Feasibility Study On Climate Change, Food, and Nutrition Security, Conservation and Land-Use in Enga Province of Papua New Guinea

Final Assessment Part 1

Improved Climate Change Mitigation and Adaptation

United Nations Development Programme (UNDP)

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LIST OF ABBREVIATIONS AND ACRONYMS

ACT	Artemisinin Based Therapy
AOI	Area of Interest
BAU	Business as usual
CA	Conservation area
CCDA	Climate Change and Development Authority
CCDS	Climate Compatible Development Strategy
CDD	Consecutive dry days
CEPA	Conservation and Environment Protection Agency
CWD	Consecutive wet days (CWD)
DAL	Department of Agriculture and Livestock
DEM	Digital Elevation Model
ENSO	"El Niño" Southern Oscillation system
EROS	Earth Resources Observation and Science
FD	Frosting days
GCM	Global Climate Models
GDP	Gross domestic product
GIS	Geographical Information System
GoPNG	Government of Papua New Guinea
INDC	Intended Nationally Determined Contribution
IPPC5	Intergovernmental Panel on Climate Change Fifth Assessment
IPPC6	Intergovernmental Panel on Climate Change Sixth Assessment
IRS	Indoor Residual Spraying
KPI	Key Performance Indicator
LLIN	Insecticide-treated bed net distribution
LULUCF	Land use, Land-use Change and Forestry
NASA	National Aeronautics and Space Administration
NDC	National Disaster Centre

NRI	National Research Institute
PA	Protected area
PA	Provincial Authority
PDRC	Provincial Disaster Risk Committee
PNG	Papua New Guinea
PNGFA	Papua New Guinea Forest Authority
PPP	Purchasing Power Parity
PRCPTOT	Total annual precipitation
PV	Solar photovoltaic cells
RCP	Representative Concentration Pathways
REDD	Reduction of emissions for deforestation and forest degradation
REDD+	Reduction of emissions from deforestation and forest degradation, the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
RF	Random Forest
RIL	Reduced-impact logging
RX1DAY	Daily maximum rainfall
SFA	Strategic Focus Areas
SFM	Sustainable Forest Management
SPCZ	South Pacific Convergence Zone
SSP	Socio-economic Shared Pathways
TMAX	Maximum temperature
TMIN	Minimum temperature
TOR	Terms of Reference
TXM	Annual maximum daily temperature
TXN	Annual minimum daily temperature
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
WB	World Bank

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WGF Women's Focus Group Discussion

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EXECUTIVE SUMMARY

The report consisted of (i) an introduction to improved climate change mitigation and adaptation, (ii) a review of climate change mitigation and adaptation, (iii) an analysis of climate change, (iv) an analysis of institutional and governance and (v) review of current development plans.

In Papua New Guinea, the main phenomena related to climate change are a rise in temperature, an increase in rainfall, the decline in frequency but increase in the intensity of droughts, a rise in sea levels, an increase in ocean acidification and a decline in frequency but increase in the intensity of cyclones. Some of the impacts that these phenomena bring can be a decrease in yield and quality of crops, an increase in vector-borne and respiratory diseases, an increase in flooding, damage to infrastructure, reduced access to drinking water and reduced food security.

In Enga province, potential mitigation options in the forest sector include the conservation and protection of forests, implementing sustainable forest management (SFM), and reducing impact logging (RIL). Moreover, it can include implementing Reduced Deforestation and Forest Degradation (REDD) schemes, sustainable and participatory land-use planning, and increasing forest areas through reforestation and afforestation activities. Potential mitigation options in the energy sector include using renewable technologies such as rooftop solar panels and reducing the consumption of firewood.

Adaptation measures in Enga province should be implemented in different key sectors such as agriculture and livestock and transportation and infrastructure. These measures include the rehabilitation or upgrade of gravel roads, culverts and drainage, construction of flood defences and landslide interventions. Agriculture-related measures include soil moisture preservation, selecting drought-tolerant sweet potato varieties, banana and cassava, implementing better farming practices, adopting water-conserving technologies and water harvesting initiatives, and funding the Enga Provincial Disaster Committee.

Minimum and maximum monthly temperatures in Enga province will increase on average by 1.8 °C, whereas total rainfall will slightly increase based on an intermediate emission scenario (SSP370) by 2050. On a higher emission scenario (SSP585), minimum and maximum monthly temperatures in the Enga province will increase on average by 2 °C, and total rainfall will increase but differentiated patterns will occur in different districts. Wabag and Wapenamanda districts will experience a few consecutive dry days, more annual and intense daily rainfall, fewer frost events and warmer temperatures. Kandep, Kompian-Ambum, and Lagaip-Porgera districts will experience more dry consecutive days, more annual and intense daily rainfall, fewer frost events and warmer temperatures.

Based on household surveys done by the consultant, the most common natural disasters reported in Enga Province are floods, landslides, droughts and frost events. Participants from Wabag, Wapenamanda and Kompian have experienced more flood and landslide events, whereas frosts were commonly reported in Kandep and Lagaip-Porgera. Most of the participants from all districts stated that these natural disasters have become more frequent in the last decade. The general perception regarding changes in climate patterns is increased rainfall and rising temperatures.

In Enga province, most people practice traditional farming, and they cope with the effects of climate change in a reactive manner. Based on the focus group discussions in all districts, when asked about climate change mitigation or adaptation actions, villagers did not mention any specific measures, probably due to the level of awareness. Nevertheless, most participants practice mixed-cropping and have multiple gardens, which serve as a backup when disasters occur. Food storage and borrowing supplies from family members are other ways villagers deal with sudden disasters (e.g. frosts). Constructing small drainage systems during heavy rainfall events is another standard reactive measure of farmers. Migration to lower areas is another way to deal with disasters, especially frosts. The patterns of migration and displacement in PNG have been primarily internal and caused by environmental change (such as natural hazards), conflict and development (IOM 2015), and the figures show that two-thirds of internally displaced persons (IDP) have been displaced by natural hazards (NRC & IDMC 2014)

The main struggles reported in the focus group discussions are: (i) lack of proper markets, (ii) low crop and coffee prices, (iii) lack of incentives and government farming extension, (iv) high fertilizer and pesticide prices, (v) increase in pests and insects affecting crops, (vi) lack of training on sustainable farming, book-keeping and financial literacy, fertilizers and pest control. The low level of pest and disease management in the villages affects food security and constrains the development of cash crops (Gurr et al. 2016)

The main struggles that the provincial authority faces regarding climate change adaptation and mitigation are lack of funding, lack of manpower and lack of capacity building and training on climate change and biodiversity issues. Provincial-level authorities could provide technical assistance to resource owners and increase extension services to remote villages by having more resources.

1 INTRODUCTION

1.1 Background

In November 2020, UNDP Country Office and European Union signed a Contribution Agreement to implement the project "Strengthening Integrated Sustainable Landscape Management in Enga Province Papua New Guinea" for 2021- 2025. The project will support the country in its continuing efforts to address climate change. It will assist in strengthening the sustainable and inclusive economic development of the Enga Province of Papua New Guinea (PNG) by three components/objectives:

i) improving climate change mitigation and adaptation.
ii) strengthening food and nutrition security and
iii) improving biodiversity and land/forest conservation.

The Project will achieve the objectives by delivering an innovative approach to rural development that brings together government systems, the private sector, and community groups to establish climate-compatible green growth models.

The current assignment is intended to closely work with the Climate Change and Development Authority (CCDA), a lead government agency and project partner and Enga Provincial Government to undertake feasibility studies within the above three project components and set a baseline for implementing the project activities on the ground.

Under the overall supervision of the UNDP International Technical Advisor and the technical guidance of the CCDA and in close coordination with Enga Provincial Administration, the Consultant will be responsible for conducting feasibility studies of the above mentioned three components.

1.2 Enga Province Context

Enga occupies 11,800 km^2 of the PNG highlands (**Figure 1**), and there are 295,031 inhabitants. In the north of the province, the Central Range is part of the main divide of PNG. The Lagaip River drains into the Fly River and the Coral Sea, while the Lai River drains into the Sepik River and Bismarck Sea. The upper valleys of both rivers support very high population densities and intensive agriculture with continuous cultivation in some places. These areas are some of the most densely settled in the country. There are large swamp areas and intensive agriculture around Kandep in the province's south. The altitude varies from 400m at the Yuat River in the province's northeast to over 3,700 meters along the Central Range (**Figure 2**). More people in Enga live above 2,000 meters than in any other province. These environments are prone to frost and disruptions to the subsistence

food supply. The upper altitudinal limit of agriculture is around 2,800 meters. Average annual rainfall varies between 2,300 and 3,800mm, increasing from south to north.[1]

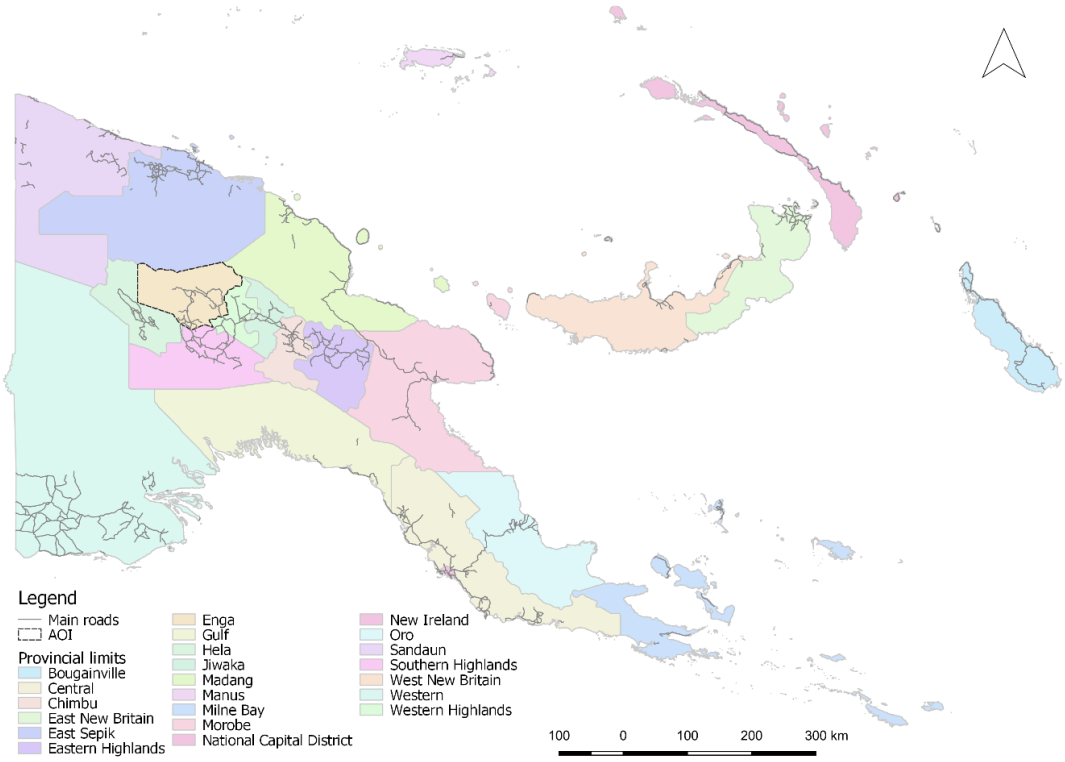


Figure 1. Provincial limits in Papua New Guinea

[1] Hanson L.W., Allen B.J., Bourke R.M. & McCarthy T.J. 2001. Papua New Guinea Rural Development Handbook. The Australian National University.

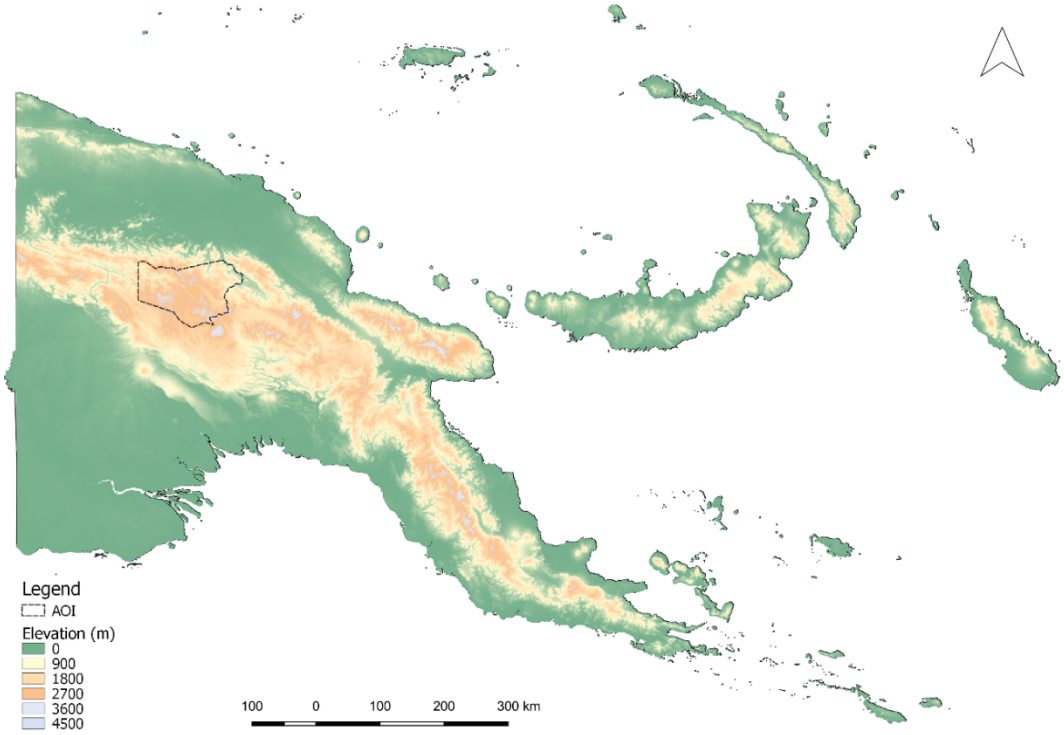


Figure 2. Elevation gradient in Papua New Guinea and Enga Province (dashed polygon)

The five districts in Enga are Kandep, Kompiam-Ambum, Lagaip-Porgera, Wabag and Wapenamanda. The main language spoken in Enga Province by all the Engans is the Enga Pii language. Population densities are highest in Wabag with 58,9 persons/km^2, while the Kompiam-Ambum District has the lowest density of only 15,0 persons/km^2. More than half of the area of the province is unoccupied mountains.

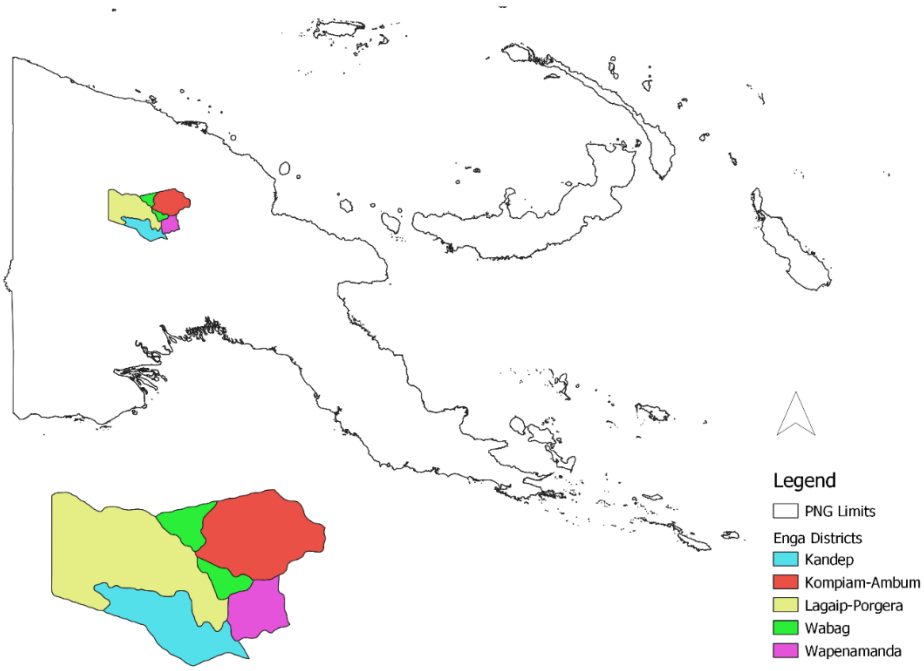


Figure 3. Districts in Enga Province

Despite having rich resources in Enga province, most people in Enga are still poor. People's incomes range between very low and moderate[2]. Agriculture provides only a low to the moderate source of income for the province, earned from the sale of coffee, food and firewood. Most of the coffee is grown around Wabag, Wapenamanda and Kompiam in areas below 2,100 meters, which is the upper altitudinal limit of Arabica coffee. People in the higher areas around Kandep and Laiagam sell small amounts of potatoes and firewood. People in the province's north are impoverished and have few cash-earning opportunities. Cultivated areas are prone to both drought and frost, which can seriously affect food security. The Porgera gold mine provides royalties and wage employment. This income is very high but only benefits people living close to the mine.[3]

[2] Very low income (0–20 kina/person/year), Low income (21–40 kina/person/year), Moderate income (41–100 kina/person/year) (Hanson et. al 2001).
[3] Hanson L.W.J., et al. 2001.

Figure 4. Mixed-crop farmer in Birip, Enga (Source: FinnOC, 2022)

A branch of the Highlands Highway runs from Mt. Hagen up to Wapenamanda and Wabag and the Porgera Goldmine. Another road connects Kandep with Southern Highlands Province. Those living in the province's north are very remote and require more than a day's travel to reach a service centre. Around 62.5 per cent of the province's population lives within 5km of a national road. The overall literacy rate for the Enga province is 35.0 per cent, with a male literacy rate of 40.2 per cent and a female literacy rate of 29.5 per cent.

Figure 5. Kandep district station in Enga, PNG (Source: FinnOC, 2022)

Regarding the universal fundamental education indicators, the net admission rate is 14.8 per cent, gross enrolment rate 64.3 per cent and net enrolment rate 51.3 per cent in the province. The life expectancy at birth in Enga is 52.5 years. The under-five mortality rate in the Enga Province is 97

per 1,000. Under one-year infant mortality rate is 69 per 1,000. Furthermore, the child mortality rate is 28 between ages 1-4 per 1,000.[4]

1.3 Objectives of the assignment

As per TOR, the Consultant will be responsible for conducting feasibility studies of the following three components:

Component 1: Improved climate change mitigation and adaptation. This component will focus principally on delivering improvements in the status of climate change mitigation and adaption by strengthening its integration into the development planning framework, supporting the development and early implementation of climate compatible provincial and district development plans, including the development of effective financing mechanisms to support climate mitigation, adaptation and disaster risk management activities.

Component 2: Strengthened food and nutrition security. This component will focus on strengthening food and nutritional security within Enga through engagement with both key commercial value chains and subsistence farmers to improve cultivation techniques and help integrate new crops and produce within production systems.

Component 3: Improved Biodiversity and land/forest ecosystems conservation, restoration and sustainable use. This component focuses on enhanced action on conservation, restoration and sustainable use of high-value areas within the landscape. These will be achieved through combining an enhanced mandate and capacity of environmental officers at the provincial level as part of CEPA's decentralization process. It will further include strengthening and coordination of local environment, climate change and forest management committees and their work with economic development committees, and targeted action at the community level to establish Community Conservation Areas and undertake reforestation, rehabilitation and woodlot development activities.

The following report tackles feasibility studies of component 1 (Improved climate change mitigation and adaptation). This component will focus principally on delivering improvements in the status of climate change mitigation and adaption by strengthening its integration into the development planning framework, supporting the development and early implementation of climate compatible provincial and district development plans, including the development of effective financing mechanisms to support climate mitigation, adaptation and disaster risk management activities.

[4] Ibid.

The report consists of the following structure:

1. Executive summary
2. Introduction
3. Methodology
4. Review of climate change mitigation and adaptation
5. Climate change analysis
6. Institutional and governance analysis
7. Review of current provincial development plans
8. Recommendations

2 METHODOLOGY

2.1 Data collection on the ground

This section presents specific methods utilized for the baseline data collection/feasibility studies in Enga. The chapter discusses the survey tools, the data collection process, and the sampling issues.

2.1.1 Survey tools

2.1.1.1 Farmers focus group survey

Farmers focus group survey aimed at revealing subsistence farmers' characteristics of crop production, cultivation/farming practices/agricultural techniques, issues related to, e.g. experimentation with unfamiliar crops, available agricultural extension services, perception of climate risk, farmer's vulnerability and adaptation measures and capacities regarding climate-induced threats (natural disasters), food security issues, access to finance and markets, the positive and negative impacts of the climate change perceived by the farmers, climate shocks and coping strategies, problems faced by farmers. A photographic annexe of the field survey is presented in **Annexe 3**.

Figure 6. Farmers focus group held in Birib village (Source: FinnOC, 2022)

2.1.1.2 Household survey

The household (HH) surveys described the livelihoods of the households. The topics covered by the HH survey included household characteristics (size and composition, education); livelihood, income generation and expenditure; household assets; access to services (health, schools), markets, and infrastructure (transport, power, water), including finance; transport, poverty and vulnerability (e.g. climate shocks and coping strategies, coping strategies of decreased food availability); nutritional

status and food security (amount of food obtained, methods of food acquisition, etc.); state of the environment, etc. Household surveys were conducted in each study village by interviewing both the male and female household members to gather also gender data. The percentage of households selected for the study villages was around 10-40 per cent. A photographic annexe of the field survey is presented in **Annexe 3**.

Figure 7. A household survey was conducted in Pandai village (Source: FinnOC, 2022)

2.1.1.3 Women's focus group discussion

The Guidelines for the Women's Focus Group Discussion (WFG) shed light on gender issues related to climate change and impacts/problems, women's vulnerability, and adaptive capacities to climate-induced threats. The aim of this survey tool was also to reveal and analyse capacity issues for women groups on climate-resilient approaches and agricultural techniques.

Data were also collected about women's engagement in agricultural sub-sectors, women's groups and networks, household division of labour, financial management, the kinds of household, agricultural, garden, coffee production and other income generation activities, etc. The data collected through this study tool also revealed the positive and negative impacts the climate change on women and children, including impacts on the environment. A photographic annexe of the field survey is presented in **Annexe 3**.

Figure 8. Women's focus group held in Pandai village (Source: FinnOC, 2022)

2.1.1.4 Focus group of coffee producers

The Consultant developed a survey questionnaire to interview coffee farmer's groups and coffee cooperatives (if available). The survey tool aimed to inform issues related to the coffee farming like characteristics of plantations, coffee farming methods and technologies, effects of climate change on coffee production, climate change-induced challenges to coffee farming, mitigation approaches to climate change impacts, market and logistics issues, quality control issues, climate investment opportunities, etc. A photographic annexe of the field survey is presented in **Annexe 3**.

Figure 9. Coffee farmers participating to focus group survey in Mambisanda village (Source: FinnOC, 2022)

2.1.1.5 Provincial authorities' *discussion guideline*

The Consultant developed a discussion guideline to obtain information regarding the authority/ /organisations interviewed in Enga, including the type of work they do and the role related to study

themes of climate change mitigation and adaption, food and nutrition security and biodiversity and land/forest conservation; policies and strategies of the organisation and their relation to study themes, projects/interventions related to study themes, gender issues (organisations' gender focal point, constraints in reaching women and their empowerment, etc.). A photographic annexe of the scoping mission is presented in **Annexe 2**.

Figure 10. Interview with Environment/Climate Change Officer, Enga Provincial Government in Wabag (Source: FinnOC, 2022)

2.1.2 Sampling strategy

One team of Research Assistants (three females and two males), with the support of the Team, conducted the surveys in the field. The group surveyed two villages in every district. The selection of study villages was made together with the Client, advised by the Environment/Climate Change Officer of Enga Provincial Government.

The researchers conducted one focus group of smallholder farmers, one focus group of coffee producers, and one women's focus group in each surveyed village. Household surveys were conducted in each study village.

The team conducted the surveys from February 13 to March 6, 2022. The field work plan and schedule are presented in **Annex 2**. The list of people met during data collection is presented in **Annex 4**. Before the data collection, a village meeting/awareness of the upcoming survey was held in each surveyed village to explain the purpose of the survey to the village/community leaders and villagers in order to ensure smooth data collection. A photographic annexe of the field survey is presented in **Annex 3**, and a summary of the household characteristics is presented in **Annex 5**.

Figure 11. Community meeting held at Yakaedes village (Source: FinnOC, 2022)

The number of household surveys collected during the data collection trip totalled 456 households. In total, ten women's focus groups, coffee farmers and farmers focus groups each and six coffee farmers' focus group interviews were conducted.

Table 1. Sample sizes for study tools in Enga (Source: FinnOC, 2022)

District	Village	HH Surveys	WFG	Farmers focus group	Coffee farmers focus group
Kandep	Luguteges	27	1	1	-
	Pindak	34	1	1	-
Kompiam	Pandai	38	1	1	1
	Par	64	1	1	1
Lagaip-Porgera	Naglum	36	1	1	-
	Tukusanda	43	1	1	-
Wabag	Birip	68	1	1	1

	Lukitap	43	1	1	1
Wapenamanda	Mambisanda	50	1	1	1
	Yaekadis	53	1	1	1
Grand Total		**456**	**10**	**10**	**6**

Coffee is not grown in the study villages of Luguteges, Pindak, Naglum and Tukusanda. Therefore, the coffee farmers' surveys were not conducted in these villages

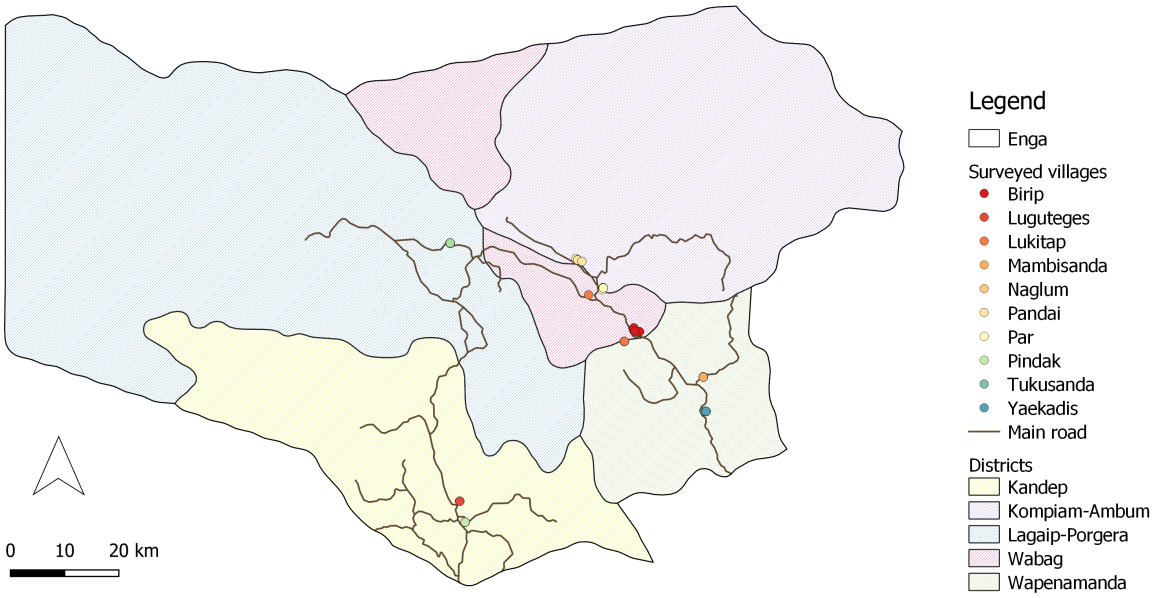


Figure 12. Location of the study villages in Enga Province (Source: FinnOC, 2022)

2.2 Spatial scoping in Enga province

The Consultant carried out a background literature review for the project. The team reviewed in detail all the available existing documentation generated by the client or by third parties, including background and preliminary studies carried out in Enga province. The documentation includes provincial development plans, national legislation, previous feasibility studies, analysis of alternatives, social studies and any other related studies.

One of the products of major importance to be generated during this stage is the identification of information gaps (Gap Analysis), which will be directed to the search and identification of key aspects that are necessary for the development of the study. The present scope assumes that all necessary information that serves as input for the development of deliverables, other than the one that will be compiled in the field, and the one that is explicitly requested to be generated, will be delivered in a timely manner by the client.

The Consultant carried out spatial analysis using available spatial information, which includes the identification of relevant environmental variables in Enga Province.

Table 2 summarizes some of the environmental variables used, which will serve as input for the spatial analyses and scoping. Some environmental layers are available at broad scales (e.g. regional scale), whereas others are finer scales (e.g. landscape scale).

Figure 13 shows examples of some physical, biological and social variables in the study area.

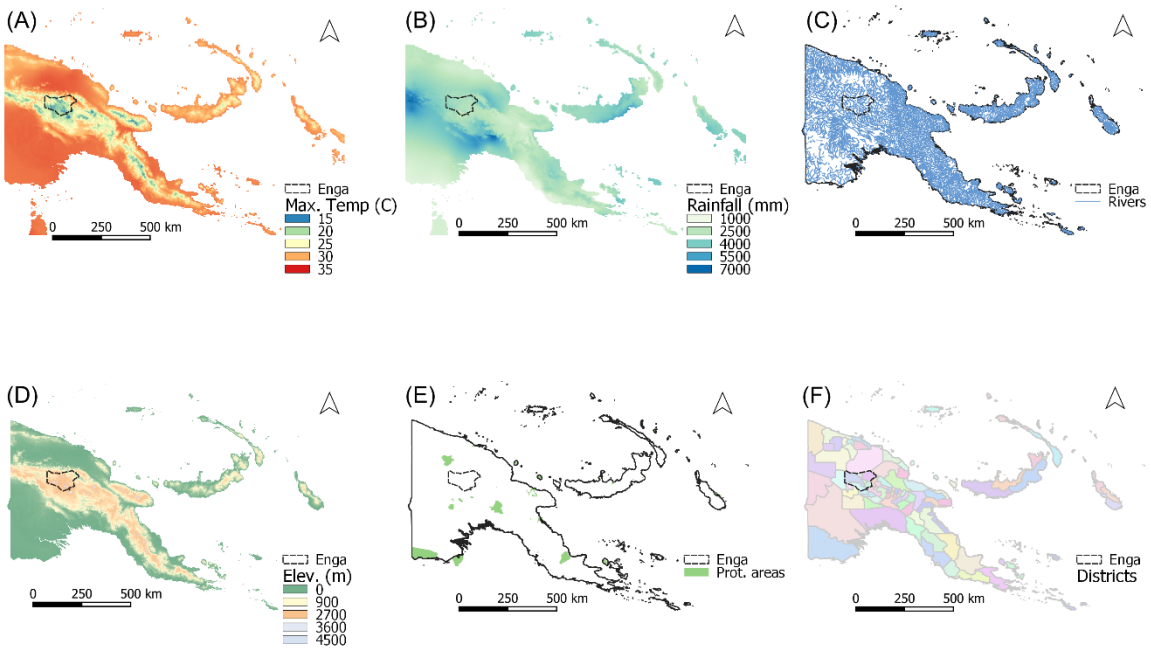


Figure 13. Examples of environmental conditions in Enga Province. (A) maximum temperature (°C), (B) annual rainfall (mm), (C) water bodies and river network, (D) elevation data from SRTM (Earth Resources Observation And Science (EROS) Center 2017), (E) protected areas, and (F) Administrative divisions, Climate data was downloaded from CHELSA-climate (Karger et al. 2017), elevation data from SRTM (Earth Resources Observation And Science (EROS) Center 2017), water data from DCW (Digital Chart of the World, administrative divisions from GDAM.

Figure 14. FinnOC's local team with the UNDP Team in Wabag Town, Enga and the location of the Provincial Government Building Ipatas (Source: FinnOC, 2022

Table 2. Geographical scale and type of environmental variables proposed for the environmental scoping and GIS analysis.

Scale	Group	Variable	Type
Regional-scale	Physical	Soils	Continuous
		Elevation	Continuous
		Monthly rainfall	Continuous
		Monthly temperature	Continuous
	Biological	Vegetation cover	Continuous
		Forest cover	Continuous
		Conservation areas	Categorical
	Social	Annual deforestation	Continuous
		Population density	Continuous
		Administrative areas	Categorical
Landscape-scale	Physical	Digital elevation model	Continuous
		Slope and hill-shade	Continuous
		Soil chemical properties	Continuous
		Soil physical properties	Continuous

		Land cover classes	Categorical
	Biological	Tree cover	Continuous

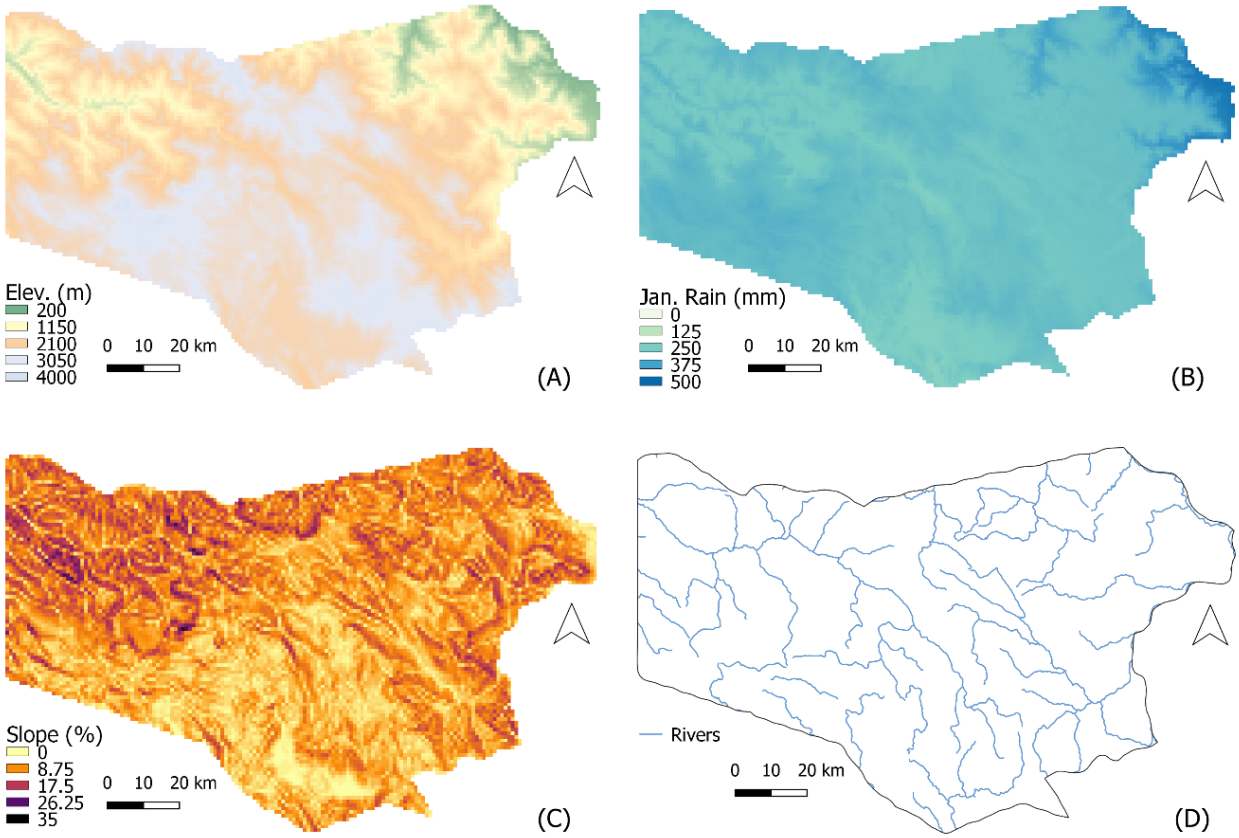


Figure 15. Examples of available environmental layers downloaded and prepared for Enga Province include (A) a digital elevation model (DEM), (B) rainfall (mm) in January, (C) a slope map derived from the DEM, and (D) water and river network.

2.3 Climate change modelling framework

Climate change scenarios were retrieved and analysed at different spatial and temporal resolutions. Daily climate data (rainfall, maximum and minimum temperature) were retrieved from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset (Sheffield et al. 2006; Thrasher et al. 2012), which are available at a spatial resolution of 25 km. Monthly climate data (rainfall, maximum and minimum temperature) were retrieved from the WorldClim dataset (Hijmans et al. 2005; Fick & Hijmans 2017), which are available at a different spatial resolutions up to 1 km. For both datasets, current and future climate conditions were retrieved and analysed.

Table 3. Available climate information for climate change assessment

Dataset	Conditions	Res.		Period	Description
		Spatial	Temporal		
WorldClim	Current	1 km	Monthly	1970-2000	Max. temperature (ºC)
					Min. temperature (ºC)
					Rainfall (mm)
	Future	1 km	Monthly	2050 & 2070	Max. temperature (ºC)
					Min. temperature (ºC)
					Rainfall (mm)
NEX-GDDP	Current	25 km	Daily	1950-2006	Max. temperature (ºC)
					Min. temperature (ºC)
					Rainfall (mm)
	Future	25 km	Daily	Until 2099	Max. temperature (ºC)
					Min. temperature (ºC)
					Rainfall (mm)

Future conditions will include the Intergovernmental Panel on Climate Change Fifth and Sixth Assessment (IPPC5 and IPPC6) climate projections from global climate models (GCMs) for different

shared socio-economic pathways (SSPs) and representative concentration pathways (RCPs). Different climate scenarios were used according to data availability of IPPC5 and IPPC **Table 4** summarizes different available global climate models (GCM), shared socio-economic pathways (SSP) and the climatic data availability, such as monthly average minimum temperature (tn), monthly average maximum temperate (tx) and monthly total precipitation (pr), whereas

Table 5, the GCMs based on the representative concentration pathways (RCPs) for the same climate parameters **Table 4.** Availability of climate projections using different global climate models (GLM) and shared socio-economic pathways (SSP)

Global Climate Models (GCM)	SSP126	SSP245	SSP370	SSP585
BCC-CSM2-MR	tn, tx, prc	tn, tx, pr	tn, tx, pr	tn, tx, pr
CNRM-CM6-1	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
CNRM-ESM2-1	tn, tx, pr,	tn, tx, pr	tn, tx, pr	tn, tx, pr
CanESM5	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
GFDL-ESM4	tn, tx, pr	--, --, --, --	tn, tx, pr	-, -, pr, -
IPSL-CM6A-LR	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MIROC-ES2L	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MIROC6	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MRI-ESM2-0	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr

Table 5. Availability of climate projections using different global climate models (GCM) and representative concentration pathways (RCP).

Global Climate Models (GCM)	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
ACCESS1-0	--	tn, tx, pr	--	tn, tx, pr
BCC-CSM1-1	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
CCSM4	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
CESM1-CAM5-1-FV2	--	tn, tx, pr	--	--
CNRM-CM5	tn, tx, pr	tn, tx, pr	--	tn, tx, pr
GFDL-CM3	tn, tx, pr	tn, tx, pr	--	tn, tx, pr
GFDL-ESM2G	tn, tx, pr	tn, tx, pr	tn, tx, pr	--
GISS-E2-R	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
HadGEM2-AO	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
HadGEM2-CC	--	tn, tx, pr	--	tn, tx, pr
HadGEM2-ES	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
INMCM4	--	tn, tx, pr	--	tn, tx, pr
IPSL-CM5A-LR	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MIROC-ESM-CHEM	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MIROC-ESM	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MIROC5	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MPI-ESM-LR	tn, tx, pr	tn, tx, pr	--	tn, tx, pr
MRI-CGCM3	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
NorESM1-M	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr

Shared socio-economic pathways (SSP) and representative Concentration Pathways (RCPs) are four different greenhouse gas trajectories adopted by IPPC6 and IPPC5, respectively. RCPs describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, refer to a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively) as shown in **Figure 16**. RCP 4.5 is considered a medium-emission scenario, whereas RCP 8.5 is a high-emission scenario.

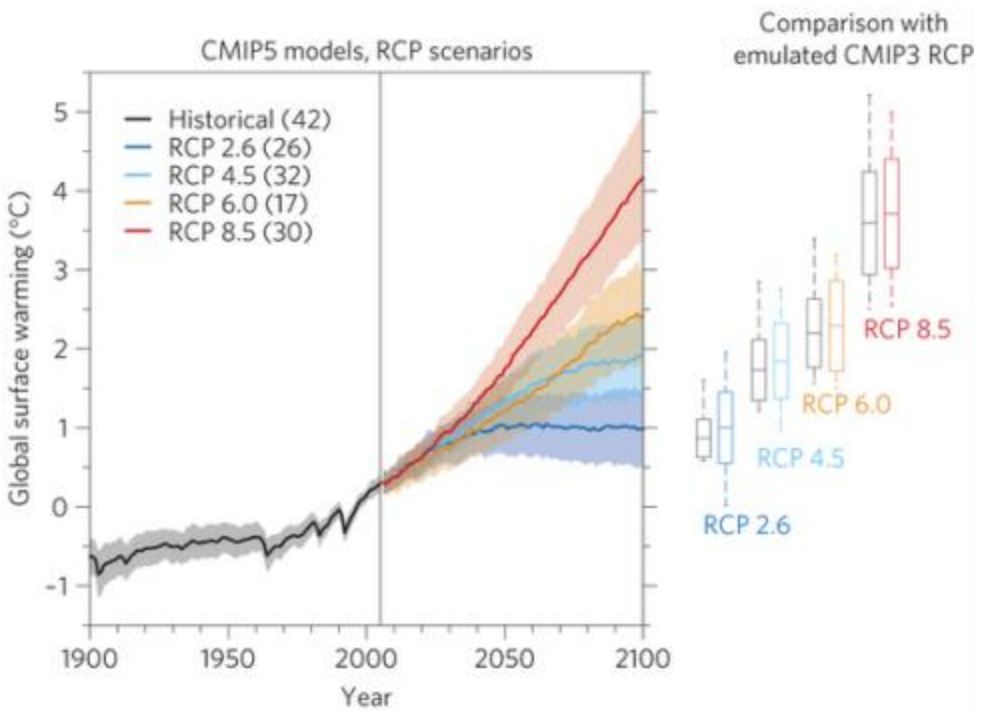


Figure 16. Global temperature change relative to 1986-2005 for the scenarios run by CMIP3 and the RCP scenarios run by CMIP5 (Knutti & Sedláček 2013).

Two of the four available scenarios were used to assess climate change in Enga Province: RCP4.5 / SSP370 (intermediate emission scenario) and RCP8.5 / SSP585 (high emission scenario). Climate model selection might lead to different climate predictions in a certain area; hence it is recommended to select a minimum of 5 rather distant models to represent a decent amount of uncertainty in climate model projections (Sanderson et al., 2015). Here we used all the available Global Climate Models described in **Table 4** and

Table 5 and derived a median ensemble model to tackle uncertainty in the future climate projections.

The data from the downscaled Global Climate Models (GCMs) of the NASA NEX-GDDP dataset was also used to derive different climate extremes indices for each District of Enga Province (Wabag, Wapenamanda, Kompiam-Ambum, Lagaip-Porgera and Kandep). Climate indices were based on the ClimPACT2-Tool, developed by the University of New South Wales, but were performed directly in R (R Core Team 2020). Daily rainfall and minimum and maximum temperature were downloaded and extracted for the centroid of each district, including 21 different GCMs under both the RCP 4.5 and RCP 8.5 scenarios. After deriving a median ensemble model, the following indices were calculated: Consecutive dry days (CDD), Consecutive wet days (CWD), Total annual precipitation (PRCPTOT), Daily maximum rainfall (RX1DAY), Frosting days (FD), Annual maximum daily temperature (TXM) and Annual minimum daily temperature (TXN).

Table 6. Climate parameters analysed.

Analysis	Dataset	Conditions	Resolution	Scope	Parameters
Monthly climate change assessment	WorldClim (IPPC6)	Current (1970-2000) & Future (2050)	5 km, monthly	Enga Province	- Monthly rainfall - Monthly minimum temperature - Monthly maximum temperature - Variation between future and current conditions
Daily climate change assessment	NEX-GDDP (IPPC5)	Current (1950-2006) & Future (2035-2064)	25 km, daily	Enga Province	- Daily rainfall - Daily minimum temperature - Daily maximum temperature - Variation between future and current conditions
Climate change extreme indices	NEX-GDDP (IPPC5)	Current (1950-2006) & Future (2035-2064)	25 km, daily	Centroid of each district in Enga (Wabag, Wapenamanda, Kompiam-Ambum, Lagaip-Porgera and Kandep)	- Consecutive dry days - Consecutive wet days - Frosting days - Total annual precipitation - Daily maximum rainfall - Annual maximum daily temperature - Annual minimum daily temperature - Variation between future and current conditions

3 REVIEW OF CLIMATE CHANGE MITIGATION AND ADAPTATION IN PAPUA NEW GUINEA AND ENGA

3.1 Review of mitigation and adaptation measures in Papua New Guinea

3.1.1 Hazards and risks in Papua New Guinea

Three sectors in Papua New Guinea (PNG) make up the bulk of the economy, with agriculture comprising 18.4% of Gross Value Added (GVA), industry at 36.8%, and services contributing the largest share to GDP at 44.9% (UN 2021). Of these sectors, only agriculture represents almost 60% of the employment. In rural areas, agriculture, fishing, and community forestry are primary livelihood activities (World Bank 2021). The formal economy (15% of employment) in PNG is mainly dominated by large-scale extractive industries (mining and oil), whereas the informal economy (85% of the workforce) is dominated by semi-subsistence agriculture (Government of Papua New Guinea 2014b). Approximately 80% of the population of PNG lives in rural and remote coastal communities, making them highly vulnerable to the impacts of climate change (CFE-DM 2019)

PNG is prone to myriad natural hazards, and climate variability and change may increase their incidence. Some of these include landslides, soil erosion, deforestation, loss of biodiversity, as well an increased occurrence of recurrent floods and droughts (World Bank 2021). Climate change impacts already affect the main economic sectors in PNG, including agricultural production, infrastructure, water resources, public health, energy and availability of ecosystem goods and services (World Bank 2021). Adaptation strategies, therefore, have focused on agriculture and water resources management (Government of Papua New Guinea 2014b).

PNG has a monsoonal climate characterized by high temperatures and humidity throughout the year. Mean temperatures range between 20°C and 30°C (higher in the coastal areas and lower in the Highlands), and average rainfall range between 1500 and 4000 mm. Two monsoon seasons are recognized: one occurring from December to March and the other from May to October (World Bank 2021). Several factors shape climate conditions in PNG, including the South Pacific Convergence Zone (SPCZ, a high pressure and rainfall zone) as well as the "El Niño" Southern Oscillation (ENSO) system which delays the start of the monsoon season and brings drought and frost conditions.

Floods in Papua New Guinea represent more than 22% of the frequency of internationally reported hazard losses (**Figure 17**), followed by volcano eruptions and landslides (CRED EM-DAT 2015; UNDRR 2015; UNDRR 2019). Floods are the main natural hazard that PNG experiences regularly. For instance, in 2020, around 61 000 people were affected by floods throughout PNG (World Bank 2022). Heavy rainfall and sea-level rise are contributing factors to floods within the country. Floods affect thousands of people and have devastating impacts on agriculture, food security, health, groundwater supplies and hydro-power generation. Similarly, droughts have devastating impacts on agricultural activities, food security and hydro-power generation. For instance, in 2015, more than 2.5 million people were affected by drought events in PNG (World Bank 2022)

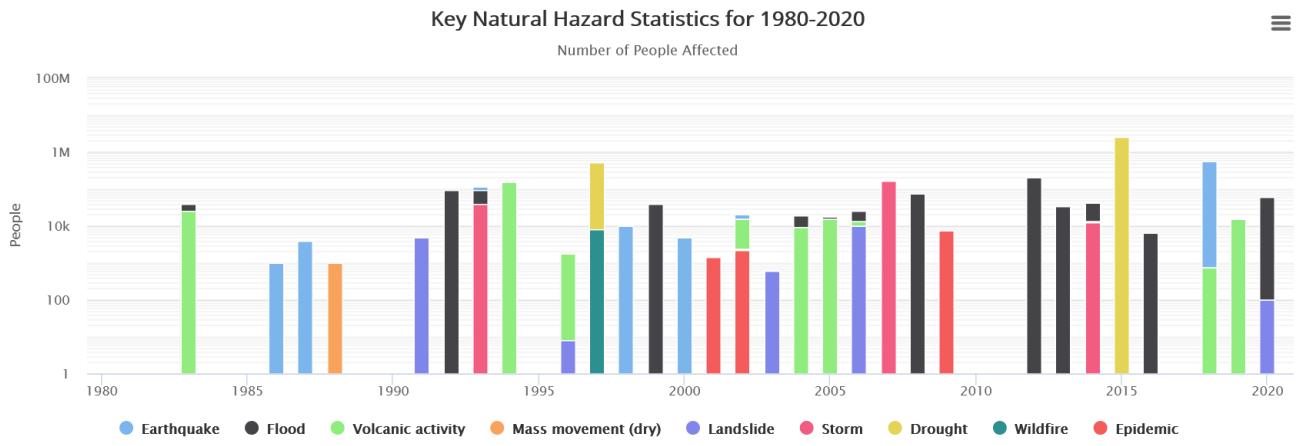


Figure 17. Number of affected people for key natural hazards statistics in PNG for 1980-2020 (World Bank 2022)

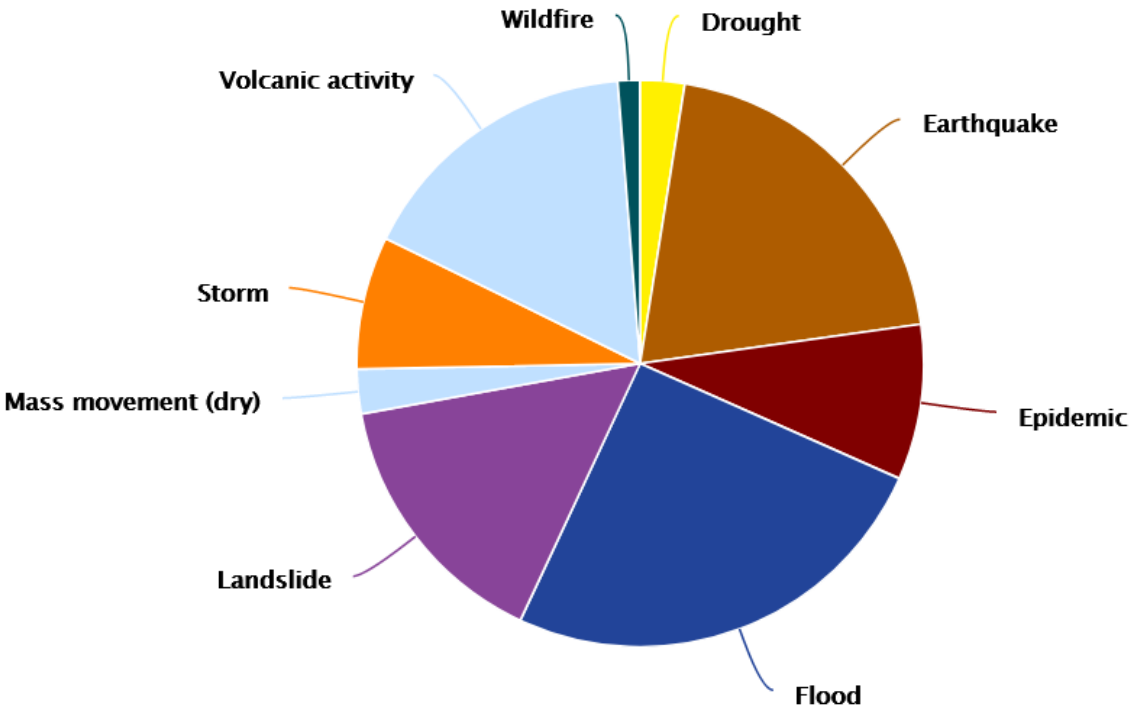


Figure 18. Average annual natural hazard occurrence for 1980-2020 in PNG (World Bank 2022)

Due to its physical and geographical characteristics, many parts of PNG are highly vulnerable to climate change and sea-level rise. Most socio-economic activities and infrastructure development are in coastal areas or vulnerable areas along rivers or in highlands (such as Enga Province). The (potential) impacts in Enga Province can be summarized as follows:

- Increased inland flooding in valleys and wetlands
- Erratic precipitation with increased risks of landslides

- Malaria could become endemic in higher mountain areas which are, up until now malaria-free
- Important climate-sensitive crops (sweet potato, coffee, cocoa) will suffer from changes in climate (temperature and rainfall)

Table 7. Impacts of climate change in PNG (Government of Papua New Guinea 2014b)

Impact	Description
Coastal flooding and sea-level rise	In the last years, flooding has affected around 8000 people per year, 500 displacements, and damages costing USD 10-20M
Malaria	About 60% of the population lives in high-risk malaria regions. In the last 20 years, climatic changes have worsened the effects of malaria due to rising temperatures. Additional rises in temperature will introduce malaria to previously risk-free regions and could worsen the impact of malaria on those living in low-risk zones.
Inland flooding	The effects of flooding are amplified by steep slopes and deforestation. Based on 19 years of data, 22,000-26,000 people are affected annually by inland floods, displacing 6,000-8,000 and typically resulting in a few deaths each year. Public records estimate annual damage at USD 8-12M. Changes in climatic conditions – both through increased average precipitation and increased extreme rainfall events – will strongly affect the impact of inland floods.
Sea temperature rise and acidification	Between 50,000 and 70,000 coastal inhabitants rely on coral reefs for their food, livelihoods and shelter. Not only do the reefs contribute to economic growth through fisheries and tourism, but they also protect the coastlines from storms and loss of land.
Landslides	In recent decades, landslides have caused considerable damage to road infrastructure and remote communities. The effect of landslides is not well understood, given the unpredictability and remote impact. At the same time, landslides have caused significant damage along the Highlands Highway, the sole lifeline for the highland communities and export businesses. Changes in precipitation patterns and land use are likely to increase the number of landslides.

Variability in agricultural yields	The highland regions are particularly sensitive to variability in agricultural yields as a result of a change in climatic conditions. Sweet potato, coffee and cocoa are examples of climate-sensitive crops that Papua New Guineans are dependent on for food and livelihood. Subsistence farmers will be the most affected by changes in climatic conditions and may need to look for alternative crops.

In the Climate Compatible Development Strategy (CCDS) (Government of Papua New Guinea 2014a), it is recognized that climate change mitigation and adaptation must be coupled with economic development to ensure (i) promotion of economic development through low-carbon growth, (ii) mitigation through participation in the global REDD+ scheme, and (iii) adaptation to climate change-related hazards. In the PNG Medium Term Development Strategy (Department of National Planning and Monitoring 2018), different key result areas (KRAs) were identified. The key result area 7, "Responsible Sustainable Development", tackles climate change adaptation and reduction of natural disasters risk. Consequently, key investments for KR7 include building resilience to climate change, disaster mitigation program and disaster response preparedness.

Some priority abatement options include: (i) reduced impact logging (RIL), (ii) secondary forest management, (iii) afforestation / reforestation, (iv) community REDD+ schemes, (iv) review of agriculture leases, (v) land use planning, (vi) agriculture extension programme and (vii) commercial plantation on non-forest land. This is aligned with the PNG National REDD+ Strategy (Government of Papua New Guinea 2017), which has the following action areas:

- Strengthened land-use and development planning
- Strengthened environmental management, protection and enforcement (including climate change, forest management, conservation and environmental management)
- Enhanced economic productivity and sustainable livelihoods (including food security and agriculture)

The overall goal of adaptation is to increase the country's resilience to climate change, reduce its adverse effects on various sectors and minimize human suffering, and maximize the use of opportunities which arise from climate change. The overarching strategies (Government of Papua New Guinea 2014b) are:

- Improvement of capacities of institutions in risk assessment; increase awareness, enhance capacities to deal with risks, promote research etc.
- Mainstreaming climate change into development planning; is done by creating entry points in priority sectors and at priority levels (adaptation technical working groups); experiences at one place are replicated elsewhere
- Adaptation research to fill gaps in knowledge and ensure adaptability
- Target vulnerable areas, sectors, ecosystems, infrastructure, and groups in society and make them resilient

Already in the Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) (Government of Papua New Guinea 2014b), the government suggested specific mitigation and adaptation options. The following table summarizes some of these proposed mitigation and adaptation actions.

In its Vision 2050 (Government of Papua New Guinea 2015b), the GoPNG developed seven Strategic Focus Areas (SFA): (i) human capital, development, gender, youth and people empowerment, (ii) wealth creation, natural resources and growth nodes, (iii) institutional development and service delivery, (iv) security and international relations, (v) climate change and environmental sustainability, (vi) spiritual, cultural and community development, and (vii) strategic planning, integration and control. The context of the project "*Consultancy Services to undertake feasibility studies on climate change, food and nutrition security, conservation and land-use in Enga Province of Papua New Guinea*" fall into the SFA-5: Environmental Sustainability and Climate Change. The following table summarizes the main objectives, outcomes, and key performance indicators (KPI) of SFA-5:

Table 8. Mitigation and adaptation alternatives in PNG (Government of Papua New Guinea 2014b)

Priority sectors/areas	Mitigation and Adaptation measures
Coastal flooding	Potential measures include infrastructure (dikes, levees, sea walls, breakwaters, beach nourishment, elevating structures, reef revival, mangrove restoration and expansion etc.), technology (e.g. adaptation in homes, storm/flood detection system), systemic (e.g. improve disaster response, Integrated Coastal Zone Management) and financial ones (e.g. insurance schemes); various locations have been selected.
Inland flooding	Potential measures include: infrastructure (dikes, levees, flood storage, river training, diversion, drainage), technology (flood monitoring network), systemic (flood warning, awareness, local reporting, monitoring of buffer zones, capacity building), and financial (mobilization of structural funds, insurance schemes)
Water and sanitation	The focus will be on (a) 19 provincial towns where the PNG Water board will upgrade or develop sustainable, reliable and environmentally friendly water and sanitation services for the population, industries and institutions; (b) rural district towns, where the PNG Water board will lead in developing the services to a level of 65% in 2015; and (c) rural communities, where the PNG Water board will support the government agencies and stakeholders with research and technology development as well as capacity building.
Agriculture sector	The challenges come mostly from erratic rainfall. The potential measures come from community best practices and additional expertise from NARI: (i) soil moisture preservation and reduction of evapotranspiration, (ii) selection of drought-tolerant

	varieties of sweet potato, banana and cassava, (iii) promote drought-coping strategies, (iv) implement better practices related to soils and fertilizers and (v) Adopting water-conserving technologies and water harvesting initiatives
Health sector	Next to the drinking water and sanitation-related issues, malaria is the main challenge for this sector. Some potential measurements include Insecticide-treated bed net distribution (LLIN), Artemisinin Based Therapy (ACT) as first-line treatment, Indoor Residual Spraying (IRS), Malaria prevention for pregnant women, Introduction of mosquito-larvae eating fish in fish ponds, Building wells and reducing mosquito breeding grounds, Building additional healthcare centres, Introduction of bio-pesticides (plants), Monitoring of mosquito resistance to treatment, Planting of trees to create shade.
Forestry	Conservation of Intact Forest Landscapes, National Parks and Wildlife Management Areas is key to biodiversity conservation in PNG and serves to cope with climate change challenges as well. Next, strengthening the protection of these areas, especially community participation in forest management (including pest control), will be enhanced. Conserve and protect local forests and shrublands
Fisheries	Strong conservation measures are required to remove most of the stresses on marine systems and allow them to cope with the changing climate. This requires an ecosystem approach with a focus on upstream control of human activities. The creation (or enlargement) of marine reserves will be necessary. Financial mechanisms will have to come from global cooperation.
Biodiversity	In addition to the measures stated under forestry: coral reef restoration and preservation, which requires a cultural shift (fishing techniques) and investment in infrastructure (sanitation and industrial waste water management); coastal site planning and mangrove management; sand dunes and sandy beaches, where especially the protection of turtles and their eggs need community-based actions.

Table 9. Strategies for Strategic Focus Area Five: Environmental Sustainability and Climate Change (Government of Papua New Guinea 2015b)

Objective	Activity	Outcome	Indicator	Evaluation
Sustainable development measures developed in all sectors to increase resilience to the impacts of climate change and environmental changes	Develop appropriate adaptation and mitigation strategies for climate change and environmental changes	Sound policy and legal framework for the sustainable management of natural resources and mitigating climate change and hazards	(i) Less logging for exports, (ii) Communities' resilience is enhanced in villages, (iii) Sustainable development policies completed, (iv) Oceans and marine and terrestrial areas protected, (v) Forests are protected and sustained	(i) Legal cases and reports on the environment, (ii) Increased forests, and land-use areas designated for carbon opportunities, (iii) Large renewable energy projects developed
Conserve and use our natural resources and environment for the collective benefit and for future generations	Strengthen research and develop infrastructure, capacity and programs	World-class education, research, and sustainable management of natural resources and mitigating climate change	(i) 70% of PNG forests are conserved and managed for carbon trade purposes, (ii) Oceans and land resources are managed, (iii) Mitigation measures for all forms in industries, mining, energy and waste	(i) Community and stakeholder feedback on services, (ii) Policies implemented
Converse and wisely use our natural resources and environment, language and cultural diversity for the collective benefit of the present and future generation	Develop policies and organizational structures to address climate change and sustainable development. Develop enabling policies through legal instruments.	Sound institutional framework for sustainable management of natural resources and mitigating climate change. Develop an inventory of biodiversity, language and cultural diversity	(i) Professional competence and world standard research programs on environment and climate change, (ii) Increased tourism sector's contribution to GDP	(i) National and international environment and Management and research, (ii) BPNG Economic Bulletin Quarterly Reports

Effective partnership and cooperation with the international community on environmental sustainability and climate	Identify strategic partners and develop programs that strengthen partnership arrangements	Participate in, and benefit from international arrangements on environmental sustainability and climate change.	Adherence to international agreements	Reports from respective departments and institutions

Funded by the European Union

Similarly, different priorities related to climate change in Papua New Guinea were recently identified (Global Green Growth Institute 2019):

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

PNG's commitment to adaptation for 2020-2030 will focus on four priority development sectors of agriculture, health, transport, and infrastructure, whereas mitigation actions will focus on the energy sector and the land use, land-use change and forestry sub-sector (LULUCF) (Climate Change and Development Authority 2020). Mitigation actions by 2030 in the LULUCF sub-sector will be based on: (i) a 25% reduction in annual deforestation, (ii) a 25% reduction in annual forest degradation and (iii) an increase in forest plantation and enhancement of ecosystem restoration (**Figure 19**).

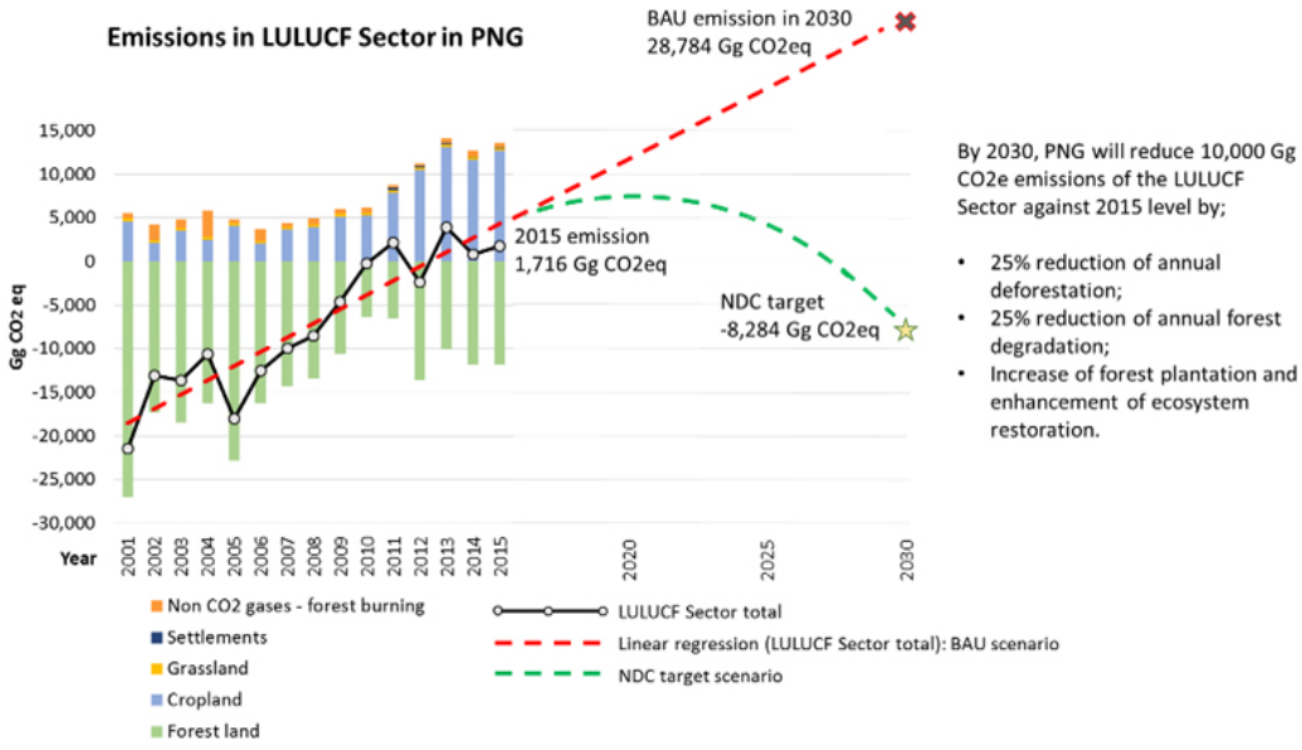


Figure 19. Emissions in the land use, land-use change and forestry sub-sector (Climate Change and Development Authority 2020)

Adaptation actions will be directed to nine priority areas: (i) Coastal Flooding and Sea Level Rise, (ii) Inland Flooding, (iii) Food Insecurity caused by crop failures due to droughts and inland frosts, (iv) Cities and Climate Change, (v) Climate-Induced Migration, (vi) Damage to Coral Reefs, (vii) Malaria

and Vector-Borne Diseases, (viii) Water and Sanitation and (ix) Landslides. The following table shows a summary of the main actions in each priority area (Climate Change and Development Authority 2020).

Table 10. Adaptation actions in the Enhanced NDC in PNG (Climate Change and Development Authority 2020)

N	Priority areas	Adaptation actions
1	Coastal flooding and sea-level rise	• Mangrove planting • Coastal defence structures • Coastal rehabilitation and relocation/resettlement • Climate risk and vulnerability assessments across five provinces (New Ireland, Oro, Madang, East Sepik and Morobe)
2	Inland flooding	• Climate risk, hazard and vulnerability assessments • Community-based flood simulation exercises • Early Warning System integration
3	Food insecurity	• Climate-Smart Agriculture Policy is socially inclusive • Progress on food security is underpinned by the National Food Security Policy 2016-2027
4	Cities and climate change	• National Energy Policy 20182028, which underpins action on PNG's energy sector, affecting cities in the face of climate change impacts • Project support has been received to create a more climate-resilient transport sector
5	Climate-induced migration	• Indirect support for action on climate-induced migration, IOM report (IOM 2015) provides an evidence base for action
6	Damage to coral reefs	• Mangrove planting • Coral rehabilitation • Establishment of marine protected areas (MPAs), locally managed marine areas (LMMAs) • Mangrove management • Marine awareness
7	Malaria and vector-borne diseases	• An environmental health management plan is under consideration • Climate Change Health Impact Policy is in draft
8	Water and sanitation	• Establishment of the WASH Policy 2015-2030 • Policy implementation in the provinces
9	Landslides	• Identify landslide risk using technology • Advisory support to engineer-design for road and infrastructure projects

Forests cover around 78% of the PNG's land (**Figure 20**). Forests in PNG are defined as "land spanning more than 1 hectare, with trees higher than 3 meters and the canopy cover of more than

10 per cent (%)" (Climate Change and Development Authority 2017b). From 2002 to 2020, PNG lost 777kha of humid primary forest, making up 51% of its total tree cover loss in the same time period. The total area of humid primary forest in PNG decreased by 2.4% in this time period. From 2001 to 2020, PNG lost 1.57Mha of tree cover, equivalent to a 3.7% decrease in tree cover since 2000, and 1.15Gt of CO_2e emissions. In PNG, from 2001 to 2019, 0.71% of tree cover loss occurred in areas where the dominant drivers of loss resulted in deforestation (GFW 2021)

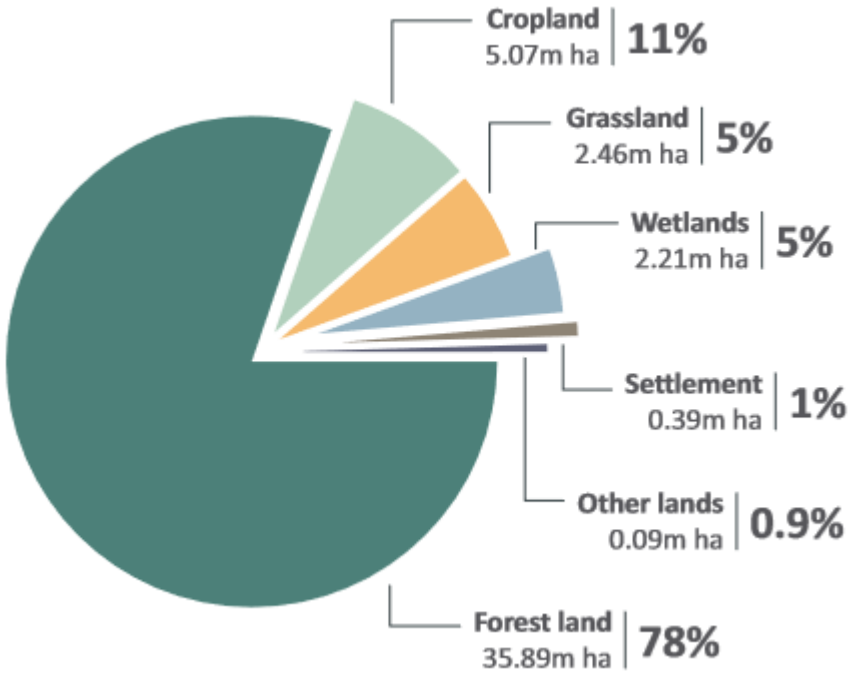


Figure 20. Land cover in PNG (Climate Change and Development Authority 2017b)Deforestation in PNG has been primarily driven by the conversion of forestland to cropland which accounts for 87% of deforestation. Of this, shifting agriculture is responsible for 63% of the land deforested and commercial agricultural developments, primarily in the form of oil palm, are responsible for 30% of the deforested land. The trend in clearance for commercial agriculture has increased in the past decade following the rapid expansion of Special Agricultural Business Leases (SABLs), which were allocated over 5.1m ha. While only a small number of these have initiated the development, and there has been an official moratorium and subsequent suspension of them, some logging and conversion have occurred. The figure below shows the primary drivers of deforestation and forest degradation in PNG.

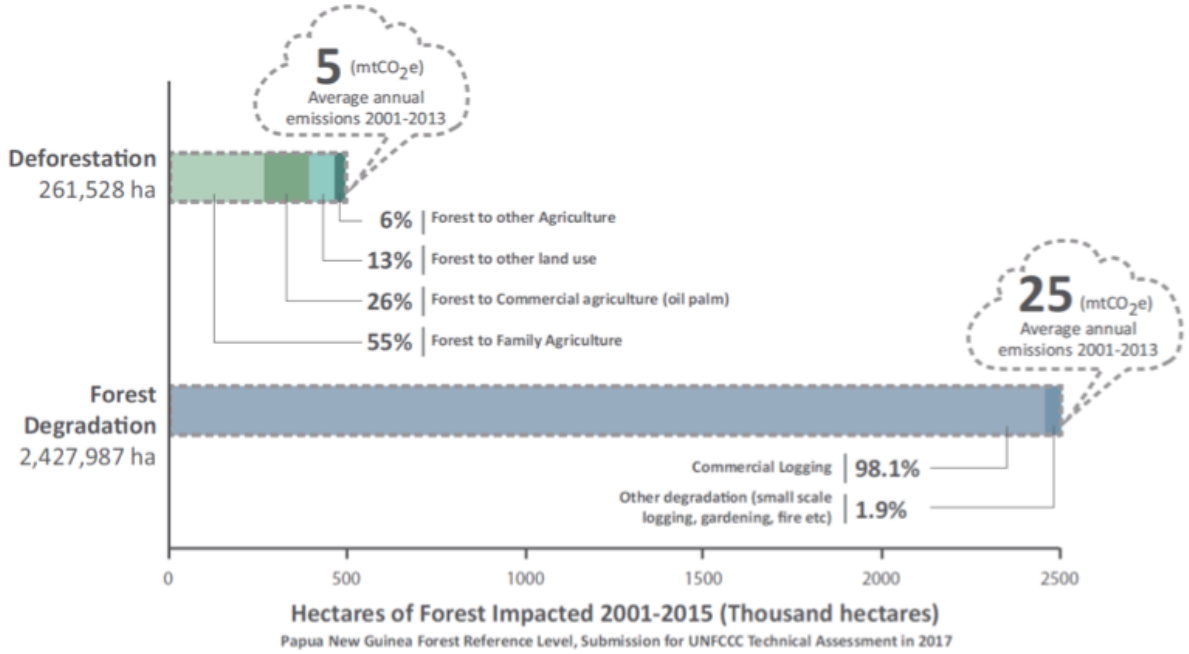
Figure 21. Primary drivers of forest cover change in Papua New Guinea (Government of Papua New Guinea 2017)

3.2 Climate change impacts in Enga province

The main climate change phenomena that will derive in impacts in Enga province are (i) rise in temperatures and (ii) changes in rainfall patterns. These changes will increase the occurrence of droughts, frost events, floods and landslides in a spatially differentiated manner throughout Enga province. Mitigation and especially adaptation measures at a provincial level in Enga should, therefore, focus on those (**Table 11**).

Table 11. Climate change impacts in Enga Province (Adapted from Enga Provincial Disaster Committee 2015; Global Green Growth Institute 2021)

Phenomenon	Confidence	Description
Rise in temperature	Very high	Decreased yield and quality of agricultural crops Increase in vector-borne and respiratory diseases Reduced habitat of montane bird species
Change in rainfall	High	Increase in flooding and damage to infrastructure Decrease in agricultural productivity Increase in vector and water-borne diseases
Occurrence of landslides	High	Decrease in agricultural productivity Reduced access to drinking water and reduced food security



Occurrence of drought events	Medium	Decrease in agricultural productivity Reduced access to drinking water and reduced food security
Occurrence of frost events	Medium	Decreased yield and quality of agricultural crops Reduced food security
The rise in sea level	Very high	Not relevant for Enga Province
Increase in ocean acidity	Very high	Not relevant for Enga Province
Occurrence of cyclones	Medium	Not relevant for Enga Province

3.3 Potential mitigation and adaptation measures in Enga province

All mitigation and adaptation measures are proposed at the national level (Government of Papua New Guinea 2010; Government of Papua New Guinea 2014b; Government of Papua New Guinea 2015b; Government of Papua New Guinea 2015b; Government of Papua New Guinea 2015a) are not necessarily applicable at the regional and provincial level (Global Green Growth Institute 2021). For instance, coastal flooding, sea-level rise, acidification and cyclones are not relevant in Enga Province, nor in the other provinces in the Highlands. Fortunately, recent studies have assessed climate change impacts in the highlands and particularly in Enga Province (Enga Provincial Disaster Committee 2015; National Disaster Centre 2015; Global Green Growth Institute 2021).

Table 12. Potential adaptation alternatives in Enga province

Measures type	Priority sectors/areas	Potential measures

Adaptation	Transportation and infrastructure	- Rehabilitation/upgrade of gravel roads - Rehabilitation/intervention of culverts and drainage - Construction of flood defences - Construction of landslide interventions (welded gabions, protected mesh, retaining walls, etc.)
	Agriculture and Livestock	- Soil moisture preservation and reduction of evapotranspiration - Select drought-tolerant varieties of sweet potato, banana and cassava - Promote drought-coping strategies - Implement better practices related to soils and fertilizers - Adopt water-conserving technologies and water harvesting initiatives - Fund the Enga Provincial Disaster Committee (distribution, medical supplies, food and water storage, rehabilitation, etc.)
	Water and sanitation	- Upgrade or develop sustainable, reliable and environmentally friendly water and sanitation services - Adopt water-conserving technologies and water harvesting initiatives
	Health sector	- Insecticide-treated bed net distribution (LLIN), Artemisinin Based Therapy (ACT) as first-line treatment, Indoor Residual Spraying (IRS) - Building wells and reducing mosquito breeding grounds - Building additional healthcare centres - Introduction of bio-pesticides (plants) - Planting of trees to create shade.

Table 13. Potential mitigation alternatives in Enga province

Measures type	Priority sectors/areas	Potential measures
Mitigation	Forestry / Biodiversity	- Conserve and protect local forests and shrublands - Implementation of sustainable forest management (SFM) and reduced impact logging (RIL) - Reduced Deforestation and Forest Degradation (REDD) schemes - Sustainable and participatory land-use planning - Increase forest areas through forest plantations - Reforest marginal agricultural land and degraded areas

	Energy	- Use of renewable technologies such as rooftop solar panels - Reduce consumption of firewood
	Transportation	- Improve technical efficiency of vehicles - Improve traffic flows and vehicle maintenance - Implement mass transit systems
	Agriculture and Livestock	- Implement better practices related to soils and fertilizers - Use more drought-tolerant species for agriculture

Both high temperatures and high-intensity rainfall are important factors in road deterioration (Qiao et al. 2015); depending on the type the road (e.g. paved and unpaved), the effect of water and temperature interact differently. For instance, water can have stripping effects on asphalt pavements and washout of unpaved surfaces (Willway et al. 2008; US EPA 2015), whereas high temperatures might lead to age hardening and cracking on paved roads (Willway et al. 2008). There are mainly four risks to road infrastructure associated with climate change (US EPA 2015): (i) rutting of paved roads from precipitation, (ii) rutting of paved roads caused by freeze-thaw cycles, (iii) cracking of paved roads due to high temperatures and (iv) erosion of unpaved roads from precipitation.

4 CLIMATE CHANGE ANALYSIS

4.1 Field surveys regarding climate change

The consultant collected data using different study tools (household surveys, focus groups and discussion guidelines) to uncover the issues related to climate change mitigation and adaptation in Enga Province. **Annex 1** presents each of the questionnaires used. A photographic annexe of the scoping mission is presented in **Annex 2**, and photos of the field survey in **Annex 3**. The fieldwork plan and schedule are presented in **Annex 4**. The list of people met during data collection is presented in **Annex 6**.

4.1.1 Household survey results

Most of the respondents throughout the Enga province (Kandep, Kompiam, Lagaip-Porgera, Wabag and Wapenamanda districts) are familiar with the term "climate change" (**Figure 22**). A photographic annexe of the field survey is presented in **Annex 3**, and a summary of the household characteristics is presented in **Annex 5**.

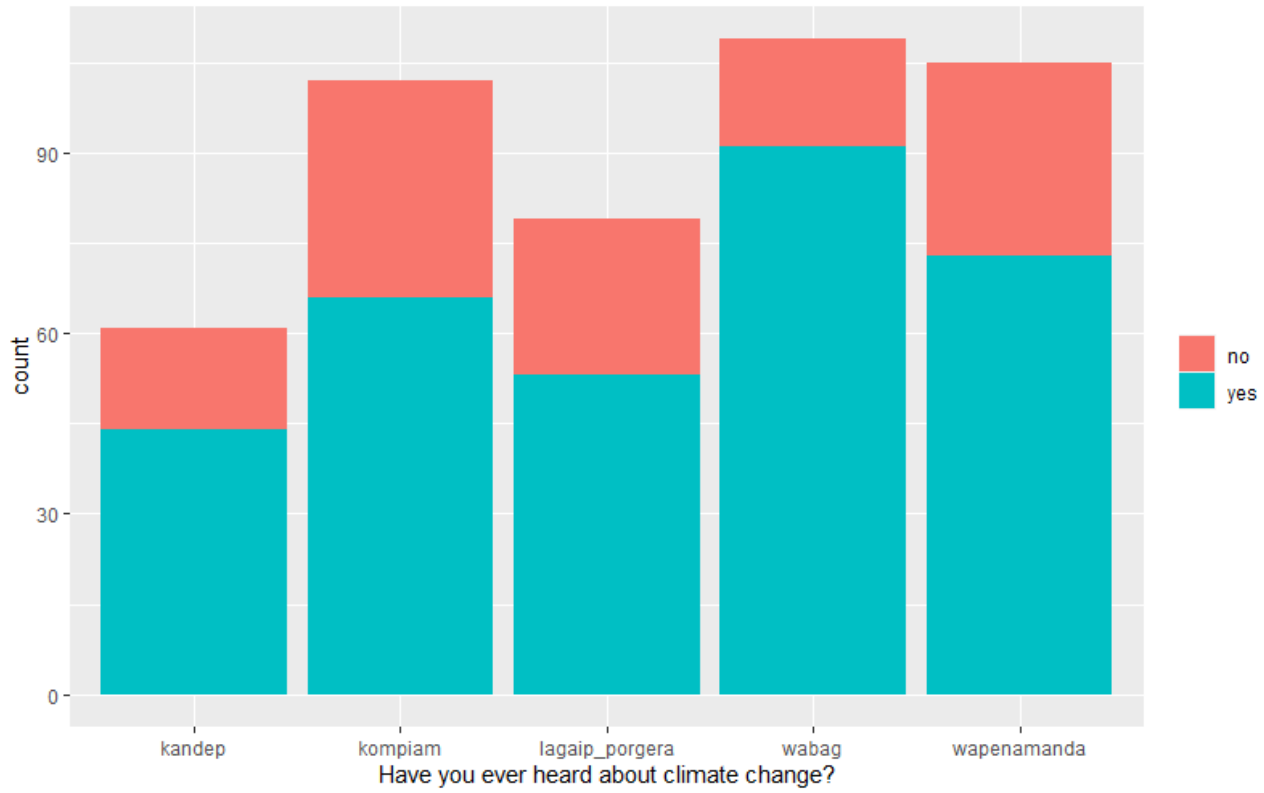


Figure 22. Climate change perception (Source: FinnOC)

The most common natural disasters reported in the Kandep district are floods and frost events, followed by droughts. In the Kompiam district, landslides and floods were the most common natural disasters, followed by droughts. A similar situation was reported in Wabag and Wapenamanda. On the other hand, besides landslides and floods, also frost events were reported in the Lagaip-Porgera district (**Figure 23**). Regarding changes in the frequency of these natural disasters, most of the participants stated that they have become more frequent in the last decade (**Figure 24**)

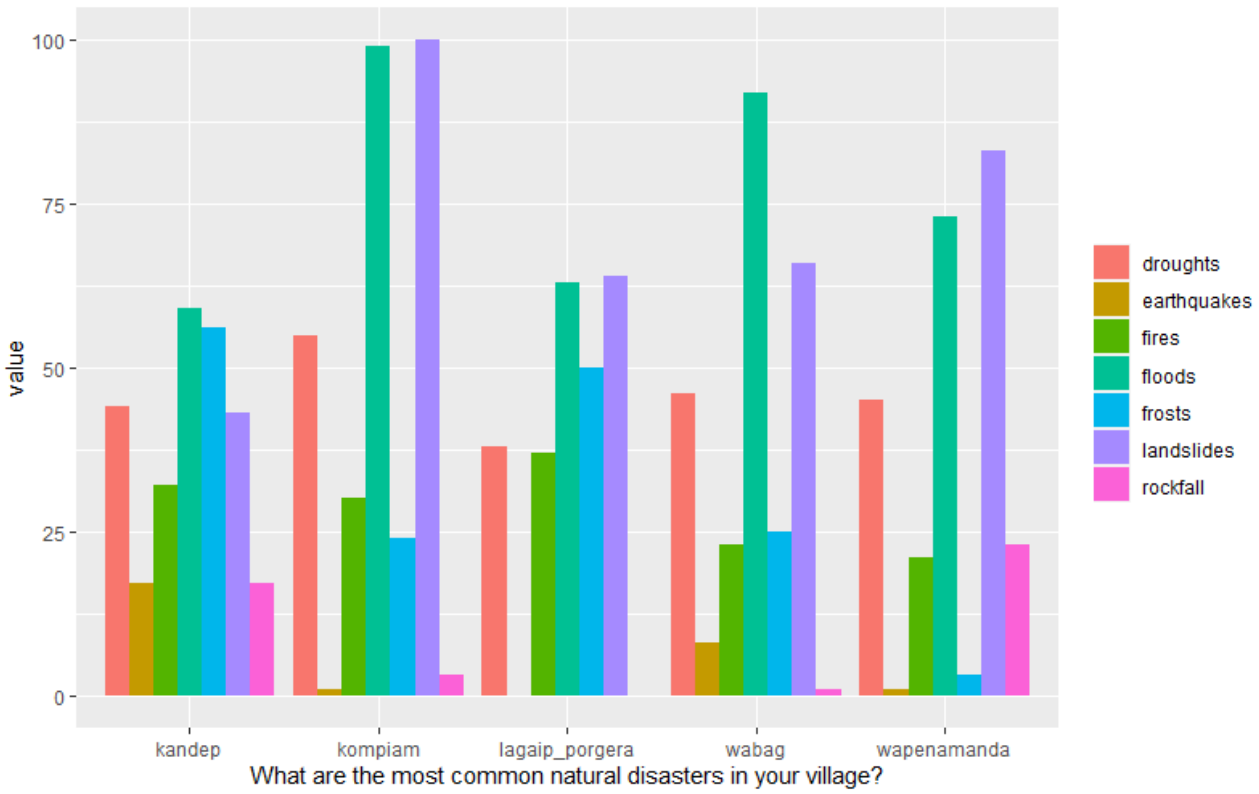


Figure 23. Common natural disasters in Enga province (Source: FinnOC)

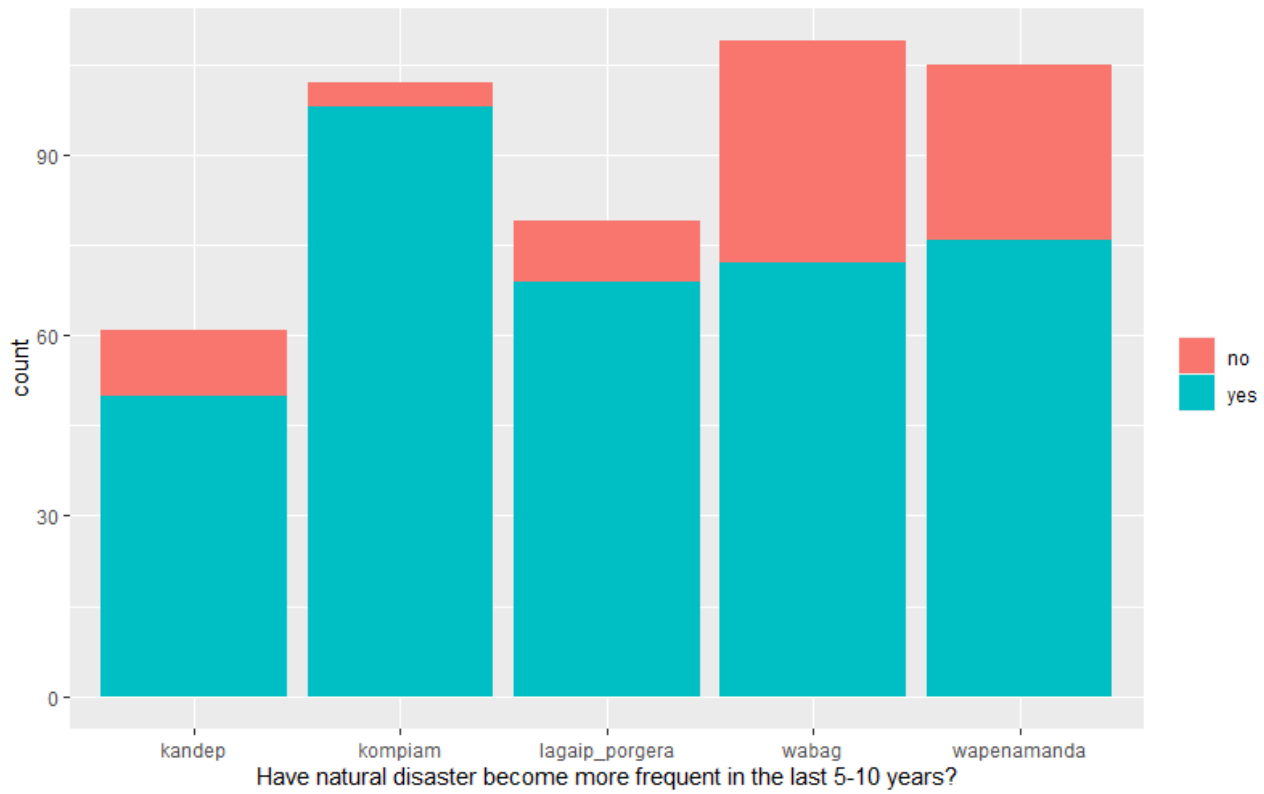


Figure 24. Changes in the frequency of natural disasters in Enga province (Source: FinnOC)

Almost 100% of the participants in all five districts have reported that there has been an increase in the amount of total rainfall in the last decades. Most of the respondents expressed that there had been much more rain than in the last 5-10 years (

Figure 25). Regarding temperature changes, there seem to be some district-level differences (**Figure 26**). In Kompiam, Wabag and Wapenamanda, almost 50% of the participants experienced much warmer temperatures in the last 5-10 years, whereas the rest had slightly warmer temperatures. The situation differs slightly in the Lagaip-Porgera district, where more than 75% of the participants have experienced only a mild increase in temperatures. In contrast, the rest mainly have significantly higher temperatures. In a particular case, in the Kandep district, around 60% of the respondents experienced only a slight increase in temperature, whereas 25% experienced, on the contrary, a bit cooler temperature (**Figure 26**).

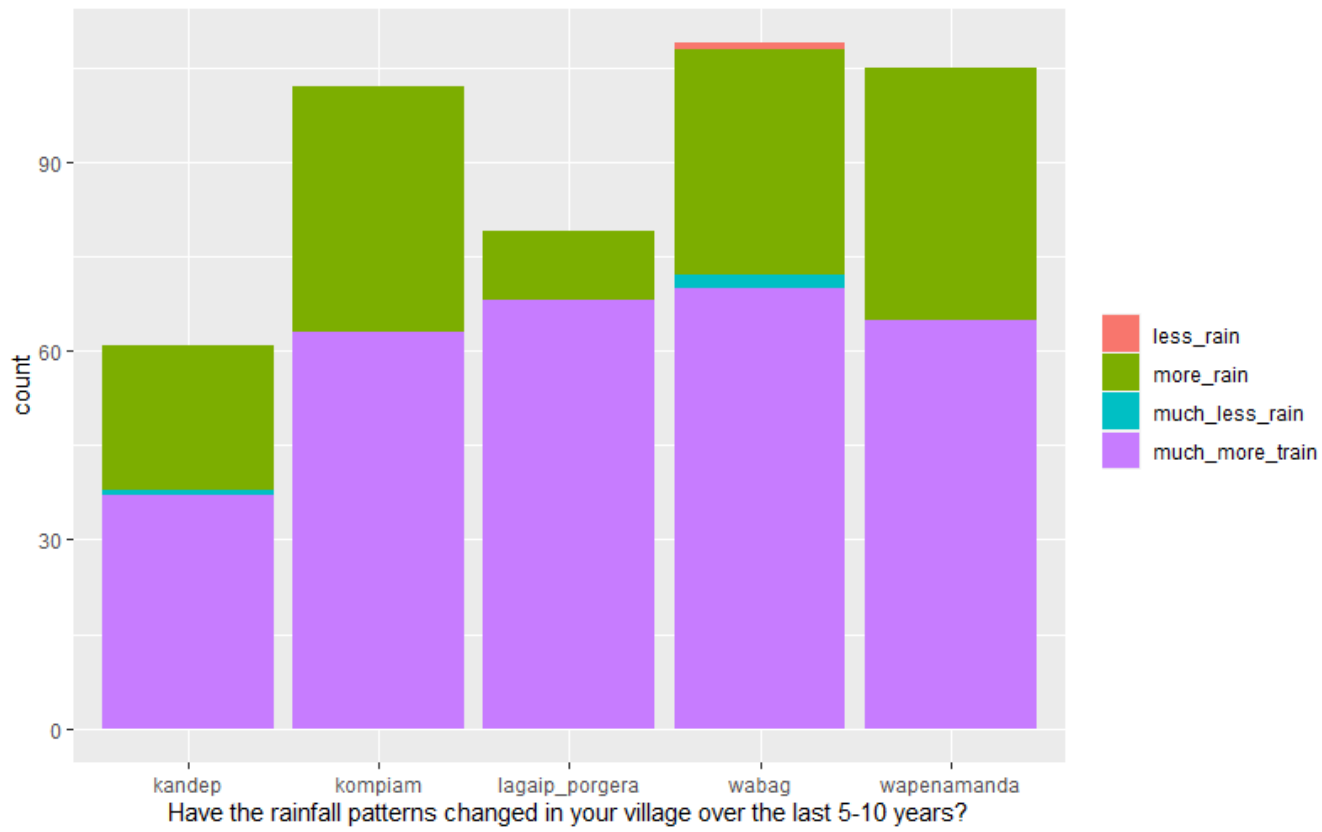


Figure 25. Changes in rainfall patterns in Enga province (Source: FinnOC)

Almost 100% of the respondents in Wapenamanda stated that frosts had not had any impact on agriculture and food production, whereas, on the contrary, around 100% of respondents in Kandep made experience impacts on frosts in food production (**Figure 27**). In Kompian and Wabag, around 70% of the respondents did not experience frost events impacting food production, and less than 50% of respondents experienced impacts of frost events in food production in Lagaip-Porgera (**Figure 27**).

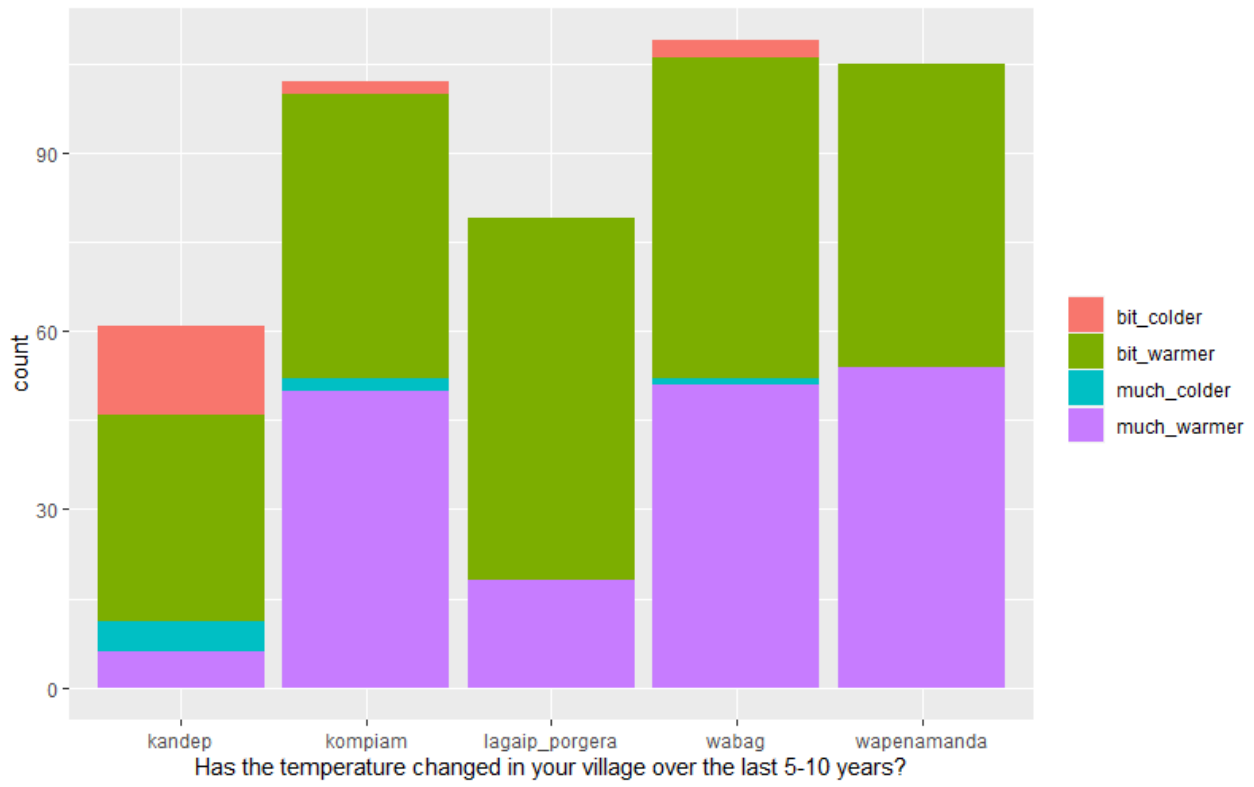


Figure 26. Changes in temperature in Enga province (Source: FinnOC)

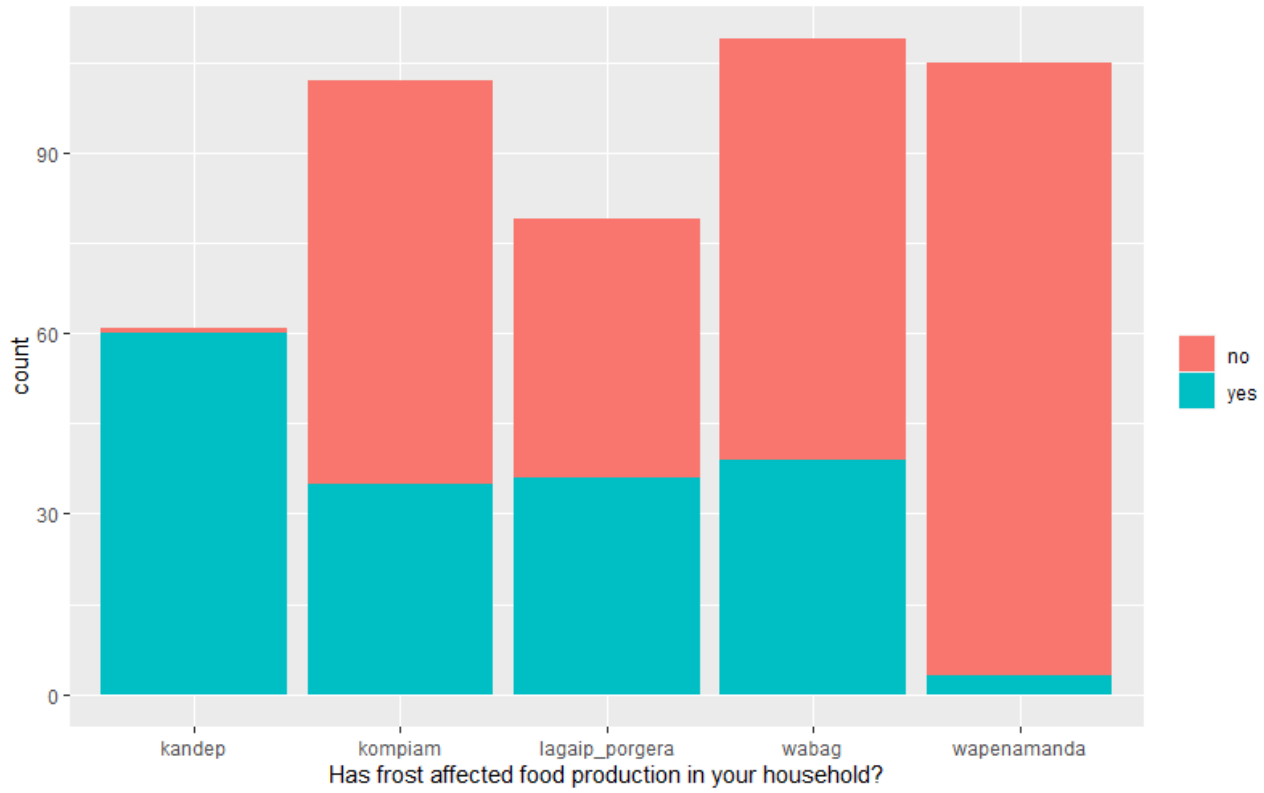


Figure 27. Impact of frost on food production in Enga province (Source: FinnOC)

Households reported different actions taken to tackle food shortages due to frost events. Some of the most common actions reported are: (i) making new gardens right after the frost event, (ii) using previously-stored food resources, (iii) migrating to lower elevation locations, and (iv) selling some stored food to buy other food products (e.g. rice), (v) using their other crops not affected by frosts, (vi) having several gardens, (vii) expecting support from the government.

Climate change has also affected work patterns in Enga province (**Figure 28**). In Kandep, around 60% of the respondents reported having less work due to climate change, whereas the rest expressed having more work. In Kompian, Lagaip-Porgera and Wabag districts, around 75% of the respondents reported doing more work due to climate change (**Figure 28**). In Wapenamanda, the perceptions include both having more work and less work due to climate change (50%-50%)

In the Kandep district, 100% of the participants have reported damages to their properties due to climate change (**Figure 29**). The situation remains similar in the rest of the districts, in which more than 90% of the participants experienced damage due to climate change. Most of the respondents mentioned that the property damages include food and crop gardens and forest areas. Other respondents also mentioned that houses, bridges and roads are also affected due to landslides and floods.

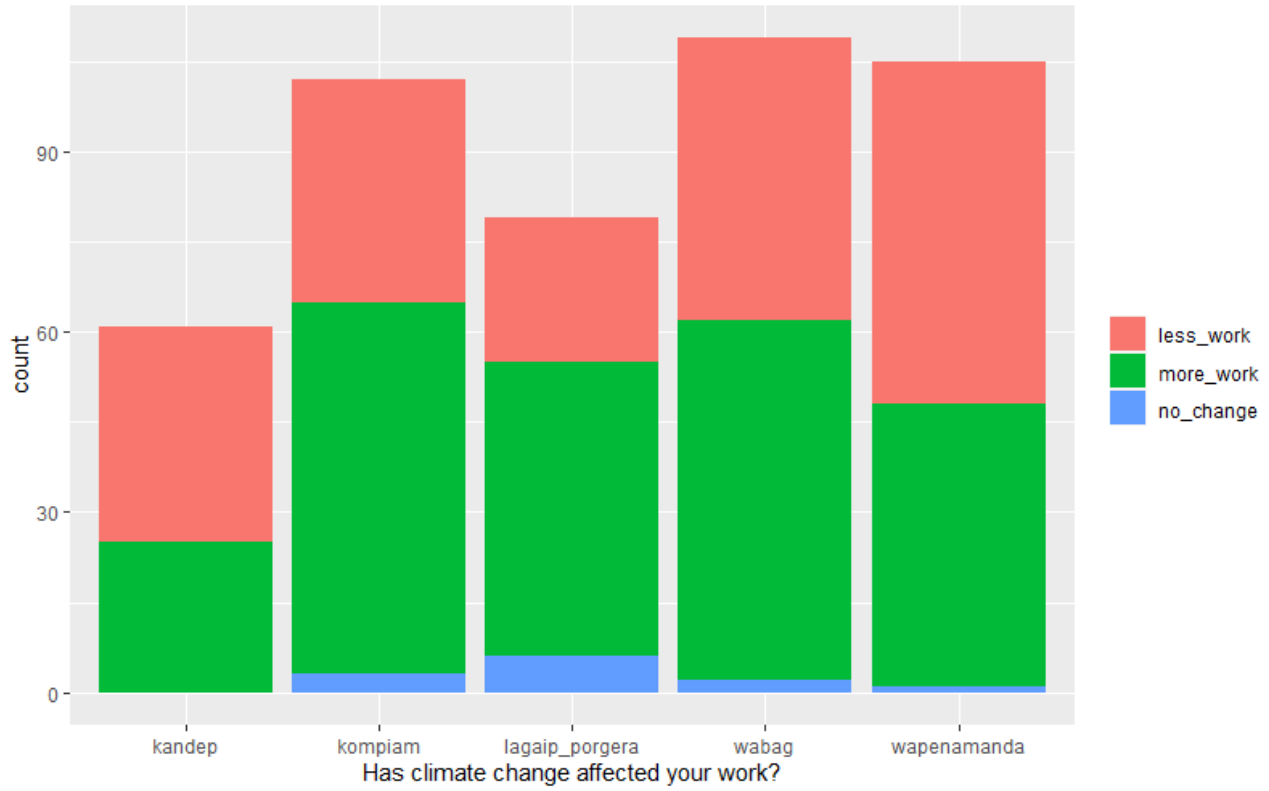


Figure 28. Impact of climate change on work patterns in Enga province (Source: FinnOC)

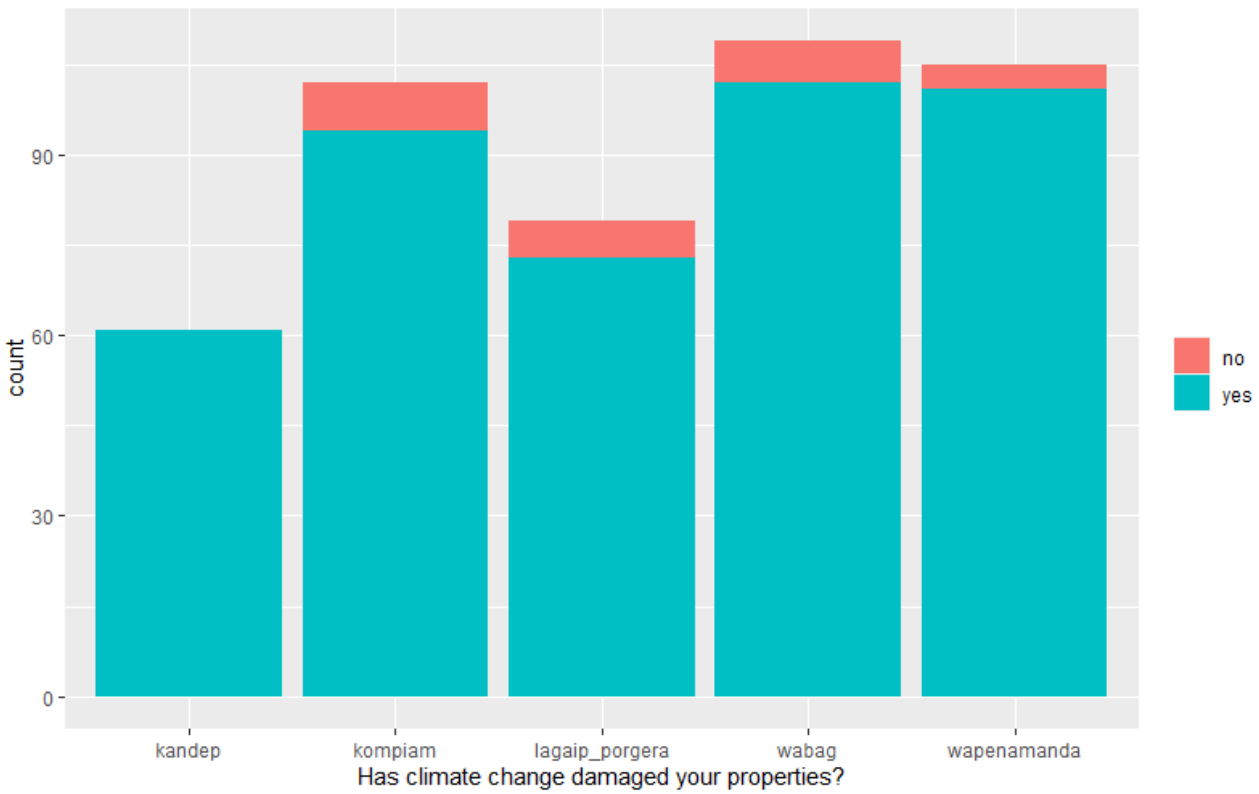


Figure 29. Impact of climate change on property damage in Enga province (Source: FinnOC)

4.1.2 Focus group results

4.1.2.1 Coffee farmer's focus group discussion

Table 14. Results of coffee farmer's focus group discussions

Village	N. of partici pants	Size of coffee areas*	Climate change perceptions	Climate change adaptation and mitigation actions	Main issues/struggles	Cooperatives or coffee associations	Capacity building necessities
Birip (Wabag)	5	1-3 ha	Both warmer and colder temperatures were reported due to climate change Both drier and wetter conditions were reported More pests affecting the coffee crops	No actions were mentioned as specific adaptation or mitigation measures (traditional farming is the main method they continue using) Nevertheless, agroforestry methods were also mentioned (pawpaws and bananas planted to give shade to coffee plants)	More pests affecting coffee plants and beans Low prices in coffee sales Lack of funds and incentives for improving practices Lack of competitive coffee buying markets	Yes, a cooperative coffee society	More agriculture training, especially for women Training on financial literacy
Lukitap (Wabag)	7	3-4 ha	Both warmer and colder temperatures were reported due to climate change Both drier and wetter conditions were reported Coffee quality is more variable nowadays than before	No actions mentioned as specific adaptation or mitigation measures	Lack of agricultural training Low prices in coffee sales Lack of funds and incentives for improving practices Lack of proper markets	None	More agriculture training

(*) Range of coffee area per household

Village	N. of participants	Size of coffee areas*	Climate change perceptions	Climate change adaptation and mitigation actions	Main issues/struggles	Cooperatives or coffee associations	Capacity building necessities
Mambi-sanda (Wapena-manda)	5	1-3 ha	Both warmer and colder temperatures were reported due to climate change Both drier and wetter conditions were reported Coffee quality has reduced More pests affecting coffee crops and beans	No actions mentioned as specific adaptation or mitigation measures Agroforestry practices in the village (banana, corn and yams grown within the coffee farms) Construction of small drainage systems (during heave rainfall events)	Low prices in coffee sales Lack of training and capacity building in coffee farming Lack of proper markets Lack of fertilizers Lack of agriculture/coffee extension activities	None	More agriculture training Training on financial literacy
Yakaedis (Wapena-manda)	6	1-4 ha	Both warmer and colder temperatures were reported due to climate change Both drier and wetter conditions were reported Coffee quality has reduced More pests affecting coffee crops and beans It is now possible to plant other crops	No actions were mentioned as specific adaptation or mitigation measures (traditional farming is the main method they continue using) Agroforestry methods (yams and bananas planted to give shade to coffee plants)	Low prices in coffee sales Lack of fertilizers Lack of training on coffee farming Lack of markets	None	Training on financial literacy Training in food security Training on climate change Training on agriculture

(*) Range of coffee area per household

Village	N. of participants	Size of coffee areas*	Climate change perceptions	Climate change adaptation and mitigation actions	Main issues/struggles	Cooperatives or coffee associations	Capacity building necessities
Par (Kompiam)	6	2.5 ha	Cooler temperatures were reported due to climate change Wetter conditions were reported More pests affecting coffee crops and beans	No actions were mentioned as specific adaptation or mitigation measures (traditional farming is the main method they continue using) Construction of small drainage systems (during heave rainfall events)	Low prices in coffee sales Lack of proper markets Lack of coffee farming training More pests affecting coffee crops and beans	None	Training on financial literacy Training on pest control Training on coffee farming for women
Pandai (Kompiam)	5	1-2 ha	Cooler temperatures were reported due to climate change Wetter conditions were reported Coffee quality has reduced More pests affecting coffee crops and beans	No actions were mentioned as specific adaptation or mitigation measures (traditional farming is the primary method they continue using) Agroforestry methods (bananas planted to give shade to coffee plants) Stock food supplies to prepare for natural disasters Construction of small drainage systems (during heave rainfall events) No pest control measures	Low prices in coffee sales Lack of proper markets Lack of incentives and government farming extension activities Lack of coffee farming training	None	Training on book-keeping and financial literacy Training on pest control Training on fertilizer management

(*) Range of coffee area per household

4.1.2.2 Farmer's and women's focus group discussions

The main climate change perceptions in farmer's and women's focus group discussions included: (i) both warmer and colder temperatures due to climate change, (ii) both drier and wetter conditions, (iii) more pests affecting crops, (iv) changes in crop yields, (v) less food supply, (vi) more soil erosion and water-logging and (vii) road deterioration/transportation issues. Regarding the climate change adaptation and mitigation actions practices at the community level, no specific measures were identified mainly because of a lack of awareness of the practices and because of reactive steps and coping mechanisms. Nevertheless, some standard measures include: (i) mixed cropping including agroforestry, (ii) multiple gardens (as storing strategy) and (iii) construction of small drainage systems in agricultural land when heavy rainfall events occur. Some of the common issues experienced and stated by farmers and women groups include: (i) lack of extension services, (ii) lack of proper markets, (iii) land shortage, (iv) increased pests and insects, (v) increased prices in fertilizers. The participants throughout the focus group discussion stated needing training, especially for women, in the following topics:

- Training on climate change and environmental issues
- Training on pest control and fertilizer management
- Training on sustainable farming
- Training on financial and market issues
- Training on innovative crop farming (adapted to frosts)

All the critical results from the farmer's group discussion in all districts are presented in Annexe 5, whereas women's focus group results are presented in Annexe 6.

4.1.3 Interviews during the scoping mission

The consultant conducted several interviews with key stakeholders in Enga during the scoping mission, such as provincial and district authorities, NGOs, and cooperative societies. The participants stated that Enga's natural disasters frequently occur, including flooding, landslides, frost, hail, and droughts.

Part of the Plans under the district DAL to mitigate climate change impacts on the land include tree planting (against strong winds and frost), crop rotation and integrated cropping and fallow (leaving the land unmanaged for some time). Under the agriculture crops divisions, the local authorities have practised several ways to sustain crops during climate change events

Table 15. Measures to sustain crops during climate conditions (Source: Interview with Mr Samson Fezamo – Scoping mission FinnOC 2022)

Village	Surveys
Frost	- Boil water until it simmers. Load the hot water into the pump and spray on food crops before the sun rise. Some potatoes are doing well with this approach. - Collect firewood and leaves and make smoke in the house to stop fros
Drought	- Cover all sweet potatoes with mulch. Water them in the mornings and afternoons to stop pest damage during the dry season.

Flooding/landslides	- Identify trees and plants like bamboo, which have widespread roots and are planted along the riverside, land slops and garden areas to stop soil erosion and landslides. - Plant plants like elephant grasses, wild pipits, and canes to plant 3 meters on either side of the river in buffer zones
Landslide / Soil erosion	- Contour farming, sideways planting to stop soil erosion Awareness to people, so they cover cropping with legumes or have plans for legume planting to put back nitrogen into the soil and prevent soil erosion.

The participants made different suggestions for improving climate change mitigation and adaptation during the interviews. Some of these consolidated suggestions are stated below:

- Improve, upgrade, and connect roads: many roads in Enga province are in poor condition, making agricultural production more complicated and expensive. Flooding, landslides and rockfall affect the condition of roads and market accessibility.
- Improve and create local markets: farmers can sell their local produce and reach more buyers from different parts of the province by having more markets.
- Increase awareness and capacity in terms of climate change and agriculture: even though people are aware of climate change, there is still mainstreaming at different levels, including the effects of climate change on agriculture and how to adapt to the direct climate change impacts.
- Provide access to safe drinking water: many villages do not have access to drinking water, which would increase food security.
- Improve farming sustainable farming practices: this includes training on sustainable farming, climate change adaptation in agriculture, and pest control
- Minimize loss of seedlings by preserving seedlings in a storage centre. After emergencies (e.g., frost and drought events), there should be enough seeds and seedling capacity to distribute to local communities to avoid significant migration patterns and food insecurity.
- Increase funding for extension and capacity building: resources and capacity are limited at the provincial level.

4.2 Climate change spatial analyses

4.2.1 Monthly climate change assessment

The following figure shows both current (1970-2000) and future monthly climate projections of rainfall and maximum and minimum temperature in Enga province for the period 2041-2060 (summarized as 2050 throughout the text) for two different emission scenarios (SSP370 – optimistic/low emission scenario and SSP585 – pessimistic / high-emission scenario) and eight different global climate models (GCMs) of the CMIP6.

Monthly minimum temperatures in Enga province range between 3 and 5°C (

Figure 30 A, D), whereas monthly maximum temperatures vary between 29 and 30.5°C (

Figure 30 B, E). Current rainfall patterns vary between 250 and 450 mm of monthly rain (

Figure 30 C, F). As shown in

Figure 30, even though global climate models vary, monthly minimum temperatures will range in 2050 from 2.5 °C to 4.5 °C; average monthly maximum temperatures will range between 34 °C and 36 °C, and monthly rainfall between 500 and 1250 mm. These changes represent an increase of 2-4°C in monthly minimum and maximum temperatures and more intense rainfall (0-200 mm) during the wet season, depending on the model and emission scenarios.

In the figure below, current climate conditions (1970-2000) are shown in the black lines, whereas the colourful lines represent the different future climate scenarios projected for 2050.

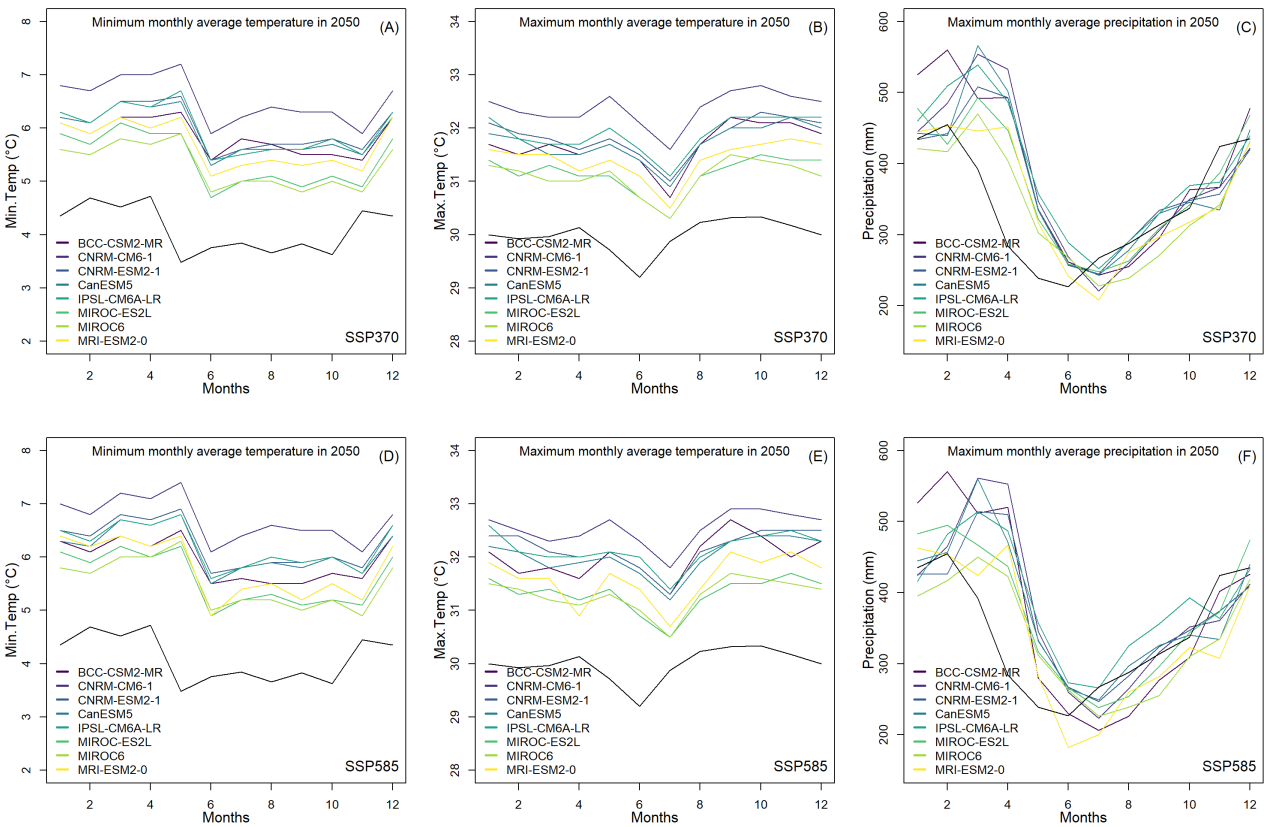


Figure 30. Future climate projections (minimum and maximum temperature and precipitation) are projected for 2050 using two shared socio-economic pathways (SSP370 and SSP585) in Enga Province.

Climate change assessments were also done spatially throughout Enga Province. The following figures show current and future climatic conditions (rainfall, minimum and maximum temperature) using SSP370 and SSP585 scenarios and the variation in those climatic parameters between current and future conditions. The future scenarios were based on a median ensemble model of the global climate models shown in **Table 4**.

In the following figures, the first row shows current (1970-2000) monthly climate conditions (minimum and maximum temperature and precipitation); the second row shows future monthly climate predictions projected to 2050, and the last row shows the difference between current and future climate conditions. This enables identifying locations where climate conditions will vary the most in the future. Hence, it will allow identifying hotspots for the development projects and making recommendations regarding climate resilience for the project implementation.

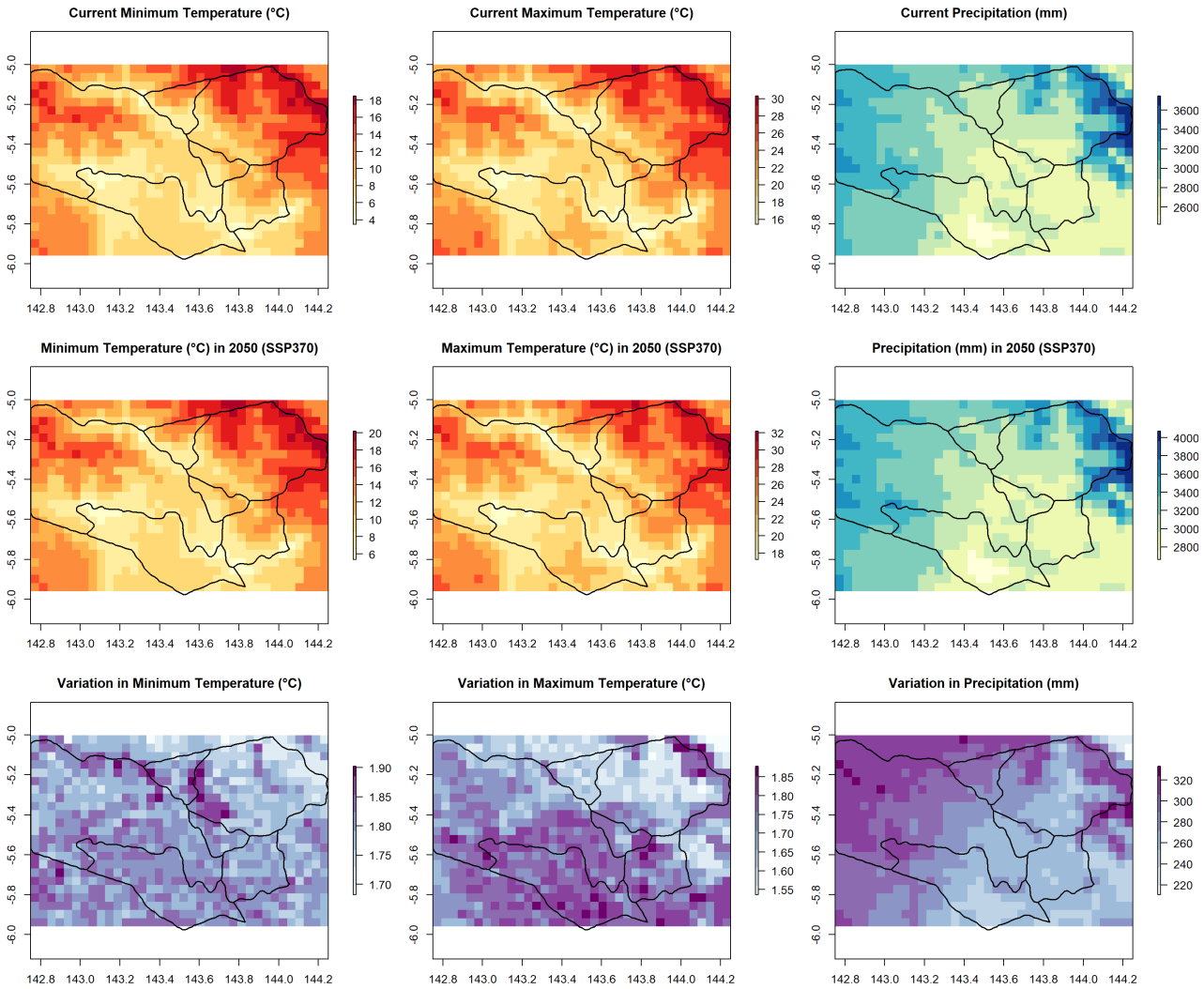


Figure 31. Spatial climate change assessment in Enga Province using SSP370. The first row shows current (1970 – 2000) climate conditions (minimum and maximum temperature and precipitation). The second row shows climate projections to 2050 using an ensemble model of 8 global climate models (GCMs) using a low-emission scenario (SSP370). The last row shows the difference between current and future climate conditions. The climate layers have a spatial resolution of approximately 17.5 km.

Minimum and maximum monthly temperatures in the project area will increase on average by 1.8 °C, whereas variation in total rainfall will be low based on an intermediate emission scenario (SSP370) by 2050. On a higher emission scenario (SSP585), minimum and maximum monthly temperatures in the project area will increase on average by 2 °C, and total rainfall will slightly increase.

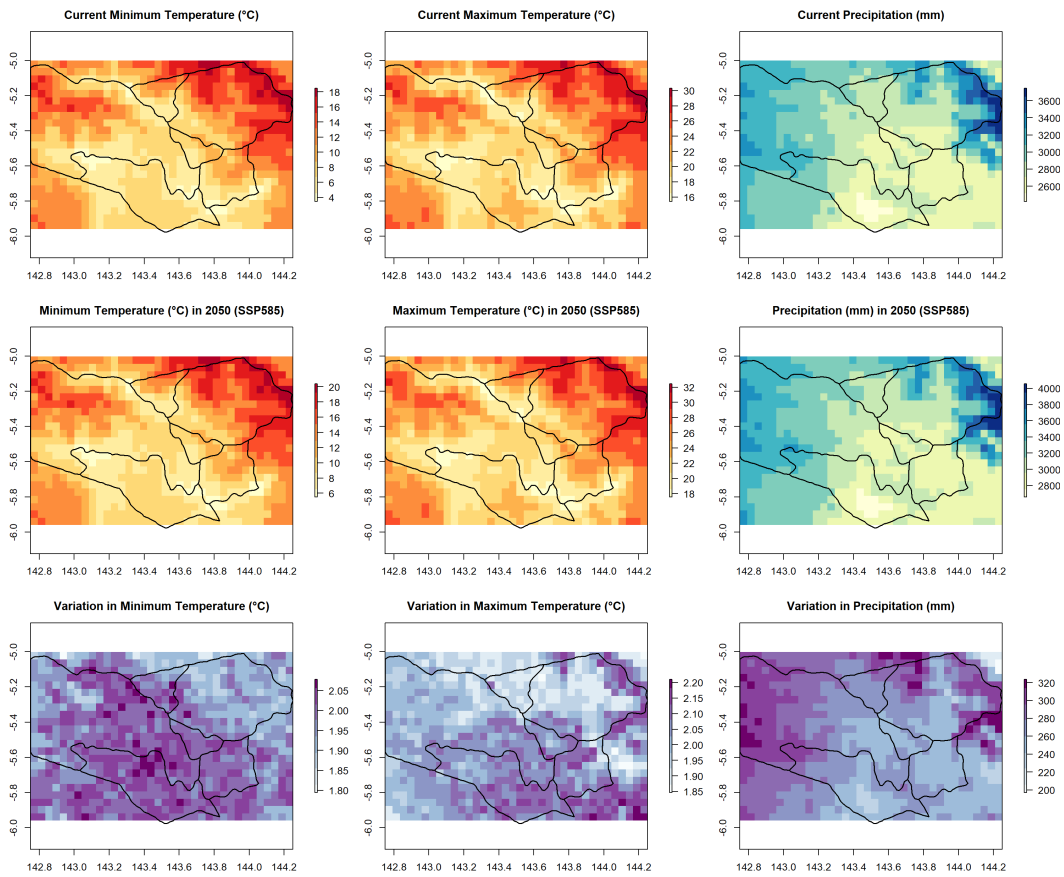


Figure 32. Spatial climate change assessment in Enga Province using SSP585. The first row shows current (1970 – 2000) climate conditions (minimum and maximum temperature and precipitation). The second row shows climate projections to 2050 using an ensemble model of 8 global climate models (GCMs) using a high-emission scenario (SSP585). The last row shows the difference between current and future climate conditions. The climate layers have a spatial resolution of approximately 17.5 km.

4.2.2 Daily climate change assessment

After downloading daily minimum and maximum temperature and rainfall values for current conditions (1950-2006) and future conditions (RCP 8.5, 2035-2064) in Enga province, different percentile thresholds (p0, p5, p25, p50, p75, p95 and p100) were derived for each climate parameter. **Figure 33** shows variation in daily minimum temperatures (p5), daily maximum temperature (p95) and daily rainfall (p95) for both current and future conditions in the study area. Daily minimum and maximum temperatures will increase between 2 and 2.5°C, and daily rainfall patterns will also increase slightly.

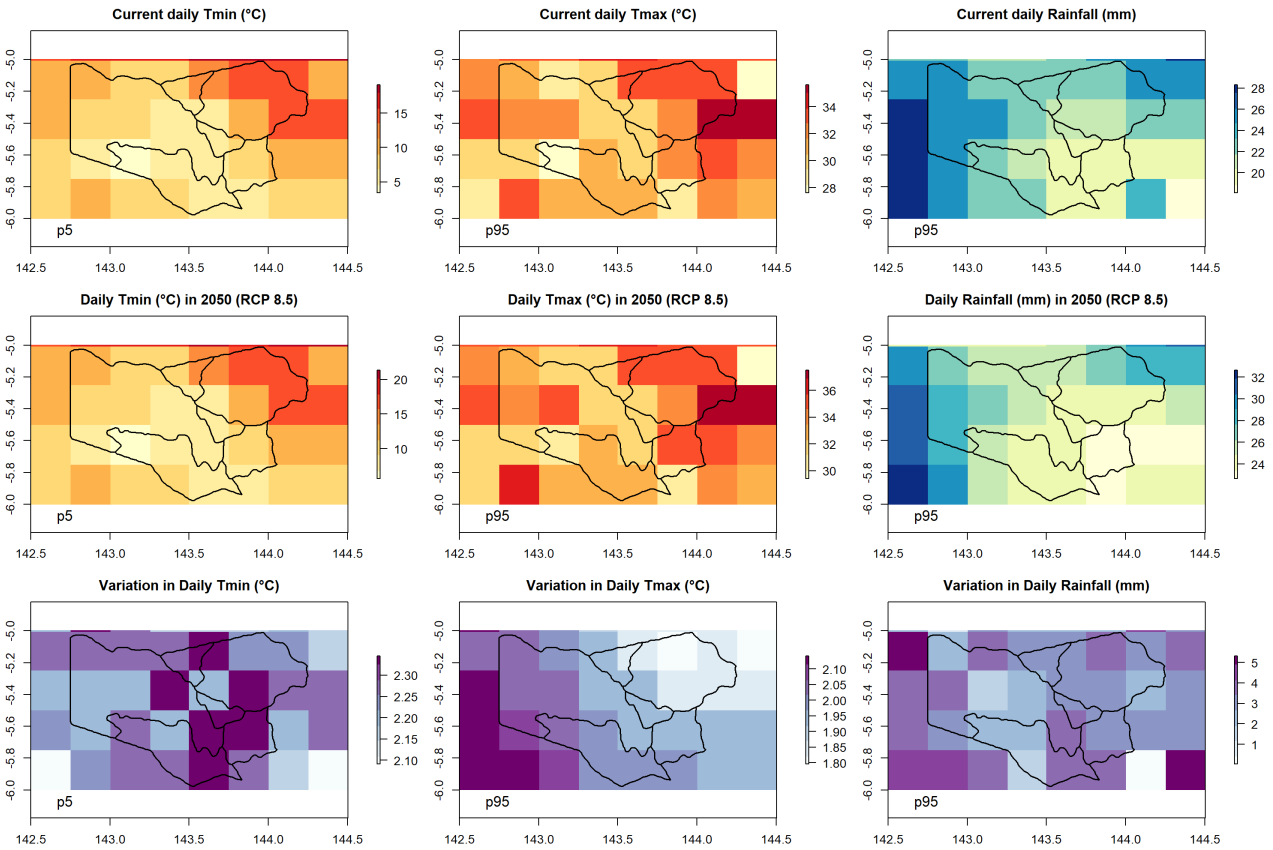


Figure 33. Spatial assessment of daily climate change in Enga Province using a high emission scenario

Daily minimum (p5) and maximum (p95) temperatures in the project area will increase on average by more than two °C. In contrast, variation in daily rainfall values will be relatively stable based on a high emission scenario (RCP 8.5) by 2050 (**Figure 33**). Daily temperature values will increase overall in 2050 (**Table 16**). The daily maximum temperatures will increase slightly in 2050 compared to the current scenario (**Table 16**), whereas daily extreme rainfall values (**Table 16**, P100) might decrease by 2050.

Table 16. Spatial statistics of the daily climate parameters' percentiles (P0, P5, P25, P50, P75, P95, P100) in Enga Province.

Period	Parameter		P0	P5	P25	P50	P75	P95	P100
Current (1950-2006)	**Tmin (°C)**	Min	-5.37	3.41	4.79	5.41	6.16	7.04	12.00
		Avg	-0.71	8.91	10.23	10.93	11.64	12.57	17.99
		Max	10.40	19.16	20.54	21.16	21.79	22.66	28.09
	Tmax (°C)	Min	21.31	23.69	24.69	25.38	26.19	27.63	33.30
		Avg	25.12	27.87	28.76	29.43	30.18	31.45	37.59
		Max	29.23	31.82	32.76	33.44	34.26	35.63	41.87
	Rainfall (mm)	Min	0.00	0.46	1.05	2.27	7.59	18.12	212.77
		Avg	0.00	0.98	2.28	5.83	11.29	22.99	411.55
		Max	0.00	2.29	3.94	7.24	14.44	28.33	854.10
Future (2035-2064)	**Tmin (°C)**	Min	1.4	5.7	6.7	7.4	8.1	9.1	10.8
		Avg	6.7	11.2	12.2	12.9	13.6	14.5	16.4
		Max	17.0	21.3	22.4	23.0	23.6	24.5	26.5
	Tmax (°C)	Min	22.9	25.2	26.1	27.0	27.9	29.4	33.0
		Avg	27.1	29.4	30.3	31.1	32.1	33.4	36.9
		Max	31.0	33.3	34.3	35.1	36.1	37.5	41.1
	Rainfall (mm)	Min	0.0	0.2	1.8	4.9	10.4	22.7	79.4
		Avg	0.0	0.2	2.5	6.4	12.8	26.2	97.9
		Max	0.0	0.3	3.6	8.2	16.1	32.6	121.2

4.2.3 Climate extreme indices

The most critical factors for climate-proofing are the projected changes in the climatic extremes. The projections regarding changes in climate extremes were made based on the ClimPACT2-Tool, which the University of New South Wales developed. The data from the downscaled GCMs of the NASA NEX-GDDP dataset was used as input data to construct climate extremes indices. We included the following extreme climate indices for the median ensemble model under both the RCP 4.5 and RCP 8.5:

- Consecutive dry days (CDD)
- Consecutive wet days (CWD)
- Total annual precipitation (PRCPTOT)
- Daily maximum rainfall (RX1DAY)
- Frosting days (FD)
- Annual maximum daily temperature (TXM)
- Annual minimum daily temperature (TXN)

The projections of changes in climate extremes were carried out for events with return periods of 25, 50, and 100 years. The 50-year and 100-year return periods can be used in the engineering design for a sensitivity analysis to see how the design would hold out for the projected extreme events. The return periods were calculated using the Gumbel distribution related to the extreme value theory. The distribution can be used to calculate the distribution of the maximum of several samples of various distributions. It should be noted that the return periods were calculated separately for both the RCP 4.5 and RCP 8.5 scenarios. Annexe 7 shows all the results regarding each extreme climate index stated above. The following figures show the extreme climate indices for current conditions (1950-2006) and future conditions projected to 2050 (RCP 4.5 and 8.5) for 50 years.

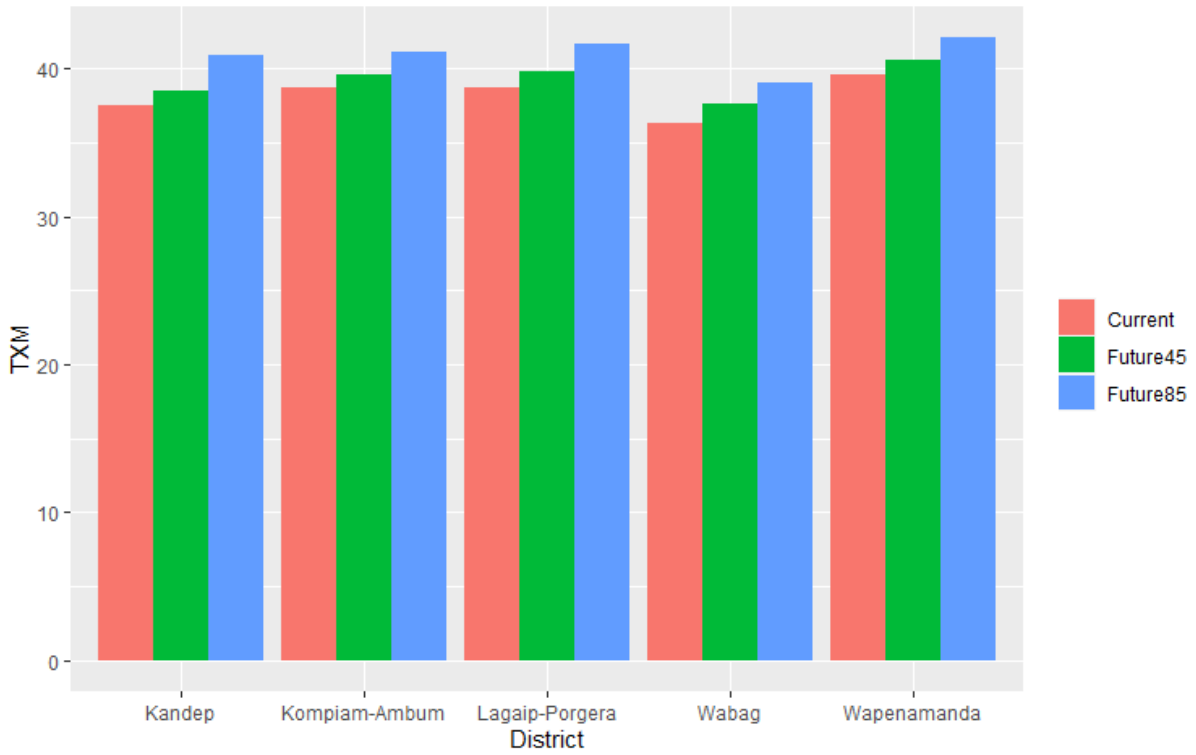


Figure 34. Maximum daily temperature (TXM) in a return period of 50 years in Enga province. This climate extreme index is calculated for current conditions (1950-2006) and projected for 2050 using an ensemble model with two emission scenarios (RCP 4.5 and 8.5)

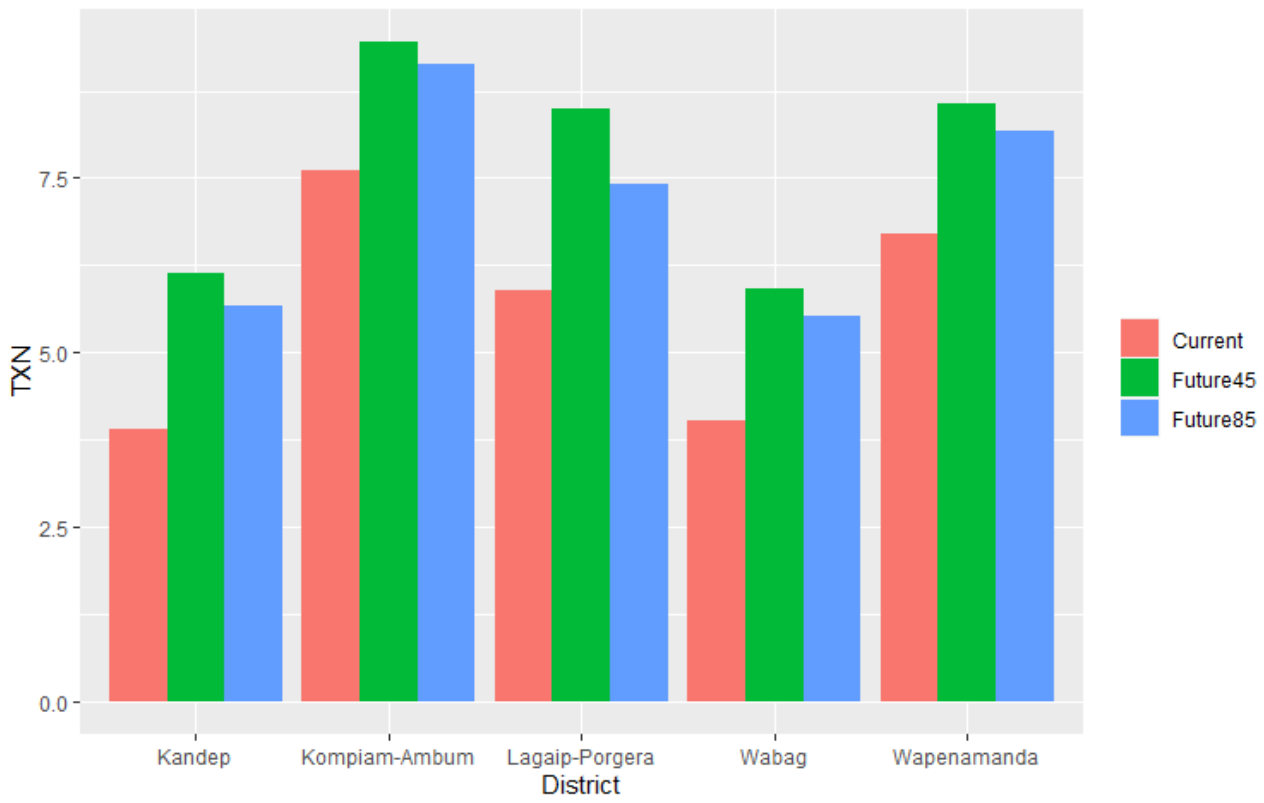


Figure 35. Minimum daily temperature (TXN) in a return period of 50 years in Enga province. This climate extreme index is calculated for current conditions (1950-2006) and projected for 2050 using an ensemble model with two emission scenarios (RCP 4.5 and 8.5)

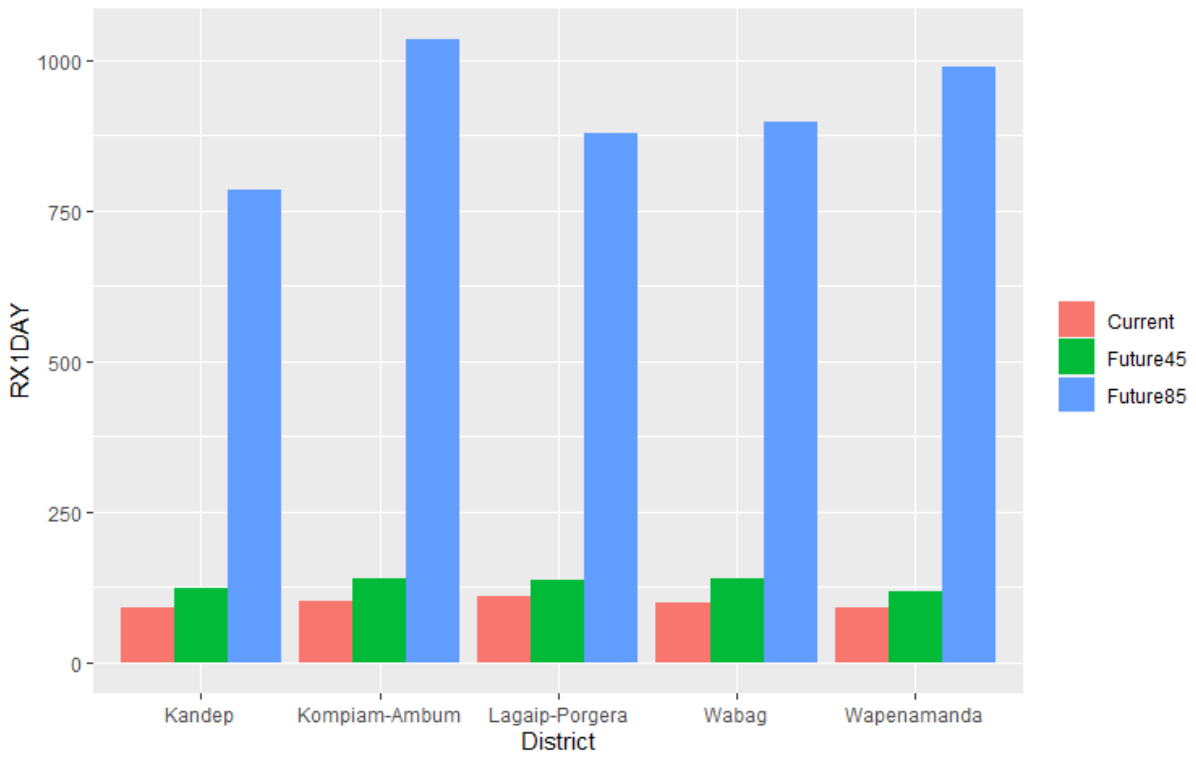


Figure 36. Maximum daily precipitation (RX1DAY) in a return period of 50 years in Enga province. This climate extreme index is calculated for current conditions (1950-2006) and projected for 2050 using an ensemble model with two emission scenarios (RCP 4.5 and 8.5)

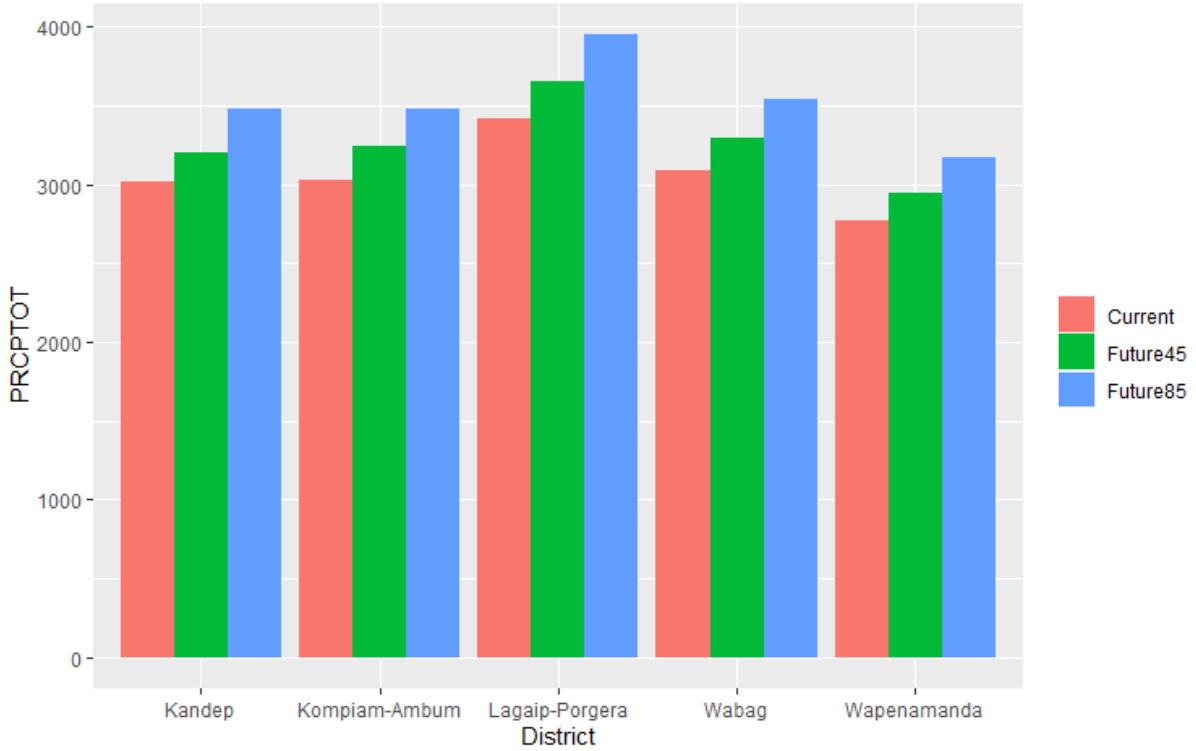


Figure 37. Total precipitation (PRCTOT) in a return period of 50 years in Enga province. This climate extreme index is calculated for current conditions (1950-2006) and projected for 2050 using an ensemble model with two emission scenarios (RCP 4.5 and 8.5)

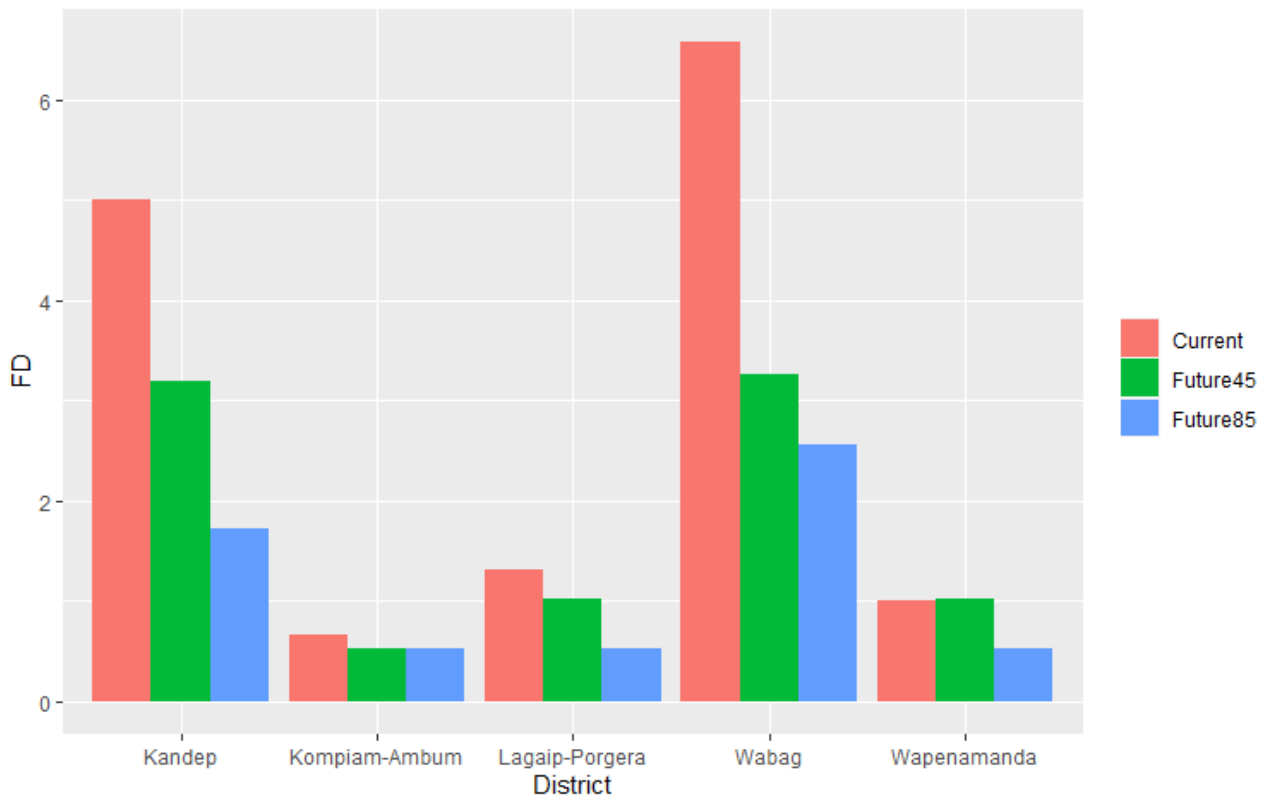


Figure 38. The number of frost days (FD) in a return period of 50 years in Enga province. This climate extreme index is calculated for current conditions (1950-2006) and projected for 2050 using an ensemble model with two emission scenarios (RCP 4.5 and 8.5)

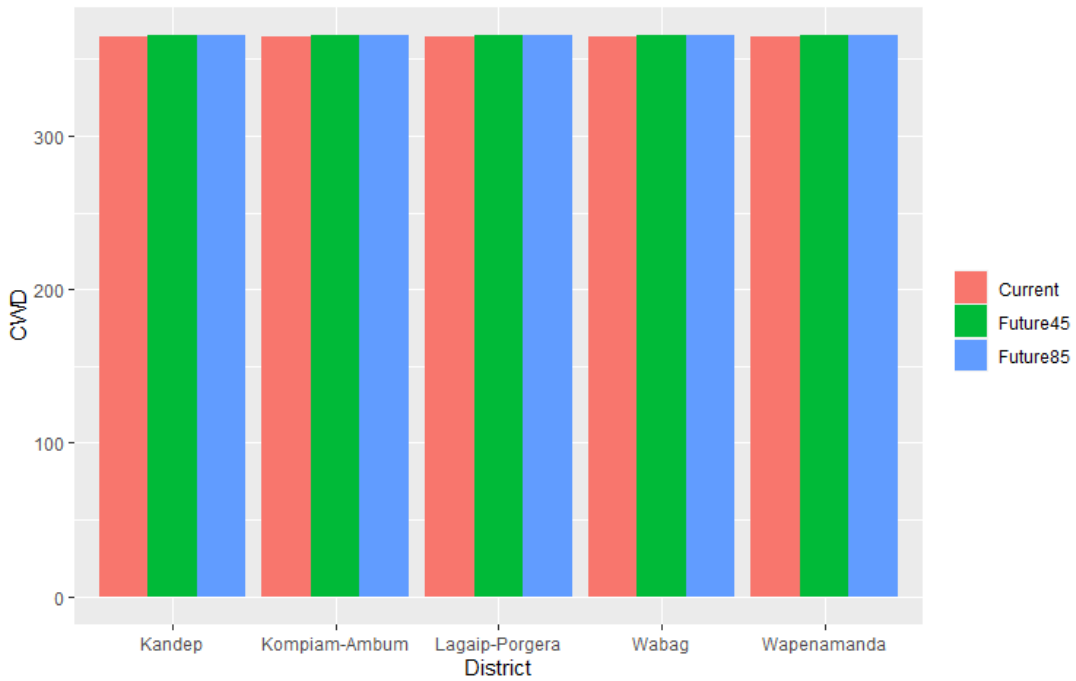


Figure 39. The number of consecutive wet days (CWD) in a return period of 50 years in Enga province. This climate extreme index is calculated for current conditions (1950-2006) and projected for 2050 using an ensemble model with two emission scenarios (RCP 4.5 and 8.5)

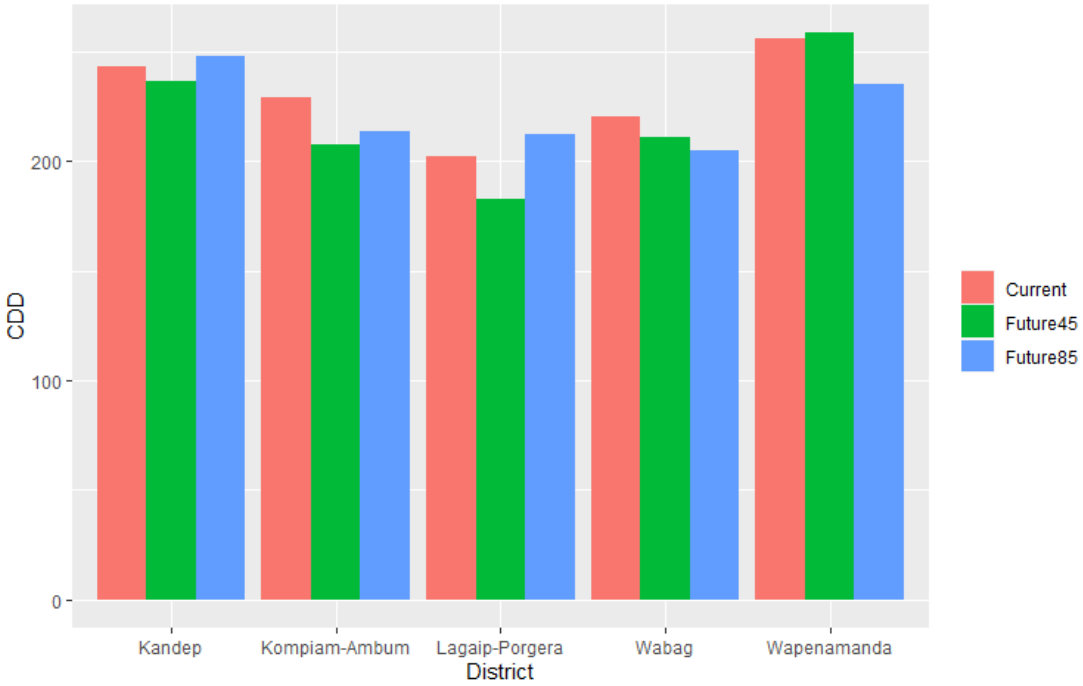


Figure 40. The number of consecutive dry days (CDD) in a return period of 50 years in Enga province. This climate extreme index is calculated for current conditions (1950-2006) and projected for 2050 using an ensemble model with two emission scenarios (RCP 4.5 and 8.5)

In the Wabag district, the consecutive dry days (CDD) will slightly decrease (between 4-7% on average) by 2050 in both an intermediate emission scenario (RCP4.5) and a high emission scenario (RCP8.5). The consecutive wet days (CWD) will remain similar. The yearly total precipitation will also slightly increase by 2050 (7-15% on average) and the maximum daily rainfall (60% on average) in both analyzed emission scenarios. The number of frosting days will decrease (between 50 and 60%) for both emission scenarios by 2050. Finally, both daily maximum and minimum temperatures will also increase.

In the Wapenamanda district, the consecutive dry days (CDD) will slightly increase (1%) by 2050 in an intermediate emission scenario (RCP4.5) but will decrease (6%) in a high emission scenario (RCP8.5). The consecutive wet days (CWD) will remain similar. The yearly total precipitation will slightly increase by 2050 (6-14% on average) and the maximum daily rainfall (30% in an intermediate emission scenario and more than 100% in a high emission scenario). The number of frosting days will decrease (around 50%) for both emission scenarios by 2050. Finally, both daily maximum and minimum temperatures will also increase.

In the Kandep district, the consecutive dry days (CDD) will slightly decrease (3-5%) by 2050 in an intermediate emission scenario (RCP4.5) but will increase (2-7%) in a high emission scenario (RCP8.5). The consecutive wet days (CWD) will remain similar. The yearly total precipitation will slightly increase by 2050 (5-15% on average) as well as the maximum daily rainfall (30% in an intermediate emission scenario and more than 100% in a high emission scenario). The number of frosting days will decrease (between 30 and 60%) for both emission scenarios by 2050. Finally, both daily maximum and minimum temperatures will also increase.

In the Kompian-Ambum district, the consecutive dry days (CDD) will decrease (3-10%) by 2050 in an intermediate emission scenario (RCP4.5) but will increase (5-15%) in a high emission scenario (RCP8.5). The consecutive wet days (CWD) will remain similar. The yearly total precipitation will slightly increase by 2050 (7-15% on average) as well as the maximum daily rainfall (25% in an intermediate emission scenario and more than 100% in a high emission scenario). The number of frosting days will decrease (between 20 and 60%) for both emission scenarios by 2050. Finally, both daily maximum and minimum temperatures will also increase.

In the Lagaip-Porgera district, the consecutive dry days (CDD) will decrease (3-10%) by 2050 in an intermediate emission scenario (RCP4.5) but will increase (4-15%) in a high emission scenario (RCP8.5). The consecutive wet days (CWD) will remain similar. The yearly total precipitation will slightly increase by 2050 (7-16% on average) as well as the maximum daily rainfall (25% in an intermediate emission scenario and more than 100% in a high emission scenario). The number of frosting days will decrease (between 20 and 70%) for both emission scenarios by 2050. Finally, both daily maximum and minimum temperatures will also increase.

4.3 Land-use change emissions in Enga province

The land cover maps of the Copernicus Moderate Dynamic Land Cover project (Marcel Buchhorn et al. 2021) were accessed and extracted for Enga Province for the years 2015 and 2019 (**Figure 41**). The land cover maps were produced by the global component of the Copernicus Land Service, derived from PROBA-V satellite observations and ancillary datasets. The 100-m spatial resolution layers include a main discrete classification with 23 classes aligned with UN-FAO's Land Cover Classification System and quality layers on input data density and the detected land-cover change confidence. For more details, the following links provide more information about the methodological framework of the land cover classification as well as the quality assessment for the years 2015 and 2019, respectively (https://doi.org/10.5281/zenodo.3939050 and https://doi.org/10.5281/zenodo.3939038)

In the PNG Climate Change and Forest Monitoring Web-Portal (Climate Change and Development Authority 2017a), it was possible to visualize a PNG Land-use map for the year 2015, which has a lower spatial resolution than the previously presented maps. Similarly, the spatial resolution is lower than the radiometric and temporal resolution. This means that the amount of land-use classes is lower in the PNG 2015 land-cover map compared to land cover maps of the Copernicus Moderate Dynamic Land Cover project. Finally, a temporal frame is needed for comparison to estimate land-use change and emissions. The PNG Land cover map was only available for the year 2015. Therefore, we used the Copernicus Moderate Dynamic Land Cover project since it has higher spatial (100-m), radiometric (more land-use classes) and temporal (from 2015 to 2019) resolution.

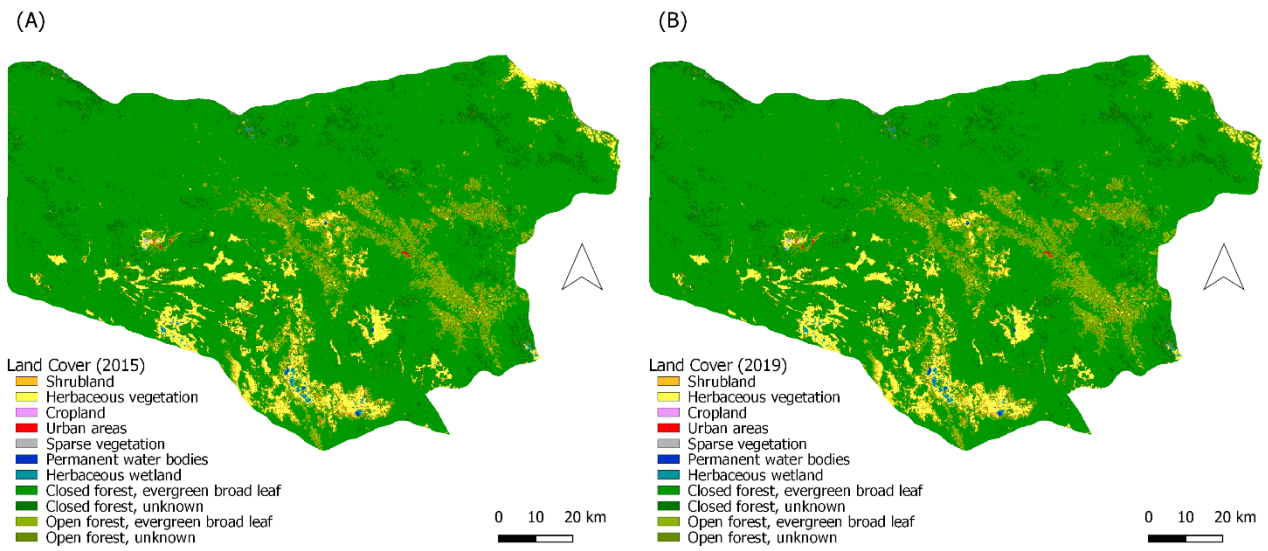


Figure 41. Land cover maps (Marcel Buchhorn et al. 2021) for Enga Province in (A) 2015 (Marcel Buchhorn et al. 2020a) and in (B) 2019 (Marcel Buchhorn et al. 2020b)

Table 17. Land cover definitions.

Land Cover Class	Definition
Shrubland	These are woody perennial plants with persistent and woody stems and no defined main stem being less than 5 m tall. The shrub foliage can be either evergreen or deciduous
Herbaceous vegetation	Plants without persistent stem or shoots above ground and lacking definite firm structure. Tree and shrub cover is less than 10 %.
Cultivated and managed vegetation/agriculture (cropland)	Lands are covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Perennial woody crops will be classified as the appropriate forest or shrubland cover type.
Urban areas	Land covered by buildings and other man-made structures
Sparse vegetation	Lands with exposed soil, sand, or rocks and never has more than 10 % vegetated cover during any time of the year
Water bodies	lakes, reservoirs, and rivers. They can be either fresh or salt-water bodies.
Herbaceous wetland	Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or freshwater
Closed forest, evergreen, broadleaf	tree canopy >70 %, almost all broadleaf trees remain green year-round. Canopy is never without green foliage.
Closed forest, unknown	Closed forest, not matching any of the other definitions
Open forest, evergreen, broadleaf	top layer- trees 15-70 % and second layer-mixed of shrubs and grassland, almost all broadleaf trees remain green year-round. Canopy is never without green foliage
Open forest, unknown	Open forest, not matching any of the other definitions

In the five years (2015-2019), most of the land cover classes decreased (especially forests, grasslands and shrublands) except herbaceous wetlands (**Table 18**).

Table 18. Land cover dynamics in Enga province between 2015 and 2019.

Land cover class	Abb.	Area (ha)		
		2015	2019	Delta
Shrubland	Shr	6369	6141	-228
Herbaceous vegetation	Her	46734	46038	-696
Cropland	Cro	83	81	-2
Urban areas	Urb	299	304	5
Sparse vegetation	Spa	23	209	-21
Permanent water bodies	Wat	289	320	31
Herbaceous wetland	Wet	3033	5307	2274
Closed forest, evergreen broad leaf	Cfd	761434	761212	-222
Closed forest, unknown	Cfu	51274	50543	-731
Open forest, evergreen broadleaf	Ofd	60153	60196	43
Open forest, unknown	Ofu	42800	42347	-453

Table 19. Land cover dynamics in Enga Province between 2015 and 2019

* LULC refers to Land Use / Land Cover Chan

LULC in 2015	LULC in 2019										
	Shr	**Her**	**Cro**	**Urb**	**Spa**	**Wat**	**Wet**	**Cfd**	**Cfu**	**Ofd**	**Ofu**
Shrubs (Shr)	6132	13	0	0	0	0	215	0	2	2	5
Herbaceous vegetation (Her)	9	45886	0	2	0	0	648	0	1	34	154
Cropland (Cro)	0	0	80	0	0	0	3	0	0	0	0
Urban areas (Urb)	0	0	0	299	0	0	0	0	0	0	0
Bare / sparce vegetation (Spa)	0	0	0	0	209	6	15	0	0	0	0
Permanent water bodies (Wat)	0	0	0	0	0	271	18	0	0	0	0
Herbaceous wetland (Wet)	0	4	0	0	0	36	2993	0	0	0	0
Closed forest, evergreen broad leaf (Cfd)	0	0	0	0	0	0	167	761185	50	3	29
Closed forest, unknown (Cfu)	0	7	0	0	0	0	604	13	50486	4	160
Open forest, evergreen broad leaf (Ofd)	0	7	0	1	0	0	5	7	0	60126	7
Open forest, unknown (Ofu)	0	121	1	2	0	7	639	7	4	27	41992

Table 20. Land cover dynamics and carbon stocks in Enga Province between 2015 and 2019.

Land cover	Total carbon (t C ha^{-1})*	Area difference (ha)	Carbon balance (t C)
Shrubland	13.5	-228	-3078
Herbaceous vegetation	3.4	-696	-2366.4
Cropland	4.13	-2	-8.26
Urban areas	0	5	0
Sparse vegetation	3.7	-21	-77.7
Permanent water bodies	7.9	31	244.9
Herbaceous wetland	3.7	2274	8413.8
Closed forest, evergreen broad leaf	82.4	-222	-18292.8
Closed forest, unknown	82.4	-731	-60234.4
Open forest, evergreen broadleaf	47.8	43	2055.4
Open forest, unknown	47.8	-453	-21653.4
Total			**-94996.86**

* Estimate values from (Mauya et al. 2019)

4.4 Capturing CO_2 through forest plantations

Tree plantations in the Pacific region have reported varied biomass and carbon sequestration rates. For instance, tree plantations can produce 10-40 m^3 biomass per hectare per year. In a conservative scenario of 10 m^3 ha^{-1} $year^{-1}$ and the use of a medium-density tree species (density of 500 kg m^{-3}), it would be possible to capture five tones (t) of biomass ha^{-1} $year^{-1}$ representing approximately 2.25 tC ha^{-1} $year^{-1}$ or 8.325 tCO_2 captured ha^{-1} $year^{-1}$(1tCO2 is equivalent to approximately 3.7 tC). Even though it could be possible to have more productive forest plantations in Enga Province due to the suitable climatic conditions, no specific studies have been found. Therefore, in a conservative scenario (depending on the purpose of the forest plantations), we are assuming biomass rates of 10 m^3 ha^{-1} $year^{-1}$.

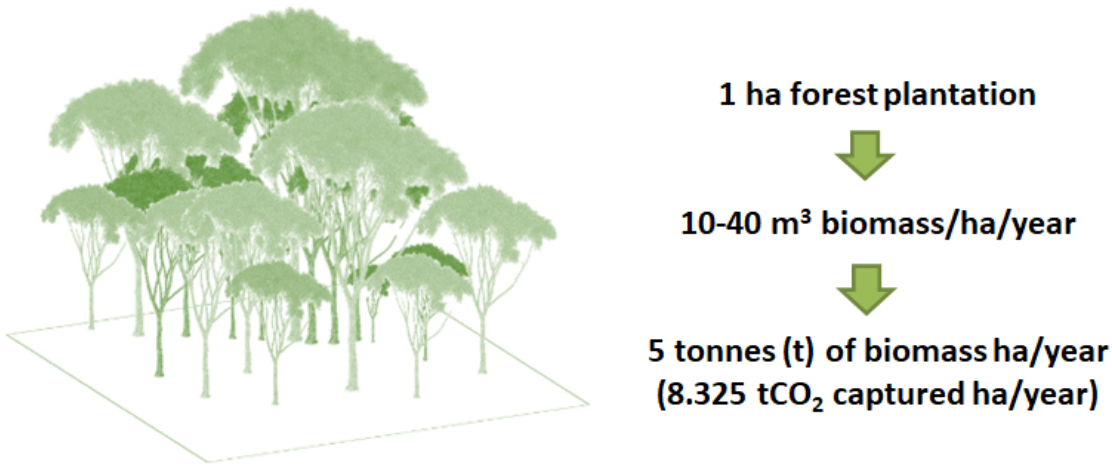


Figure 42. Scheme of CO2 capture through forest plantations

5 INSTITUTIONAL AND GOVERNANCE ANALYSIS

5.1 Institutional stakeholders in Enga province

There are different institutions directly or indirectly involved in climate change adaptation and mitigation issues in Enga province. The list below presents some of the most relevant institutions for the current climate change feasibility study in Enga:

Enga ***Provincial Authority (PA)*** is the main institution that decentralized government decisions in Enga, including agriculture, fishing, trade and industry, land and land development, forestry and natural resources. Provincial governments also have certain limited powers to raise revenue, including the right to impose sales and services tax, subject to certain conditions.

The ***Climate Change and Development Authority (CCDA)*** is the leading institution that coordinates the Climate Change efforts of the Government of Papua New Guinea. CCDA has four divisions: (i) Corporate Services, (ii) Adaptation and Projects, (iii) REDD+ and Mitigation, and (iv) Measurement, Reporting and Verification (MRV) and National Communication.

The ***National Disaster Centre (NDC)*** is part of the Provincial & Local Level Government Affairs Department. It provides the necessary and appropriate disaster management services to the people of Papua New Guinea. There are two divisions at NDC: Risk Management (RM) and Community Government Liaison (CGL). The Risk Management Division deals with pro-active matters through research, analysis, awareness, education and training, whilst the Community Government Liaison handles rapid response and operations. Similarly, NDC has Provincial Disaster Centres, including Enga. Under emergencies, the Provincial Disaster Relief Committee (PDRC) might also conduct disaster situational assessments.

The ***National Research Institute (NRI)*** aims at providing quality research which contributes to evidence-based public policies and decision-making processes that improve service delivery, leading to a better quality of life for all Papua New Guineans. NRI has eight research programs: (i) Building Safer Communities Program, (ii) Development Indicators Program, (iii) Economics Policy Program, (iv) Gender in PNG Program, (v) Governance Program, (vi) Informal Economy Program, (vii) Sustainable Land Development Research Program and (viii) Education Research Program.

The ***Department of Agriculture and Livestock (DAL)*** is the lead government agency responsible for managing the agriculture sector in Papua New Guinea. It is divided into three deputy secretary sections: (i) Provincial Agriculture Technical Services, (ii) Corporate Services and (iii) Policy. Under the Deputy Secretary of Provincial Agriculture Technical Services, there are 4 (Southern Region, Highlands Region, Island Region, Northern Region) Provincial and Industry Support Services (P&ISS)

The ***Papua New Guinea Forest Authority (PNGFA)***, part of the ***Department of Forestry***, is the government body responsible for monitoring and controlling the wood and forest-based industries and managing PNG's forest resources. There are three critical arms of the forestry administration of PNG: (i) the National Forest Board, (ii) Provincial Forest Management Committees and (iii) the National Forest Service.

The ***Conservation and Environment Protection Agency (CEPA)*** ensures that natural and physical resources are managed to sustain environmental quality and human well-being. The roles of CEPA include Environment management policy development, Biodiversity protection policy development, Pollution control and the regulation of hazardous substances, Management of Water Resources, Environmental Impact Assessments, Biodiversity assessment and data management, Hydrological investigation, data collection and analysis, Coordination of donor-funded programs and Education & Awareness.

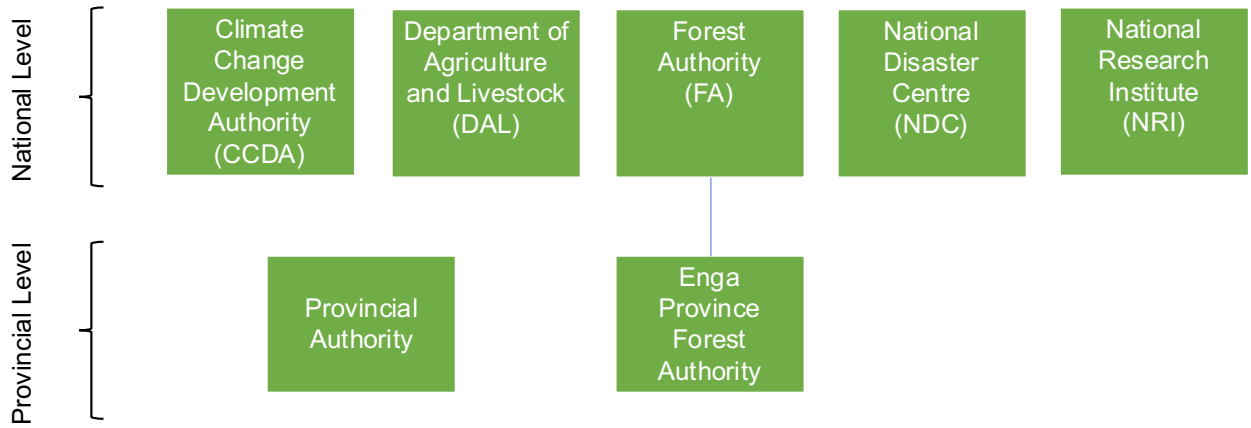


Figure 43. Relevant national and provincial level institutions

5.2 Institutional and governance necessities and opportunities

After discussions with provincial authorities in Enga Province, the consultant team identified institutional and governance gaps. The main struggles stated during the consultation were:

(i) lack of funding ("*Funding is an obstacle that hinders our work to be flexible to work closely with our rural communities*", "*Currently funding is a major issue, we have budget constraints, new projects to implement and our budget is cut down due to Pogera shut down*"),

(ii) lack of manpower ("*The main critical issue to implement the project is short of manpower at the Provincial Level*", "*We also have capacity issues at the Provincial Level that is not enough manpower*"),

(iii) Lack of capacity building and training on climate change and biodiversity issues. Provincial-level authorities could provide technical assistance to resource owners and increase extension services to remote villages by having more resources.

5.2.1 Lack of funding and budget constrains

The provincial economy in Enga is directly linked to the mining industry. The currently closed Pogera mine, which has been one of the primary revenue sources of Enga Provincial Authority (EPA), has an important impact on the provincial budget. This is due to revenues and direct and indirect employment to many local people in Enga. This represents an opportunity to diversify the economy at the provincial level in the long term. Shorter-term opportunities could be seeking technical and capacity support for other organizations, including NGOs, international donors and financial institutions.

5.2.2 Lack of manpower

Linked to lack of funding, the provincial authority and the Enga Forest Authority currently experience a lack of manpower. A key component in reaching out to local communities is extension activities related to agriculture, livestock and forestry. During interviews with local communities and government institutions, the lack of extension activities and technical support to communities was mentioned several times.

5.2.3 Lack of training and capacity building

Provincial-level authorities could provide technical assistance to resource owners and increase extension services to remote villages by having more resources. Similarly, data access and data transfer are hindered by unstable internet connections in the province and a lack of online and digital databases at the institutional government level. Implementing digital databases would improve data flow and facilitate and speed up specific processes.

New and existing agricultural techniques and technologies play vital roles in climate risk management. Technologies relevant to climate change adaptation include improved seed and crop varieties that can tolerate or are resistant to drought, heat, salt, insects or pests. New technology is essential, but farmers already possess valuable knowledge and seed varieties, and local and traditional knowledge of crop management and ecosystem services can support adaptation to climate change by marginal rural and indigenous communities. The value of local innovations that do not need external inputs should not be underestimated because they can easily be scaled up in similar ecosystems. Promoting, revitalizing and scaling up existing technologies and strengthening the deployment of new ones is a straightforward pathway for scaling up because when technologies are successful, they are spontaneously taken up by the private sector (IFAD 2015).

6 REVIEW OF CURRENT PROVINCIAL DEVELOPMENT PLANS

6.1 Previous development plans

For the Agriculture and Livestock branch, the strategic direction for Enga from the 2011-2015 development plan was to develop and grow the agriculture sector (food crop, cash crop and livestock), manufacturing, forestry, inland fisheries and eco-tourism sectors. Key areas on which the plans focused were: (i) Promotion of household food security and commercial food crops through expanded smallholder productions, (ii) Development of commercial cash crops using high potential agricultural land, (iii) Land rehabilitation and land tenure reform for poor households and new commercial farming enterprise.

For the Commerce branch, the five-year development plan from 2011-to 2015 was to redirect profits from non-renewable resources into supporting agriculture, forestry, tourism and inland freshwater fisheries. The aim is to grow and expand commercial activities and industry in the five districts. Key areas that the plans focused on were (i) Promoting local economic empowerment through small business development and community-based tourism initiatives. Contribute to GDP growth through increased job creation, redistribution and transformation using tourism and improving seasonality patterns; (ii) promote and maintain cultural education.

For the community development branch, the key areas of focus in the 2011-2015 Development Plans were: (i) Create partnerships between NGOs, donor agencies, churches, CBOs, and private companies for the community development sector, (ii) Mobilise youth and women's group to address law and order and social problems affecting communities and ambitions to curb tribal fighting in the province, (iii) Mobilize women and youth to participate in development programs, township clean-up and economic projects for rural areas. (iv) Ensure Gender equality and equity in community-based activities, and (v) improve village people's social security and harmony.

6.2 Ongoing development plans

During the scoping and field survey phase, the consultant team requested provincial development plans for Enga. The consultant team was informed that the Enga Strategic 2022-2030 development plan is still being drafted, so it could not be fully incorporated and analysed in the present report. Nevertheless, some components of this development plan are discussed during discussions with provincial authorities. The following table presents some findings regarding the upcoming provincial development plan (2002-2030) under different development sectors.

Table 21. Some preliminary components of Enga's Provincial Development Plan (2022-2030)

Priority sectors/areas	Initiatives
Forestry / Biodiversity	- Implementation of REDD+ activities at the provincial level - Giving out tree seedlings to all farmers to plant along the river Lai together with the Department of Forestry (as natural barriers against flooding events) - Giving women tree seedlings to make a nursery to start tree planting - Community engagement to make a nursery for the seedlings of trees (*Eucalyptus*)
Energy	- Promotion of solar energy initiatives - Implementation of hydroelectric power plants in all Enga districts - Feasibility study regarding whether Lomban hydroelectric plant in Wabag can power the new hospital being built
Agriculture and Livestock / Food and Nutrition Security	- Crop rotation and integrated cropping - Poultry Processing Plan to encourage households to go into chicken raising - Support increase of fallow arable land - Introduction of new "kaukau" and sweet potato vine to farmers to breeding crops in less time - Issuing new corn seedlings to farmers - Supply of seedlings to farmers - Create an SME revolving finance to assist farmers in increasing the production and quality of livestock and cash crops. - Establish livestock and cash crop seedling distribution centres - Establish base camps for plant breeding and variety trials for smallholder farmers - Support coffee production - Support water harvesting and irrigation - Improve access to land for agriculture - Increase expenditure on extension services and agriculture research base camps and training to help smallholder farmers - Building food storage facilities (food/vegetable depots) and processing facilities to improve food security - Enhancing agroforestry to support food security - Promote food security through expanded smallholder village base productions - Establish soft finance as seed money for helping smallholder farmers to start agribusiness enterprise - Support SMART Family Business approach developed by the Community Development Branch of Provincial Authority to create enabling environment for resilient communities to improve food security and farming methods and to address law and order issues in the wards by networking with different actors and other branches of Enga Provincial Government

During conversations with provincial authority stakeholders, it was stated that the vision of Enga is to "*be a place of strong, healthy and safe communities able to provide for the social and economic*

well-being of its people while sustaining its unique culture, language and environment". Similarly, the strategic plan includes eight key principles of action to support the vision:

- Partnerships
- An inclusive and tolerant society
- Environmental stewards
- Effective and efficient Enga Provincial Administration
- Growing Financial Self-sufficiency
- Awake to the transition from traditional to modern
- Leverage natural and human resources for long term prosperity
- Enga Provincial Government and Administration the driving force of change

The plan recognises the need for five (5) strategic game-changers: (i) law and order, (ii) climate change, (iii) jobs and skills development, (iv) access to renewable electricity and water, and (v) financing for development. To achieve Enga's vision, twenty (20) strategic initiatives were chosen

Table 22. Enga Strategic Initiatives (Enga Provincial Administration 2022)

Topics	Strategic initiatives
Governance and Administration	1. Create and maintain Law and Order in Enga
	2. eEnga
	3. Improve Public Service Delivery
	4. Donor and development partner support
	5. StepUp! Enga Project Implementation Unit (PIU)
Environmental Sustainability	6. National Electricity Grid Supplied by Enga Hydropower and Renewable Energy Powe Stations
	7. Solar Household & Farm Pumps
	8. Climate Resilient Green Growth Projects
Social and Community	9. Improved Health Outcomes
	10. Sustainable Population Growth
	11. Tourism Ramp Up
	12. Tertiary and Vocational Education Excellence
	13. Improved Early Childhood, Junior and High School Outcomes
	14. Harmonise Local. District and Provincial Planning and Implementation
Economy and Infrastructure	15. 70% Access to Electricity and Water
	16. Enga Infrastructure Facility
	17. Commercial Agriculture
	18. Enga SME and Agribusiness Microfinance Facility
	19. Boosting Employment
	20. Enga Business, Investment and Trade Office

Strategic Initiative 8 (Climate Resilient Green Growth Projects) is directly linked to the scope of this report (Feasibility Studies on Improved Climate change mitigation and adaptation in Enga province). The main actions under this initiative include (i) sustainable forests (REDD+) and sustainable landscape, (ii) climate-smart agriculture, (iii) water conservation and access, (iv) green industries and jobs, (v) green infrastructure, transport, energy and buildings and (vi) cross-cutting inclusive green growth interventions.

7 RECOMMENDATIONS

An essential aspect of the "Improved climate change mitigation and adaptation" component is related to developing policies and strategies. It is recommended that provincial development plans include climate change mitigation and disaster risk management. Similarly, it is recommended that plans and guidelines on sustainable land-use management are included in provincial development plans. The agriculture sector and food security are key in Enga, especially considering climate change's current and future effects and impacts. Therefore, we recommend that management plans for economically and traditionally important tree species are drafted, such as "karuka" (*Pandanus julianetti*), "kapiak" (*Ficus dammaropsis*) and "breadfruit" (*Artocarpus altilis*). These species provide habitat and food for fauna and are also crucial for food security and economic support in Enga.

The main climate change phenomena that will derive in impacts in Enga province are (i) rise in temperatures and (ii) changes in rainfall patterns. Based on our climate change modelling findings, floods and landslides will likely increase in a spatially differentiated manner throughout Enga province by 2050. Therefore, it is recommended to derive flood and landslide risk maps in Enga to identify and prioritize jurisdictions and further develop disaster risk management plans. Potential disaster risk management plans include revegetation of riverbanks within flooding areas and revegetation of mountain tops with high slopes where vegetation or forest cover has been removed. Different bamboo species (*Guadua spp*) are currently used and propagated in Enga province mainly for construction purposes. Bamboo species tend to have high growth rates and are suitable in areas with water accessibility, such as riverbanks. Another potential practice to be further developed is the creation of practical drainage systems in agricultural areas when storm events and high precipitation occur in a short period of time.

After discussions with provincial authorities in Enga Province, the consultant team identified institutional and governance gaps. The main struggles stated during the consultation were: (i) lack of funding, (ii) lack of manpower and (iii) lack of capacity building and training on climate change issues. Provincial-level authorities could provide technical assistance to resource owners and increase extension services to remote villages by having more resources. Hence, it is recommended that provincial authority's capacities be strengthened in cross-cutting issues such as climate change. Similarly, it is recommended that different provincial and district stakeholders receive training in climate change issues and land-use planning. Communities should also be aware of the impacts of climate change on livelihoods. Therefore climate change issues should be mainstreamed to men and women of the different districts in Enga province.

For the estimates of land-use change emission, we used available reference values (Cauya et al., 2019). We acknowledge that accurate carbon reference data should be provided in order to properly estimate the carbon balance due to land-use change (Vincent et al., 2015). GoPNG has advanced significantly in estimating carbon reference levels for forest ecosystems (Government of Papua New Guinea 2017) but not for all land cover or vegetation classes. For future estimates, it is recommended to use, if existing, primary calculations of carbon stock per land-cover type. Similarly, Enga province must have maps of high conservation value (HCV) and high carbon stock (HCS) areas. We recommend accessing the following datasets currently visually available but not downloadable from

the PNG Climate Change and Forest Monitoring Web-portal: (i) HCV probability map, (ii) above ground biomass carbon map, (iii) soil organic carbon map and (iv) accessibility. The methodological framework of these available layers should as well be made accessible in order to follow and adapt the same methodology but at the provincial level in Enga.

We accessed the PNG Land-cover map for the year 2015. Nevertheless, it is outdated, and higher resolution maps will be required at the provincial level. We used the Copernicus Moderate Dynamic Land Cover project since it has higher spatial (100-m), radiometric (more land-use classes) and temporal (from 2015 to 2019) resolution. Nevertheless, it is recommended that these maps are validated in the field for more detailed studies at the provincial level. Similarly, we recommend carrying out participatory campaigns on land-use cover classification, where different stakeholders participate (e.g. forest authority, UNDP, provincial authority and members of local communities).

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