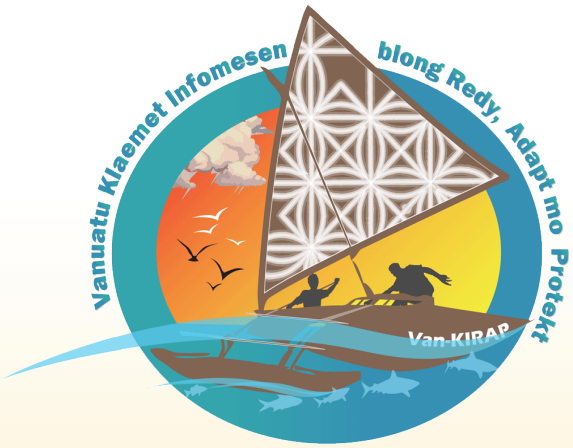

Climate Information Services Mitigation of Climate Change Impacts for Vanuatu.

30 SPREP PROE

Sustainable, transformative and resilient for a Blue Pacific

Climate Information Services Mitigation of Climate Change Impacts for Vanuatu

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Report prepared for CSIRO within the context of the Socio-Economic Benefit Analysis of the Green Climate Fund-funded Van KIRAP Vanuatu Climate Information Services for Resilient Development project.

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Summary

This study is focussed on evaluating the potential of climate information services (CIS) mitigation of climate change impacts, at a macro-economic and more detailed sectoral level for Vanuatu. This report is prepared for CSIRO Climate Intelligence Program, as a designated Delivery Partner for the Green Climate Fund supported Van KIRAP *Vanuatu Climate Information Services for Resilient Development* Project, led by the Secretariat of the Pacific Regional Environment Programme and the Vanuatu Meteorological and Geohazard Department (Government of Vanuatu).

This study illustrates the potential avoidable socio-economic damages of climate change if governments invest and implement policies to improve climate information services. CIS development and implementation potentially would provide decision makers with more accurate information of the impacts of sea level rise on current and future infrastructure, economic investments, coastal adaptation measures, and changes in agricultural productivity.

We evaluate the CIS mitigation potential of the economic impacts of two global climate change scenarios for the western tropical Pacific by 2050 (Scenario #1: a global average temperature increase of 1.7° C, and Scenario #2: an average increase of 2.4° C). These scenarios correspond to standardised global emissions scenarios, climate model output and associated large-scale climate processes, as specified by CSIRO for the Van KIRAP project.

Our methodology involves the translation of physical impacts of changes in the mean condition of relevant climate hazards and associated scenarios, in terms of economic variables inside a Computable General Equilibrium modelling framework. We make use of a recently developed Input-Output data for Vanuatu as part of the CSIRO scope of work for the Van KIRAP project. We consider estimates of potential CIS mitigation of sea level rise and agricultural productivity impacts based on CSIRO's climate investment scenarios research.

We find that under Scenario#1, climate change would decrease Vanuatu's GDP by US$ 130 million. CIS development and implementation corresponding to a 10% mitigation could potentially save Vanuatu US$ 17.8 million, and US$ 40.4 million with a 25% mitigation. These figures correspond to a benefit/cost ratio of CIS investment and operation ranging from 1.9 to 2.2, which means the monetary benefits of CIS almost double the investment costs.

When considering Scenario#2, climate change would decrease Vanuatu's GDP by US$ 276 million. CIS development and implementation corresponding to a 10% mitigation could potentially save Vanuatu US$ 34.2 million, and US$ 83 million with a 25% mitigation. The benefit/cost ratio of CIS investment and operation ranges from 3.7 to 4.5, implying an almost fourfold economic gain from CIS investment, if climate change impacts are more severe.

These estimations represent conservative lower-bound possibilities of the economic impacts of climate change, as they are based on changes in the mean global average temperature. It is expected that extreme climate events induced by climate change could markedly exacerbate economic impacts. As such, the development of improved climate information services is imperative from both a scientific and practical policy perspective, to better understand climate variability and implement mitigation strategies.

Introduction

Vanuatu and the rest of the Pacific Island nations are among the most vulnerable regions to the impacts of climate change. Changes in the frequency and intensity of extreme climate events, higher temperatures, shifts in rainfall patterns, and rising sea levels could result in loss of infrastructure and agricultural land, alteration of crops cycles and coastal fisheries, higher incidence of certain diseases, and marked loss of labour productivity due to heat.

The impacts of climate change could potentially be reduced through mitigation and adaptation efforts supported by climate information services (CIS), which encompasses the provision and use of climate data, information, and knowledge to assist decision-making. CIS is an overarching framework based on actual and projected data of climate variables (including temperature, precipitation, wind, soil, moisture, and ocean conditions), risk and vulnerability assessments, and socioeconomic variables and non-meteorological data (e.g., agricultural production, health trends, water and air quality, human settlement in high-risk areas, and road and infrastructure management) (Engility 2013; WMO 2019-2023; GFCS 2023).

This study is focussed on evaluating the potential of climate information services (CIS) mitigation of climate change impacts, at a macro-economic and more detailed sectoral level for Vanuatu. This report is prepared for CSIRO Climate Intelligence Program, as a designated Delivery Partner for the Green Climate Fund supported Van KIRAP *Vanuatu Climate Information Services for Resilient Development* Project, led by the Secretariat of the Pacific Regional Environment Programme and the Vanuatu Meteorological and Geohazard Department (Government of Vanuatu).

This research illustrates the potential avoided socio-economic damages of climate change if CIS are implemented. CIS development and implementation might provide decision makers with more accurate information of the impacts of sea level rise on current and future infrastructure, economic investments, coastal adaptation measures, and changes in agricultural productivity.

We evaluate the CIS mitigation potential of the economic impacts of two global climate change scenarios for the western tropical Pacific by 2050 (Scenario #1: a global average temperature increase of 1.7° C, and Scenario #2: an average increase of 2.4° C).

These scenarios correspond to standardised global emissions scenarios, climate model output and associated large-scale climate processes, as specified by CSIRO for the Van KIRAP project (Scenario #1: RCP2.6, low warming, SPCZ moves south, and Scenario #2: RCP8.5, high warming, SPCZ moves north).

Our methodology involves the translation of physical impacts of changes in the mean condition of relevant climate hazards and associated scenarios, in terms of economic variables inside a Computable General Equilibrium modelling framework (Valenzuela 2023). We make use of a recently developed Input-Output data for Vanuatu (Valenzuela and Vallecilla 2023a) produced as part of the CSIRO scope of work for the Van KIRAP project. We consider estimates of potential CIS mitigation of sea level rise and agricultural productivity impacts based on CSIRO's climate investment scenarios previous research (Newth 2020).

The next section outlines the methodology and data to be used. The following section presents estimates of the climate change impacts and two counterfactuals of climate information services investment. The final section draws out implications of the results.

Methodology

Our methodology utilises damage function estimates corresponding to Scenarios #1 and #2 as 'economic shock' inputs into a combination of a general equilibrium modelling framework contextualised by the Input-Output model of Vanuatu's economy. Following Newth *et al.* (2017) and Newth (2020), we use estimates of potential CIS mitigation of sea level rise and agricultural productivity reduction based on counterfactuals of climate information services investment.

We use the latest version of the comparative static general equilibrium GTAP model (Version 7, see Corong *et al.* 2017). The GTAP model is a comparative static computable general equilibrium model, with detailed economic theory and producer and consumer behaviour (Hertel 1997). We use a recently developed database for the Pacific region (Hanslow and Newth 2021) providing preliminary detailed estimates of production, consumption, and trade for 14 Pacific Island countries. We supplement this database with newly developed Input-Output table estimates tailored specifically for Vanuatu (Valenzuela and Vallecilla 2023a, b).

Climate Change Impacts and CIS mitigation

The physical impacts of climate change for each of the specified Scenarios (#1 and 2) are derived from an interdisciplinary assessment of published sources including a World Bank study (Roson and Sartori 2016), and CSIRO Van KIRAP project modelling computations and estimates (Hennessy *et al.* 2023; Valenzuela 2023). Following Newth *et al.* (2017) and Newth (2020), we consider the potential of tailored CIS to support decision-making around coastal adaptation and infrastructure investments, and agricultural activities adaptation. This is operationalised in our modelling as: (a) a mitigation of the sea level rise physical impacts and economic shocks, and (b) as adaptation of agricultural crops to negative variation in yields resulting from changes in temperature and rainfall. Table 1 shows the physical impacts and economic shocks for the specified scenarios (#1 and 2) considering climate services that reduces climate impacts by: (a) 10% after 2030 correspond to a scenario of early investment of 0.05% of GDP per year; and (b) 25% after 2030 correspond to a scenario of early investment of 0.1% of GDP per year (Newth 2020 using Carsell *et al.* 2004).

The climate hazard-based impacts and associated damage functions under consideration are further defined as:

a) Mean sea level rise impacting coastal infrastructure: CSIRO estimates of the replacement value of inundated coastal assets across Vanuatu (included in area inundated by the highest astronomical tide plus 0.2 m and 0.4 m for scenario 1 and 2 correspondingly). These estimates are translated into the economic modelling framework as a loss of land and capital productivity. We modelled the potential of CIS mitigation as a 10 and 25 percent reduction of these impacts.

b) Changes in mean temperature and rainfall impacting variation in agricultural crop yields: higher temperatures, higher concentration of carbon dioxide in the atmosphere, and different precipitation patterns will affect crop yields and agricultural productivity; CSIRO estimates of change in agricultural land suitability for four distinct crops across Vanuatu (cocoa, taro, coffee and kava). We modelled the potential of CIS adaptation as a 10 and 25 percent reduction of these impacts for coffee and kava.

We make no assumption on the effect of CIS over labour productivity, human health, or energy consumption. We model these estimates following Valenzuela (2023)[1].

[1] Changes in working atmospheric conditions will affect labour productivity across Vanuatu, depending on the degree of heat exposure and physical labour intensity. Increases in temperature and changes in precipitation patterns imply changes in mortality and morbidity incidence of some vector-borne diseases, heat and cold related diseases, and diarrhea.

Table 1: Economic shocks of climate change impacts by specified increases in mean annual temperature (Scenario #1 and 2) and CIS mitigation (investment)* scenarios for Vanuatu.

			Scenario 1: 1.7° C RCP2.6, low warming, SPCZ moves south			Scenario 2: 2.4° C RCP8.5, high warming, SPCZ moves north		
Physical impacts	**Economic shocks**		**no mitigation**	**10% CIS mitigation**	**25% CIS mitigation**	**no mitigation**	**10% CIS mitigation**	**25% CIS mitigation**
Sea level rise- Mean sea level rise causing inundation.	Replacement value of inundated coastal assets included in area inundated by the HAT plus 0.2 and 0.4 m.		+22%	+19.8%	+16.5%	+52%	+46.8%	+39%
	Capital and land productivity (%)		-22	-19.8	-16.5	-52	-46.8	-39
Changes in agricultural land suitability	Agricultural productivity (%)							
	Coffee		-44	-39.6	-33	-93	-83.7	-69.8
	Kava		-40	-36	-30	-97	-87.3	-72.8
	Cocoa		+ 22	+ 22	+ 22	+ 103	+ 103	+ 103
	Taro		+ 30	+ 30	+ 30	+ 85	+ 85	+ 85
			There is no CIS change in the following effects:					
Heat effects	Loss of labour productivity (%)	High physical intensity	-11			-15.5		
		Medium physical intensity	-3.7			-6.6		
		Low physical intensity	-0.1			-2.0		
Human health (mortality and morbidity)	Loss of labour productivity (%)		-0.4			-0.5		
Energy cost increase	Increase in cost of electricity (%)		0.2			6.6		

Source: Based on CSIRO Van KIRAP project estimates (Hennessy *et al.* 2023; Newth 2020; Valenzuela 2023).

***** Climate services that reduces climate impacts by: (a) 10 percent after 2030 correspond to a scenario of early investment of 0.05 percent of GDP per year. (b) 25 percent after 2030 correspond to a scenario of early investment of 0.1 percent of GDP per year. (Newth 2020 using Carsell *et al*. 2004).

Results

The results are presented for the two climate change scenarios with no mitigation and two counterfactuals of CIS mitigation of 10 percent and 25 percent, at an aggregate national income and at a detailed sectoral production and income levels.

Changes in Vanuatu's Gross Domestic Product

The gross domestic product (GDP) of Vanuatu in the reference year of 2018 was US$ 915 million (VNSO 2022). Under the Scenario #1 (increase of 1.7° C) Vanuatu's GDP is expected to decrease by US$ 130.5 million (14 percent of GDP). The two CIS mitigation counterfactuals result in a GDP reduction of US$ 112.7 million (a cost reduction equivalent to 1.9 percent of GDP) for the 10 percent mitigation case, and of US$ 90.1 million (a cost reduction equivalent to 4.4 percent of GDP) for the 25 percent mitigation case (Table 2).

Under the Scenario #2 (increase of 2.4° C) Vanuatu's GDP is expected to decrease by US$ 276.4 million (30.2 percent). The two CIS mitigation counterfactuals result in a GDP reduction of US$ 242.2 million (a cost reduction equivalent to 3.7 percent of GDP) for the 10 percent mitigation case, and of US$ 193.4 million (a cost reduction equivalent to 9.1 percent of GDP) for the 25 percent mitigation case (Table 2).

Table 2: Changes in Vanuatu's GDP for climate change increases of 1.7° C and 2.4° C (Scenarios # 1 and # 2, correspondingly), and CIS potential mitigation by 10 and 25 percent.

	Scenario 1			Scenario 2		
	Base case	CIS mitigation		Base case	CIS mitigation	
		10 %	25 %		10 %	25 %
US$ millions	-130.5	-112.7	-90.1	-276.4	-242.2	-193.4
Reduction in GDP %	-14.2	-12.3	-9.8	-30.2	-26.5	-21.1

Source: Author's simulations

Changes in Sectoral Income by aggregated Van KIRAP priority sectors

Changes in income (sectoral value added) in the Van KIRAP's five priority sectors (agriculture, fishing, tourism, infrastructure and water) are shown in Table 3. CIS potential mitigation would significantly reduce the impacts of increase of temperature for both considered scenarios.

Agricultural activities, not including forestry, account for almost one fifth of Vanuatu's GDP (Valenzuela and Vallecilla 2023a). Under Scenario #1, agricultural income could be offset in US$ 4.3 million for the 10 percent mitigation case, and in US$ 10.5 million for the 25 percent mitigation case. Under Scenario #2, agricultural income could be offset in US$ 8.6 million for the 10 percent mitigation case, and in US$ 22.4 million for the 25 percent mitigation case.

Value added in the fishing sector would decrease by US$ 2.2 million and US$ 4.4 million under Scenarios #1 and #2, correspondingly. Under Scenario #1, fishing income could be offset in US$ 0.3 million for the 10 percent mitigation case, and in US$ 0.6 million for the 25 percent mitigation case. Under Scenario #2, it could be offset in US$ 0.4 million for the 10 percent mitigation case, and in US$ 1 million for the 25 percent mitigation case.

Tourism income would decrease by US$ 22 million and US$ 55 million under Scenarios #1 and #2, correspondingly. Under Scenario #1, tourist income could be offset in US$ 12 million for the 10 percent mitigation case, and in US$ 13.7 million for the 25 percent mitigation case. Under Scenario #2, it could be offset in US$ 29.5 million for the 10 percent mitigation case, and in US$ 33.7 million for the 25 percent mitigation case.

Value added in the infrastructure sector would decrease by US$ 47.1 million and US$ 108.2 million under Scenarios #1 and #2, correspondingly. Under Scenario #1, value added in this sector could be offset in US$ 5.6 million for the 10 percent mitigation case, and in US$ 12.5 million for the 25 percent mitigation case. Under Scenario #2, it could be offset in US$ 10.5 million for the 10 percent mitigation case, and in US$ 24.8 million for the 25 percent mitigation case.

Value added in the Water sector (commercial value) would decrease by US$ 2.5 million and US$ 5.4 million under Scenarios #1 and #2, correspondingly. Under Scenario #1, value added in this sector could be offset in US$ 0.2 million for the 10 percent mitigation

case, and in US$ 0.5 million for the 25 percent mitigation case. Under Scenario #2, it could be offset in US$ 0.5 million for the 10 percent mitigation case, and in US$ 1.1 million for the 25 percent mitigation case.

Changes in production

Changes in the value of production for all 26 sectors of the economy (as depicted in the Vanuatu Input-Output table produced for Van KIRAP) are presented for both climatic projections and the two CIS mitigation counterfactuals. Scenario #1 is presented in Figure 1 and Scenario #2 in Figure 2.

As shown in Valenzuela (2023), increases in global average temperature decrease output values of all activities, with the exception of 'roots and vegetables' driven by increases in potential agricultural suitability as defined in CSIRO Van KIRAP project modelling (Hennessy *et al.* 2023). The potential of CIS adaptation in agriculture increases the value of production of 'roots and vegetables'. In all other sectors, the potential of CIS mitigation significantly reduces the negative impact in the value production of both climatic projections.

Table 3: Changes in sectoral income by aggregated Van KIRAP priority sectors (US$ million) for climate change increases of 1.7° C and 2.4° C (Scenarios # 1 and # 2, correspondingly), and CIS potential mitigation by 10 and 25 percent.

(US$ million)

	Scenario 1			Scenario 2		
	Base case	CIS mitigation		Base case	CIS mitigation	
		10 %	25 %		10 %	25 %
Agriculture	-16.9	-12.6	-6.4	-19.5	-10.9	2.9
Fishing	-2.2	-1.9	-1.6	-4.4	-4.0	-3.4
Tourism	-22.0	-10.0	-8.3	-55.0	-25.5	-21.3
Infrastructure	-47.1	-41.5	-34.6	-108.2	-97.7	-83.4
Water	-2.5	-2.3	-2.0	-5.4	-4.9	-4.3

Source: Author's simulations

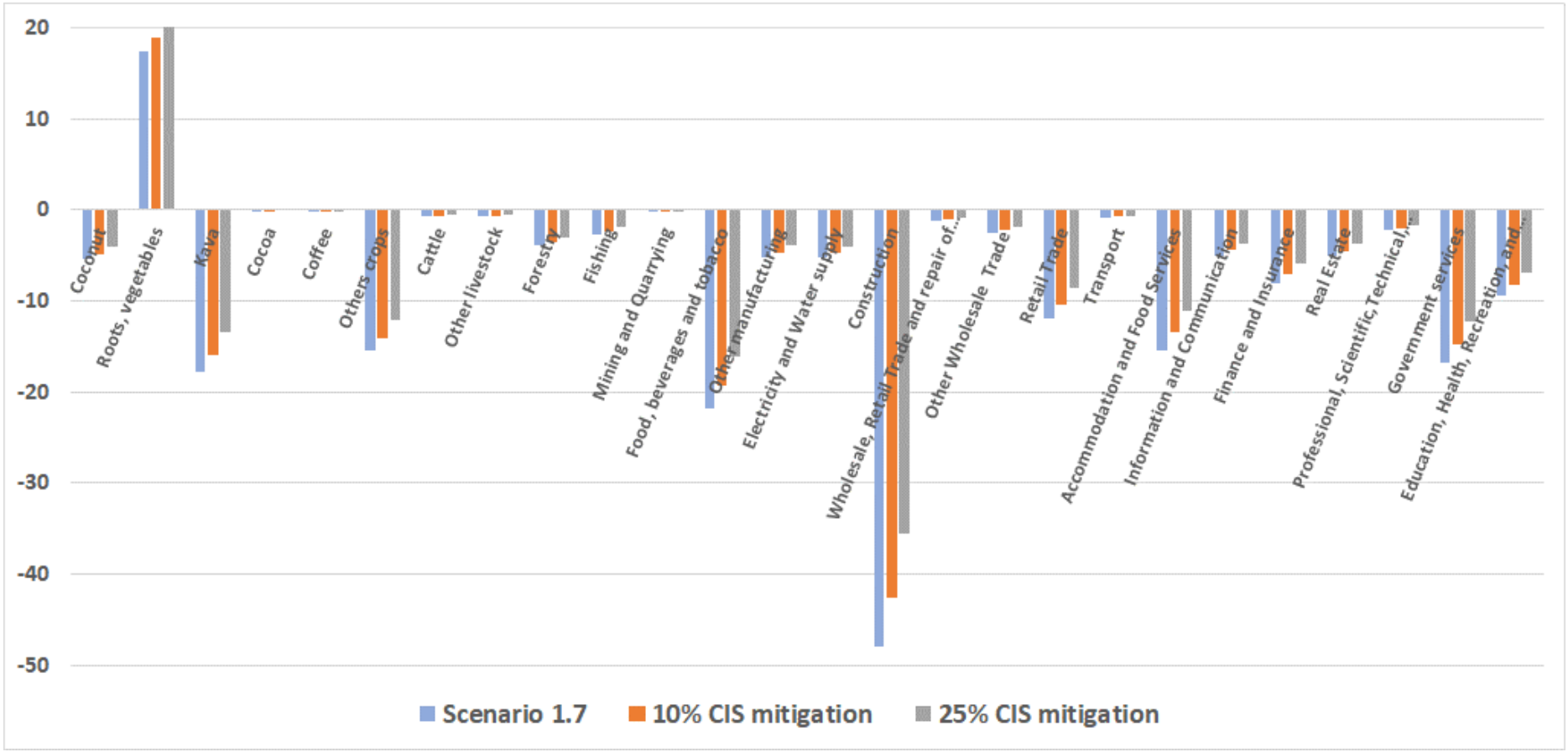

Figure 1: Changes in Vanuatu's value of production (US$ million) for Scenario 1: 1.7° C increase (RCP2.6, low warming, SPCZ moves south), considering CIS potential mitigation by 10% and 25%.

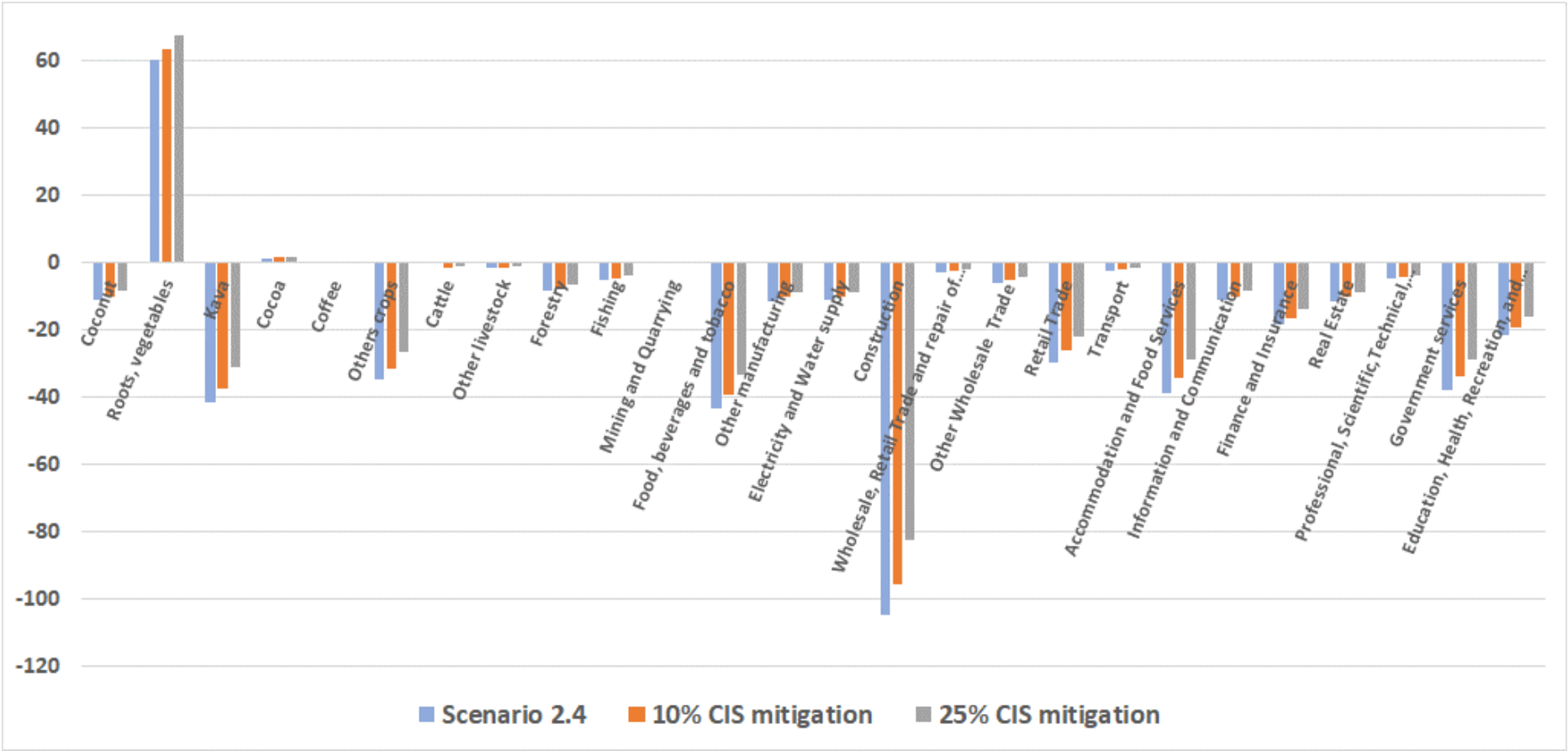

Figure 2: Changes in Vanuatu's value of production (US$ million) for Scenario 2: 2.4° C increase (RCP8.5, high warming, SPCZ moves north), considering CIS potential mitigation by 10% and 25%.

Cost – Benefit analysis of CIS investment

We have considered two CIS mitigation of climate change analysis, namely 10 and 25 percent; corresponding to Newth et al.'s (2020) CIS early investment settings. These early investment settings are defined as the cost of implementing and operating CIS as a share of GDP on annual basis after 2030: (a) 0.05 percent of GDP per year, corresponding to a 10 percent CIS climate change mitigation, (b) 0.1 percent of GDP per year, corresponding to a 25 percent CIS climate change mitigation.

Box 1 presents the cost-benefit ratio and net benefit in US$ millions of the two CIS investment settings under the two climate projections defined scenarios (namely 1.7° C and 2.4° C increase in average temperature). In order to estimate the cumulative cost of the two CIS investment settings, we used 2030 as the starting year of the CIS investment, 2050 as the projected year of the physical impacts, and Vanuatu's GDP (US$ 915 million for the 2018 base year). We abstain from using an economic growth projection as we are using a comparative static modelling framework [2].

The benefit/cost ratio of CIS investment and operation ranges from 1.9 to 2.2 under scenario 1, which means the monetary benefits of CIS almost double the investment costs. When considering scenario 2, this ratio ranges from 3.7 to 4.5 implying an almost fourfold economic gain from CIS investment, if climate change impacts are more severe. In dollar terms, CIS net benefits range from almost US$ 9 to 65 million (from almost one to seven percent of Vanuatu's GDP). Albeit these estimates are considerable, they are necessarily lower bound estimates of potential CIS investments gains as this simple benefit-cost analysis does not account for gains in productivity of labour due to reductions in mortality and morbidity of diseases, and savings in the cost of human health emergencies and lives lost.

[2] Our choice of a comparative static modelling allows us to concentrate on the economic effects of the damage functions parameters of the two temperature projections without forcing additional assumptions on economic trajectories over an extended period of time.

Box 1: Cost- Benefit of CIS investment.

Cost, benefit in US$ million

	Cost	Benefit	
		Scenario 1	Scenario 2
10 % CIS mitigation	9.2	17.8	34.2
25 % CIS mitigation	18.3	40.4	83.0

* Costs are calculated using Vanuatu's GDP (US$ 915 million for the 2018 base year) times 20 years (2050-2030) times the GDP cost share of CIS investment.

	Benefit/Cost ratio (Net Benefit US$ million)	
	Scenario 1	Scenario 2
10 % CIS mitigation	1.93 (8.7)	3.72 (15.9)
25 % CIS mitigation	2.21 (31.3)	4.54 (64.7)

Discussion

This study evaluates the potential of climate information services in mitigating the climate change impacts of two global climate change scenarios by 2050, at a macro-economic and more detailed sectoral level for Vanuatu. A computable general equilibrium framework is utilised to translate a consensus of widely projected physical impacts of climate change into economic shocks (Roson and Sartori 2016; Hennesy *et al.* 2023; Valenzuela 2023). This framework utilises recently databases developed by CSIRO Van KIRAP: (a) estimates of production, consumption, and trade for the Pacific Island countries (Hanslow and Newth 2021), and (b) Input-Output estimates tailored specifically for Vanuatu (Valenzuela and

Vallecilla 2023a, b). Following Newth *et al.* (2017) and Newth (2020), we evaluate two CIS climate mitigation counterfactuals considering the potential of tailored CIS to support decision-making around coastal adaptation and infrastructure investments, and agricultural activities adaptation.

This analysis finds that under the climate projection Scenario #1 (an increase in global average temperature of 1.7° C by 2050), CIS development and implementation corresponding to a 10 percent mitigation could potentially save Vanuatu US$ 17.8 million, and US$ 40.4 million with a 25 percent mitigation. When considering the climate projection Scenario #2 (an increase in global average temperature of 2.4° C by 2050), CIS development and implementation corresponding to a 10 percent mitigation could potentially save Vanuatu US$ 34.2 million, and US$ 83 million with a 25 percent mitigation.

How do these estimates compare with previous studies? Empirical information on the valuation of CIS is limited due to restricted representation of sectors of the economy and geographic range. Using an extrapolation over a period of 30 years of Adams *et al.*'s (2003) study, the value of a El Niño-Southern Oscillation (ENSO)-based climate forecasts accounts for almost one percent of Mexican agriculture. In a different study, Hallstrom (2004) estimated the value of climate services for global agriculture to be approximately US$ 900 million. Lazo *et al.* (2011) estimated the effect of weather variability on U.S. economic output (but not how this was impacted by the use of climate services) to be around 3.2 percent of annual national GDP. Hallegatte (2012) assessing the potential benefits of providing early warning systems in developing countries, controlling for differences in population, increased hazard risk due to climate and geography, as well as increased exposure to weather due to the state of infrastructure; estimated that upgrading early warning capacity in all developing countries would result in between US$ 300 million and two billion per year of avoided asset losses due to natural disasters.

While this economic evaluation is dependent on both the accuracy of the projected physical climate change hazard-based impacts and associated economic shocks, and the cost/benefit parameterization of climate information services development and implementation; it is also the case that these results are to be considered conservative as they relate to projected 'average' change in the climate for sea level, temperature and rainfall, without consideration of increases in intensity and frequency of extreme climate events (e.g. extreme temperature and rainfall, drought and flooding, tropical cyclones, marine heatwaves,

etc), and climate variability from large-scale natural processes. It is expected that extreme climate events induced by climate change variability could markedly exacerbate economic impacts. As such, the development of improved climate information services is imperative from both a scientific and practical policy perspective, to better understand climate variability and implement mitigation strategies.

Concluding comments

Climate information services offers the potential to build more resilient communities through mitigation and adaptation to climate change challenges. Our analysis suggests that in the context of Vanuatu, and the Pacific Island nations, the cost/benefit ratio of CIS investment ranges from two to four for every dollar invested, depending on the severity of future climate change impacts.

Our analysis shows the mitigating potential of CIS, and in such a way increases awareness of its benefits. This framework lends itself to improvement as new data on climate change physical impacts, CIS mitigating capacity, and geospatial socio-economic mapping information of the Pacific nations become available, including for Vanuatu.

Our findings contribute significantly to the discussion of climate change impacts and the mitigating potential of CIS in the Pacific, and Vanuatu in particular, as they confirm the potential large differentiated negative effects to the Pacific Island countries region.

References

Adams, R.M., Houston, L.L., McCarl, B.A., Tiscareño, M., Matus, J., and Weiher, R.F. (2003). The benefits to Mexican agriculture of an El Niño-southern oscillation (ENSO) early warning system. Agricultural and Forest Meteorology 115:183–194.

Corong, E.L., Hertel, T.W., McDougall, R., Tsigas, M.E. and, van der Mensbrugghe, D. (2017). "The Standard GTAP Model, Version 7". *Journal of Global Economic Analysis* 2(1): 1-119.

Engility (2013). The Value of Climate Services across Economic and Public Sectors: A review of relevant literature. Report prepared for: United States Agency for International Development Climate Change Resilient Development Project Climate Services Partnership, Economic Valuation Working Group. October 2013.

GFCS (2023), Global Framework for Climate Services. *What are Climate Services?* Accessed December 2023 from https://wmo.int/site/global-framework-climate-services-gfcs/what-are-climate-services

Hallegatte, S. (2012). *A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-meteorological Services, Early Warning, and Evacuation*. Policy Research Working Paper Series 6058. The World Bank, Washington, DC.

Hallstrom, D.G. (2004). Interannual climate variation, climate prediction, and agricultural trade: The costs of surprise versus variability. *Review of International Economics* 12(3):441–455.

Hanslow, K., and Newth, D. (2021). Disaggregation of the 14 Pacific Islands countries, Viehar file resource. Unpublished research work. Australian Government's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Earth Systems and Climate Change Hub.

Hertel, T. (ed.) (1997). *Global Trade Analysis: Modeling and Applications,* Cambridge and New York: Cambridge University Press.

Hennessy, K., Wilton, D., Webb, L., and Hoeke, R. (2023). Climate change damage functions for Vanuatu. Unpublished research work. Australian Government's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Earth Systems and Climate Change Hub, August.

Lazo, J.K., Lawson, M., Larsen, P.H., and Waldman, D.M. (2011). U.S. economic sensitivity to weather variability. *Bulletin of the American Meteorological Society* 92(6):709–720.

Newth, D. (2020). A conceptual framework for socio-economic benefit analysis of science-based climate change services. Australian Government's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Earth Systems and Climate Change Hub Report No. 15, April.

Newth, D., Gooley, G., and Gunasekera, D. (2021). "Socio-Economic Analysis of Climate Services in Disaster Risk Reduction: A Perspective on Pacific SIDS". *Frontiers in Environmental Science*, 26 October 2021. https://doi.org/10.3389/fenvs.2021.681747

Newth, D., Gunasekera, D., and Gooley, G. (2017). Framework for Undertaking Socio-Economic Cost-Benefit Analysis for Climate Information Services in the Western Tropical Pacific. Report to the Green Climate Fund Readiness and Preparatory Support (Activity Area 4) for Vanuatu (Readiness Grant Agreement VUT-RS-001). Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia.

Newth, D., and Hanslow, K. (2021). Macro-Economic Impacts of Climate Change in the Western Tropical Pacific. Unpublished paper. APCP NextGen Climate Projections for the Western Tropical Pacific Project. Australian Government's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Earth Systems and Climate Change Hub. V1, July.

Roson, R., and Sartori, M. (2016). Estimation of Climate Change Damage Functions for 140 Regions in the GTAP 9 Database. World Bank Policy Research Working Paper 7728, Washington DC, June. Available at https://openknowledge.worldbank.org/bitstream/handle/10986/24643/Estimation0of00n0the0GTAP90database.pdf?sequence=1&isAllowed=y

Valenzuela, E., and Newth, D. (2022). Economic Impact of Climate Change for the Western Tropical Pacific: preliminary regional analysis and sectoral case study for Vanuatu. Report prepared for CSIRO, Green Climate Fund-funded Van KIRAP Vanuatu Climate Information Services for Resilient Development project, and Australia Pacific Climate Partnership-funded Next Generation Climate Change Projections for the Western Tropical Pacific project. March 2022. Available at https://www.rccap.org/library/item/62e744bb69824

Valenzuela, E. (2023). Preliminary Economic Assessment of Climate Change Impacts for Vanuatu. Report prepared for CSIRO, Green Climate Fund-funded Van KIRAP Vanuatu Climate Information Services for Resilient Development project, and Australia Pacific Climate Partnership-funded Next Generation Climate Change Projections for the Western Tropical Pacific project. November 2023.

Valenzuela, E., and Vallecilla, J. (2023a). Vanuatu's Input-Output Table – Construction of a Foundational IOT for Vanuatu. Database prepared for the Australian Government's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Earth Systems and Climate Change Hub, May 2023.

Valenzuela, E., and Vallecilla, J. (2023b). The Input-Output Table construction for Vanuatu – Methodology Report. Prepared for the Australian Government's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Earth Systems and Climate Change Hub, June 2023.

VNSO (2022), Vanuatu National Statistics Office. Statistical Release Gross Domestic Product 2020.

WMO (2019), World Meteorological Organization. State of Climate Services: Agriculture and Food Security. WMO Report No. 1242.

__ (2020), World Meteorological Organization. State of Climate Services: Risk Information and Early Warning Systems. WMO Report No. 1252.

__ (2021), World Meteorological Organization. State of Climate Services: Water. WMO Report No. 1278.

__ (2022), World Meteorological Organization. State of Climate Services: Energy. WMO Report No. 1301.

__ (2023), World Meteorological Organization. State of Climate Services: Health. WMO Report No. 1335.