Assessment Report of the Impact of Climate Change on Timor Leste's Coffee Value Chain

Final Report

Prepared for Australia Pacific Climate Partnership Support Unit

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Acronyms

ADB – Asian Development Bank
Ai-Com - Agricultural innovations for communities for intensified and sustainable farming systems in Timor-Leste
APCP - Australia Pacific Climate Partnership
CCT – *Cooperativa Café Timor*
CIFC - *Centro de Investigação das Ferrugens do Cafeeiro* (Coffee Leaf Rust Research Centre, Portugal)
CLR – Coffee Leaf Rust
COP – Conference Of Parties
DFAT – Department of Foreign Affairs and Trade
FAO – Food and Agriculture Organisation
FCOTI - FUNDAÇÃO CARBON OFFSET TIMOR (National Carbon Foundation)
GCF – Green Climate Fund
GDS – General Directorate of Statistics
GHG – Greenhouse Gas
HdT - *Hibrido de Timor*
IPCC – Intergovernmental Panel on Climate Change
MALFF – Ministry of Agriculture, Livestock, Forestry and Fisheries
MDF – Market Development Facility
MFAT – Ministry of Foreign Affairs and Trade (New Zealand)
NCSDP - National Coffee Sector Development Plan Timor-Leste 2019-2030
PNDS – *Programa National Desenvolvimento Suco* (National Village Development Program)
RDTL – *Republica Democratica de Timor-Leste*
UNDP – United Nations Development Program
UNEP – United Nations Environment Program
UNFCCC - United Nations Framework Convention on Climate Change

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Executive Summary

Coffee is Timor-Leste's most important non-oil export and is a significant source of livelihood for almost 20% of Timor-Leste households. Despite Timor-Leste having contributed a miniscule amount (less than 0.003%) of the greenhouse gas emissions that cause global climate change, the impact of climate change on the coffee sector in Timor-Leste is likely to be very severe and efforts to improve the climate resilience of the sector will need to be made.

This assessment report has been produced by the Australia Pacific Climate Partnership in collaboration with the Australian Government funded Market Development Facility to support the coffee sector in Timor-Leste to better understand how climate change may impact the coffee sector and to develop strategies to adapt to these impacts. The report also incorporates key findings and analysis from a separate, more technically detailed, climate projections report commissioned by the Australia Pacific Climate Partnership - *Future climate change scenarios and implications for coffee cultivation in Timor-Leste* (Magee, 2023).

Arabica coffee is grown in the upland high-altitude areas of Timor-Leste, mostly by smallholder farmers with less than one hectare of land. Coffee growers are concentrated in the municipalities of Ainaro, Ermera, Aileu with smaller numbers in the high-altitude areas within Manufahi, Bobonaro and Liquiçá. Average yields are less than 200kg per hectare which is less than a quarter of the global average. Households that sell coffee are poor, even poorer than the national average (48% of households compared to 40%) (Inder and Qu 2019).

Recent developments indicate that the coffee sector is starting to improve and there is significant potential for development of the sector. A key initiative currently guiding the strategic development of the coffee sector in Timor-Leste is the National Coffee Sector Development Plan 2019-2030, developed in partnership between the Asian Development Bank, the Ministry of Agriculture, Livestock, Forestry and Fisheries and a broad range of coffee sector stakeholders in Timor-Leste. One of the goals of this plan is to increase the value of coffee exports by 270% by 2030.

Climate change impacts have the potential to significantly curtail these nascent improvements and ambitious goals in the coffee sector. Arabica coffee grows in a narrow band of temperature with an optimal annual temperature range of 18-21°C. In Timor-Leste this occurs in the elevation range from 1000 to 1550 m above sea level (ADB 2020). Consistent with global trends, future warming is expected across Timor-Leste with a high degree of certainty. Projections for warming scenarios indicate increases in air temperatures in both a low emissions future (increase by ~1.1°C by 2050) and a high emissions future (increase of 1.8°C by 2050) (Magee 2023). This is likely to push the low end of altitude with optimal annual temperature to around 1200 m above sea level.

Increased temperatures driven by climate change is expected to lead to an up to 50% reduction in the overall area suitable for arabica growing in Timor-Leste by 2050. Modelling carried out for this study indicates that this reduction will be less in Municipalities with more high altitude areas (such as Ainaro, which is expected to have a similar suitable area to what it currently has) and more significant in areas that have small areas of high altitude (such as Liquiçá which is expected to have reductions of between 61% and 77% by 2050. The

table below summarises the projected changes in each of the main coffee growing municipalities of Timor-Leste.

Coffee growing areas with declines in areas of suitability for growing arabica (adapted from Magee 2023)

Municipality	Baseline (1970-2000) % of area suitable	(Low emissions future - 2050)		(High emissions future - 2050)	
		% of area suitable	% reduction from baseline	% of area suitable	% reduction from baseline
Aileu	91.3	77.7	15%	63.9	30%
Ainaro	47.5	47.7	+0.02%	47.6	+0.01%
Bobonaro	33.7	22.3	34%	16.1	52%
Ermera	72.9	65.8	10%	57.2	22%
Liquiçá	33.7	13.3	61%	7.9	77%
Manatuto	38.3	24.8	35%	17.3	55%
Manufahi	36.6	24.5	33%	18.9	48%
Timor-Leste	**33.2**	**22**	**34%**	**16.6**	**50%**

Other impacts of climate change to which the coffee sector in Timor-Leste is vulnerable include increased frequency of extreme rainfall events leading to soil erosion; increased temperatures leading to declines in soil moisture; increases in the spread of pests and diseases such as coffee leaf rust and coffee berry borer. Climate change is also likely to cause challenges to post-harvest activities such as drying of coffee beans which can be disrupted by increased humidity. A key challenge for the coffee supply chain is rural roads which transport coffee to market. These will need to be designed and built to climate resilient standards to cope with increased risk of landslides from extreme rainfall events.

The Timor-Leste coffee sector can build resilience in the face of these pressures through a range of measures. These will require engagement from all stakeholders in the coffee value chain. The National Coffee Sector Development Plan provides a good framework to guide this development. Climate resilience measures would readily align with the existing plan and should be integrated at the earliest opportunity. Some key recommendations included in this report include:

Strengthen research and development capacity – this should include field research and testing capacity for coffee leaf rust and coffee leaf rust resistant plants as well as research on climate resilient arabica varieties that can maintain yield in warmer temperatures.

Integrate climate resilient agriculture practices into existing arabica coffee production – the National Coffee Sector Development Plan includes a focus on rejuvenation of poorly managed coffee plantations. This includes activities consistent with climate resilient agriculture practices such as terracing on steeper slopes to reduce erosion; mulching and composting to improve soil nutrition and soil moisture retention. The overall focus of rejuvenation is consistent with a climate resilience approach but a key element of climate change consideration is missing - targeting rejuvenation efforts at areas that will remain suitable for arabica cultivation in the long term. Based on climate change analysis that informs this report, a reasonable estimate is that by 2050 areas below 1200m asl will no longer be optimal for arabica production and these areas should transition to other cash crops, including robusta coffee.

Promote crop diversification for smallholder coffee farmers – in the long term, coffee farmers on plantations below 1200 m above sea level should be encouraged and supported to switch to robusta or another cash crop more suited to a changing climate in that location.

Diversification can also be a strategy to mitigate risk from vulnerabilities from growing a single crop and should also be encouraged in areas deemed suitable to continue arabica for the long term.

Strengthen the coffee sector enabling environment – smallholder coffee farmers have little or no access to finance and the National Coffee Sector Development Plan identifies working with financial service providers to offer pre-harvest credit and access to micro-savings accounts. Additional finance to support smallholder coffee farmers may be able to be accessed through climate finance mechanisms such as the Green Climate Fund and the newly created Loss and Damage Fund (via development agency intermediaries).

Other enabling factors that can help build the resilience of smallholder coffee farmers in Timor-Leste include access to early warning systems and access to insurance.

1. Introduction

Coffee is Timor-Leste's most important cash crop and the largest earner of export income after oil and gas revenue. Coffee accounts for up to 90% of Timor-Leste's annual non-oil merchandise exports since independence. Arabica makes up approximately 90% of coffee production by value with robusta making up the remaining 10% (ADB 2019). The value of coffee exports in 2021 was USD 27.6 million (GDS 2022). By comparison, the next largest non-oil export commodity was Konjac (*Amorphophallus konjac*) which generated just USD 1.57 million in 2021 (GDS 2022).

Timor-Leste's contribution to the causes of climate change has been minimal with current national emissions equivalent to 0.003% of global emissions (RDTL 2022). Coffee production itself in Timor-Leste is mostly based on an agroforestry system that is likely carbon positive (absorbs more CO^2 than it produces) (de Araujo *et al* 2023). Despite this practically non-existent contribution to causing the problem of global warming, climate change is expected to significantly impact the coffee industry across Timor-Leste. Most significantly, increasing average annual temperatures across Timor-Leste indicates a 33% to 50% overall decrease in areas suitable for arabica coffee production by 2050. This reduction will not be evenly spread between coffee growing municipalities, with Liquiçá expected to have a decline of up to 76% by 2050 while the total area suitable in Ainaro is expected to remain stable due to its higher elevation. Other impacts of climate change are expected to be an increase in the frequency and severity of extreme rainfall events, and an increase in the spread of pests and diseases that affect coffee. Strategies for adapting to these changes is a key focus of this report.

This assessment report has been produced by the Australia Pacific Climate Partnership (APCP), in collaboration with the Market Development Facility (MDF) to support the coffee sector in Timor-Leste to better understand how climate change may impact the coffee sector in Timor-Leste and also develop strategies to adapt to these impacts. The report has been based on a desk review of relevant literature as well as consultations with stakeholders in the Timor-Leste coffee sector. The report also incorporates key findings and analysis from a separate climate projections report commissioned by the APCP - *Future climate change scenarios and implications for coffee cultivation in Timor-Leste* (Magee, 2023).

2. Coffee in Timor-Leste

2.1 Socio-economic context

Arabica coffee is mostly grown in the upland high-altitude areas (marked in dark brown in the map at Figure 1 below). These areas are 900m asl and are concentrated in the Municipalities of Ainaro, Ermera, Aileu with smaller high-altitude areas in Manufahi, Bobonaro and Liquiçá. These six upland Municipalities account for around 97% of total coffee production in Timor-Leste (ADB 2019).

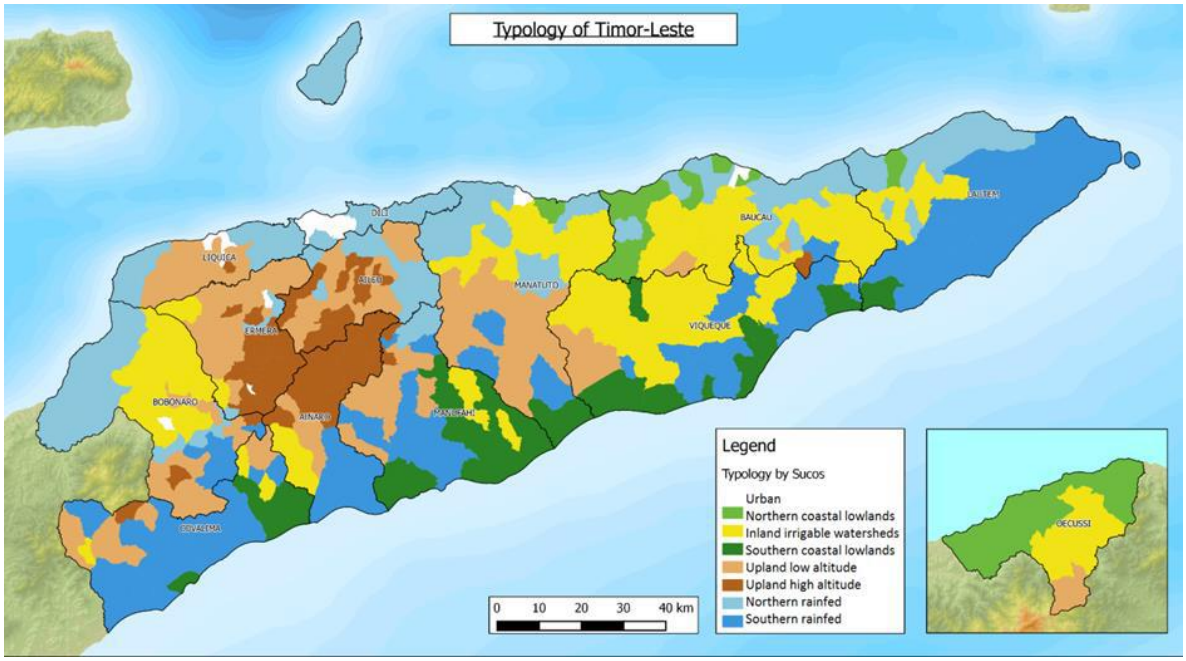

Figure 1 Map of livelihood zones in Timor-Leste

Coffee is grown as a cash crop by over 75,000 households which is 18.9% of all households in Timor-Leste (ADB 2019), though the bulk of production is concentrated in just a few municipalities. In the major coffee growing municipalities of Ermera, Aileu and Ainaro up to 44% of households grow coffee for cash. Most of these households grow coffee on very small plots of land with 62% of households producing on less than one hectare of land, and 95% of all coffee producing households produce coffee on less than 5 hectares of land. Coffee yields in Timor-Leste are very low with an average yield of less 200kg of coffee beans per hectare which is less than a quarter of the global average of 880 kg (MDF 2023). Many coffee selling households live in poverty with higher levels of poverty (47.9%) compared to the national average (40.3%) (Inder and Qu 2019).

Despite these rates of poverty, there is possibly greater potential for economic improvement in coffee selling households than there is in other rural households that don't sell coffee. Inder and Qu (2019) calculate that the poverty rate in coffee selling households would reduce from 47.9% to 28.4% if coffee income could be doubled. As noted already the productivity of Timor-Leste coffee farmers is extremely low with yields per hectare of less than a quarter the global average. Just improving yields per hectare to half the global average would equate to a doubling of coffee income.

There is significant potential for the coffee sector in Timor-Leste to be a greater component in the Timor-Leste economy. Realising this potential will require significant focus on the part of government, donors and the whole of the coffee sector. A key initiative currently guiding the strategic development of the coffee sector in Timor-Leste is the National Coffee Sector Development Plan (NCSDP) 2019-2030, developed in partnership between the Asian development Bank (ADB), the Ministry of Agriculture, Livestock, Forestry and Fisheries (MALFF) and a broad range of coffee sector stakeholders in Timor-Leste. The NCSDP has a goal of a 270% increase in export income from coffee by 2030 but the NCSDP. also identifies a number challenges and capacity constraints that hinder the performance of the coffee sector including: low and volatile productivity; inconsistent quality; poor sector management and coordination; and a weak public sector extension system.

Despite these identified challenges, the collaborative development of the NCSDP is a major achievement and provides a guiding strategy for the development of the coffee sector in Timor-Leste. This assessment report should be seen as complementary to that effort and adds a specific focus on how consideration of climate change impacts and measures to address them can strengthen the NCSDP.

2.2 Biophysical context

Climate

Timor-Leste's climate is characterised by distinct wet and dry seasons heavily influenced by the West Pacific Monsoon. The wet season takes place between December and May and dry season between June and November, with the southern parts of the country experiencing a longer wet season of seven to nine months. Rainfall is variable across the country, with the northern areas receiving less rainfall than the south.

The pattern of rainfall over the year is very suitable for coffee production with many of the mountain areas recording rainfall volumes of 1200 to 2000 mm which is ideal for coffee growing (ADB 2020). Timor-Leste's climate is strongly impacted by the El Niño Southern Oscillation (ENSO) which can cause 50% or more variation between a dry year and a wet year (World Bank 2021).

Altitude

Timor-Leste's highest peak is Mount Ramelau at 2986 m asl which sits at the centre of the main coffee growing areas of Ermera, Ainaro and Aileu (see figure 1.). Arabica varieties are generally grown in Timor-Leste from 800m to up to 1800 m asl (MFAT 2018) which includes most of the area of the three aforementioned Municipalities as well as parts of Bobonaro, Liquiçá and Manufahi. Robusta is generally grown below 800 m asl (ADB 2020).

The Asian Development Banks Coffee and Agroforestry project identifies the optimal annual temperature range for arabica as 18-21°C and observes that this occurs in the elevation range from 1000 to 1550 m asl in Timor-Leste (ADB 2020). However, the same report notes that arabica varieties derived from the *Hibrido de Timor* (HdT - which is a hybrid of arabica and robusta) has improved tolerance to higher temperatures and this has allowed arabica coffee plantations to be spread to marginal regions with average temperatures as high as 24-25°C, correlating with areas as low as 800m asl (although yield levels are this altitude are likely to be significantly lower than at higher altitudes). A similar study of climate change impacts on the coffee sector in Papua New Guinea noted a range of upper and lower average temperature thresholds from different studies and used the range of 17-24°C to inform assessments of suitable areas for coffee production (CSIRO and SPREP 2022). Given the prevalence of HdT in Timor-Leste, the same temperature parameters are deemed as appropriate for assessing arabica suitability in Timor-Leste.

2.3 Coffee pests and diseases

Arabica is particularly vulnerable to a range of pests and diseases compared to robusta which is generally more resistant to a broad range of pests and diseases as well as being able to cope with warmer temperatures.

Cafea Arabica is particularly vulnerable to coffee leaf rust (CLR – a fungal infection caused by *Hemileia vastatrix*). CLR is the most significant plant disease affecting arabica and causes defoliation resulting in reduced quantity and quality of fruit (Rhiney *et al* 2021). Timor-Leste coffee trees were long considered to have high resistance to CLR due to the predominant plantings of the *Hibrido de Timor* (HdT) (a hybrid of arabica and robusta, robusta is generally

not affected by CLR). In fact, HdT was recognised globally as crucial to stopping the spread of CLR and HdT formed the basis of cultivar development with CLR resistance[1]. The Coffee Leaf Rust Research Centre (CIFC) in Portugal was established in the 1950's and served as the global centre for research and training on CLR resistance. The two main strains of HDT based cultivars developed by CIFC (Catimor and Sarchimor) have recently shown a decline in resistance to CLR, and CIFC predicted (in 2015) that over the next decade almost all the resistant varieties will become susceptible due to the emergence of highly virulent races of CLR[2]. Coffee leaf rust can have devastating impacts on coffee plants so the decline in CLR resistance is one of the more significant threats facing the coffee industry globally (Rhiney *et al* 2021).

CLR resistance in Timor-Leste HDT based varieties seems to have diminished in recent years. Staff from MAF and Quinta Portugal have identified three new races of CLR in Timor-Leste and these appear to be some of the most virulent in the world and are increasingly affecting coffee plants in Timor-Leste.

Coffee berry borer (*Hypothenemus hampei*) is one of the most destructive pests that affects the coffee industry globally. As the name suggests, the coffee berry borer attacks the coffee beans directly causing damage estimated at USD 500 million globally (Jaramillo *et al* 2011). The pest is already present in Timor-Leste but it is not clear how widespread it is. Coffee farmers in Leorema (Liquiçá) reported that the weevil is worse now than in the past (ADB 2020). A more recent scientific assessment of the prevalence of coffee berry borer in Liquiçá Municipality found an average incidence of 7.8% with the borer found in all but three of the 15 plots surveyed (Marques *et al* 2022).

3. Future climate change scenarios and their impacts on the coffee sector in Timor-Leste

This section of the report draws on the climate analysis produced in the more detailed technical report on future climate change scenarios in Timor-Leste prepared by Andrew Magee (2023). Consistent with global trends, future warming is expected across Timor-Leste with a high degree of certainty. Projections for warming scenarios indicate increases in air temperatures in both a low emissions future (increase by ~1.1°C by 2050) and a high emissions future (increase of 1.8°C by 2050).

Changes to rainfall are not so clear with models indicating a low degree of confidence in the degree or directionality of changes in overall rainfall. There is however a high degree of confidence in the likelihood of increased extreme rainfall events. Increased temperatures and increases in extreme rainfall events will have significant negative impacts on the coffee sector in Timor-Leste.

3.1 Projected changes in air temperature

The report by Magee (2023) on future climate change scenarios and their implications for coffee cultivation in Timor-Leste develops detailed analysis based on two scenarios, one based on low future emissions scenario (SSP1-1.9) and one based on a high future emissions scenario (SSP5-8.5). If we look at current global emissions and policies in place by major emitters it is increasingly clear that the global commitment to limit global warming to well

[1] https://www.ico.org/documents/cy2014-15/Presentations/115-pscb-coffee-leaf-rust-research-centre.pdf
[2] *Ibid*

below 2°C and preferably below 1.5°C above pre-industrial levels (the 'Paris Agreement') is going to be very difficult if not impossible to achieve (King 2023; Harvey 2022). It is likely that a 1.5°C increase will be breached before 2030 (Tolefson 2023) and a majority of climate scientists surveyed by the prestigious journal *Nature* think temperature increases will hit 3°C by the end of the century (Harvey 2022). In this regard, it would be prudent to plan around temperatures rising by more than the lowest IPCC scenario.

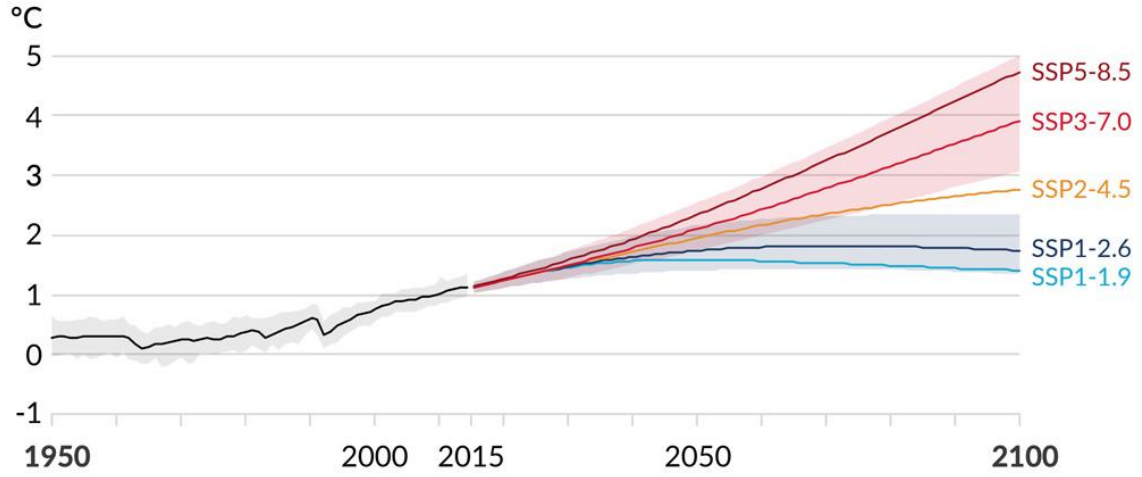

Figure 2: Projected temperature changes (°C) according to five tier-one future emissions pathways from the IPCC

Consistent with global trends, future warming is expected across Timor-Leste. Projections for both warming scenarios indicate increases in mean, minimum and maximum air temperatures for all three future time horizons (Table 1). For a low emissions future, mean temperatures are expected to increase by ~1.1°C by 2050 and 2070. However, for a high emissions future, mean temperatures are expected to increase by 1.8°C and 2.6°C, respectively. These figures are average temperatures for the country as a whole and will vary based on altitude.

Table 1: Projected mean, minimum and maximum temperature changes for Timor-Leste (adapted from Magee 2023)

		Mean temperature	**Minimum temperature**	**Maximum temperature**
Baseline (1970-2000)		**24.3**	**20.0**	**28.5**
Low emissions scenario	2030	25.1	20.9	29.4
	2050	25.4	21.1	29.7
	2070	25.4	21.2	29.7
High emissions scenario	2030	25.2	21.0	29.5
	2050	26.1	21.7	30.2
	2070	26.9	22.6	31.2

In the series of panels in **Figure 3** below we can see the projected temperature changes across the emissions scenarios across the three timeframes (2030, 2050 and 2070). The areas in blue fading to yellow correlate broadly with the current main coffee (arabica) growing areas shown in Figure 1. The initial larger panel represents baseline conditions with

subsequent panels all showing varying degrees of contraction of cooler areas and increases in warmer areas.

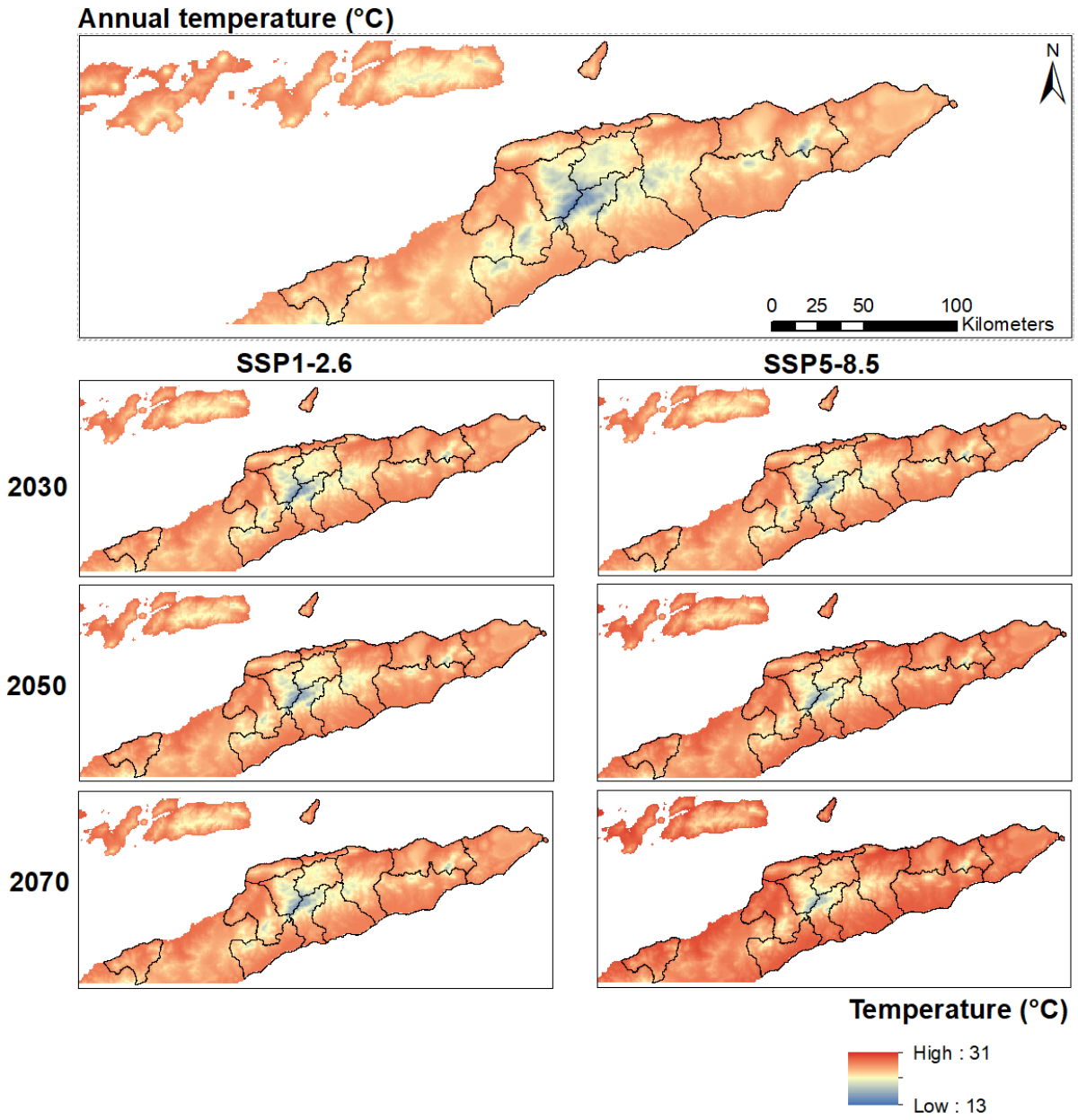

Figure 3: Annual temperature change (°C) across Timor-Leste (Magee 2023).

3.2 Projected changes in rainfall variability and intensity

In contrast to the high levels of certainty in projected temperature increases, the projections around rainfall are much less clear. Climate models do not agree on whether rainfall will increase or decrease or by what volume ((World Bank and ADB 2021; CSIRO and SPREP 2021; BOM and CSIRO 2014). Climate models do however indicate high confidence in an increase in extreme rainfall events. Future drought frequency is uncertain but could increase (World Bank and ADB 2021).

Inter-annual rainfall variability is already high (up to 50%) (World Bank and ADB 2021). In Timor-Leste, rainfall variability is influenced by several factors that contribute to the variability of rainfall totals and changes in the seasonality of rainfall. Some key drivers of rainfall variability in Timor-Leste include:

- **El Niño-Southern Oscillation (ENSO):** ENSO is a climate phenomenon characterised by the periodic warming (El Niño) and cooling (La Niña) of the central and eastern tropical Pacific Ocean. During El Niño events, Timor-Leste often experiences drier conditions, reduced rainfall, and an increased risk of drought. Conversely, La Niña events tend to bring above-average rainfall to the region (Bacon et al., 2014).
- **Indian Ocean Dipole (IOD):** The IOD is characterised by an oscillation of sea-surface temperatures between the western and eastern parts of the Indian Ocean. In its positive phase, Timor-Leste is likely to experience reduced rainfall and drier conditions due to cooler water in the eastern Indian Ocean. On the other hand, the negative phase, with warmer water in the eastern Indian Ocean, often results in increased rainfall for Timor-Leste.
- **South Pacific Convergence Zone (SPCZ):** The SPCZ is a band of low-level convergence and cloud formation that meanders across the South Pacific. Its position varies with weather patterns and seasons, influencing the distribution of rainfall, which can have a tangential impact on Timor-Leste.
- **Trade Winds:** The prevailing trade winds in the South Pacific, which blow from the southeast, play a role in influencing rainfall patterns. These winds interact with the island's topography, causing orographic lifting and resulting in enhanced rainfall on windward slopes and relatively drier conditions on leeward sides.
- **Topography and Terrain:** Timor-Leste's diverse topography, including mountains, valleys, and coastal areas, contributes to local variations in rainfall patterns. Orographic effects, such as uplift of air masses over mountains, can lead to increased rainfall on windward slopes, while rain shadow effects can cause decreased rainfall on the leeward side.

The high degree of uncertainty in projections of long-term rainfall trends in Timor-Leste is compounded by the current low level of understanding of the relationship between the ENSO cycle and the monsoon, as well as the impact climate change may have on this relationship (World Bank and ADB 2021).

Table 2 below summarises projected rainfall changes (note that these figures are based on the median of several models that do not agree on either if rainfall will increase or decrease or on the range of increase or decrease). The ensemble median indicates very small decreases (1-2%) in wet season rainfall with slightly larger decreases in dray season rainfall (up to 4% by 2050).

Table 2: Annual, wet season (December-May) and dry season (June-November) rainfall (adapted from Magee 2023)

		Annual	**Wet Season (December-May)**	**Dry Season (June-November)**
Baseline (1970-2000)		**1625**	**1280**	**345**
Low emissions scenario	2030	1634	1291	343
	2050	1591	1261	331
	2070	1576	1256	320
	2030	1603	1267	336
	2050	1628	1297	331

High emissions scenario	2070	1593	1267	326

Extreme rainfall

While there is low confidence in average rainfall change projections, there is a high confidence in an increase in extreme rainfall events (World Bank and ADB 2021). Analysis carried out in the separate climate change scenario report indicates that the increase in extreme rainfall events would be around 12% by 2050 in a low emissions scenario and 18% in a high emissions scenario (Magee 2023). Extreme rainfall events are likely to increase the risk of localised flooding and landslide events (World Bank and ADB 2021).

Tropical cyclones

Timor-Leste's proximity to the equator means that tropical cyclones are infrequent and are weak in intensity. There is strong scientific modelling evidence that anthropogenic activities will influence the magnitude, duration and frequency of future TC events.

Specific to Timor-Leste, the number of tropical cyclones is expected to decrease in the future, however, those that occur are expected to become more intense. Although projections suggest an overall reduction in TC frequency, increased TC intensity means that the region may see a greater proportion of severe category 3-5 TC events (IPCC, 2021).

Drought

Although the climate projection models do not agree on the likelihood of drought frequency increasing or decreasing, the high degree of certainty around temperature increases would indicate higher levels of evaporation which would impact the levels of soil moisture.

3.3 Potential impacts of climate change on the coffee sector in Timor-Leste

Reduction in areas suitable for growing arabica due to increased temperatures

Arabica is particularly sensitive to increases in temperature so this is the climate change impact that should be of most concern to the coffee sector. As noted previously in this report, annual average temperatures of between 17°C and 24°C are considered suitable for arabica production in Timor-Leste. These criteria are modelled for both low emissions and high emissions scenarios across four time periods (present, 2030, 2050 and 2070). The % of land area where conditions are suitable is calculated for each municipality, focused on the six main coffee cultivation regions of Aileu, Ainaro, Bobonaro, Ermera, Liquiçá and Manufahi (with the addition of Manatuto as there is some potential to expand coffee growing into higher elevation areas of that municipality). The results are summarised in **Table 3** below:

Table 3: Percentage (%) of land area where annual average temperatures are suitable for coffee cultivation (17-24°C). Arrows indicate directionality of change compared to the baseline (adapted from Magee 2023).

		SSP1-2.6 (Low emissions future)			SSP5-8.5 (High emissions future)		
Name	**Baseline (1970-2000) % of area optimal**	**2030**	**2050**	**2070**	**2030**	**2050**	**2070**
Aileu	91.3	↓ 82.2	↓ 77.7	↓ 76.8	↓ 79.5	↓ 63.9	↓ 40.7
Ainaro	47.5	↓ 47.4	↑ 47.7	↑ 47.6	↑ 47.7	↑ 47.6	↓ 42.4

Bobonaro	33.7	↓ 25.1	↓ 22.3	↓ 21.6	↓ 23.2	↓ 16.1	↓ 9.3
Ermera	72.9	↓ 68.1	↓ 65.8	↓ 65.4	↓ 67.5	↓ 57.2	↓ 46.0
Liquiçá	33.7	↓ 17.2	↓ 13.3	↓ 12.8	↓ 15.6	↓ 7.9	↓ 2.5
Manatuto	38.3	↓ 27.9	↓ 24.8	↓ 23.7	↓ 26.4	↓ 17.3	↓ 11.8
Manufahi	36.6	↓ 27	↓ 24.5	↓ 24.2	↓ 25.8	↓ 18.9	↓ 11.8
Timor-Leste	33.2	↓ 24.3	↓ 22	↓ 21.5	↓ 23.1	↓ 16.6	↓ 11.3

During the baseline period from 1970 to 2000, suitable average temperatures were experienced across 33% of Timor-Leste. Under both low and high-emission scenarios, projections indicate a reduction in area with these suitable temperatures. Specifically, under a low emissions future, the proportion decreases to 24% by 2030 and further decreases to 22% for both 2050 and 2070. Conversely, under a high emissions future, areas with suitable temperatures are anticipated to decline to 23%, 17% and 11% by 2030, 2050, and 2070, respectively.

Regardless of future emission scenario and time horizon, all municipalities experience a reduction in land area where annual average temperatures are suitable for arabica cultivation (17-24°C), except for Ainaro which only sees a small reduction by 2070 in a high emissions scenario. However, in Aileu, Ainaro and Ermera over 40% of the total land area remains suitable for arabica coffee cultivation in each municipality.

Manufahi has more significant declines with less than 12% of the land area suitable for arabica coffee production by 2070 (in a high emissions scenario) less than a third of the baseline. In Bobonaro there are even more significant declines and in Liquiçá there are almost no areas suitable for arabica production by 2070 in a high emissions scenario. Manatuto has a very similar profile to Manufahi across all scenarios.

What does this mean in terms of elevation levels suitable for coffee production?
In Timor-Leste, arabica is the preferred coffee species and is grown from 800m asl but the ideal conditions are from 1000 to 1550m asl (ADB 2020). Temperatures in Timor-Leste increase by about 0.55°C with each 100m rise in altitude. (ADB 2020). If arabica in Timor-Leste is currently best grown at altitudes above 1000m asl, a 1.1°C rise by 2050 (low emissions scenario) would raise this low point to 1100m asl. With a 1.8°C rise by 2050 (high emissions scenario) the lowest level at which arabica could suitably be grown would be at least 1300 m asl. Given the low emissions scenario is looking increasingly unlikely (King 2023; Harvey 2022; Tolefson 2023) it would be prudent to factor this into long term planning in the coffee sector and assume that by 2050 the lowest suitable elevation for productive arabica cultivation will be at the higher end of the range between 1100m asl and 1300 m asl.

Increases in extreme rainfall events causing erosion
Climate models give low confidence in rainfall increase or decrease but high confidence in an increase in extreme rainfall events (Magee 2023). Heavy rainfall can increase the risk of soil erosion and if accompanied by high winds can cause damage to shade trees in coffee agroforestry systems.

Increased temperatures causing reduced levels of soil moisture

Although it is unclear if overall precipitation levels will increase or decrease, high temperatures will lead to increased evaporation and therefore a decrease in soil moisture during the dry season. This can have a negative impact on coffee tree health and productivity.

Increased spread of pests and diseases

Increasing temperatures are likely to increase the spread of both the major disease affecting arabica – coffee leaf rust, as well as the main pest affecting arabica – coffee berry borer.

One of the factors that increases the spread of CLR is higher temperatures. Studies in PNG indicate that CLR is more prevalent in arabica grown at lower elevations (800-1400 m asl). Altitudes with minimum temperatures above 15°C were defined as having a higher risk of fungal spread (CSIRO and SPREP 2022a). In the PNG study, large areas under coffee production currently meet these low-risk parameters, but when the same analysis is applied to the Timor-Leste context, baseline levels of CLR risk is higher, with most coffee growing municipalities having less than 2% of land area meeting this low risk definition. Only Ainaro and Ermera currently have relatively large areas deemed low risk (13.6% and 10. 8% respectively. Due to these comparatively higher baseline temperatures, nearly all of Timor-Leste's coffee growing area is already at risk of CLR spread and this will likely worsen as temperatures increase.

Studies on East Africa indicate that coffee berry borer will increase its range and affect more areas where arabica is currently grown (Jaramilla *et al* 2011). Increased temperatures are also likely to provide more favourable for coffee berry borer persistence with breeding cycles increasing two or three-fold (Jaramilla *et al* 2011).

Labour productivity

Increased temperatures can impact labour productivity with some studies indicating declines of 20% by 2050 (World Bank and ADB 2021). The impact on labour productivity will be more pronounced in lowland areas compared to cooler, high altitude areas where arabica is grown but hotter dry seasons during the harvest period are likely to have some impact on labour productivity. Existing gender based gaps in productivity could be exacerbated by increased temperatures as women's lower levels of literacy, less access to extension services and agricultural implements (Perova and Caminha 2018) makes them particularly vulnerable.

4. Vulnerability of coffee production in Timor-Leste

Smallholder coffee farmers in Timor-Leste face significant barriers to overcoming poverty and achieving sustained improvements in their livelihoods and living conditions. Climate change adds an additional layer of difficulty. We can see there is significant scope to improve the quantity and quality of coffee harvests (Inder and Qu 2019) but this improvement is vulnerable to climate change impacts. This section of the report looks in more detail at those climate change vulnerabilities before looking at recommendations to improve coffee farmers livelihoods resilience to climate change impacts both now and in the future.

4.1 Vulnerability of production in current coffee producing areas to increases in temperature

Climate change driven increases in temperature underpin the greatest vulnerability faced small holder coffee farmers in Timor-Leste. In areas that are currently near the lower altitude threshold where it is suitable to grow arabica it will become increasingly unviable to continue to grow arabica. Using the temperature parameters outlined previously, **Table 4** below looks at the six current primary coffee-producing municipalities (plus Manututo) from the perspective of changes from baseline of areas suitable for coffee production to 2050, based on temperature increases in both low and high emissions scenarios:

Table 4 Coffee growing areas with declines in areas of suitability for growing arabica (adapted from Magee 2023)

Municipality	Baseline (1970-2000) % of area suitable	(Low emissions future - 2050)		(High emissions future - 2050)	
		% of area suitable	% reduction from baseline	% of area suitable	% reduction from baseline
Aileu	91.3	77.7	15%	63.9	30%
Ainaro	47.5	47.7	+0.02%	47.6	+0.01%
Bobonaro	33.7	22.3	34%	16.1	52%
Ermera	72.9	65.8	10%	57.2	22%
Liquiçá	33.7	13.3	61%	7.9	77%
Manatuto	38.3	24.8	35%	17.3	55%
Manufahi	36.6	24.5	33%	18.9	48%
Timor-Leste	33.2	22	34%	16.6	50%

The long-term viability of continued production of arabica in these municipalities varies with some locations badly affected and some minimally affected (the degree of change is indicated by the green, amber and red in the table above).

Aileu, Ainaro and Ermera remain highly suitable to continued arabica production. Bobonaro and Manufahi lose around half their current area by 2050 in a high emissions scenario (similar for Manututo if coffee was to be expanded there). In Liquiçá, 61% of what is already one of the lowest areas of suitability is no longer suitable in a low emissions scenario by 2050. In a high emissions scenario this is 77%. Overall there is a 50% reduction in areas suitable for arabica production in Timor-Leste, this is consistent with the overall global expected reduction in suitable growing area by 2050 (Bracken *et al*. 2023).

The changes in suitability are indicated across a series of maps in **Figure 4** below (colour coding not the same as in Table 4 above):

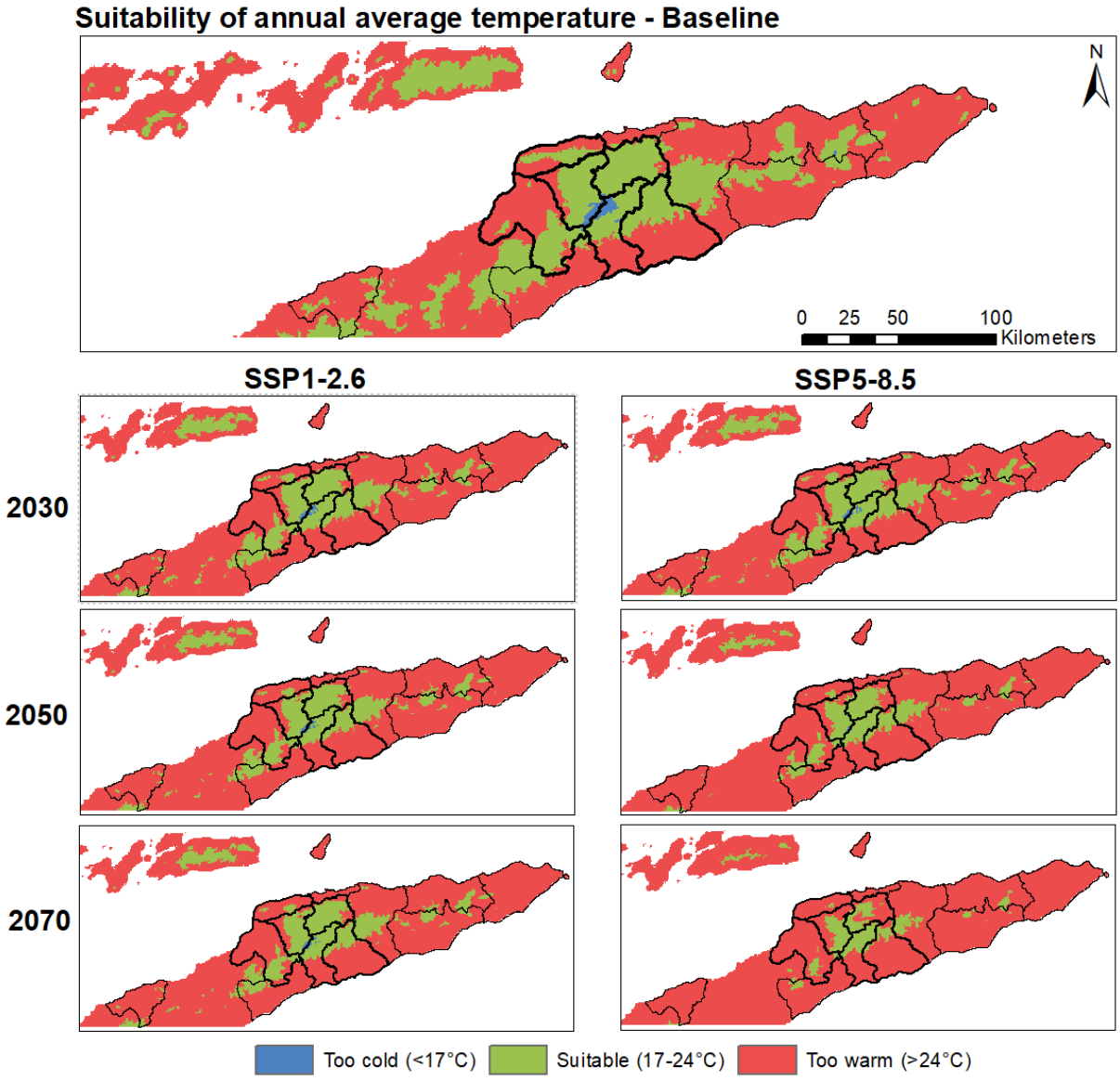

Figure 4: Suitability map of Timor-Leste outlining areas that are too cold (<17°C), suitable (17-24°C) and too warm (>24°C) for coffee cultivation (annual average temperature) for the baseline (1970-2000; top panel), and future emission scenarios including SSP1-1.6 (left panels) and SSP5-8.5 (right panels) for 2030, 2050 and 2070, considering p50. The municipalities in bold represent the six primary coffee-producing municipalities across Timor-Leste (from Magee 2023).

Long term planning in the coffee sector will need to take into account these potentially significant changes in areas suitable for growing arabica. It is highly likely that many areas currently growing arabica will need to transition to other livelihood strategies. There may be some scope to develop more climate resilient varieties of arabica but it is likely some lower elevation areas currently growing arabica will need to transition to robusta and/or another cash crop. The ADB Coffee and Agroforestry Livelihood Improvement Project in Timor-Leste identifies 1000 to 1550m asl as the altitude range where arabica grows best in Timor-Leste (ADB 2020). As noted previously, the low end of this range is very likely to increase by 100m and more likely closer to 200m due to projected increases in temperature by 2050 therefore a reasonable level to focus on arabica would be at above 1200m asl.

The NCSDP has a strategic objective to increase the total hectares of coffee production (ADB 2019). Given some current lower elevation coffee growing areas will be increasingly

unviable, increases will need to come from expansion in higher elevation areas. Any expansion will need to take into account environmental considerations consistent with the National Biodiversity Strategy and Action Plan and the Basic Environmental Law (Paudel *et al* 2022) as well as land tenure issues. It may be appropriate to commence a process of planning for achieving the NCSDP objective to expand coffee production areas taking into account likely future climate related constraints.

Although not related to climate change, a key vulnerability faced by smallholder coffee farmers is limited access to extension services (ADB 2019; MFAT 2018). Extension services could support farmers to implement climate smart agricultural practices that would improve the resilience of coffee plantations such as improved management of soil and water resources that improve soil health and moisture retention and reduce the risk of erosion, as well as improve plant health. This would also require extension officers that have this knowledge and the capacity to impart it effectively.

4.2 Vulnerabilities to changes in rainfall

It is important to note that there is considerable uncertainty in global future rainfall projections. Modelling indicates that in all municipalities, there are no significant trends in changes in rainfall across the time periods modelled.

The impact of interannual climate variability (e.g. ENSO and the IOD) on rainfall are more likely to induce significant shorter-term impacts (e.g. drought or intense rainfall) that impacts production and challenges growers. This variability, including phenomena such as the El Niño and La Niña cycles, can abruptly alter precipitation patterns, creating conditions that may stress coffee plants or foster environments conducive to pests and diseases. These short-term climate perturbations may result in more volatile coffee yields, affecting both the quantity and quality of the harvest.

Smallholder coffee farmers have little or no access to climate and weather information and early warning systems due to the limited in country capacity for meteorology. This means that farmers have little or no warning before extreme weather events occur apart from their own observations.

4.3 Vulnerabilities to increased pests and diseases

Increases in temperature are likely to lead to increases in pests and diseases such as coffee leaf rust and coffee berry borer. Studies indicate that CLR also spreads more easily as humidity increases (CSIRO and SPREP 2022). Coffee plantations in Timor-Leste are generally grown under a high shade environment using *Madre de Cacao* (*Paraserianthes falcataria*, formerly *Albizia falcataria*). Shade levels from these trees generally exceed the 60% coverage that is ideal for arabica (ADB 2019) and also creates a more humid environment under which CLR can thrive.

In contrast to CLR, coffee berry borer prefers a low humidity environment so a shaded coffee plantation will decrease its spread (Jaramilla *et al* 2011). Maintaining biodiversity is likely as important a determinant as shade on pest and disease spread as it has been demonstrated that diversity and structural complexity in mixed plant systems maintain a healthy system, so a focus on agro-biodiversity can contribute to healthy coffee plantations (Soto-Pinto *et al* 2002; Venzon 2021). Research on optimum conditions for reducing the spread of pests and diseases in the Timor-Leste coffee sector should be ongoing.

Capacity for applied research on coffee in Timor-Leste is very limited (ADB 2019). A lot of research on CLR was conducted from 1956 to 1975 when many CLR races were identified. From 1975 to 2009 no studies were carried out. Current testing is done by sending samples to the CIFC in Portugal and MAF staff have been sent there for training. In-country capacity for CLR testing could be established quite quickly if the institutional commitment is made.

4.4 Post-harvest vulnerabilities (drying, processing, etc)

Many smallholders sell their berries direct to large processors such as CCT and Timor Global who have their own centralised drying facilities using mechanical dryers that are not vulnerable to the weather. Smallholders who do their own drying tend to just lay the beans out to dry on raised beds in the sun. Where there is rain during the post-harvest period (as happened in 2022) coffee is dried under tarpaulins which can increase humidity resulting in some spoilage due to mould. Erratic rainfall may increase due to climate change. Increased humidity can also present challenges for coffee bean storage with the risk of increased rates of spoilage.To address this would require more investment in post-harvest processing and storage facilities that are accessible to all coffee farmers. Most smallholder farmers do not have access to finance to make these kind of investments

Access to microfinance at the smallholder household level is a significant gap that is acknowledged in the NCSDP. Many smallholder farmers sell a significant portion of their coffee crop to larger processors such as CCT. An evaluation of MFAT's support to CCT found that smallholder growers sell around half their crop to CCT immediately after harvest and keep the remainder for incremental sale/trade throughout the remainder of the year to ensure they have a more even cash flow (MFAT 2018). Access to micro-credit or some form of community managed savings and loans association would be very beneficial to smallholder coffee farmers financial well-being and could also provide a source of funds for investing in livelihood diversification and resilience building activities to adapt to the impacts of climate change.

4.5 Vulnerability of supply chain

Public investment in rural roads would improve the coffee sector's competitiveness. Inadequate roads significantly affect businesses' ability to source coffee as they restrict access to remote growing areas, increase transportation costs, and cause delays and quality deterioration. (MDF 2023). Timor-Leste has been extensively expanding and upgrading its arterial road network and one recent project is important for the coffee sector. The Dili-Ainaro Climate Resilient Road Corridor was implemented incorporating principles of climate resilience but the project evaluation noted significant capacity constraints on the part of key Timor-Leste government agencies with responsibility for the national road network (Rijal and Alves 2019). The projected increase in extreme rainfall events as a result of climate change (Magee 2023) means that roads will be at increased risk of damage. Ensuring the climate resilience of major roads should be a priority of the government to support the development of the coffee sector.

Minor feeder roads are particularly important for remote communities. Access to market can be difficult for coffee farmers in remote areas and this is particularly the case in parts of Ainaro (MFAT 2018) and also parts of Ermera. One of the main sources of finance for village level infrastructure (roads, bridges, water systems, irrigation) is the National Village Development Program (PNDS). Construction of local roads and bridges are a significant component to the PNDS and greatly complement larger arterial road projects such as the

Dili-Ainaro climate resilient road project. An evaluation of PNDS economic impacts found that roads and bridges funded by PNDS gave an estimated rate of return on investment of an average of 25% (Pomeroy 2018). Farmers noted that the benefits included easier access to market to sell their produce as well as better access for buyers to come and purchase direct from the grower. Also, 14% or respondents said they were now able to sell coffee whereas previously market access prevented this (Pomeroy 2018).

5. Recommendations for sector reforms and adaptive capacity.

This report has highlighted how the coffee sector in Timor-Leste is exposed and sensitive to a range of current and future climate driven pressures. The Timor-Leste coffee sector can build resilience in the face of these pressures through a range of measures. These will require engagement from all stakeholders in the coffee value chain. The NCSDP has many of the elements that will support the coffee sector in Timor-Leste to build resilience to climate change. The recommendations here are generally in alignment with the NCSDP.

The NCSDP mentions climate change as a threat to the sector on numerous occasions but does not integrate an explicit climate resilience strategy into the plan. Climate resilience measures would readily align with the existing plan and should be integrated at the earliest opportunity. This would include:

- Include an explicit focus on climate resilient coffee varieties within Focus Area 1: Research and Development.
- Include an explicit focus on climate smart agricultural practices in Focus Area 2: Production and Productivity.
- Include an explicit reference to climate resilient rural road repair and upgrade in Focus Area 4: Market Access and Promotion
- Include climate change technical expertise (National Climate Change Directorate?) in the NCSDP Implementation Team under Focus Area 6: Coffee Sector Management and Coordination

The rest of this section elaborates further on recommendations for integrating a specific focus on climate change in the coffee sector.

5.1 Strengthen Research and Development Capacity

There is a strong existing need for research and development in the coffee sector in Timor-Leste. Adapting to the impacts of climate change amplify this need. Research and development is the first focus area of the NCSDP and this assessment report agrees with that focus. A key element of research and development is for MALFF to develop a coffee variety improvement program that can provide improved varieties to the sector (ADB 2019). This should include a focus on research on varieties that exhibit increased resistance to CLR and/or can maintain yield in higher temperatures. This will include mapping the genetic makeup of Timor-Leste coffee varieties and establishing a germplasm garden. Similar work has already begun at the Quinta Agroforestry Centre in Aileu that can be built on.

A key priority of research and development should be to focus on developing field research and testing capacity for CLR and CLR resistant coffee plants. MALFF have already sent several technical staff to CFIC in Portugal who now have the skills to set up and operate a CLR testing laboratory. CLR resistant plants can be easily identified in an infected plantation and germplasm collected for analysis. A CLR testing laboratory and field research program will provide MALFF and the broader coffee sector increased capacity to manage CLR in Timor-Leste.

HDT varieties grown in Timor-Leste may have greater resilience to higher temperatures and further research on climate resilient varieties may provide some altitudinal range extension. Starbucks has reportedly bred six new arabica varieties that exhibit improved climate resilience and is also working on trials of another coffee variety called Liberica that has

greater heat tolerance[3]. Timor-Leste also has Liberica and further research should be conducted in Timor-Leste on climate resilient varieties that can maintain yield in warmer temperatures.

5.2 Integrate climate resilient agriculture practices into existing arabica coffee production

The second focus area of the NCSDP is production and productivity. This includes improving on-farm yields through rejuvenation (renovation and rehabilitation) of existing coffee plantations; promoting organic production; increasing extension services; enhancing support services; and increasing the total hectares of coffee production.

The overall focus of rejuvenation is consistent with a climate resilience approach but a key element of climate change consideration is missing - targeting rejuvenation efforts at areas that will remain suitable for arabica cultivation in the long term. Based on climate change analysis that informs this report, a reasonable estimate is that by 2050 areas below 1200m asl will no longer be optimal for arabica production and these areas should transition to other cash crops, including robusta coffee.

Low yields in Timor-Leste are driven by a range of factors especially low rates of adoption of good agricultural practices (use of compost, lack of pruning overgrown trees and replacement or rehabilitation of older unproductive trees (ADB 2019)). Rejuvenation of coffee plantations involves a cluster of integrated activities, including the pruning of trees. Due to initial declines in production from pruned trees, before they regrow and produce at higher levels, MAF recommends staggering rejuvenation of a coffee plantation over a 10 year period (MFAT 2018).

Rejuvenation activities include:

- Shade trees need to be replanted to achieve the 60 per cent cover that is optimal for arabica coffee cultivation. Recommended shade trees include Casuarina sp., Gliricidia sp., and a low-seeding cultivar of Leucaena (to reduce its weed potential);
- Damaged and/or diseased coffee trees needs to be removed;
- Large and unproductive coffee trees need to be pruned;
- Missing coffee trees need to be replanted;
- Terracing needs to be undertaken wherever needed on steeper slopes; and
- Mulching and composting need to commence.

Terracing can reduce the risk of erosion from extreme rainfall events and mulching can also contribute to reduced erosion as well as increase soil moisture retention during dry periods (Bracken *et al.* 2023).

Evidence is being generated that rejuvenated coffee plantations show significant improvements in productivity with data collected from an evaluation of CCT's rejuvenation program showing yields from pruned arabica coffee 2.5 years after pruning were on average three times (302%) that of the unpruned trees (MFAT 2018). This yield increase is compounded by the fact that pruned trees take much less time to harvest by as high as a

[3] https://sustainablebrands.com/read/supply-chain/starbucks-climate-resistant-coffee-varietals#:~:text=Starbucks%20announced%20today%20it%20is,giving%20them%20away%20for%20free

factor of six to one (MFAT 2018). These figures indicate that not only would coffee yield per hectare increase very significantly, time spent harvesting coffee would greatly decrease. The inputs of time to make coffee plantations more productive and resilient would use up some of that saved time (pruning, planting, mulching, composting, building terraces etc) but overall, the livelihoods of women and men coffee farmers should improve significantly.

Improved extension services

THE NCSDP envisages conducting an assessment of training needs for extension agents (both public and private sector) and development of a national extension training manual based around coffee plantation rejuvenation methodologies. This should include strategies for improving climate resilience including clear understanding of how projected increases in temperature will mean arabica cultivation will become increasingly unviable below 1200m asl and alternatives will need to be adopted by coffee farmers growing below this altitude. Gender is to be mainstreamed through all training and extension work and this should include increased focus on hiring female extension officers.

5.3 Promote crop diversification for smallholder coffee farmers

In instances where growing arabica coffee is no longer viable, coffee farmers should be encouraged and supported to switch to robusta or another cash crop more suited to a changing climate in that location. Diversification can also be a strategy to mitigate risk from vulnerabilities from growing a single crop and should also be encouraged in areas deemed suitable to continue arabica for the long term. Each of the crops suggested here are suitable to be grown (and are currently grown) in Timor-Leste but there are a range of factors to consider before widespread promotion, particularly market access considerations (competitiveness, returns to labour, processing infrastructure, trade barriers, etc) that are beyond the scope of this assessment.

Agrobiodiversity/diversification within a broader agroforestry approach is itself a climate resilience strategy that can reduce the risk of soil erosion and maintain soil fertility (Paudel *et al* 2021) as well as reduce the risk of pest and disease outbreaks (Soto-Pinto *et al* 2002). A diverse agroforestry-based coffee growing system, should integrate other crops that can be grown with coffee including konjac, vanilla and other spices (pepper, cloves, cinnamon) as well as fruit trees (durian, mangosteen, rambutan, dragon fruit). Konjac is a high value crop that grows well in Timor-Leste and is suitable to be grown at similar altitudes as arabica. Sandalwood (*Santalum album*) is endemic to Timor-Leste and can be integrated in coffee areas (grows to up to 1200 m asl) as part of a diversification strategy.

Other fruit trees also suitable as shade trees such as mango, durian, rambutan, also Petai or ‘stinky bean’ (*Parkia speciosa*), which is a protein rich food. These large shade trees are slow growing so you need another fast growing shade tree in the interim such as banana or papaya which can generate income in the interim.

Robusta

In lower elevations (below 1200 m asl) farmers growing arabica should strongly consider replanting with robusta. This would apply to most coffee farmers in Liquiçá where the relatively low elevation indicating there would be only around 3% of the land area remaining suitable for growing arabica in the long term. MFAT’s CACAO program has been supporting coffee farmers in lower altitude areas of Ermera, Liquiçá and Manufahi to switch

to robusta (MFAT 2018). Robusta gets a lower price but this is partly offset by the higher yields robusta generates.

Cocoa

Cocoa production is at an early stage in Timor-Leste but can be a viable alternative in lower elevations and can be grown in the same altitudinal range as robusta. CCT has worked with the Indonesian Coffee and Cocoa Research Institute (ICCRI) to select a cocoa hybrid that has good disease resistance, and is better-adapted than previous varieties to the Timorese climate and to low input, organic production (MFAT 2017).

Carbon Farming

Farmers receiving payments for carbon credits generated from growing trees is a well established model in Timor-Leste. With support from the Australia-based xPand Foundation, Ho Musan Ida (With One Seed[4]) began working with farmers in Baguia in Baucau Municipality in 2011[5]. Farmers are part of a cooperative that raise seedlings which are then planted on smallholder farms with farmers paid an annual fee based on the monitored growth of the trees on their property. In partnership with Oxfam (and funding from the European Union) the model was scaled out to other Municipalities (Cova Lima and Liquiçá) in 2020. Importantly, the scaled-up initiative also includes funding to support the establishment of a National Carbon Foundation (FCOTI) as well as supporting legislation and monitoring and regulatory frameworks. The framework is expected to be in place in 2024.

In the coffee sector, there is some potential to integrate carbon farming through credits for shade trees (new plantings, not existing trees), regrowth from pruning coffee trees, and more significantly, reforestation of degraded areas on coffee farmers land. Carbon farming can provide an additional income stream for small holder coffee farmers.

Sandalwood

The most valuable of the various species of sandalwood (*Santalum album*) is an endemic tree in Timor-Leste and was historically the most valuable commodity on the island with Chinese traders coming to Timor to collect sandalwood since at least the 1400's (Monk *et al* 1997). Sandalwood was once widespread across Timor but is now reduced to a few remnant patches. It grows naturally between the elevations of 300 and 1300 m asl so could be grown in those areas at the lower range where arabica is currently grown and would be a good option to include in a livelihood diversification strategy. Sandalwood is semi parasitic and has been perceived as difficult to grow but in the last two decades has been widely grown in Timor-Leste with a variety of private landholder, government and NGO plantings estimated at over 3000 hectares (Thu *et al* 2023). The main obstacle to sandalwood as a financially viable livelihood option is the current regulatory framework that prohibits its sale.

Although the Timor-Leste government actively encourages sandalwood planting there is currently no formal markets or regulations supporting the sale of sandalwood. Due to the dramatic decline in sandalwood stocks through (mostly illegal) overharvesting, a national moratorium on harvesting and marketing of sandalwood was put in place in 2012 for a period of 25 years (Thu *et al* 2023). MAF is currently reviewing the 2012 Dispatch in a step towards establishing a formal market and to minimise illegal trade. Due to the long lead time between planting and harvesting sandalwood (ideally, at least 20 years) sandalwood

[4] https://withoneseed.org.au/

[5] A similar project, 'Halo Verde' is in place in Manatuto and Viqueque Municipalities. The project is managed by FCOTI and was registered with Plan Vivo in 2020 - https://www.planvivo.org/halo-verde

should be planted as part of a diversified strategy. Financial analysis and growing trials conducted through the Ai-Com project in Timor-Leste indicates that sandalwood can add significant value to a diversified cropping system (Page *et al* 2022). The Ai-Com trails used Leucaena and Sesbania as in-row hosts and Casuarina as between row hosts so similar to trees currently used in coffee agroforestry systems. A variation on this system could be adapted for use in lower elevation coffee plantations.

5.4 Strengthen the coffee sector enabling environment

Access to Finance

At the household level, microfinance and/or savings and loan groups are a significant gap and measures should be explored for addressing this. The NCSDP identifies working with financial service providers to offer pre-harvest credit and access to micro-savings accounts but recognises that credit is poorly suited to facilitate coffee farm rejuvenation to increase productivity. In the interim, the NCSDP recommends that cash for work programs be considered to support smallholder coffee growers rejuvenate coffee farms and achieve higher productivity in the long term (ADB 2019).

Savings and loans groups, focused on women members, can provide a local structure for ensuring households have access to funds after natural disasters to pay school fees, repair houses and recover livelihoods. Savings and loans groups are also a forum for improving financial literacy but need external support to be established.

At the community or village level, there are existing programs that can be accessed to finance initiatives that can help communities adapt to the impacts of climate change. PNDS is the main national mechanism for funding village level infrastructure including roads, bridges, water systems and irrigation. For example, poor roads are a key constraint in the coffee supply chain in many remote communities and PNDS funding could be directed to building climate resilient local roads through village planning processes that identify PNDS funding priorities.

Similarly, climate finance mechanisms supported by the Green Climate Fund (GCF) could be accessed to support the coffee sector. One such project is the ADB's Community Resilience Partnership Program[6], a seven country (including Timor-Leste) flexible funding facility that aims to scale-up adaptation measures that address the nexus between climate change, poverty, and gender inequality at the community level.

Future funds may also be available through the Loss and Damage Fund that was agreed to be established at the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2023 (COP 28 in Dubai).

Climate and weather information and early warning

Currently smallholder coffee farmers have little or no access to climate and weather information and early warning systems due to the limited in country capacity for meteorology. The recently commenced GCF funded, UNEP implemented project 'Enhancing Early Warning Systems to build greater resilience to hydro-meteorological hazards in Timor-Leste'[7] is focused on strengthening that meteorological capacity by 2027. A key activity is to strengthen climate modelling and impact-based forecasting, including establishing a

[6] https://www.greenclimate.fund/project/fp215
[7] https://www.greenclimate.fund/project/fp171

National Forecasting Centre. This will have the capacity to provide sub-seasonal forecasts (2-week, 3-week and 4 -week) as well as monthly and seasonal (3-month) forecasts. This information will be useful to all farmers to plan harvest and post-harvest activities and coffee sector stakeholders (government and private) should ensure this information reaches as many coffee farmers as possible. For example, sub-seasonal forecasts can provide farmers with advanced warning of increased risk of rainfall and high humidity during coffee harvest drying and give them more time to take mitigation actions.

Insurance

Investing in climate resilience costs money and carries risk. Smallholder farmers can mitigate risk through insurance products but the insurance sector in Timor-Leste is underdeveloped with suitable and affordable agricultural insurance products currently unavailable.

Globally, there is an emergent focus on supporting smallholder coffee farmers through climate information and tailored insurance products. In 2018, Nestle partnered with insurance company Blue Marble to develop a climate change related weather insurance product to smallholder coffee farmers in Columbia[8]. The program has since been scaled up to include Indonesia, Kenya and Zimbabwe with further scale up to Honduras, Guatemala and Peru in 2023.

Another pilot project, funded by USAID in Kenya in 2023 in partnership with Sprout, combines seasonal climate insurance with weather monitoring and alerts to farmers. To make insurance more affordable while still commercially viable, Sprout bases insurance payouts on predetermined, explicit conditions, called index insurance. Index insurance lowers claims processing costs and increases trust with smallholder farmers[9]. Sprout also provides weather-prompted information and advice to farmers via mobile phones, such as guidance for dealing with unexpected weather patterns, to enable farmers to manage more climate risks independently.

The coffee sector in Timor-Leste should look for opportunities to trial similar initiatives with smallholder coffee farmers in Timor-Leste.

[8] https://bluemarblemicro.com/building-supply-chain-resilience-toclimate-related-shocks-for-nespresso/
[9] https://sproutprotect.com/

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