical_brief_final.pdf

von Essen, L.-M., S.C.A. Ferse, M. Glaser, and A. Kunzmann, "Attitudes and Perceptions of Villagers Toward Community-Based Mariculture in Minahasa, North Sulawesi, Indonesia." *Ocean Coast Management* 73 (2013): 101–112.

Vorgrimler, Daniel, "Die Delphi-Methode und ihre Eignung als Prognoseinstrument." *Wirtschaft und Statistik* 8 (2003): 763–774.

Wamala, Maia and Shamsul Akanda, "Effect of Late Water Stress on Growth and Tuber Yield of Nineteen Sweet Potato Genotypes." *Niugini Agrisaiens*, Vol 2, no. 1 (January–December 2010): 17–25. Lae, Papua New Guinea: PNG University of Technology, Department of Agriculture. https://www.unitech.ac.pg/sites/default/files/Volume%202%202010.pdf

Waru, Sammie and Sven Frijlink, *Market Survey of Mangrove Shellfish from Northern New Ireland Province, Papua New Guinea. An Assessment of Sales Quantities, Economic Impacts and Harvest Locations of Four Species of Mangrove Associated Shellfish Sold at the Kavieng Market, New Ireland.* Wildlife Conservation Society, undated.

WaterAid, *Assessing the Water, Sanitation and Hygiene Needs of People Living with HIV and AIDS in Papua New Guinea,* 2013.

Watson, Sue-Ann, Paul C. Southgate, Gabrielle M. Miller, Jonathan A. Moorhead, and Jens Knauer, "Ocean acidification and warming reduce juvenile survival of the fluted giant clam". *Tridacna squamosa. Molluscan Research* 32 (2012): 177–180.

WCS (Wildlife Conservation Society), *Country Situation Analysis Report and Indicators*. Pacific-European Union Marine Partnership Programme, undated.

WHO (World Health Organization), *Protecting Health from Climate Change: Vulnerability and Adaptation Assessment,* 2013. https://apps.who.int/iris/handle/10665/104200

WHO, *Protecting Health from Climate Change: Connecting Science, Policy and People*, 2009. https://www.who.int/globalchange/publications/reports/9789241598880/en/

WHO, *Health, Economic Growth and Poverty Reduction: The Report of Working Group I of the Commission on Macroeconomics and Health*. Geneva: WHO, 2002. https://apps.who.int/iris/bitstream/handle/10665/42492/9241590092.pdf?sequence=1&isAllowed=y.

Wohlfahrt, Damien J. and Kambowa Kukyuwat, "Village Rural Water Supplies in the Western Highlands Province of Papua New Guinea." *Papua New Guinea Medical Journal*, Vol, 25, no. 3 (September 1982): 168–172. https://www.ircwash.org/sites/default/files/828-1133.pdf

World Bank, *Papua New Guinea. Climate Data—Projections. Climate Change Knowledge Portal.* World Bank Group, 2020a. https://climateknowledgeportal.worldbank.org/country/papua-new-guinea/climate-data-projections

World Bank, *Population, Total—Papua New Guinea*, 2020b. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=PG

World Bank, *Population Growth (Annual %)—Papua New Guinea,* 2020c. https://data.worldbank.org/indicator/SP.POP.GROW?locations=PG

World Bank, *Systematic Country Diagnostic—The Independent State of Papua New Guinea,* Washington, DC: World Bank Group, 2018. http://documents1.worldbank.org/curated/en/360291543468322518/pdf/127800-28-11-2018-11-12-10-PNGSystematicCountryDiagnosticFinal.pdf

World Bank, *Papua New Guinea Rural WaSH Sustainability Study*. Washington DC: World Bank, 2017. https://openknowledge.worldbank.org/handle/10986/28594

World Bank, *The Fruit of Her Labor: Promoting Gender-Equitable Agribusiness in Papua New Guinea, 2014.* http://documents.worldbank.org/curated/en/654201468289175577/pdf/ACS100040REVIS0ank0rev0March0202015.pdf

World Bank, *Papua New Guinea – Country Risk Profile (English).* Washington, DC: World Bank Group, 2011. http://documents.worldbank.org/curated/en/443831468189247504/Papua-New-Guinea-country-risk-profile

World Bank, *Forests Sourcebook: Practical Guidance for Sustaining Forests in Development Cooperation*. Washington, DC: World Bank, 2008.

WWAP (World Water Assessment Programme), *United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Paris: UNESCO, 2012.

Zardari, Noorul Hassan, Kamal Ahmed, Sharif Moniruzzaman Shirazi, and Zulkifli Bin Yusop, *Weighting Methods and their Effects on Multi-Criteria Decision Making Model Outcomes in Water Resources Management*. Cham: Springer International Publishing, 2015.

Appendices

APPENDIX A. PARTICIPANTS LIST

	Name	Affiliation
1	Max Kuduk	Catholic Church
2	Darius Logo	PNG National Forest Service
3	Betty Kapi	National Development Bank
4	Joseph Absalom	oil palm industry
5	Thaiya Wokasup	Department of Land and Physical Planning
6	Jordan Gerson	Live & Learn
7	Milton Temeni	Live & Learn
8	Roline Likas	National Broadcasting Commission
9	Samuel Apisai	New Ireland Provincial Tourism Authority
10	Theresa Endy	New Britain Palm Oil Limited
11	Yvette Owen	New Ireland Community Development office
12	Ben Lutamba	New Ireland Provincial Budget and Planning office
13	Isaac Boski	New Ireland Province Youth Association
14	Dominic Sahamie	New Ireland Provincial Health Authority
15	Jonathan Booth	Wildlife Conservation Society
16	Kiapin Tana	Kavieng Urban local-level government (LLG)
17	Ngasmul Lengkulong	Kavieng Urban LLG
18	Stanley Paulus	Provincial climate change office
19	Lyle Alicksan	Red Cross
20	Nigel Tahija	New Ireland Provincial Planning and Budget Office
21	Peter Unanoli	Kavieng Urban LLG
22	Gideon Bogosia	Department of Primary Industries, Division of Agriculture, Livestock, Fisheries, Forestry and Climate Change
23	William Carlua	New Ireland Provincial Administration
24	Barbra Makapa	Department of Primary Industries, Division of Agriculture and Livestock
25	John Joseph	PNG Cocoa Board
26	Nicholas Daniels	National Fisheries Authority
27	Nathaniel Takinai	Lavongai LLG, Department of Primary Industries
28	John Aini	Ailan Awareness Association
29	Dr. Jeff Kinch	National Fisheries Authority

APPENDIX B. WORKSHOP AGENDA

CLIMATE-RESILIENT GREEN GROWTH IN NEW IRELAND PROVINCE CONSULTATION WORKSHOP

7 October 2020
Kavieng, New Ireland Province, Papua New Guinea

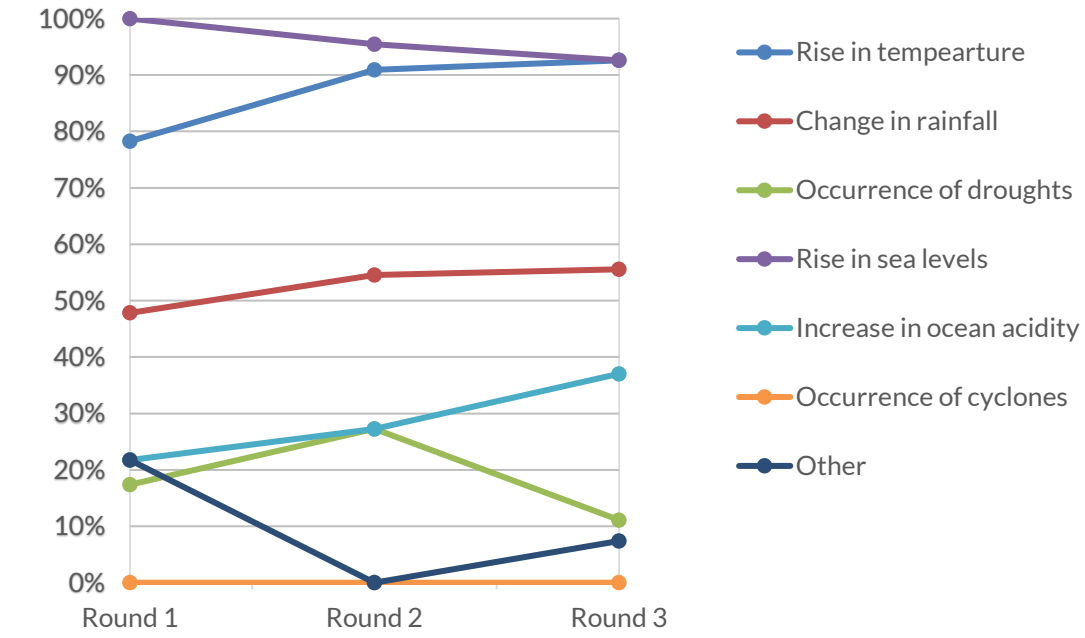
Agenda

1. Opening remarks
2. Introduction of Climate Resilient Green Growth
3. Guided plenary discussion, including stakeholder survey rounds 1 and 2
4. Guided plenary discussion, including stakeholder survey round 3
5. Guided group discussion
6. Consensus building, including stakeholder survey round 4
7. Closing remarks

Time	Item(s)	Note(s)
8:30 – 9:00	Participant registration	
9:00 – 9:45	**1. Opening remarks** • Remarks from New Ireland Administrator • Remarks from CCDA Representative • Remarks from DFAT • Remarks from GGGI Country Representative	CCDA, DFAT, New Ireland Provincial Administration and GGGI
9:45 – 10:30	**2. Introduction of climate-resilient green growth** • Overview of methodology • Q&A and interactive exercise	Ms. Sharon Tubal, Provincial Officer, GGGI Mr. Jan Stelter, Senior Analyst, GGGI
10:30 – 10:45	*Coffee break and group photo*	
10:45 – 12:00	**3. Guided plenary discussion** • Identification of climate change priorities • Stakeholder survey—rounds 1 and 2	Ms. Sharon Tubal Mr. Jan Stelter
12:00 – 13:00	*Lunch*	
13:00 – 14:30	**4. Guided plenary discussion** • Identification of climate change priorities • Stakeholder survey—round 3	Ms. Sharon Tubal Mr. Jan Stelter
14:30 – 14:45	*Coffee Break*	
14:45 – 16:00	**5. Guided group discussion** • Refinement of climate change priorities	Selected facilitators
16:00 – 16:45	**6. Consensus building** • Discussion of group results • Confirmation of climate change priorities	Ms. Sharon Tubal Mr. Jan Stelter
16:15 – 16:30	**7. Closing remarks**	CCDA, New Ireland Provincial Administration and GGGI

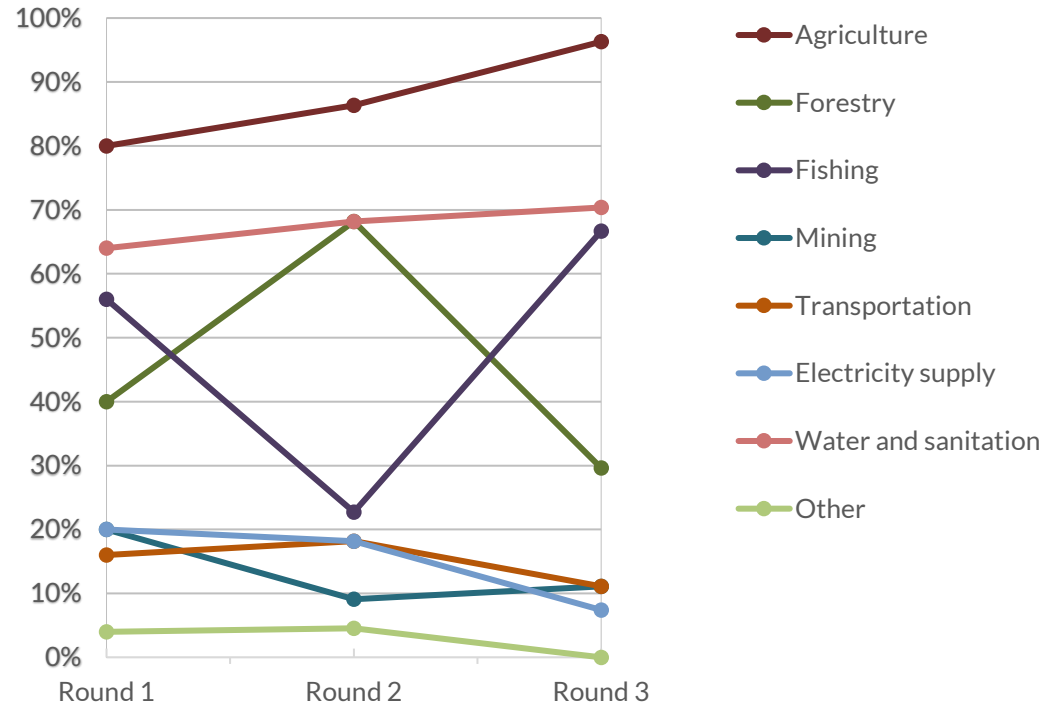
APPENDIX C. CHANGES IN SURVEY RESULTS

Figure 34. Changes in survey results for exposure



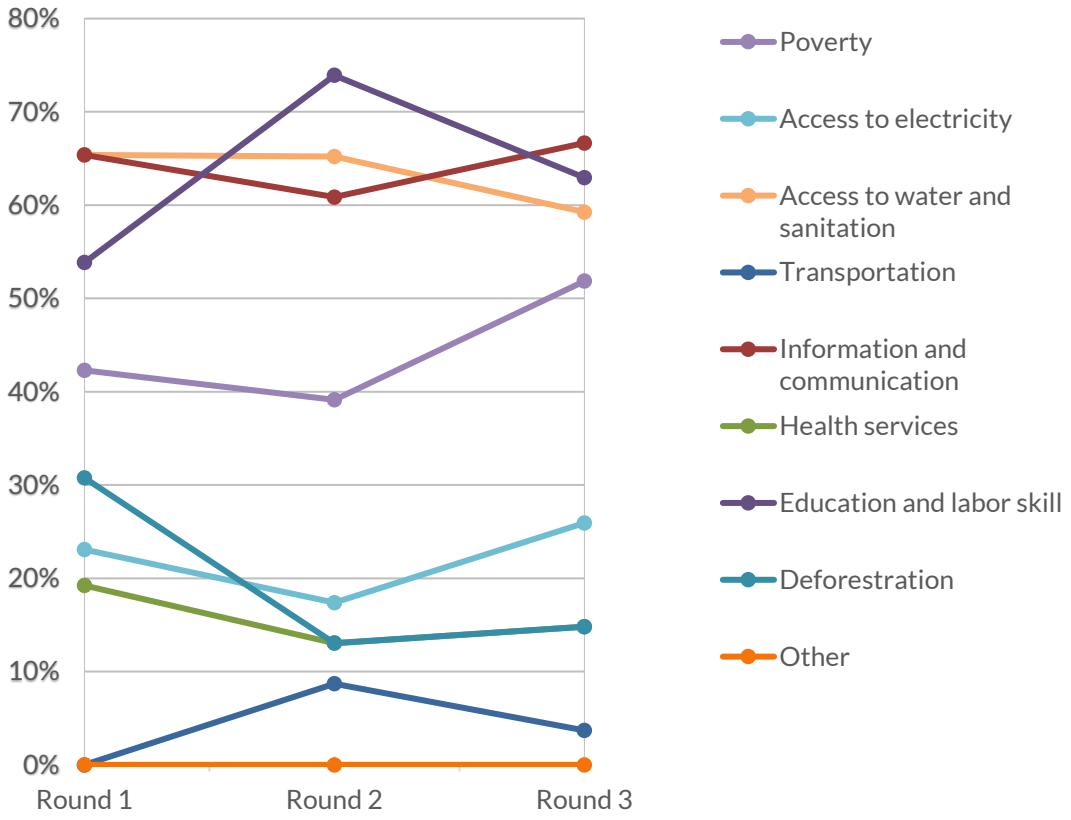
Source: GGGI

Figure 35. Changes in survey results for sensitivity



Source: GGGI

Figure 36. Changes in survey results for adaptive capacity



Source: GGGI

APPENDIX D. BREAKOUT GROUP TASKS

Task 1: Priorities for resilience (45 minutes)

Please discuss whether you agree with the priorities selected in the plenary. If you disagree, please indicate the priorities for your group. Please indicate the connection between the priorities across the three categories of exposure, sensitivity, and adaptive capacity.

Relationships between priorities for resilience			
Category	**Exposure**	**Sensitivity**	**Adaptive capacity**
Relationship 1			
Relationship 2			
Relationship 3			

Task 2: Strengthen resilience (45 minutes)

Please select the relationships you have identified in task 1. For each relationship, please identify measures to strengthen resilience. You can choose from the measures listed below or suggest different measures. The list of measures is also shown on a slide in the plenary.

Measure to strengthen resilience			
Relationships agreed in task 4			
Measure 1			
Measure 2			
Measure 3			

14 measures

1. Coastal protection
2. Forest conservation
3. Drainage and wastewater infrastructure
4. Climate resilient agriculture
5. Agroforestry
6. Intercropping
7. Irrigation
8. Off-grid electrification
9. Early warning
10. Transport infrastructure
11. Standards and regulation
12. Access to finance for private sector
13. Data collection and monitoring
14. Other

APPENDIX E. RESULTS OF GROUP DISCUSSIONS

Group 1

Group 1 agreed with the priorities identified in the plenary session but added access to electricity as a relevant aspect to strengthen adaptive capacity. Group 1 identified a total of three relationships between the priorities.

Relationship between priorities	Rationale behind choice	Related interventions
Rise in temperature – agriculture – poverty	Rise in temperature regarded as certainly affecting crop productivity and subsequently poverty Important role of agriculture sector in New Ireland Province for income and subsistence	Forest conservation as a means to retain soil fertility and reduce soil erosion Introduction of climate-resilient agriculture, such as crops that are more tolerant to droughts and hydroponics Agroforestry, intercropping and mixing livestock with crops to maximize the use of the limited land Improvement of financial services and trainings to enhance financial literacy Economic diversification
Rise in sea level – fishing – access to electricity	Fishing sector under stress, with increase in effort needed to catch bigger size fish Limited storage and refrigeration for catch	Planting of mangroves as nursery grounds for fish (and protection of coast lines) Electrification to enable communication (charge phones), access to information (news, early warning, weather forecast), and support refrigeration and storage
Change in rainfall – water and sanitation – access to water and sanitation	Prolonged rainy periods lead to inland flooding and sea surge, affecting fresh water sources	Need for improved access to water, either through decentralized solutions (local storage) or extension of Water PNG services Data collection to improve planning and budgeting and to access more funding to address WASH Access to finance for private sector to extend water supply in partnership with the government

Group 2

Group 2 agreed with the priorities identified in the plenary session and identified a total of three relationships between those priorities.

Relationship between priorities	Rationale behind choice	Related interventions
Rise in temperature – fishing – information and communication	Relevance of fishing as source of protein and income	Aquaculture as an alternative to fishing Conservation and rehabilitation of mangroves as breeding grounds for the marine life Early warning and weather forecasting
Change in rainfall/ occurrence of drought – agriculture – poverty	Important role of agriculture sector in New Ireland Province for income and subsistence	Introduction of climate-resilient agriculture, such as crops that are more tolerant to droughts and hydroponics Irrigation to respond to potential droughts, with solar water pumps regarded as a relevant technology Agroforestry, intercropping and mixing livestock with crops Improvement of financial services and trainings to enhance financial literacy
Rise in sea level – water and sanitation – access to water	Lack of clean drinking water and proper sanitation as a threat to children's health	Rainwater harvesting and storage Coastal protection to prevent salinization of groundwater Water storage Drainage and decentralized wastewater treatment to avoid contamination of water sources from runoffs Assess possibility of insurance schemes

Group 3

Group 3 agreed with the priorities identified in the plenary session but added access to electricity, economic diversification, and relocation of affected populations as a relevant aspect to strengthen adaptive capacity. Group 3 identified a total of three relationships between the priorities.

Relationship between priorities	Rationale behind choice	Related interventions
Rise in temperature – agriculture – poverty, access to electricity	Important role of agriculture sector in New Ireland Province for income and subsistence	Intercropping of cocoa and coconut with food crops Integrating food crops with forestry Reforestation and forest conservation for soil retention Introduction of drought-resilient crops Access to finance as an enabler
Rise in temperature/ change in rainfall/ rise in sea level – fishing – poverty/access to electricity	Relevance of fishing as source of protein and income Limited storage and refrigeration for catch	Conservation and rehabilitation of mangroves as nursery grounds for the marine life Rehabilitation of jetties with proper anchorage Access to electricity for storage and refrigeration, with solar energy being regarded as the most appropriate due to cost advantage and abundance of sunlight Economic diversification needed, such as tourism
Change in rainfall/ rise in sea level – water supply and sanitation – access to electricity/ access to water	Contamination of fresh water sources due to inland flooding and sea surges	Drainage and wastewater treatment to avoid contamination of water sources from runoffs Relocation of population on atolls as a response to salinization

ABOUT THE GLOBAL GREEN GROWTH INSTITUTE (GGGI)

Based in Seoul, Republic of Korea, the Global Green Growth Institute (GGGI) is a treaty-based international, inter-governmental organization that supports developing country governments transition to a model of economic growth that is environmentally sustainable and socially inclusive. GGGI delivers programs for more than 30 Members and partners – in Africa, Asia, the Caribbean, Europe, Latin America, the Middle East and the Pacific – with technical support, capacity building, policy planning and implementation, and by helping to build a pipeline of bankable green investment projects.

GGGI supports its Members and partners to deliver on the Sustainable Development Goals and the Nationally Determined Contributions to the Paris Agreement.

Members

Angola, Australia, Burkina Faso, Cambodia, Costa Rica, Denmark, Ecuador, Ethiopia, Fiji, Guyana, Hungary, Indonesia, Jordan, Kiribati, Republic of Korea, Lao PDR, Mexico, Mongolia, Norway, Organisation of Eastern Caribbean States (OECS), Papua New Guinea, Paraguay, Peru, Philippines, Qatar, Rwanda, Senegal, Sri Lanka, Thailand, Tonga, United Arab Emirates, United Kingdom, Uganda, Uzbekistan, Vanuatu, Viet Nam

Operations

Burkina Faso, Cambodia, Organisation of Eastern Caribbean States (OECS), Colombia, Costa Rica, Ethiopia, Fiji, Guyana, Hungary, India, Indonesia, Jordan, Kiribati, Lao PDR, Mexico, Mongolia, Morocco, Myanmar, Nepal, Papua New Guinea, Peru, Philippines, Qatar, Rwanda, Senegal, Tonga, Uganda, United Arab Emirates, Vanuatu, Viet Nam

Follow our activities on
Facebook and Twitter

www.gggi.org