

Enhancing risk assessments for improved country risk financing strategies

FINAL REPORT:
THAILAND



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List of acronyms

AEI	Annual Expected Impacts	GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
AR5/6	5th/6th Assessment Report	GUI	Graphical User Interface
BMA	Bangkok Metropolitan Area	HOTOSM	Humanitarian OpenStreetMap Team
BMZ	German Federal Ministry for Economic Cooperation and Development	ICRM	Integrated Climate Risk Management
CCA	Climate Change Adaptation	IPCC	Intergovernmental Panel on Climate Change
CDC	Center for Disease Control	IRR	Incidence Rate Ratio
CDRFI	Climate and Disaster Risk Finance and Insurance	ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
CLIMADA	CLIMate ADaptation	ITCZ	Intertropical Convergence Zone
CMIP6	Coupled Model Intercomparison Project Phase 6	IUCN	International Union for Conservation of Nature and Natural Resources
CORDEX	Coordinated Regional Climate Downscaling Experiment	MCDA	Multi-Criteria Decision Analysis
CRED	Climate Resilient Economic Development	MCII	Munich Climate Insurance Initiative
DGE-CRED	Dynamic General Equilibrium model for Climate Resilient Economic Development	NAPs	National Adaptation Plans
DoA	Thailand Department of Agriculture	NbS	Nature-based solutions
ECA	Economics of Climate Adaptation	NDCs	Nationally Determined Contributions
EIOPA	European Insurance and Occupational Pensions Authority	RCM	Regional Climate Model
EIU	Economist Intelligence Unit	RCP	Representative Concentration Pathway
ENSO	El Niño-Southern Oscillation	SDGs	Sustainable Development Goals
ERA	Enhancing Risk Assessment	SPFI	Standard Precipitation and Evapotranspiration Index
ETCCDI	Expert Team on Climate Change Detection and Indices	SPI	Standardized Precipitation Index
GCM	Global Circulation Models	SSPs	Shared Socioeconomic Pathways
GDP	Gross Domestic Product	UNU-EHS	United Nations University Institute for Environment and Human Security
GHGs	Greenhouse Gases	WCRP	World Climate Research Programme
GIS	Geographic Information System	WOCAT	World Overview of Conservation Approaches and Technologies

Foreword from the Department of Agriculture

This report is part of the "Enhancing Risk Assessments (ERA) Project for Improved Country Risk Financing Strategies" in Thailand supported by GIZ. The purpose of this report is to present the findings of the ERA in Thailand. This project has delivered critical insights into the climate challenges faced by Thailand, particularly the impacts of floods, droughts, and heatwaves on our farmers and the agricultural systems they rely upon. Farming in Thailand is becoming increasingly challenging due to these intensified climate-related risks, which threaten not only crops and livelihoods but also the future resilience of our rural communities.

With the support of the ERA Project, we now have a clearer picture of where these risks are most severe and which areas need targeted interventions. Using the Economics of Climate Adaptation (ECA) framework, we have identified specific regions and assets at greatest risk. This enables us to plan smarter, allocate resources more effectively, and prioritize measures that yield the highest benefits, allowing us to better protect the livelihoods of Thai farmers. These findings are the foundation for developing actionable risk financing strategies essential for bolstering Thailand's socio-economic resilience and agricultural sustainability. As we move forward, this knowledge will help inform decisions that bring real support to farmers, equipping them to face both present challenges and future uncertainties.

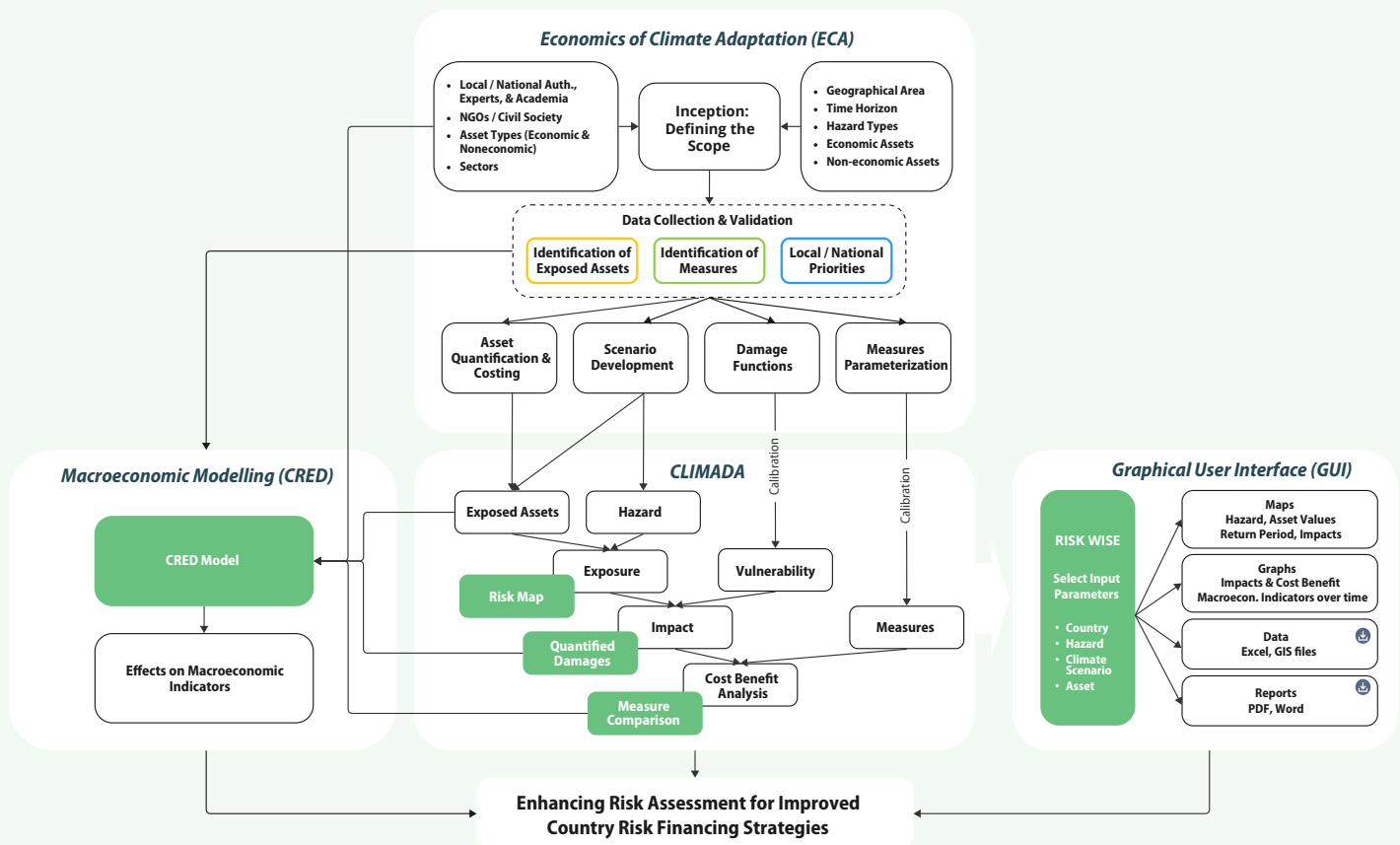
I hope that these insights will inspire our policymakers, partners and stakeholders in government and beyond to work toward a secure, sustainable future for Thai agriculture and the communities it supports.

Pongthai Thaiyothin (PhD)
Deputy Director General
Department of Agriculture

Executive summary

Addressing climate change impacts on ecosystems and livelihoods requires formulating adaptation options, economic diversification, mitigation measures, and climate-smart policies (Lalthapersad-Pillay & Udjo, 2014). A crucial step in planning these adaptations in developing countries is quantifying the diverse impacts of climate change. However, estimating the effects on macroeconomic and non-monetary indicators (e.g., access to health, education, and cultural loss) remains challenging, making it difficult to develop comprehensive financial protection strategies (Nasr Ahmed et al., 2021).

The *Enhancing Risk Assessments (ERA) for Improved Country Risk Financing Strategies* project provides the Thai Government partners with a new generation of risk assessments for developing their climate change adaptation. The figure below presents the ERA integrative modelling framework, designed to inform comprehensive country risk financing strategies through an enhanced risk assessment approach that addresses climate impacts. This framework builds a comprehensive national-level system for assessing and managing climate-related risks by integrating economic, non-economic, and macroeconomic models to enhance decision-making for risk financing. By incorporating the outputs from the Economics of Climate Adaptation (ECA) framework, the CLIMADA modelling platform, the Dynamic General Equilibrium model for Climate Resilient Economic Development (DGE-CRED), and a Graphical User Interface (GUI) called Risk Wise, ERA strengthens the ability of countries to develop robust adaptation and risk-financing strategies. This integration ensures that a thorough understanding of risks, economic and non-economic impacts, and the effectiveness of potential adaptation measures informs decisions. Ultimately, this leads to more resilient and sustainable development planning.





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Scope

Through stakeholder consultation, the project defined the study’s hazards, assets, and other parameters, which are presented in the table below. The analysis was done on a country level, which limits the decision-making that can be done locally but provides a strategic overview of current and future climate risks in Thailand.

Table: Key elements for the risk assessment

Key elements	Selected components
Hazards	Floods, droughts, and heatwaves
Time horizon	2050
Climate scenarios	RCP4.5 (moderate GHG emission scenario) & RCP8.5 (extreme GHG emission scenario)
Economic assets	Agriculture (Tree crops, Grass crops), Markets (Wet markets)
Non-economic assets	Religious services (Buddhist monks and shelter), Education (Students), Mobility (Road users), Agriculture (Tree and grass crop farmers), Water (Access), and Health (Diarrhoea and heat exhaustion patients)
Sectors for macro-economic impacts	Agriculture, Energy, Tourism, Financial Sector, Manufacturing, Services, and Real Estate (Housing)

Key findings

- ▶ **Geographic exposure:** Flooding poses significant risk to river basin areas, while droughts and heatwaves have wider-reaching effects. Flood-prone river basins expose agricultural and economic assets to high risk, whereas urban areas face heatwave impacts, particularly in dense population centres like Bangkok.
- ▶ **Adaptation portfolio needs:** Effective climate resilience requires a mix of solutions tailored to hazard types and asset categories. Nature-based solutions (NbS) show cost-effective potential, particularly for floods. However, they need to be complemented by grey and green infrastructure to cover diverse risk profiles across economic and non-economic assets.
- ▶ **Sector-specific risks:** Macroeconomic modelling reveals that floods, droughts, and heatwaves will strain Thailand's economy, with the energy and agriculture sectors being particularly vulnerable. Targeted adaptation measures could mitigate GDP losses by 50 per cent, showcasing adaptation's potential for economic stability.

Recommendations

- ▶ **Develop a national multi-hazard climate resilience policy:** Implement a comprehensive policy to address resilience against floods, droughts, and heatwaves across sectors, focusing on high-risk regions and aligning adaptation strategies with specific sectoral needs, such as energy, agriculture, and tourism.
- ▶ **Invest in a diverse adaptation infrastructure portfolio:** Scale up funding for nature-based solutions (NbS) alongside grey, green, and blue infrastructure, prioritizing grey infrastructure for economic assets in flood-prone areas and NbS for environmental and rural resilience.
- ▶ **Strengthen climate risk data integration and decision support:** Deploy tools like RISK WISE at all levels of government to integrate climate data into policy, planning, and budgeting. Training for local officials will be critical to effectively using this data in localized adaptation planning.
- ▶ **Promote early investment in climate adaptation:** Prioritize early adaptation measures in high-exposure sectors such as energy and agriculture to maximize economic benefits and minimize long-term impacts on GDP.
- ▶ **Enhance localized risk management and climate-smart agriculture:** Implement targeted flood management in river basins, climate-smart agriculture in drought-prone areas, and urban green infrastructure to build resilience against specific risks while supporting food security and community health.

Conclusion

The ERA Project's integrated analysis provides a roadmap for Thailand to address the diverse impacts of climate risks across sectors and regions. By advancing data-driven adaptation strategies, Thailand can reduce vulnerabilities, enhance resilience, and support sustainable growth. The RISK WISE tool plays a pivotal role in making these insights actionable, enabling stakeholders to design targeted, informed climate resilience strategies that align with Thailand's unique geographic and economic landscape.



1. Introduction

1.1 Context

Climate change is leading to increased frequency and severity of extreme weather events, conflicts, and global instabilities in many regions, disrupting supply chains, causing economic downturns, and reducing food security and socioeconomic stability. Vulnerable communities in developing countries, such as Thailand, are hardest hit by these events, particularly those facing extreme poverty and harsh geographic conditions (Lalthapersad-Pillay & Udjo, 2014). These disruptive events have diverse effects, including impacts on macroeconomic variables, such as unemployment and income losses. For example, as a direct result of climate change, the agriculture sector in Thailand is expected to decrease the total yield of the country's major crop production (rice, maize, and sugarcane) by up to 15 per cent by the year 2050 (UNDRR, 2020).

Addressing climate change impacts on ecosystems and livelihoods requires formulating adaptation options, economic diversification, mitigation measures, and climate-smart policies (Lalthapersad-Pillay & Udjo, 2014). A crucial step in planning these adaptations in developing countries is quantifying the diverse impacts of climate change. However, estimating the effects on macroeconomic indicators and non-monetary indicators (e.g., access to health, education, and cultural loss) remains challenging, making it difficult to develop comprehensive financial protection strategies (Nasr Ahmed et al., 2021).

Considering the difficulties outlined above, the Enhancing Risk Assessment (ERA) for Improved Country Risk Financing Strategies project provides the government partner, the Thailand Department of Agriculture (DoA), with a new generation of risk assessments for the development of their climate change adaptation, which can subsequently inform

their climate and disaster risk financing strategies. The ERA project is commissioned by the Deutsche Gesellschaft für International Zusammenarbeit (GIZ) GmbH and implemented in collaboration with the United Nations University – Institute for Environment and Human Security (UNU-EHS) and the Munich Climate Insurance Initiative (MCII). The project offers participating government partners an enhanced risk assessment and subsequent understanding of selected climate risks in Thailand. Overall, the project aimed to answer three guiding questions:

- What is the potential climate-related damage over the coming decades?
- How much of that damage can be averted, and what type of Climate Change Adaptation (CCA) measures can be used?
- What investments will be required to fund those CCA measures, and will the benefits of these investments outweigh their costs?

The report is structured to present the Enhancing Risk Assessment (ERA) approach comprehensively. It introduces the project, its objectives, and ERA's contributions in addressing climate risk. The subsequent sections detail the study area and the impact of climate change, demonstrating why risk management is crucial for Thailand. The report is then divided into the three components of ERA, which are the Economics of Climate Adaptation (ECA), Climate Resilient Economic Development (CRED), and the Graphical User Interface (GUI). Each component will present an overview of the methodologies used and the data input-output results from the modelling. Then, the final chapter will bring all components together and present ERA's conclusions and recommendations.

1.2 Approach to enhancing risk assessments (ERA)

As the name implies, the overall objective of the ERA project was to provide the partners in the Thai government with an enhanced risk assessment for developing climate change adaptation and informing climate and disaster risk financing strategies. To accomplish this, the Economics in Climate Adaptation (ECA) framework was applied, which,

together with the open-source modelling platform CLIMADA, enables a probabilistic outlook of the current and future climate risks faced by the country and compares the available options for adaptation. The project extended the applications of ECA to cover non-economic impacts related to access to essential services.

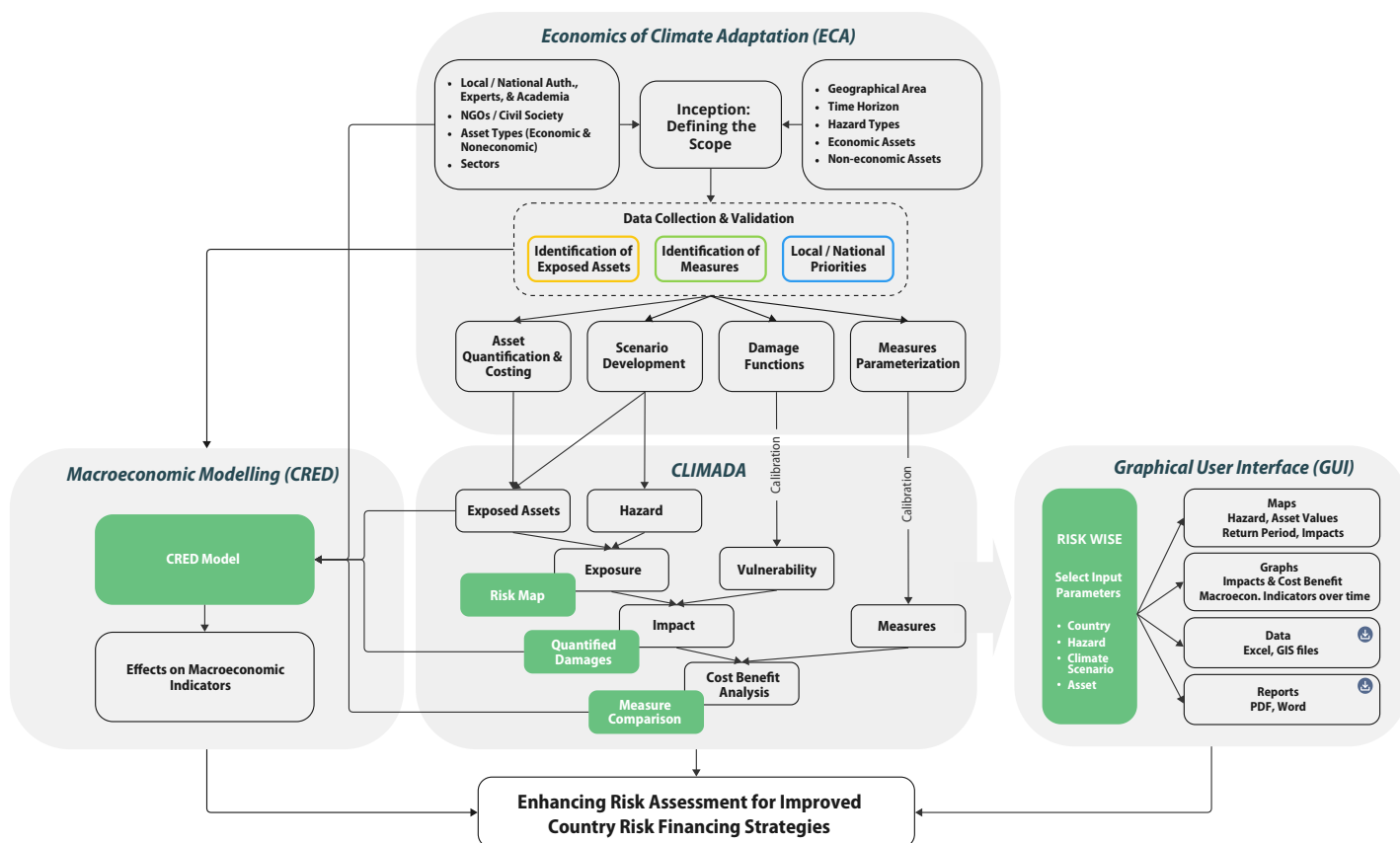
Furthermore, because CLIMADA was not initially designed to analyze the impact of specific hazards on macroeconomic indicators, the Dynamic General Equilibrium model for Climate Resilient Economic Development (DGE-CRED) was integrated into CLIMADA. This integration offers insight into the effects of extreme weather events on macroeconomic indicators, pioneering the coupling of these models to enhance the relevance of CLIMADA and its potential to highlight the broader impact of climate change on relevant partner ministries.

Figure 1 presents the ERA integrative modelling framework, designed to inform comprehensive country risk financing strategies through an enhanced risk assessment approach that addresses climate impacts. This framework builds a comprehensive national-level system for assessing and managing climate-related risks by integrating economic, non-economic, and macroeconomic models to enhance decision-making for risk financing. By incorporating the outputs from the ECA, CLIMADA, CRED, and GUI components, the framework strengthens the ability of countries to develop robust adaptation and risk-financing strategies. This integration ensures that a thorough understanding of risks, economic and non-economic impacts, and the effectiveness of potential adaptation

measures informs decisions. Ultimately, this leads to more resilient and sustainable development planning.

While represented as individual entities, each of the four components draws from or feeds into one another. Without the ECA framework, CLIMADA offers top-down results that are not shaped or validated by local stakeholders. Similarly, the consultation activities from ECA allowed us to identify the most relevant macroeconomic sectors for the partner organizations involved in the project, as well as other parameters for the risk assessments, such as economic and non-economic assets, hazard duration, for example. Coupling CLIMADA and DGE-CRED combines the geolocated, physically based results from the former with the large-scale macroeconomic variables from the latter. This mix offers an important improvement from most macroeconomic models, which view the impacts of climate change as a slow-onset process specified by a small set of parameters (Burns et al., 2021). Finally, developing an accessible tool like a GUI to navigate complex results eases different audiences' engagement with the project's outcomes. These components (ECA, CLIMADA, CRED, and the GUI) are described in detail, and their interrelationships are explained in full in the following chapters.

Figure 1: ERA Integrative modelling framework



1.2.1 Economics of climate adaptation (ECA)

ECA is a decision-making support framework integrating climate vulnerability and risk assessments with economic and sustainability impact studies to identify the most effective adaptation measures for various climate risks. ECA initiates the risk assessment process by defining the scope of the study, which includes identifying the types of climate hazards (e.g., floods, droughts, heatwaves) and the economic and non-economic assets at risk. The ECA framework provides a comprehensive and systematic process to evaluate climate hazards and identify cost-effective adaptation measures.

The main objective of ECA is to support decision-makers in developing their adaptation strategy and climate change adaptation (CCA) investment portfolios, including risk transfer. ECA offers a systematic and transparent approach that fosters trust and initiates in-depth inter-sectoral stakeholder discussions. The framework can be flexibly applied from the national down to the local level to different stakeholder groups and hazards. It further guides what aspects to focus on during a feasibility study. It provides key information for program-based solutions insurance approaches and has the potential to support National Adaptation Plans (NAPs) development.

The ECA framework evaluates the potential climate-related damages projected for the coming decades and determines how various measures can mitigate these damages. Additionally, the framework assesses the investments needed to implement these measures. It compares them to the benefits of avoiding damages from extreme events, ensuring that the reduction in damages justifies the investments.

ECA offers a unique approach towards a flexible identification of cost-efficient CCA measures for a variety of projects and sectors.

1.2.2 CLIMADA

CLIMADA is a modelling platform that enables probabilistic climate risk modelling and estimating the averted damages (benefits) of different adaptation measures. It involves several steps: geospatial asset localization, asset evaluation, and scenario development to simulate different climate risks, impact functions to estimate potential impacts, and parameterization of adaptation measures. CLIMADA evaluates the exposure, vulnerability, and impact on assets and conducts cost-benefit analyses to compare different adaptation strategies. This model provides a comprehensive view of the potential risks and the effectiveness of various adaptation measures.

The ERA approach aims to further expand upon the current usage of CLIMADA by investigating the effects of new parameters on CLIMADA's output results to accomplish the following goals:

- i. Encompass different hazards and their economic and non-economic impacts (e.g., access to health and access to education);
- ii. Analyze impacts on macroeconomic indicators (e.g., GDP, employment); and
- iii. Enable dynamic application by partner institutions through a simple GUI.

1.2.3 Macroeconomic modelling (CRED)

The Climate Resilient Economic Development (CRED) program, which guides this project, aims to use economic planning and adaptation tools for climate-resilient economic planning. To take the ECA insights to a country-wide socioeconomic scale, we use the Dynamic General Equilibrium model for Climate Resilient Economic Development (DGE-CRED) model. This macroeconomic model is designed to support decision-makers in understanding the long-term effects of climate change on national economies and to explore the effectiveness of different adaptation policies.

CLIMADA models the direct impacts of events on people, locations, crops, animals, or any objects of interest. By feeding these impacts into a macroeconomic model such as DGE-CRED, we can look at the effects of events on the entire economic system and how their effects interact with different components of the economy.

By integrating the quantified damages from CLIMADA into a broader macroeconomic context, DGE-CRED assesses how these climate-induced damages affect key economic indicators, such as GDP, employment, and public finances, even years after an event. The inclusion of DGE-CRED into CLIMADA acts as a pilot that improves the relevance of the models and the potential to highlight the impact of climate change on a higher level to relevant partner ministries. The approach is used to quantify the socioeconomic impacts of climate change and evaluate specific adaptation measures as part of long-term strategies for better understanding and mitigating the economic and social risks resulting from climate change (Banning et al., 2023).

Moreover, the benefits of CRED include macroeconomic model-based recommendations that support economic policy and adaptation processes, such as National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs). These

benefits collectively create a more resilient economic framework by providing Thailand with the necessary tools, knowledge, and strategies to respond to climate change effectively (GIZ, 2020).

1.2.4 Graphical user interface (GUI)

The Graphical User Interface (GUI) is a user-friendly platform that allows stakeholders to interact with the data and models generated by the other components, especially from the ECA framework. “RISK WISE”,

which is the name of the GUI designed for this project, enables users to select and display the results of specific parameters, such as the country, hazard type, climate scenarios, economic and non-economic assets at risk, and cost-benefit analysis of adaptation measures. The GUI then produces visual outputs like maps, graphs, and reports from the CLIMADA modelling, which helps to interpret and communicate the results of the risk assessments. This component is essential for translating complex model outputs into actionable insights for decision-makers.

1.3 Thailand and climate change

Located in Southeast Asia, Thailand shares borders with Cambodia to the southeast and south by the Gulf of Thailand, the Andaman Sea, Malaysia, Myanmar to the west, and Laos to the north and northeast. The country spans roughly 513,000 square kilometres, stretching approximately 1,715 kilometres from north to south and 915 kilometres at its widest point. As of 2023, Thailand had a population of 71.9 million, making it the fourth largest in Southeast Asia (UNFPA, 2023), with a largely homogeneous population and small ethnic communities, including Chinese, Malays, and Cambodians. The country is divided into four natural regions: the mountainous north, the semi-arid northeast plateau bordered by the Mekong River, the hilly, forested isthmus of the south, and the central Chao Phraya River basin. The latter constitutes Thailand's most fertile and important rice-growing area and serves as the country's administrative, industrial, and commercial hub (UNDRR, 2020).

Thailand experiences a tropical monsoonal climate with three distinct seasons: a cool season from November to January, a hot season – often characterized by droughts – from February to April, and a rainy season from May to October. Over 80 per cent of the precipitation occurs during these six months, with the bulk occurring in September and August (Gale & Saunders, 2013; UNFPA, 2023). The cooler season is a product of the northeast monsoon, while the rainy season that follows is driven primarily by the southwest monsoon. Additionally, the country is exposed to El Niño-Southern Oscillation (ENSO), which is responsible for the commonly discussed climatic anomalies associated with its cycle. Lastly, Thailand can also receive the remnants of tropical cyclones as they make landfall along the South China Sea. The fluctuating climatic behaviour is further complicated by the shifting Walker circulation in the Pacific and the Intertropical Convergence Zone's (ITCZ) influence (Arpornrat et al., 2018; Singhrattana et al., 2005). As an example of this wide variability,

Bangkok, the nation's largest city and capital, is located in the Chao Phraya Basin and experiences these alternating periods of high humidity and temperatures ranging from 20°C in the cool season to 38°C in the hot season as well as periods of severe flooding and drought associated with the tropical monsoonal climate type (Power et al., 2020). In part due to the climatic extremes that affect Thailand, the country is highly vulnerable to the effects of climate change, ranking as the ninth most affected country in the period of 2000-2019 by the Global Climate Risk Index Report (Eckstein et al., 2021).

The heavy reliance of the Thai economy on agriculture, including forestry, livestock, and fisheries, which employed roughly one-third of the workforce in 2018, further exacerbates its vulnerability to climate change. These climate impacts pose significant risks to key agricultural systems and the livelihoods of those dependent on them (IOM, 2024). Moreover, extreme events such as increased droughts disrupted workers' livelihoods from neighbouring countries, pushing them to seek employment in Thailand's agricultural sector, which is highly vulnerable to climate change (IOM, 2024; Vigil & Kim, 2023). This movement of individuals seeking opportunities in the already stressed agriculture sector exacerbates an already unstable system, further threatening those whose livelihoods depend – particularly rural farmers – upon agricultural output in an increasingly unpredictable climate.

Other sectors in Thailand share a similar outlook to the Agricultural sector. Prolonged droughts, severe flooding, and rising sea levels are expected to compound an already extensive list of challenges for Thailand in the twenty-first century (Hilly et al., 2018; Marks, 2011). These include water management difficulties, heightened social tensions exacerbated by wealth inequality, increased immigration and refugee flows, damage to the tourism sector, and potential

conflicts with neighbouring countries over water management practices. Lastly, due to the increased frequency and severity of hazards such as flooding and drought, disruption of day-to-day activities in Thai society can also be expected – normal activities such as going to the temple, school, and markets, among other things, will all be affected in some capacity by climate change and its adverse effects. Although the Thai government has begun formulating policies to adapt to and mitigate climate change, its efforts are limited by shortcomings in both planning and execution. Political instability further distracts decision-makers from effectively addressing these issues. In the future, Thailand's institutional structure and political dynamics may hinder its ability to combat climate change. While capacities are expected to improve with democratization, they will remain limited. Consequently, climate change will likely slow Thailand's growth and put immense pressure on its already strained political system, environment, and society (UNDRR, 2020).

1.3.1 Flooding

Floods are among the most devastating disasters worldwide, known for causing thousands of casualties annually and significant economic loss in many countries. Between 2002 and 2022, floods emerged as a dominant natural hazard, affecting an average of 74.6 million out of 175.5 million individuals impacted by various disasters worldwide (CREED, 2024). Flooding in Thailand occurs in three regimes: pluvial, fluvial, and coastal. It is frequently combined because of Thailand's unique hydrometeorological and geographic characteristics, causing major damage and loss of life throughout the country.

The 2011 flood was the worst Thailand had experienced in over 50 years. This flood stemmed from multiple factors: the remnants of various tropical storms combined with the monsoon causing increased precipitation, as well as water management infrastructure and strategies that were unable to handle the increased runoff. As such, the 2011 flood affected 65 of the country's 76 provinces, equalling more than 100,000 km². The Chao Phraya River Basin was the most affected region, which includes much of the country's farmland, industrial estates, and the nation's capital and largest city, Bangkok. Property losses were over 45 billion USD, most of which were incurred by the private sector. Over 13.5 million people were affected by this flood, and 813 people lost their lives (Singkran, 2017).

Many other smaller, more localized floods have occurred throughout the country in recent decades. Ranging from flash floods in the country's highlands

in the north to overland flooding in Bangkok's Khlong Toei neighbourhood, these events are occurring with increased frequency and severity throughout Thailand (Chaithong, 2022). Flooding at any scale causes disruptions, ranging from the inability for people to go about their day-to-day activities (i.e., driving to and from work, school, temple, etc.), disruptions to the economy (destruction of infrastructure, crops, etc.), or reduction in water quality (Chaturongkasumrit et al., 2013).

1.3.2 Drought

Thailand's climate has extreme swings, oscillating between periods of extreme precipitation and drought conditions. Like flooding, climate change is causing these droughts to occur more frequently and with greater severity. The Southeast Asian Monsoon plays a significant role in dictating these drought conditions in the affected area – including Thailand. Due to the slow onset nature and subtle vital impact, the effects of these droughts are often underestimated, especially in comparison to the flood mentioned above (Bangkok Post, 2020; Tanguy et al., 2023; Zhang et al., 2021). Severe loss of crop production played a significant role in the total economic losses of upwards of 1.4 billion USD in Thailand because of the 2020 drought (Tanguy et al., 2023).

A notable example occurred in 2020 when a shorter-than-average monsoon season and an uncharacteristically strong El Niño contributed to severe water shortages, disrupting crop production and quality. Being the second largest exporter of rice and sugar, any disruption in production can have large ripple effects throughout the economy. In 2020, sugar production dropped by 28 per cent, and similar losses were seen across the agriculture sector (Bangkok Post, 2020; Tanguy et al., 2023). Severe loss of crop production played a large role in the total economic losses of upwards of 1.4 billion USD in Thailand because of the 2020 drought (Tanguy et al., 2023).

1.3.3 Heatwaves

Unsurprisingly, the frequency of occurrence and severity of heatwaves in Thailand is also increasing with climate change. From 1999 to 2008, a higher intensity of heatwaves was directly attributed to the deaths of many individuals in Northern and Central Thailand, with the elderly population in particular suffering greatly. More recently, the 2016 heatwave set new records for duration and intensity – with each day in April exceeding 40°C, and one day reaching 44.3°C. This heatwave event disrupted crop production and catalyzed societal distress and extremely high energy consumption during this period (Dong et al., 2021).

As alluded to previously, heatwaves are particularly dangerous to vulnerable populations, such as children, the elderly, and individuals with health conditions exacerbated by high temperatures (Arsad et al., 2022; Chung & Pin, 1996; Dong et al., 2021). Due to climate change and the dramatic demographic shift in Thailand, the number of elderly people exposed to heatwaves and, therefore, vulnerable to heatwaves, is increasing at a high rate. That said, other populations are also finding themselves vulnerable to the adverse effects of prolonged extreme heat.



2. Economics of Climate Adaptation (ECA)

2.1 Further on the ECA framework

The ECA framework was applied in this project as a decision-making support framework to integrate climate risk assessments and optimal adaptation solutions. ECA provides a practical portfolio of cost-efficient adaptation measures by combining climate vulnerability and risk assessments with economic and sustainability impact studies.

The ECA framework evaluates the potential climate-related damages projected for the coming decades and determines how various measures can mitigate these damages. Additionally, the framework assesses the investments needed to implement these measures. It compares them to the benefits of avoiding damages from events such as floods and heatwaves, ensuring that the reduction in damages justifies the investments.

The outcomes of the ECA, including projections of potential climate-related damage over the coming decades, the amount of damage that can be mitigated through adaptation measures, and their cost-effectiveness, offer countries tangible opportunities to access climate finance and other risk financing tools. The results offer a reliable basis for managing climate risks and planning adaptation measures, demonstrating the reliability and effectiveness of ECA and providing stakeholders with confidence in using this approach for climate adaptation efforts.

The standard ECA approach contains three elements supported by the modelling platform CLIMADA:

1. **Climate-risk identification:** Conduct an identification of climate risk in a defined region (e.g., rural area), identify areas and people at risk, spanning all significant climate hazards and the full range of possible impacts for different sectors.
2. **Climate-risk quantification:** Calculate the expected damage across multiple climates and economic scenarios
3. **Identification and prioritization of CCA measures** (using cost-benefit analysis of CCA measures): Determine strategies, including a portfolio of specific CCA measures with detailed cost/benefit assessment.

The cost-efficiency of adaptation measures and values of the assets are modelled up to the year 2050 and incorporate the country's anticipated economic, demographic, and climatic shifts. ECA quantifies the benefits of adaptation measures by calculating the expected damage averted by their implementation. The economic measures are described in monetary terms, and therefore, their efficiency (in terms of impact or investment) can be directly compared. Further, this report also includes non-economic assets, considering the impacts on the physical assets and the services provided by some of them.

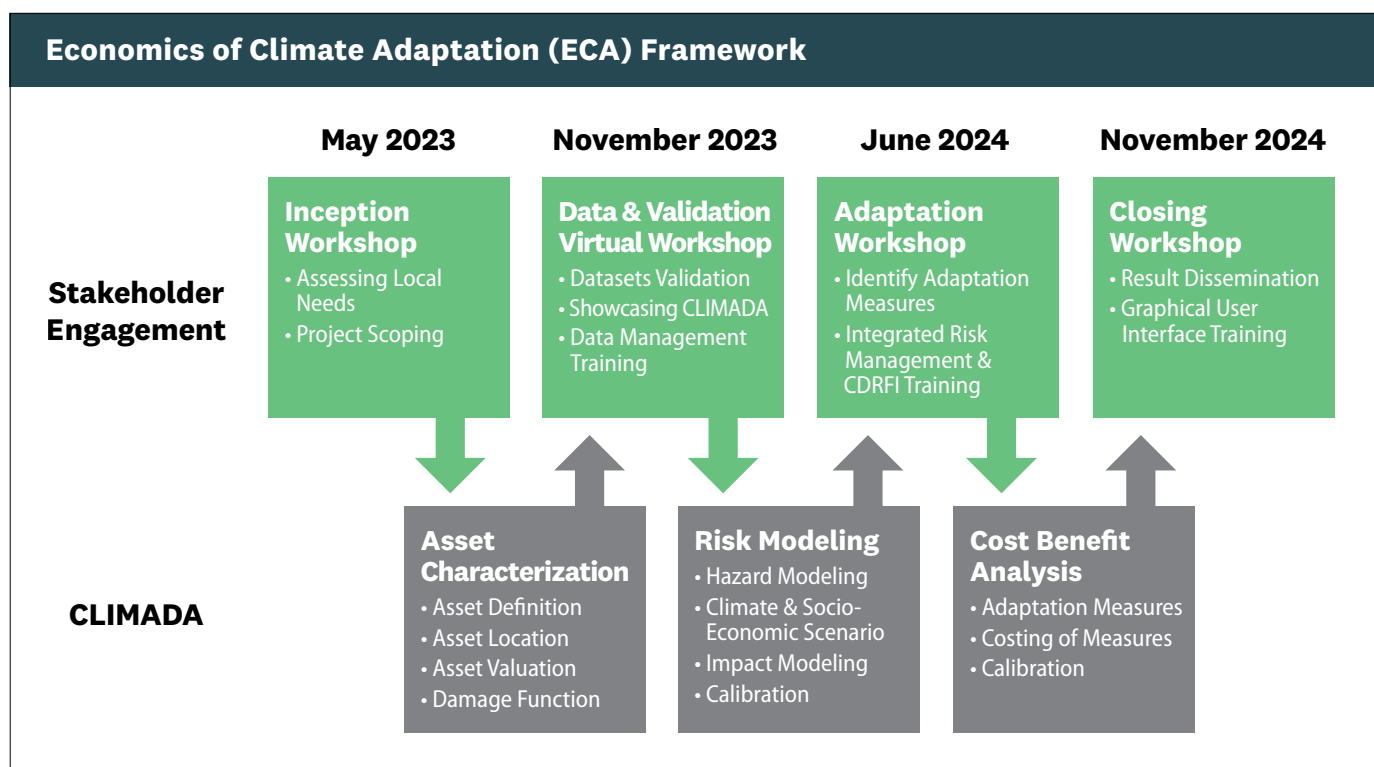
A plethora of approaches have already been designed to respond to the complexity of climate change-related projects. Concerning the development of climate change adaptation strategies, they range from climate vulnerability assessments, risk assessments, and economic and/or sustainability impact assessments to decision-making support tools. Among these approaches, none integrates the full range of processes from risk assessment to a feasibility study of CCA measures. Integration is the strength of ECA; it is linked to the open-source modelling platform CLIMADA. The latter calculates the potential impact of current and future hazards on several selected assets using available data, including the cost/benefits of selected measures.

However, there is still a need to include non-economic assets and macroeconomic impacts in ECA and CLIMADA. Figure 2 presents the steps ERA followed to integrate these assets – the CRED model for macroeconomic assessments and the GUI for enhanced access to project results – into the ECA framework. It also illustrates the stakeholder engagement workshops conducted with GIZ, UNU-EHS, MCII, and local partners.

2.1.1 Stakeholder engagement

The ERA project and the ECA framework were designed to emphasize stakeholder engagement. A series of workshops was conducted to incorporate the expertise and guidance of stakeholders from various sectors. These workshops served multiple purposes, including gathering crucial data, validating assumptions, and facilitating exchanges between parties. Stakeholder input is vital to the ECA

Figure 2: ERA approach for the ECA framework



approach, ensuring the accuracy and relevance of the project's data and assumptions. Below is a brief overview of these workshops, their objectives, and their importance within the ERA project.

1. Inception workshop

The project commenced with an inception workshop co-hosted by the Department of Agriculture of Thailand and GIZ. The workshop aimed to understand the needs and expectations of local stakeholders and define the scope of the risk assessment elements. This activity marked a critical step in fostering stakeholder awareness and ownership essential for the project's overall success.

The objectives of the workshop were:

- i. To introduce the ERA project and ECA framework, including their objectives, expected outcomes, and examples from other countries implementing the ECA framework and CLIMADA tool.
- ii. To identify and understand the interests and expectations of stakeholders on climate risk assessments to shape the CLIMADA risk assessment tool for Thailand.
- iii. To jointly scope the risk assessment by defining the hazards, climate scenarios, priority regions (if any), time horizon, economic and non-economic assets, and sectors for the macroeconomic impact analysis.
- iv. To present the data needs and identify collaborations for data collection and access to data sources.

- v. To present the project timeline and the next steps for the project implementation.

The workshop was a crucial component of the project as it established a common understanding of the objectives and approach of ERA. It engaged participants representing diverse stakeholder groups to define the scope of the related studies, variables such as the hazards, climate scenarios, time horizons, and economic and non-economic assets for the risk assessments were selected, as well as the sectors for the macroeconomic impacts analysis. Table 1 presents the key elements for the risk assessment agreed upon during the inception workshop. Further details of the assets can be found in [Annex I. Economic and Non-Economic Assets](#).

Data collection and literature review

Information on data owners, contact persons, data availability, formats, and quality was identified during the workshop with the support from the participants. Following the inception phase, data for flooding, drought, and heatwaves were collected. Further, specific indicators and quantification methodology were developed for the economic and non-economic assets, all based on a comprehensive literature review of journals, articles, published reports, and government websites. The numbers of datasets per category are presented in Table 2.

After the inception workshop, the data collection was carried out. The Thai government provided most of

Table 1: Key elements for the risk assessment

Key elements	Selected components
Hazards	Floods, droughts, and heatwaves
Time horizon	2050
Climate scenarios	RCP4.5 (moderate GHG emission scenario) & RCP8.5 (extreme GHG emission scenario)
Economic assets	Agriculture (Tree crops, Grass crops), Markets (Wet markets)
Non-economic assets	Religious services (Buddhist monks and shelter), Education (Students), Mobility (Road users), Agriculture (Tree and grass crop farmers), Water (Access), and Health (Diarrhoea and heat exhaustion patients)
Sectors for macro-economic impacts	Agriculture, Energy, Tourism, Financial Sector, Manufacturing, Services, and Real Estate (Housing)

Table 2: Number of datasets under different groups

Group name	Number of datasets
1. Economic	9
2. Socio-economic	6
3. Historical events	7
4. Climate data	6
5. Hydrology	9
6. Non-economic assets	10
7. Mobility	12
Total	59

the data required for modelling. The required data was supplemented with open databases when necessary. A simultaneous and extensive literature review was carried out during the data collection phase to gather information about the hazards and how they relate to the assets selected during the inception workshop.

2. Data validation workshop

The dynamic between data availability and the hazard/asset interrelationship made modelling certain assets, particularly non-economic ones, more complex. The ECA framework anticipated this challenge and included a data validation workshop early in the process. This workshop aimed to inform relevant stakeholders about the data sources and assumptions used in CLIMADA modelling, allowing them to provide feedback as needed. This step was crucial to ensure that the hazard/asset relationship assumptions were sound and that the best available data sources were utilized. The workshop also allowed for slight adjustments to the initial stages of the project with minimal disruption to its overall workflow.

The main objectives of the data validation workshop are as follows:

1. To present the status of current data collection.
2. To validate the collected data as best available.
3. To present the identified indicators to assess non-economic impacts.
4. To have an in-depth discussion regarding data usage for CLIMADA.

The workshop also demonstrated the CLIMADA platform. This session briefly explained the data inputs and outputs for CLIMADA within this project's context and the capabilities and limitations of the model. After the conclusion of the data validation workshop, slight adjustments were made based on the received feedback, and the project proceeded to the impact modelling phase.

Modelling and calibration

We begin creating and modelling the hazard while simultaneously finding the assets to make the Entity Files. These files contain all the necessary information for CLIMADA to model the hazard impacts on the assets, including the damage function, adaptation measures, and other required data. Following the creation of the initial hazard models and visualizations, the damage functions require further calibration – using impact data from past events, literature reviews, and expert input – to more accurately reflect real-world conditions.

3. Adaptation workshop

After the inception and data validation workshops, the collected data were used in CLIMADA to assess the risk of floods, droughts, and heatwaves for the selected economic and non-economic assets identified

during the inception workshop. The next step involved prioritizing relevant adaptation measures to be included in the model.

For this purpose, the adaptation workshop was carried out with the following objectives:

- i. To update stakeholders on the status of the ERA project, including an overview of the preliminary results of the risk assessment.
- ii. To select and prioritize adaptation measures to be included in the CLIMADA analysis.
- iii. To provide learning opportunities for participants:
 - a. Integrated climate-risk management and climate.
 - b. Disaster-risk financing strategies.

The preliminary results from the risk modelling of flooding and heatwaves and the initial "long list" of adaptation measures developed by UNU-MCII were presented to stakeholders during the Adaptation Workshop. This list, compiled through a comprehensive literature review, was a starting point for discussion and was open to adjustments and amendments. The workshop emphasized stakeholder involvement in selecting and prioritizing these adaptation measures. Participants were well-versed adaptation practitioners and academics from governmental agencies, think tanks, NGOs, and academia. The workshop followed a so-called "hand-holding approach", in which participants were asked similar questions several times to ensure they shared as much of their knowledge with the organizers as possible. The different activities inquired into what adaptation measures have been used in the country, where they were used, what was learned from those experiences, what other measures are promising, and further details like costs. By the last session, the organizers collected in-depth details of the Thai adaptation history and sorted criteria to select the "short list" of measures to be modelled in CLIMADA.

The workshop also covered training on Climate and Disaster Risk Finance and Insurance (CDRFI) to provide a better understanding of the ICRM approach and its benefits for the country's risk management strategy, including an insurance simulation board game. [Chapter 2.2.4](#) gives further details on the methodology for selecting adaptation measures. A detailed overview of the methodology for adaptation measure selection can be found in [Annex II. Methodology for Adaptation Measures Selection](#).

4. Closing workshop

The closing workshop aims to deliver the project results to participants and discuss the follow-up opportunities practically and realistically. The

sessions are organized so participants can engage with groups of results and visualize adaptation strategies informed by the information they are receiving.

Similarly, the workshop includes an interactive session to introduce the GUI to participants, so they learn to easily access the results beyond what is presented in the report.

2.1.2 CLIMADA

As previously mentioned, CLIMADA is a modelling platform that enables probabilistic climate risk modelling and estimating the averted damages (benefits) of different adaptation measures. The initial setup of CLIMADA for the purposes of this project involved two foundational phases: the inception phase for establishing the project's scope and the base data phase, which focused on gathering and validating essential data in collaboration with key stakeholders to set up the CLIMADA tool effectively. The following sections of the report outline the inputs for CLIMADA, covering hazard data, asset inventories, damage functions, and adaptation measures. The report also addresses the assumptions and uncertainties encountered throughout the modelling process.

Due to the limited availability of historical damage data for some assets, various sources were utilized to construct and validate assumptions, including a comprehensive literature review. An iterative calibration process refined the model's performance in adeptly simulating observed risks. Similarly, local knowledge and expertise were leveraged to develop a prioritization methodology, scoring adaptation measures based on specific criteria to better align with local conditions. The approach led to the identification of eight shortlisted adaptation measures, including nature-based solutions, technical and engineering solutions, hybrid measures, and risk transfer/insurance options. Details on the selection process and the final shortlist are provided in [Annex I. Economic and Non-Economic Assets](#).

Briefly summarized below are the steps taken for CLIMADA – often in parallel to the Stakeholder Engagement aspect of the project. It is important to note that the iterative process is needed to provide CLIMADA with the most accurate data possible. To do this, expert consultation and discussion (stakeholder engagement) were necessary. Broadly speaking, the information gathered from stakeholders was analyzed further via the processes summarized in the following paragraphs.

1. Asset characterization

After the conclusion of the inception workshop, the data collection phase fully commenced. Various

Thai Government agencies provided large portions of the data needed for modelling. When necessary, the required data was supplemented with open-use databases. In conjunction with the data collection phase, a simultaneous and extensive literature review was conducted to provide context for the hazards and how they relate to the assets chosen during the inception workshop.

This data collection focused mainly on how hazards affected the chosen hazard, at what rate the damage occurred, and where these assets were located within Thailand, with GIS being utilized extensively for the geolocation of these assets. Lastly, an estimated valuation of the total assets was created using information gathered during the various workshops and by our own literature review. More detailed explanations of the process with specific examples can be found in [Annex I. Economic and Non-Economic Assets](#).

2. Risk modelling and calibration

The entity files were created after the hazard modelling assumptions were finalized, and data sources were fully explored. In short, the entity files contain information on the location and values of the selected assets, such as exposure, the damage functions that link the hazard intensities to the expected proportion of damages, and the parameters specific to the adaptation measures considered in the study. The entity files were created after the asset modelling assumptions were finalized, and data sources were fully explored. After the input data was fed into CLIMADA, the initial guess of the damage function was further calibrated to ensure that the model accurately represents real-world damage values corresponding to the hazardous events. This calibration is further enhanced based on previous literature reviews and expert consultation.

3. Cost-benefit analysis and calibration

One of the main results of CLIMADA is the cost-benefit analysis of adaptation measures. In the ECA framework, this analysis is carried out to understand the relationship between the costs (investment and maintenance cost) and the net averted damage of a set of measures. A detailed overview of the Methodology for Adaptation Measure Selection can be found in [Annex 2](#). Here, we present a brief description of such methodology in the context of flood, drought, and heatwave risks in Thailand, which involves a systematic four-step process:

1. First, a comprehensive “long list” of potential adaptation measures is defined, drawing on existing knowledge and expert input.

2. Next, this list undergoes validation and refinement through stakeholder consultation, including the selection and weighting of the criteria that are later used to prioritize the most relevant measures to be included in the model.
3. The third step employs a multi-criteria decision analysis (MCDA) to narrow down the long list to a short list of high-priority adaptation measures using the criteria from the step before, which includes various factors such as cost-effectiveness, stakeholder acceptance, and potential maladaptation.
4. Finally, the cost of implementing and maintaining these shortlisted measures across the entire country is estimated, providing a good basis.
5. Finally, the cost of implementing and maintaining these shortlisted measures across the entire country is estimated, providing a good basis for comparing against the benefits projected by CLIMADA for their implementation.

4. Limitations and uncertainties of the study

The CLIMADA model provides a robust framework for assessing the risks and impacts of floods, heatwaves, and droughts, which, in the case of ERA, offers valuable insights for national-level decision-making. While the model relies on secondary data and global climate projections downscaled to local contexts, this probabilistic approach is commonly used and enables the comparison of risk trends across regions (Chokkavarapu & Mandla, 2019; Giorgi & Gutowski, 2015). The lower resolution applied at the national level is a necessary trade-off for capturing the broader picture, ensuring results remain relevant to country-level planning. Although these assumptions do not fully capture the granularity of localized events, they are grounded in research and provide a strong foundation for resilience-building actions.

One key challenge with national-level models using CLIMADA is the introduction of uncertainties due to the coarser resolution used. While effective at understanding broad trends, the model's large-scale grid can lead to inaccuracies when zooming in on specific areas. Despite these limitations, national-level assessments are essential for comparing risks across regions and identifying priority areas for further investigation and action. These results serve as a critical starting point for decision-makers, offering insights that can be refined as more granular data becomes available. However, these projections remain the most reliable global data available, particularly in regions with limited or inaccessible data (Foley, 2010; Landström, 2017).

Another important source of uncertainty is the impact functions, derived from extensive literature reviews but not fully validated with ground-level data in all cases. However, consultations with local experts and calibration against historical data improved the model's accuracy throughout the project. The impact functions are calibrated to reflect a reasonable hazard-specific plausibility. As more local data becomes accessible, these functions are expected to be refined. Nevertheless, CLIMADA currently provides a solid framework for estimating impacts across various climate scenarios, even as it evolves (Ylhäisi et al., 2014). The CLIMADA model offers a robust framework for assessing the risks and impacts of the hazards selected for this project: floods, heatwaves, and droughts. In doing so, CLIMADA offers valuable insights to decision-makers to avoid or mitigate the worst-case scenarios predicted in the models. CLIMADA, like all models, has its limitations because these hazard models rely on secondary data and global projections that were downscaled to local contexts; assumptions were necessary to apply them to the context of the studies. This approach is common in probabilistic assessments and allows for comparing risk trends across regions. The wider resolution used at the national level is a necessary trade-off for capturing the broader picture, ensuring results remain meaningful and applicable to country-level strategic planning. The assumptions made at this scale are well-researched and reasonable for guiding resilience-building actions despite not being able to capture the exact granularity of any localized event.

One of the challenges in using these models is that national-level hazard assessments can introduce uncertainties due to the broader resolution of the models. The national scale provides a large grid, which works well for understanding the general landscape. However, as you zoom in for further details, more uncertainties arise because localized conditions might not be perfectly represented when applying the average of a much larger area. Nonetheless, these broader results are essential for comparing risk across regions and provide a crucial first step toward identifying priority areas for further investigation and action.

Another consideration is that the impact functions, also referred to as damage functions, derived from a thorough literature review have not yet been fully validated with ground-level data in all cases. Although these impact functions are vital for CLIMADA to function properly and offer a credible foundation

for estimating potential impacts, these functions are expected to be refined over time as more data becomes available. Impact functions and their role in CLIMADA will be further explained in the following section. As with most models, in later stages, to more accurately reflect real-world conditions, calibration of the results with historical data and consultations with local experts occurred, thereby improving the accuracy of the models. However, it is important to remember that complete on-the-ground verification is the only way to provide accurate results, and it remains a future goal. Barring this, CLIMADA and the functions it derives its results from serve as a solid starting point for estimating impacts across different climate scenarios, despite their limitations.

Our analysis utilizes IPCC global models that have been downscaled to local levels, introducing some degree of uncertainty that is unavoidable in forward-looking climate risk assessments. While these projections carry the inherent uncertainties of large-scale modelling and regional averaging, they remain the most reliable global data source available, particularly in regions where accurate or easily accessible data is lacking. As a foundational layer, these results provide a valuable lens through which to assess potential future risks and identify broader trends at the national scale.

However, the downscaling process can introduce accuracy challenges when applying regional averages to more granular, localized levels. To capture local realities more effectively, further validation through localized research in key areas is necessary. Despite these limitations, our analysis offers a critical starting point for guiding strategic planning and climate adaptation efforts at the national level. Future work should focus on refining these findings with localized data, but in the meantime, this study serves as a reliable baseline to inform decision-makers and help prioritize areas requiring deeper exploration.

Finally, while the current adaptation recommendations offer feasible solutions, their effectiveness will ultimately need validation through more detailed local research. This iterative approach ensures that the model's outputs remain a useful and ever-evolving tool for decision-makers, with the flexibility to adapt as more localized information becomes available. In this way, CLIMADA helps set the stage for a more resilient future, even as the CLIMADA model continues to evolve and improve through ongoing refinement and validation efforts.

2.2 Modelling inputs

2.2.1 Hazard models

1. Flooding

Flood events are rapid in their onset, and an affected area is heavily dependent on the natural characteristics of the surrounding region. The flood hazard map is created using CLIMADA River Flood API, an open-source platform for probabilistic multi-hazard risk modelling. The API extracts flood data simulated within the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP)¹. It focuses specifically on river flood hazards and uses the RiverFlood class to create datasets that include flood depth and the flooded fraction of each centroid. These datasets are derived from global hydrological models driven by various climate factors.

One of the key strengths of CLIMADA's River Flood API is its integration with other components of the CLIMADA framework, allowing users to combine flood hazard data with exposure and vulnerability information to calculate comprehensive flood impacts (Riedel et al. 2024). The CLIMADA River Flood API calculates socio-economic impacts by translating flood depth into potential damages. It is designed to be accessible and computationally efficient, making use of freely available data to enable widespread adoption and application in flood risk assessment and management. Operating at global and local scales, it offers resolutions ranging from 10 km to 100 m. The River Flood hazard class in CLIMADA allows users to generate spatially explicit flood depth and flooded fraction data, which are crucial for accurate flood risk assessment. It can create hazard sets for specific countries and years, enabling localized and global-scale analyses. The API provides flexibility in modelling different flood protection standards, including scenarios with no protection and those with protection against 100-year return period events. This feature is valuable for evaluating the effectiveness of flood mitigation strategies.

The input flood hazard data is generated from global hydrological models, specifically the ISIMIP2a and ISIMIP2b simulation rounds. These incorporate output from the CaMa-Flood river routing model².

In this study, we attempt to estimate the future changes in flood hazards driven by climate change.

These datasets are derived from global hydrological models driven by various climate forces. The inundation levels are presented separately for different return periods³ (T2, T5, T10, T25). Two flooding scenarios are provided, present (2024) and future (2050), according to the time horizon selected by participants during the inception workshop. The results show the impact of flood hazards in increasingly affected areas in Thailand.

2. Drought

Droughts are natural hazard events with slower onsets and, in general, often larger geographical reach than other climate-related extreme events like floods and storms. The definition of drought changes depending on the duration and the intensity of the water deficiency. Meteorological droughts are mostly reflected in a reduction in the water balance, with lower precipitation, higher temperatures, and evapotranspiration. Agricultural drought exhibits soil moisture deficit and stress for plants, crops, livestock, and biomass in general. Hydrological droughts affect water bodies like rivers (stressing energy production), lakes, and wetlands, while socio-economic droughts are identified when communities and societies are significantly impacted by the conditions above (Wilhite & Glantz, 1985).

Many indices exist for meteorological drought, and they vary not only in their data requirement but also in their level of complexity (Svoboda et al., 2016). The most used indices worldwide for studying drought are the Standard Precipitation Index (SPI) and its variant, the Standard Precipitation and Evapotranspiration Index (SPEI), which express the gap between a given period and the average observed SPEI values on standard deviation units. These indices are especially useful in areas with a limited amount of data collected on the ground by weather stations (Billi, 2015).

For studying droughts in Thailand, the methodology using CLIMADA considers the precipitation deficit as a drought indicator to model meteorological and/or agricultural drought. For this, the Standardized Precipitation Index (SPI) was chosen for the study. SPIs have been globally used as a standard index for the characterization of meteorological drought conditions at different timescales. The SPI quantifies

1 ISIMIP develops and provides climate and socioeconomic forcing datasets for cross-sectorally consistent climate impact modelling and curates related model output data. For more information visit: <https://www.isimip.org/about/#mission>

2 The CaMa-Flood (Catchment-based Macro-scale Floodplain) model is designed to simulate the hydrodynamics in continental-scale rivers. The entire river networks of the world are discretized to the hydrological units named unit-catchments for achieving efficient flow computation at the global scale. For more information visit: <https://hydro.iis.u-tokyo.ac.jp/~yamada/cama-flood/index.html>

3 A return period, also known as a recurrence interval, is an estimate of the likelihood of an event to occur. For more information visit: <https://www.sciencedirect.com/topics/engineering/return-period>

the standardized deviation of the observed precipitation from a probability distribution function (typically a gamma, Pareto, or a Pearson Type III) or a synergy of several probability distributions, representing the historical raw observational series (Keyantash & National Center for Atmospheric Research Staff, 2023). As this indicator is only based on precipitation inputs, this provides additional simplicity in computations, especially for detailed spatial studies, and allows temporal flexibility (e.g., 1 month, 3 months, 6 months, 12 months) for tracking different drought scenarios.

In this study, the SPI-based drought hazard was modelled standalone outside of the CLIMADA environment. For this, the Regional Climate Model (RCM) downscaled precipitation data was sourced from the CORDEX Southeast Asia (SEA) domain. The Coordinated Regional Climate Downscaling Experiment (CORDEX) is a scientific and international initiative from the World Climate Research Programme (WCRP), which aims to provide higher-resolution regional climate projections for different climate-related indicators around different regions around the world to support climate change planning, impact assessments, and adaptation. The CORDEX products are regionally downscaled versions of the Global Circulation Models (GCM) that provide a better picture of the regional climate dynamics.

The climate projections used here are from RCA4 RCM runs driven by the Had-CGCM2-ES GCM, which are based on IPCC AR5 future projection scenarios, namely RCP 4.5 (intermediate scenario) and the RCP 8.5 (high-emission scenario). The SPIs were modelled for Thailand based on the monthly precipitation data for current baseline conditions from 1979-2005 and future projected scenarios (2025-2050 at a resolution of 0.22x0.22 degrees (roughly 25km), aligning with the periods selected by participants during the inception workshop. Furthermore, drought intensities for five return periods were also calculated: T5, T10, T25, T50, and T100 years.

3. Heatwaves

The heatwave hazard information, as an input for CLIMADA, was also modelled in a standalone manner outside the CLIMADA environment. The Warm Spell Duration Index (WSDI) was selected to characterize the heatwave conditions in Thailand. This climate indicator provides a measure of persisting warm spells as a robust proxy for heatwave based on the daily maximum temperature information and is predominantly focused on heatwave duration. WSDI is also one of the temperature-related indicators recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI) specifically for

detecting heat spells. Considering spatiotemporal variability and the frequent prevalence of heatwaves, WSDI was deemed the best available indicator for Thailand. This index relies on the number of consecutive days (higher than two) and does not employ a generic reference temperature threshold; instead, using a percentile-based (90 per cent) approach makes it more adapted to local conditions.

Given the pertinent information on heatwave signals, albeit the computational simplicity, there are, however, some limitations related to the use of the WSDI. Specific local phenomena such as heat islands, humidity, and wind effects are not considered. Further, it does not fully account for the intensity of the heatwave but rather only the duration. As is the case in most regions with ungauged catchments, several assumptions are necessary to represent physical processes. Even with the limitations, the WSDI generously provides a reliable proxy for heatwaves, owing to its capability to encompass spatio-temporal variability in fluctuations in maximum temperature. Furthermore, the ease of communication with policymakers due to computational simplicity, historical consistency, memory, and adaptability in defining local scale thresholds and variables provides a strong basis for WSDI in this study. We have strived to collect the best available data in this ECA study, given the priority to have ample historical and future projections at a reasonably sound spatial detail, which was provided by the higher resolution (0.22 degrees) products of CORDEX SEA.

4. Climate scenarios

The Sixth Assessment Report from the IPCC (AR6) and the Coupled Model Intercomparison Project Phase 6 (CMIP6) include over 100 models from over 50 modelling centres and provide the latest climate projections based on the Shared Socioeconomic Pathways (SSPs). However, applying the raw data of these Global Climate Models (GCMs) at a local scale without downscaling to a region-specific lower resolution is a rigorous task, and imparts huge uncertainties owing to the spatial detail required for ECA studies. In recent years, the Regional Climate Model (RCM) projections based on IPCC AR5 RCP scenarios from the CORDEX have proven to be more accurate and outperformed any other simulation independently of the data used over countries, especially due to the domain-specific downscaling approach. However, CORDEX-based RCMs are unavailable for the latest CMIP6 simulations to date. Therefore, due to the higher resolution datasets available for the CORDEX CMIP5-based RCM simulations, the Representative Concentration Pathways (RCP) based scenarios were employed in this study.

Regarding the different emission-based scenarios proposed by the AR5, there is no consensus on which of the four RCPs (RCP2.6, RCP4.5, RCP6, or RCP8.5) is most likely; the IPCC considers all RCPs to be within the likely range of actual radiative forcing. As part of the inception workshop, participants were asked to select for which scenarios the future impacts should be projected. Both RCP4.5 and RCP8.5 were chosen and are thus used to provide a range of possible effects and consider a less optimistic scenario in the analysis. However, in the case of floods, RCP 2.6 (weak climate change signal) was used instead of the requested 4.5 because the acquired projections were of better quality and more consistent with other studies.

The scenarios are based on validated scientific data and models. However, not all climate scenarios are consistent in their conclusion. Further, the models are calibrated for certain regions, and precipitation simulations are particularly sensitive to the scale. It is essential to note that usually, less confidence exists in the case of extreme scenarios compared to moderate scenarios, the latter being often the result of a consensus among different models.

2.2.2 Assets characterization (Economic and non-economic)

The report evaluates the impact of floods, droughts, and heatwaves on various assets and assesses the cost-efficiency of adaptation measures to minimize these impacts. Research was conducted to gather accurate data on the selected assets, which provided crucial insights into how best to represent them in the model. The following sections explain the rationale behind the asset characterization. [Annex I. Economic and Non-Economic Assets](#) presents further details on this process.

Data for this analysis were sourced from online research centres, databases, and the Thai authorities. Given the limited availability of historical damage data for some assets, additional sources were utilized to confirm and refine the assumptions, including insights from international publications and adjustments made using the CLIMADA model.

CLIMADA relies on georeferenced data to simulate risk scenarios and assess damage, making it crucial to accurately map each asset's location. Similarly, the model requires numerical values for all assets to compare an initial and a post-disaster state. Economic assets are valued in USD, and non-economic assets are valued in the number of people (students, patients, etc.). As mentioned previously, the methodologies by which these parameters were collected and validated through:

- Literature review,
- Discussions with experts during the inception workshop

After the asset location and valuation, the damage or impact function (See [Annex I. Economic and Non-Economic Assets](#) for more details) of the assets is prepared, which indicates the expected impact on assets at different hazard intensities, allowing the assessment and quantification of damage from weather-related hazards such as floods, droughts, and heatwaves. Damage functions can be constructed using various approaches. One approach is to contrast historical data on hazard intensity and the recorded damages estimated through reconstruction cost or the depreciated values of the asset. This approach is usually preferred and can be accurately utilized within a specific context with adequate data. Alternatively, estimating the probable damages based on expert opinions or related reports is possible. Lastly, a third approach can be used that relies on a generic or empirical damage function, which requires significant calibration using specific local values.

However, regardless of the methods employed, all damage functions need some degree of calibration to reflect historical data before they can be used for future projections. In this study, we employed a combination of methods. We used existing damage functions on different assets with the intensity parameter of depth, SPI, and WSDI for floods, droughts, and heatwaves, respectively, supplemented with historical data from Thailand, and finally calibrated. Various data sources were reviewed to prepare the initial shape of the damage functions, including government reports and reports from other international organizations on the impacts of floods, droughts, and heatwaves on the assets.

The following sections present an overview of the various asset categories included in this report. The assets were selected by Thai stakeholders during the inception workshop and characterized for the model through extensive research and expert consultation, which was later validated during the Data Validation Workshop. The analysis includes ten asset groups for floods, six for droughts, and two for heatwaves. As described before, for non-economic assets, the quantification is based on population counts at a specific resolution, representing the distribution of these assets across Thailand. In contrast, economic assets are quantified with an associated monetary value, allowing a detailed analysis of the cost-benefit ratio of adaptation measures in reducing financial losses.

2.2.2.1 Economic assets

1. Grass and tree crops

This report evaluates the impact of flooding and drought on grass (rice, sugarcane, and maize) and tree (durian and rubber) crops in Thailand. Agriculture plays a crucial role in Thailand's economy; one in six individuals, or roughly one-third of the country's workforce, are employed in the agricultural sector, making it one of the country's main employment sectors. By 2020, almost half (46.54 per cent) of the nation's land use is dedicated to agriculture, with roughly half of that being devoted to rice cultivation specifically (MoNRE, 2024). This sector is crucial for maintaining economic stability and food security. However, climate hazards, such as flooding and drought, threaten agricultural outputs significantly. These hazards, coupled with the projected decrease in population and ongoing rural-to-urban migration amongst the nation's youth, could further weaken an already strained agricultural sector and, subsequently, Thailand's economy (Wuttisorn, 2014).

Projections indicate that rice, by far the nation's most important agricultural product, could decline 10 per cent to 13 per cent due to these climate impacts. These reductions, combined with a similar decrease in maize yields, will affect food availability and food stability dimensions in Thailand (Attavanich, 2023).

The predicted weakening in these areas has many dimensions, derived from non-optimal moisture levels in grain kernels, negative physical changes to the grain kernel, effects on pollination, or changes in planting and harvest schedules due to disruptions in weather patterns, along with many other factors (Yokying, 2024). As such, it is essential to understand the impact of climate hazards such as flooding and heatwaves in Thailand.

Figure 3 shows the grass and tree crops, respectively, exposed to flooding. Because most regions in Thailand rely heavily on agriculture, one can see that the exposure of both crop types is high throughout the country. The most notable difference is present in the far south region of the country; this area grows a much higher proportion of rubber trees for latex production as well as fruit trees to a lesser extent, when compared to the rest of the country, which typically focuses on rice production. Again, because flooding is mainly limited to waterways and their floodplains, similar areas are exposed to flooding across all exposure maps. The two crop types have a large discrepancy in their resilience to flooding, with tree crops generally faring better. While the two grass crops modelled, rice and sugarcane, are resistant to flooding, yields are still negatively affected when exposed to flood conditions (Teinseree et al., 2024).

Figure 3: Flood-exposed grass (left) and tree (right) crop areas

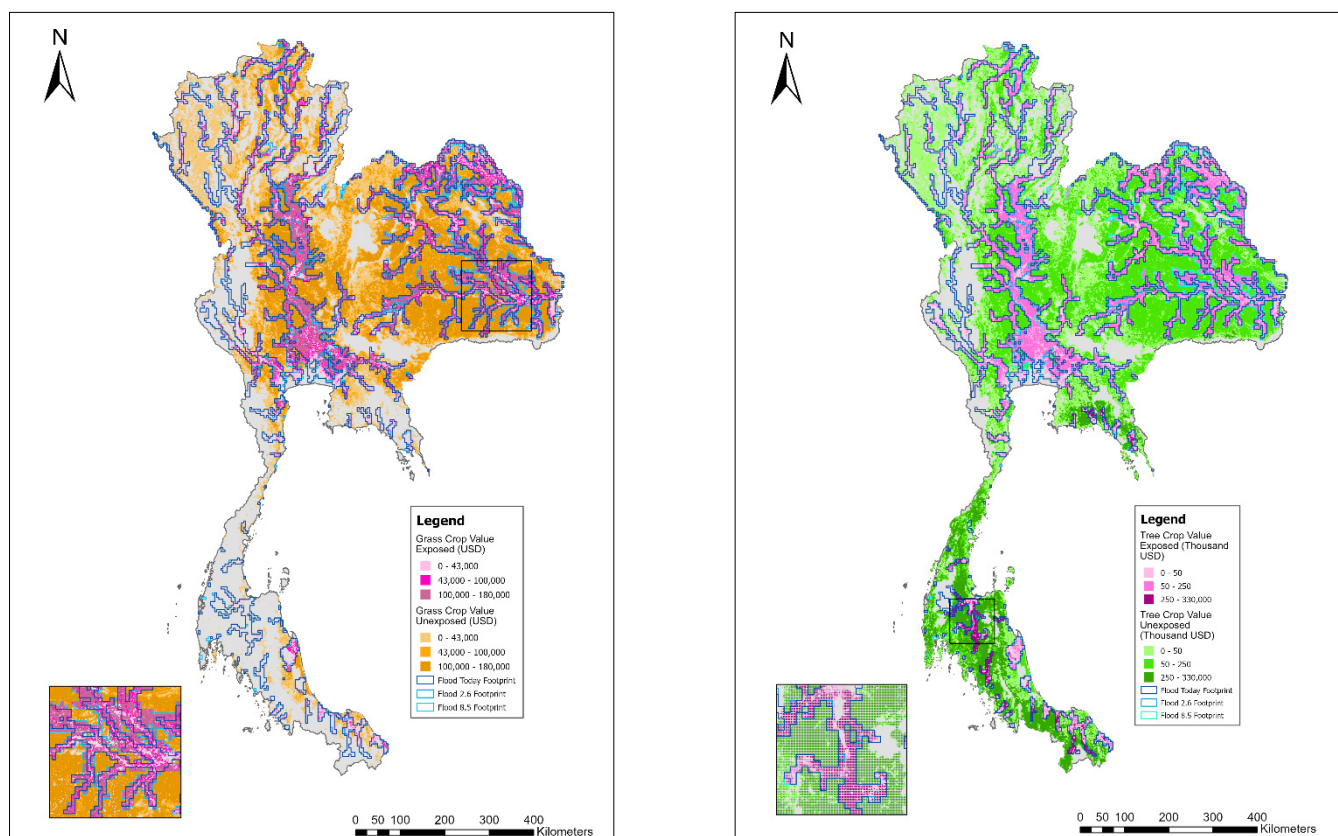
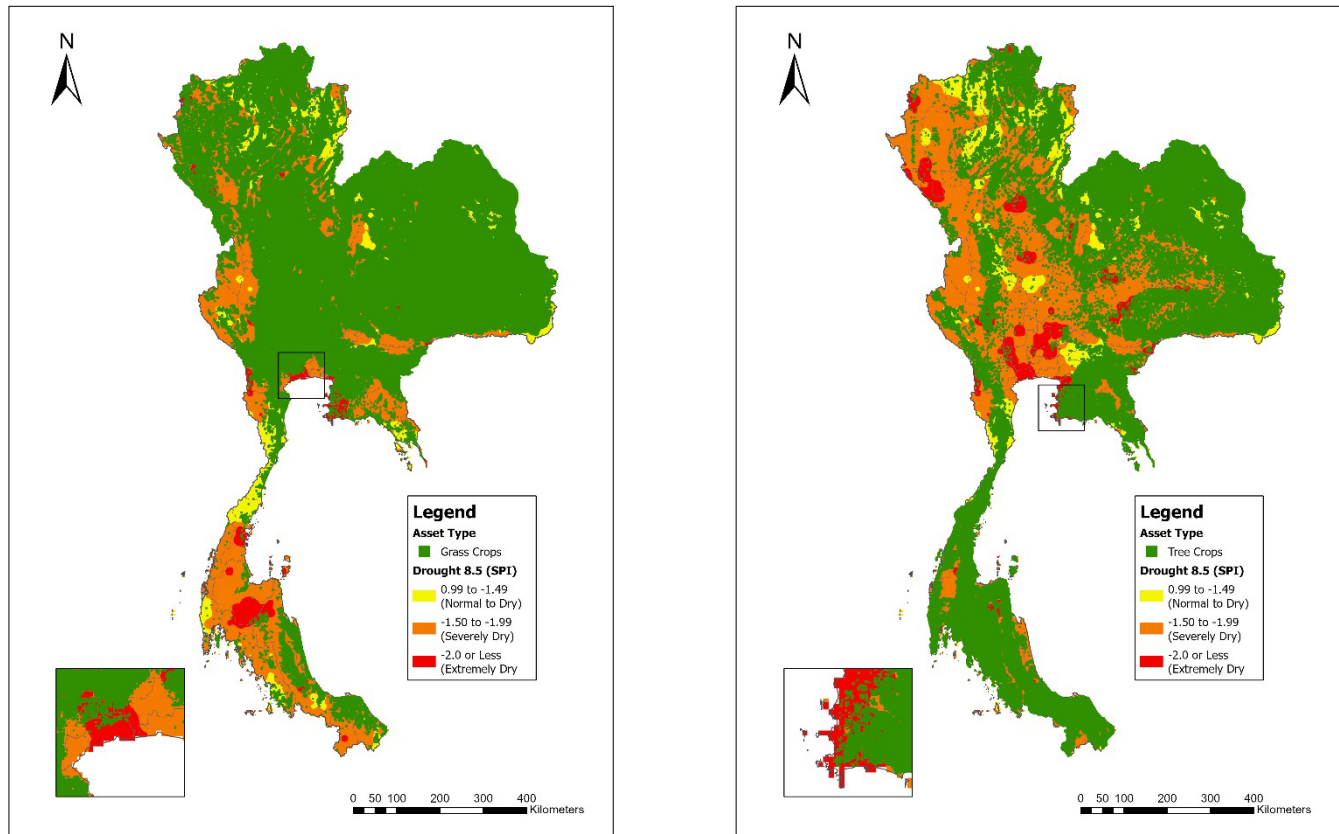


Figure 4: Drought-exposed grass (left) and tree (right) crops



When considering the drought effect on grass and tree crops, in Figure 4, one can see that regardless of type, all crops are exposed to some extent due to the nature of droughts. Still, the exposure varies in intensity depending on geographical location. As can be seen in the figure below, the geographic distribution of grass and tree crops overlaps considerably. Still, one can make general observations regarding the prevalence of tree crops in the Southern Region and along the eastern borders. At the same time, grass crops are more widespread throughout Northern, Central, and Northeast Thailand. While the figures do not show the degree to which each crop type is affected by droughts in Thailand, we can also consider how grass plants often have a higher tolerance to drought than tree crops and, as such, are affected to a lesser degree despite still being exposed to the same conditions (Belovitch et al., 2023).

2. Markets

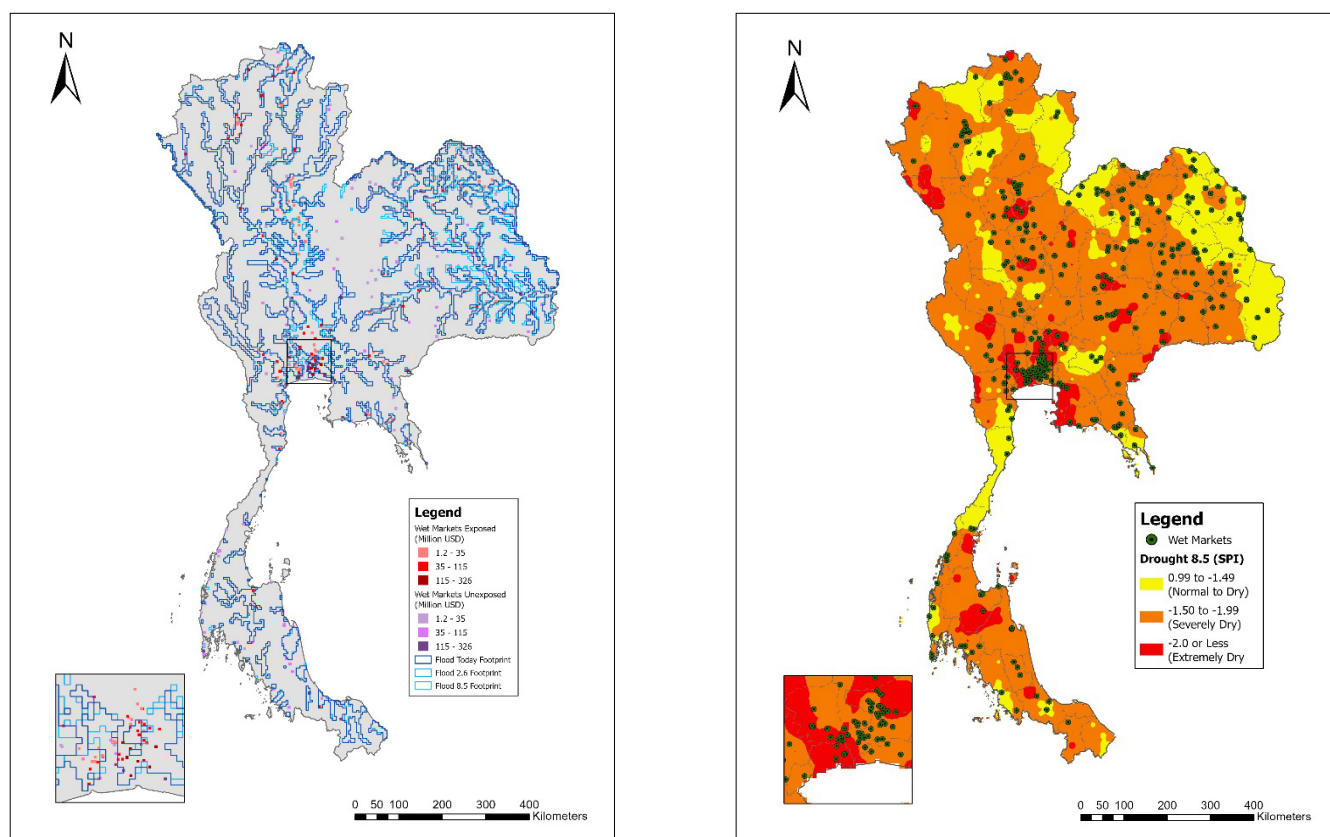
Despite the recent increase in modern supermarkets in Thailand, wet markets, also known as traditional or fresh markets, still hold a large percentage of the market share – roughly half as of 2016 (Poapongsakorn et al., 2019). These wet markets play an important role in Thai society; until recently, markets were visited multiple times a week and, as such, were a community’s social and economic hub. Additionally, modern supermarkets target the urban

and often wealthier Thai population who value a “one-stop-shop” philosophy and the convenience of supermarkets or hypermarkets. In contrast, wet markets, which usually focus on fresh produce and prepared food, can keep prices low for consumers by cutting out costs associated with the packaging and sorting/grading of products related to modern retailers (Gorton et al., 2011).

The loss of wet markets affects not only those who rely on said markets for foodstuffs but also the individuals who sell the goods. The vendors operate on thinner margins than modern supermarkets and cater to a clientele that is more sensitive to price increases. Any disruption in business, including loss of sales from unavailable products, has a disproportionately negative effect on all parties when compared to modern supermarkets (Gorton et al., 2011). For these reasons, it is important to understand the effect that floods and droughts have on markets and the physical damage they could incur because of these hazards.

In Figure 5 below, the reader can observe the number of wet markets throughout Thailand that are exposed to both flooding and drought. Based on the figure, one can see that most markets exposed to flooding are in and around the Bangkok Metropolitan Area (BMA). Other urban areas throughout the country are also affected, but to a lesser extent. This observation is

Figure 5: Flood-exposed (left) and drought-exposed (right) wet markets in Thailand



a function of how the exposure maps showcase the information provided – displaying the exposure of markets rather than to which extent they are affected by flooding. Conversely, the markets affected by drought are not limited to specific areas because of the nature of drought; rather, there are areas of more extreme, moderate, and minor drought, and as such, the markets are affected to varying degrees depending on the levels in which the surrounding areas from which the market vendors draw products from. It is important to highlight the Bangkok Metropolitan Area, and the high number of wet markets dispersed throughout have the potential to be severely impacted by future drought conditions.

2.2.2.2 Non-economic assets

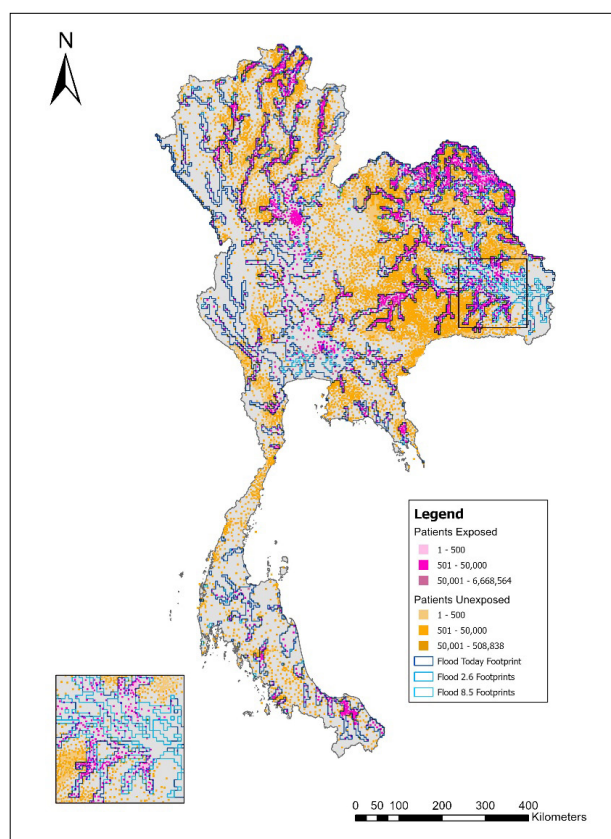
1. Water (*Diarrhoea patients*)

Flooding in Thailand severely degrades water quality and compromises the sanitation infrastructure, which, in turn, leads to an increased incidence of waterborne diseases such as diarrhoea. Studies have shown a correlation between diarrhoea morbidity rates in flood areas in Southeast Asian Countries, including

Thailand. This increased incidence of diarrhoea during flood events can strain healthcare facilities, reduce overall public health, and impede socioeconomic development (Cao et al., 2021; Saulnier et al., 2018; Schwartz et al., 2006; Yomwan et al., 2012; Yomwan et al., 2015). Addressing the vulnerability of diarrhoea patients in the context of flooding is especially important when aiming to develop further effective public health interventions and climate adaptation strategies aimed at safeguarding the vulnerable population. This report aimed to evaluate the number of people affected by diarrhoea due to low-quality water because of flood events in Thailand. The location of these people was derived by using the Thiessen polygon of water reservoirs throughout the country to estimate the number of people getting their water from the nearest water reservoir. By overlaying flooded areas, we calculate the morbidity rate per 100,000 people in any given area based on the inundation rate of the flood waters and the population of the flooded region. For this case, the American Center for Disease Control (CDC) Incidence Rate Ratio (IRR) was utilized:

$$\text{Incidence Rate Ratio (IRR)} = \frac{\text{New cases occurring during a given period}}{\text{Size of population during the same period}} \times 10^n$$

Figure 6: Diarrhoea incidence because of flooding



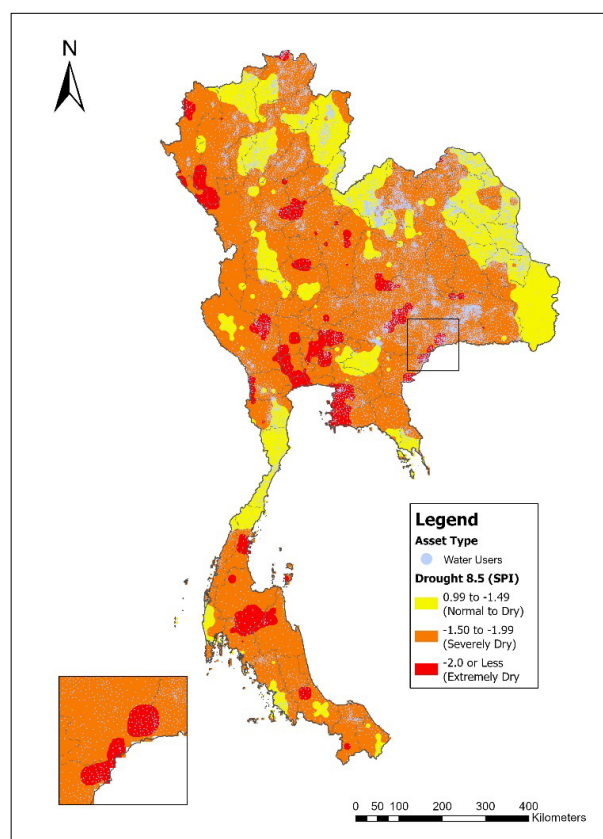
By defining the period based on flood duration and keeping it constant, the resulting weekly IRR (cases per 105 people) was calculated from the weekly report of diarrheal patients from hospitals in the study area.

Figure 6 shows areas of Thailand in which people are exposed to flooding, causing diarrhoea from waterborne illnesses. As evident in the figure, Northeast Thailand – a region known as *Isan* is a collection of 20 mainly agricultural provinces and is historically one of the poorest regions of Thailand. The figure shows that Isan is highly susceptible to waterborne illness outbreaks, especially along the Laos border, where the Mekong River creates a natural boundary between the two countries (Myers, 2005). This high incidence rate of diarrhoea is not limited to Isan because of the correlation between flood inundation rates and diarrhoea patient exposure rates; this pattern can be found in most populated areas where flooding is also predicted to occur, though not as prevalent as in the Northeast.

2. Water (Water users)

Because of its monsoon climate, Thailand oscillates between periods of intense precipitation and drought/heat. As climate change intensifies, so do periods of drought. Studies have shown a direct correlation between the intensification of drought and an increase in unmet water demand amongst the Thai population

Figure 7: Exposed water users during drought



(Ikhwali, 2021). This unmet demand for water puts additional pressure on an already stressed system that must meet the population’s needs at the two extremes: during drought conditions as well as during extreme precipitation and flooding.

Figure 7 displays the exposure of water users to drought conditions. This figure showcases the vulnerability of individuals with unmet water needs that will be further exacerbated by future drought conditions within Thailand. These water users have a relatively homogenous distribution throughout the Northern and Northeast Regions, with less density in the Central and Southern Regions. Within the Northern and Northeast Regions, there are localized areas with a noticeably higher density of water users. When discussing the Northeast Isan Region, the concentration of people can mainly be attributed to two factors. Firstly, the Isan region has a higher concentration of reservoirs – large and small – than other regions of the country. Because the damage function, in part, uses water reservoirs as a geolocator of water users, it is understandable that the maps would display this relationship (Hungspreugs et al., 2002). Lastly, the region is considerably more rural and less developed than other regions of Thailand, and as such, water infrastructure is lacking; this is especially apparent during periods of low water availability. Generally speaking, the areas with the

highest concentration of water users are found in regions that will experience low to moderate drought conditions; areas of concern would be those mentioned above, the highly concentrated and highly exposed localized areas of the southern Northern Region, and the southern Isan Region. While the Central Region contains fewer exposed water users, the country's capital and most populous city, Bangkok, is predicted to be amid severe drought conditions in the future, potentially exposing the city and its residents to disruptions.

3. Religious services

The ERA-ECA report also evaluates access to religious services, interpreted here as an individual's access to Buddhist monks during floods and heatwaves and people seeking flood shelter. Buddhism is the predominant religion in Thailand, with over 95 per cent of the population—meaning roughly 64 million people within Thailand follow Buddhism as of 2015 (NSO, 2015). Additionally, a large proportion of young men become Buddhist monks temporarily – these monks rely on the charity of others, seeking food from the surrounding population and residing in temples interspersed throughout the country and, in return, provide the local community with spiritual guidance and other religious services (Cassaniti, 2023; Tharika Kamkokgruad, 2019). During times of extreme heat or flood, monks are unable to collect their daily sustenance and go about their daily duties.

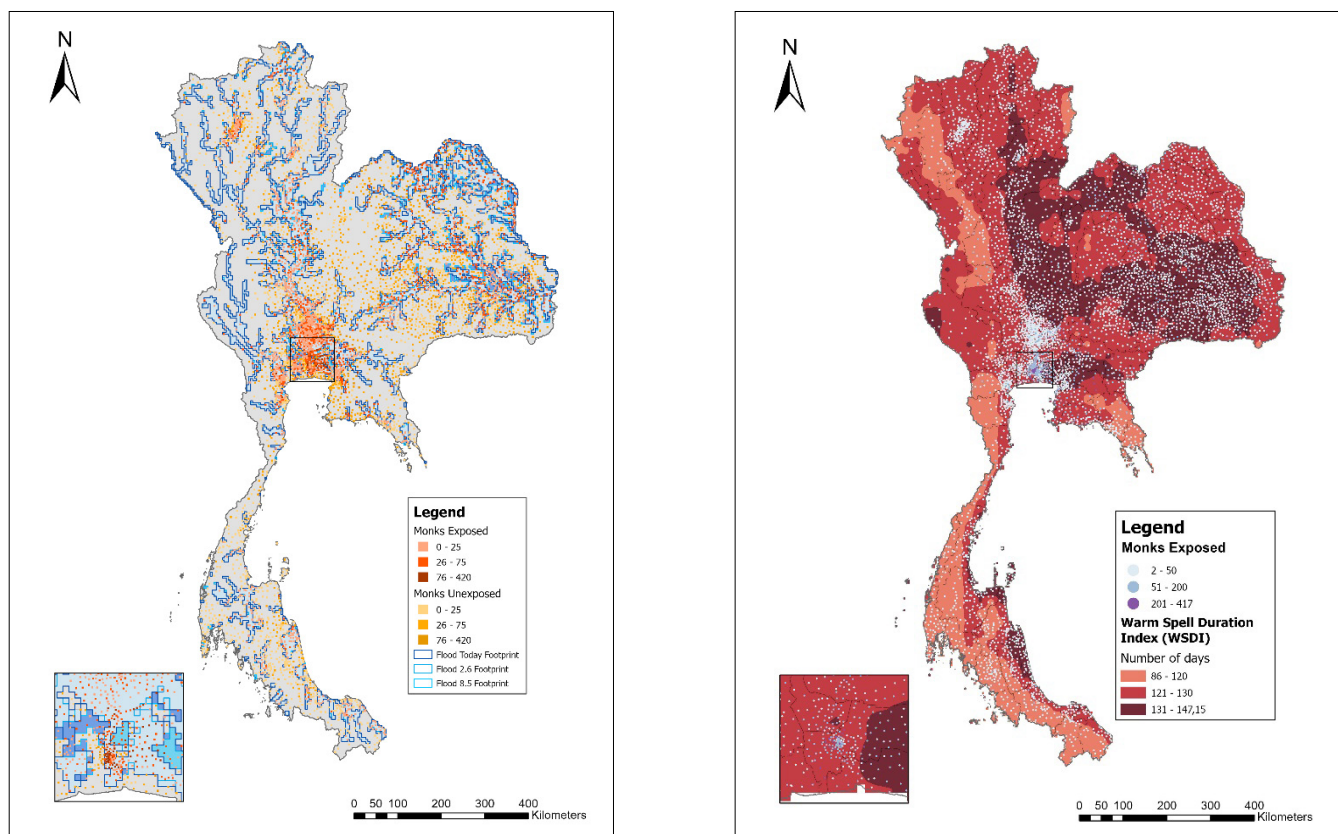
Practitioners are unable to seek guidance or visit temples, thereby temporarily severing this important and symbolic aspect of Thai culture.

Similarly, a religious service offered during extreme events is a shelter for those in need. Schools, multi-purpose facilities, and Buddhist temples make up the bulk of shelter locations for people to take refuge, with temples being particularly desirable due to their importance in Thai society. Temples can be used day and night, and their unique design enables high capacity when the complex is composed of a large compound with multiple, sometimes stone buildings and open spaces (Manawongcharoen & Panbamrungkij, 2021). It is understood that under conditions necessitating evacuation from their homes, people have a preference to seek shelter in Temple compounds (Alam, 2024; Andrew et al., 2013), with one study stating that 44.4 per cent of people prefer to do so (Manawongcharoen & Panbamrungkij, 2021).

Impacts on Buddhist monks

Buddhist monks in Thailand face challenges regarding climate hazards. On the one hand, they play a key role in communities, providing health services and emergency relief as part of their religious work. On the other hand, monks have specific vulnerabilities linked to their beliefs and practices, such as a proclivity to obesity and hypertension (Jeamjitvibool T et al., 2022). This give-and-take social contract is expected

Figure 8: Flooding (left) and heatwave (right) exposed Buddhist monks



only to become more strained as the negative effects of climate change worsen within Thailand, increasing the impacts of disasters. As such, it is important to understand how access to religious services, represented here by access to the monks as well as temples for shelter, is affected by flooding and heatwaves in Thailand.

Figure 8 shows the number of Buddhist monks exposed to flooding (left) and heatwaves (right). These monks are distributed relatively evenly throughout most of the country, with the exceptions being along the far western Myanmar border, where few monks reside, as well as in the highly populated urban areas, such as the Chao Phraya River Basin, the Bangkok Metropolitan Area, and to a lesser extent the Chiang Mai region in Northern Thailand where the density of people is much higher. As such, Buddhist temples and monk populations are much higher in these densely populated regions because the monks cater to these populations. These exposure maps follow a similar pattern to the previous maps in the sense that the largest density of monks is in the Chao Phraya Basin. Where things differ is the high population of monks dispersed throughout the country, particularly in the Isan region. This region, along with parts of the Central and Northern regions, is exposed to extreme heatwave conditions. While the densest monk populations in the Chao Phraya basin are not projected to be affected by the most severe conditions, these conditions are near these high-density areas. When discussing monks exposed to heatwaves, the effect is more widespread because of the nature of said heat waves, with exposure taking place at a country-wide level, with pockets of higher and lower levels of exposure.

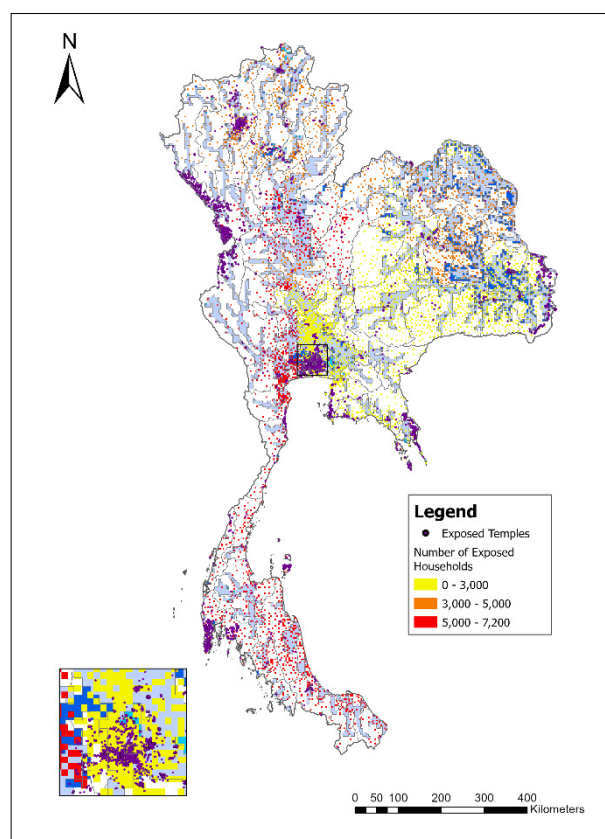
People seeking shelter

The flood of 2011 is a prime example of the need for shelters during flood events, with a large number of people exposed to flooding evacuating their homes to designated shelters throughout the country, often the closest suitable public space (Chanta & Sangsawang, 2012). Due to their importance, temples are often more resistant to flooding because of their design and building type, but they are still not completely impervious to flooding. Additionally, people seeking shelter are not only limited to the availability of the shelter but also people's ability to travel to the shelter to seek aid, thus adding another factor to the evaluation of this asset.

As an extension of the religious services asset described above, the changes in demand for shelter due to climate change are included in this study, with shelter being limited to temples. The need for shelter was defined in this study as the number of people

living in housing buildings that are impacted by over 80 per cent due to flood events, which is considered in scientific literature as a destroyed building (Mohd et al., 2016). For households, we utilized the HOTOSM database of buildings, considering the places of dwelling as houses, apartments, attached housing, condos, condominiums, dormitories, homes, houses, residential, semi-detached houses, and detached houses (HOTOSM, 2024a). Lastly, the locations of temples were acquired from the National Office of Buddhism and Open Government Data of Thailand's list of Buddhist temples (NOB, 2024). As can be seen in Figure 9, the exposure is widely distributed, with the highest concentrations of exposed buildings occurring around large urban areas. Additionally, the spatial distribution of exposed housing in the southern region is of note due to the homogenous distribution of exposure throughout the region, the high number of exposed housing units, and the seeming lack of temples in which to take shelter if necessary.

Figure 9: Flooding exposed households and temples



4. Education (Students)

Access to education represents an important non-economic asset with direct benefits to the nation's future potential and socio-economic development. That said, students in Thailand face significant climate-related risks affecting their education, health, and overall well-being. Different student groups exhibit distinct vulnerabilities to climate

risks. Children are more vulnerable and less able to withstand climate hazards such as floods, droughts, and severe heatwaves (UNICEF 2022). During floods, schools may become inaccessible to teachers and students and are often repurposed as shelters, thereby disrupting normal learning activities (Akello, 2014).

Additionally, extreme heat can significantly impact education, with students showing lower levels of achievement during hotter school years. Research indicates that a one-degree Fahrenheit increase in temperature can reduce the amount learned in the school year by 1 per cent (Goodman et al., 2018). Heat exposure can exacerbate educational inequalities, as students from lower-income homes are more likely to live in areas impacted and less likely to have access to air conditioning. In 2022, it was estimated that over 10 million children were exposed to heatwaves (UNICEF, 2024).

In Figure 10 below, the reader can see the number of students affected by both flooding and heatwaves in Thailand. When discussing flooding, most affected students are in the periphery of the country, in the mountainous north, the Isan region to the east, and the far south region. The reason is, in part, the comparative lack of development and flood protection measures outside of the central region, specifically in and around the Bangkok Metropolitan Area.

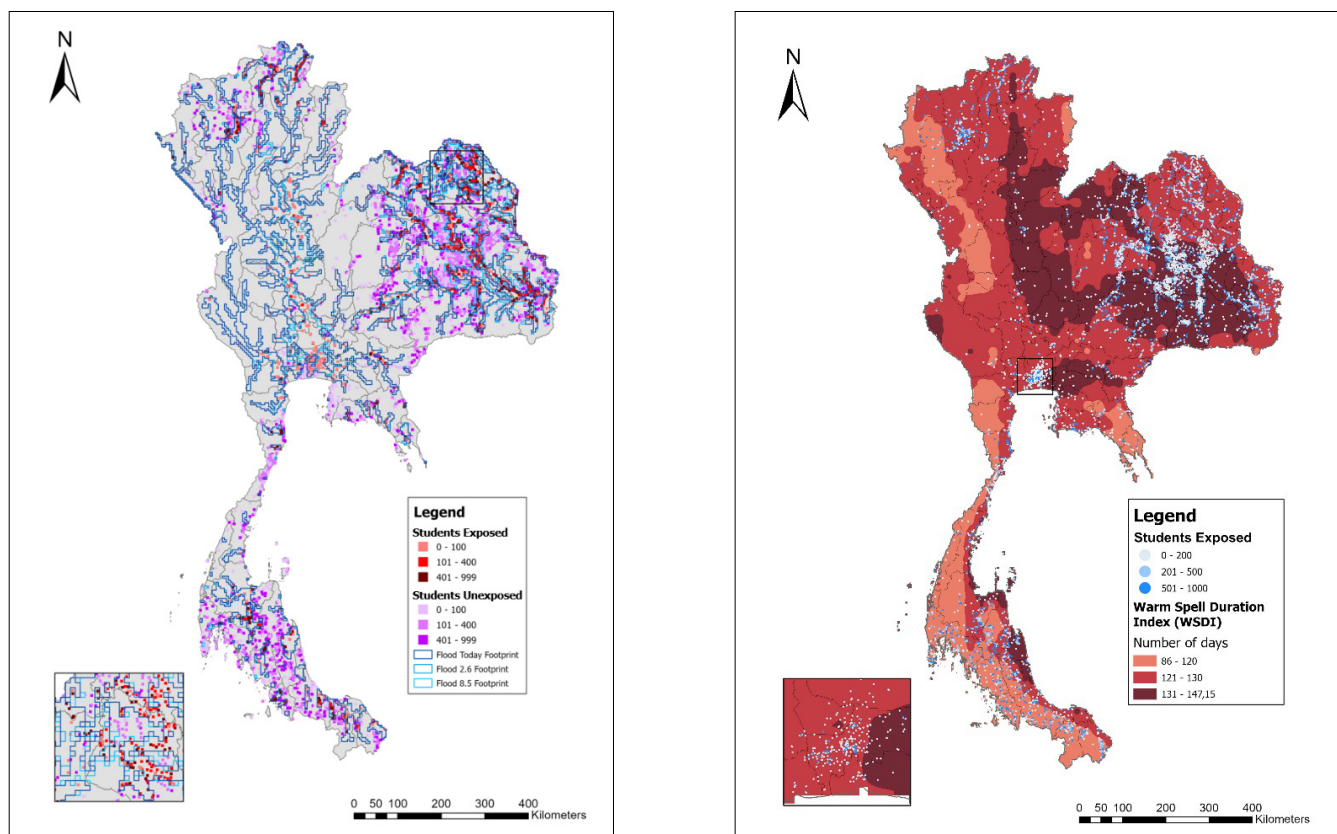
Additionally, often in more mountainous and hilly regions outside of the central region, communities and education facilities are in narrower river valleys, which are more prone to minor but more frequent flooding. In contrast, the central region experiences less frequent but more major flood events.

In terms of students' exposure to heatwaves, the hazard is more like drought in the widespread affected area, with areas of lower intensity in the southern region continuing north into the western highlands. Areas of highest concern are in the south-central Isan region, where a larger concentration of students are exposed to extreme heatwave conditions, as well as parts of the central and northern regions, where, fortunately, these areas have a low density of student populations. While the southern region is the least exposed to extreme heatwaves, the eastern coast has a high density of students with small areas of extreme heatwaves. Luckily, the Bangkok Metropolitan Area does not experience the worst of the conditions but is near extreme conditions, making the city and surrounding region highly vulnerable to future heatwave conditions.

5. Crop farmers (Tree and grass crops)

In addition to the grass and tree crops discussed previously, the study also explored the non-economic impact of floods and droughts on grass and tree

Figure 10: Students exposed to flooding (left) and heatwaves (right)



crop farmers throughout Thailand. The arguments made regarding crops affected by these hazards can be applied here – as climate change increasingly affects the agricultural sector in Thailand, the individuals relying on said crops for their livelihood and sustenance are also negatively affected. As stated previously, one in six individuals, or roughly one-third of the country's workforce, are employed in the agricultural sector – making it one of the country's main employment sectors (MoNRE, 2024). Coupled with the ongoing rural-to-urban migration amongst the nation's youth, the ageing rural farmers in Thailand are becoming increasingly vulnerable as climate change continues to intensify instances of flood and drought throughout the country (Wuttisorn, 2014).

Figure 11 follows a similar pattern as described when looking at grass and tree crops, with a few notable differences. The population is more concentrated in certain areas, namely the Chao Phraya River Basin in Central Thailand. Here, we can see the concentration of rice farmers in this region being exposed to flood events. An appropriate analogy to this predicted scenario is the 2011 flood event that heavily affected Thai farmers throughout this central region, as well as other areas of the country (Sinpeng, 2012). Regarding tree crop farmers, the most notable areas of concern are in the far northeast of the country and smaller pockets in the southern region. The prior is along

the Laos border, which the Mekong River and its tributaries dominate. At the same time, the southern areas cannot be attributed to one major river system but rather a series of smaller ones. Again, this is a function of where the farmers are located; because the Isan region in the east and the southernmost region are areas with higher densities of rubber and fruit trees, it is an appropriate conclusion that the respective farmers will be exposed to higher numbers in these areas in the future.

Like previous exposure maps displaying drought hazards, Figure 12 shows the population of farmers in Thailand who are exposed to droughts. When analyzing the figures, one can see the widespread distribution of grass crop farmers throughout the Northeastern, Central, and, to a slightly lesser extent, Northern regions. This situation can be mainly attributed to the dominance of rice in Thailand's agricultural sector. Conversely, tree crop farmers are more localized in the Northeastern Isan region, mainly along the border, as well as in the Southern region. The effect of drought in these regions is also relatively homogeneous, attributable to the widespread nature of droughts throughout the country.

6. Mobility (Road users)

Floods significantly impact road users and mobility in Thailand by disrupting transportation infrastructure

Figure 11: Exposed grass crop farmers (left) and tree crop farmers (right) during flooding

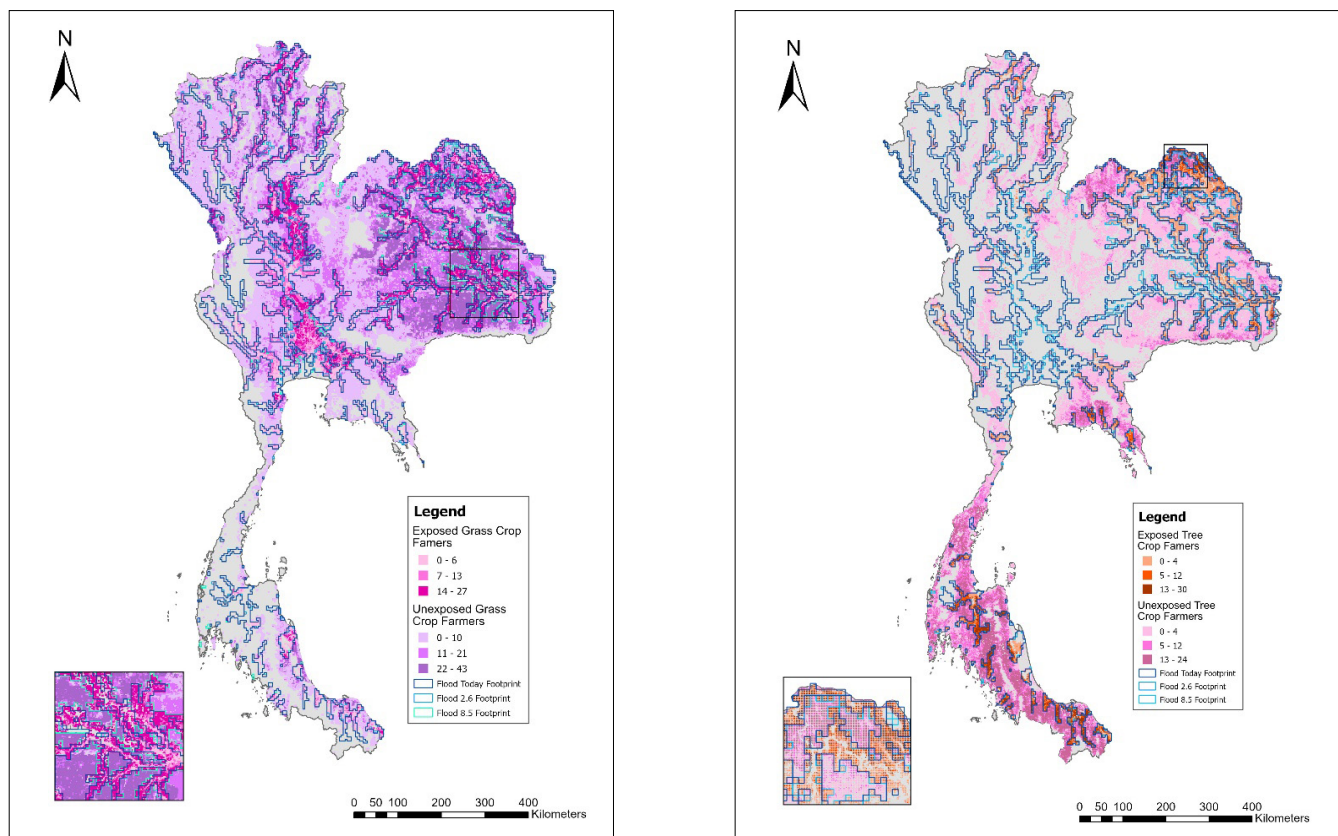
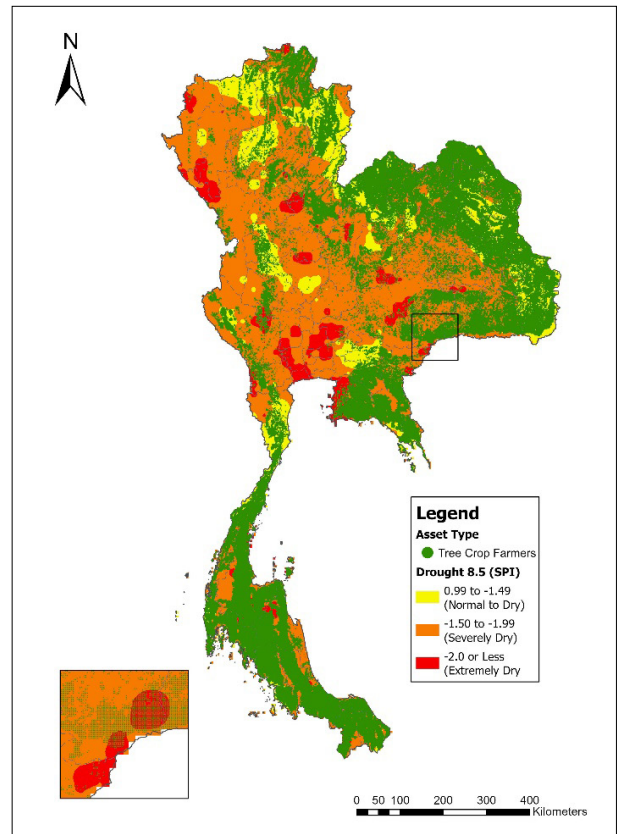
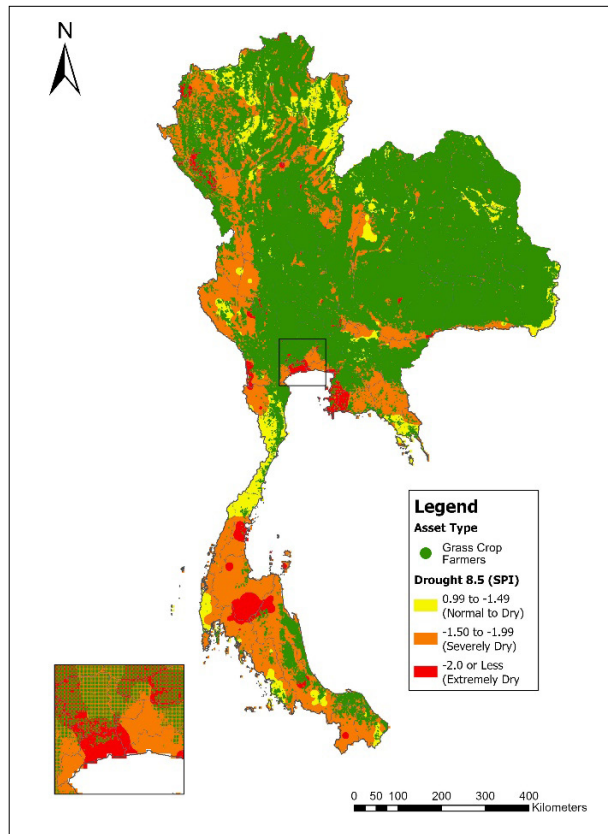


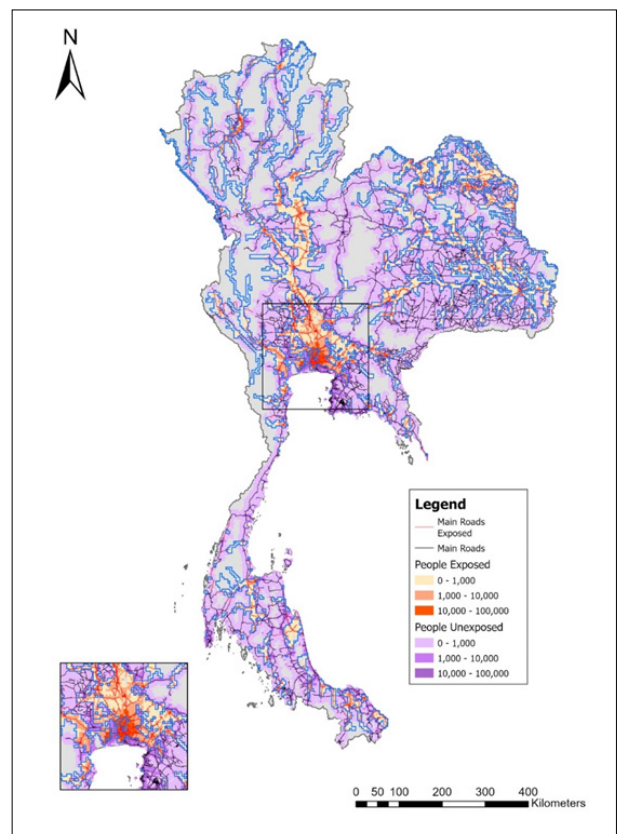
Figure 12: Exposed grass crop farmers (left) and tree crop farmers (right) during drought



and posing immediate safety hazards. During flooding, inundated roadways are rendered impassable, increasing congestion on unaffected roads and increasing the risk of accidents. Floodwaters can cause road surfaces to erode more quickly, undermine bridges, and wash out critical infrastructure, leading to traffic delays, detours, and road closures, further complicating emergency response and evacuation efforts (Suwanno et al., 2021). The disruption to transportation networks affects not only daily commutes but also emergency services and the delivery of goods, highlighting the need for robust flood management and infrastructure resilience to protect road users and maintain mobility during extreme weather events.

When discussing road users, such as those displayed in Figure 13, it is important to note the centralization of Thailand around the Bangkok Metropolitan Area. Nearly one in four people live in this region directly surrounding the capital, and as such, the country’s infrastructure, roadways included, is heavily concentrated in the immediate vicinity. Taking this into account, when this region floods, as was the case in 2011, major disruptions in a population’s mobility occur. This same pattern also occurs in other areas of the country, such as the far Northeast along the Lao border and in and around Chiang Mai, albeit to a much lesser extent than what is seen in the Chao Phraya River Basin.

Figure 13: Exposed road users during flooding



2.2.3 Socio-economic scenarios

As outlined in [Chapter 1.2](#) of the ERA approach, ECA and CLIMADA utilize socio-economic development indicators, including population growth, GDP growth, and discount rate, to project future climate scenarios such as RCP 2.6, 4.5, and 8.5. These indicators are essential for modelling how Thailand's economic and demographic dynamics will evolve under varying climate pathways. The climate scenarios considered for this report and described in [Chapter 2.2.1](#) are the RCP 2.6, which represents a low-emission future with sustainable growth; RCP 4.5, a moderate scenario with balanced development; and the RCP 8.5, a high-emission trajectory with potentially rapid population increases and economic strain. By considering socio-economic factors, the models help to assess Thailand's potential vulnerabilities and adaptive capacity under different climate conditions.

1. Population growth

The average annual population growth rate of -0.22 per cent until 2050, published by the United Nations Department of Economic and Social Affairs, is considered in this study (United Nations Department of Economic and Social Affairs, 2024). Thailand's population is projected to reach its peak in 2028-2029 and will start to decline in 2030 (World Population Review, 2024). This negative growth rate reflects a significant demographic shift driven by declining fertility rates and an ageing population. Thailand has experienced this negative trend since the 1980s. As birth rates continue to fall and the proportion of elderly individuals rises, Thailand faces potential challenges related to labour shortages, increased healthcare demands, and economic sustainability.

2. Economic growth

The Economist Intelligence Unit (EIU) projected an average annual growth rate of 2.94 per cent in Thailand until 2050 based on the analysis of Thailand's economic growth trends (EIU, 2024). In 2021, the economy was predominantly driven by the services sector, which accounted for 59.7 per cent of GDP, followed by industries at 30.6 per cent, while agriculture contributed just 9.7 per cent (Government of Thailand, 2023). Historically, Thailand experienced rapid economic growth, averaging 7.5 per cent annually between 1960 and 1996, but growth slowed significantly to 1.3 per cent between 2009 and 2017. The COVID-19 pandemic further exacerbated economic challenges, with a World Bank rapid survey indicating that 70 per cent of households, particularly vulnerable groups, faced income reductions since March 2020 (The World Bank, 2024). These projections underscore the importance of economic resilience and recovery efforts as Thailand looks to navigate future challenges and achieve sustained growth.

3. Discount rate

The discount rate data, derived from the projected yearly average percentage change of the GDP Deflator provided by the EIU, averaged 0.90 per cent for the period between 2024 and 2050 (EIU, 2024). The discount rate is a crucial concept in economic modelling, reflecting the time value of money by quantifying how much future economic benefits are worth in present terms. It accounts for inflation, opportunity cost, and risk, guiding decisions on investments and policy by determining the present value of future costs and benefits. In the context of climate change scenarios, a higher discount rate generally suggests a lower present value placed on future impacts, which can influence the urgency and scale of adaptation measures (Stern, 2007). A low discount rate of 0.9 per cent indicates that the country is prioritizing future generations and the long-term impacts of its current policies, including sustainability and investments in climate action. It would also impact the viability of NbS adaptation measures that would only show benefits far into the future. This type of measure performs better with low discount rates.

2.2.4 Adaptation measures

This chapter presents Thailand's shortlisted flood, drought, and heatwave adaptation measures. These measures aim to reduce the disaster impact on selected assets and population groups by lowering the intensity or frequency (return period of floods) of the impact, the vulnerability of the assets, the number of assets expected to be affected, or a combination of all of them. The cost-benefit analysis of implementing these measures was calculated according to the potential averted damage. The result will be presented in [Chapter 2.3.2](#).

The adaptation measures were selected based on a literature review and consultation with local experts, partner organizations, and government representatives. Initially, a total of 37 floods, 25 droughts, and 20 heatwave adaptation measures were identified (referred to as a 'longlist'). This list was then reduced to 15 floods, 7 droughts, and 2 heatwave adaptation measures (referred to as a 'shortlist'), which were then introduced to CLIMADA. A detailed methodology for this transparent and participative measures selection procedure can be found in [Chapter 2.2](#). Table 3 presents an overview of adaptation measures for floods, droughts, and heatwaves in Thailand.

The measures were categorized into five measure types. The categorization of adaptation measures into grey, nature-based, hybrid, systemic, and insurance provides a structured approach to addressing climate

Table 3: Overview of flood, drought, and heatwave adaptation measures for Thailand

Hazard	Adaptation measures		Type	Cost (2024 USD)
Flood	1	Green spaces	NbS	32,301,429
	2	Wetland restoration and rehabilitation	NbS	3,021,000
	3	Detention swales along roads	Hybrid	5,000,000
	4	Improved solid waste management	Systemic	4,726,000
	5	Retention reservoirs	Hybrid	5,027,925
	6	Training for agricultural topics for adaptation	Systemic	1,620,000
	7	Dredging of canals	Grey	50,800,807
	8	Early warning system	Systemic	12,690,000
	9	Retention furrows	Hybrid	30,674,921
	10	Improved drainage system	Grey	21,895,244
	11	Sandbags	Grey	13,617,110
	12	Agricultural zoning	Systemic	13,500,000
	13	Water tolerant crops	Systemic	13,500,000
	14	Floodwall	Grey	382,421,959
	15	Flood index insurance	Systemic	92,345,330
Drought	1	Wetland restoration and rehabilitation	NbS	3,021,000
	2	Soil, water, and pest management	NbS	6,616,533
	3	Legume seed production and propagation	NbS	3,777,900
	4	Climate-smart agriculture	Hybrid	12,870,472
	5	Management of protected environmental areas	Systemic	13,233,065
	6	Improvement of water storage systems	Grey	21,420,000
	7	Improvement of water distribution facilities	Grey	105,000,000
Heatwave	1	Green spaces	NbS	32,301,429
	2	Green roofs	NbS	1,493,891

risks. Grey measures involve conventional engineering solutions, such as dams, levees, and urban drainage systems that rely on infrastructure to mitigate impacts. Nature-based solutions (NbS) harness natural processes and ecosystems, like restoring wetlands or planting urban forests, to enhance resilience. Hybrid measures combine elements of grey and nature-based solutions, integrating infrastructure with ecological enhancements, such as using constructed wetlands. Systematic measures focus on policies, governance frameworks, and community-based strategies that improve overall adaptive capacity, such as early warning systems or improved solid waste management. Insurance provides financial protection against the economic impact of climate-related disasters, serves as a risk transfer

mechanism within climate disaster risk financing and insurance (CDRFI), and complements other adaptation approaches by providing crucial financial support and facilitating recovery. This comprehensive categorization balances immediate protective needs with long-term sustainability and resilience.

Detailed descriptions and cost estimations for each adaptation measure presented in Table 3 will be described. By examining these measures individually, we will better understand their specific features, estimations, and assumptions taken to calculate the total financial investment needed to implement and maintain this measure at the suggested scale from 2024 to 2025. Most cost assumptions were taken from publicly available budgets for projects in Thailand. However, such projects reflect localized

considerations, and they had to be adjusted to represent national averages to be used in CLIMADA. The adjustments are based on cost-benefit ratios from comparable studies and literature reviews, and the benefits are estimated using the model. The table below presents more detailed information regarding the measures.

1. Green spaces	
NbS	32,301,429 USD

Expanding green spaces in urban areas is important for flood and heatwave adaptation and mitigation in cities. One way to increase green space is through tree planting, which helps lower ambient temperatures and reduce the impact of heatwaves while enhancing stormwater management by regulating surface runoff and decreasing the risk of floods. Tree canopies intercept rainfall, slowing the flow of water, and their root systems absorb water, reducing stormwater runoff, nutrient pollution in waterways, and soil erosion. Thailand’s Office of Natural Resources and Environmental Policy and Planning developed Operating Guidelines for Sustainable Green Space Management (2023-2027), which includes annual budget allocations for implementation (Office of Natural Resources and Environmental Policy and Planning, 2022). The costs in this budget were assumed to include all implementation and maintenance activities between 2024 and 2028. The cost from 2029 to 2050 was assumed to be the same as the cost in 2028.

Key initiatives under this plan involve the restoration of watershed and mangrove forests, forest fire prevention, promoting urban tree planting to expand green spaces, and raising public awareness about the importance of environmental conservation.

2. Wetland restoration and rehabilitation	
NbS	3,021,000 USD

Wetland restoration and rehabilitation are vital nature-based solutions for combating drought in Thailand, providing essential ecosystem services that help regulate water supply and improve resilience to climate change. As part of broader efforts to address water scarcity, the Mekong River Commission’s joint project on flood and drought management outlines detailed plans and budgets to rehabilitate and manage wetlands effectively (Mekong River Commission, 2021). By restoring degraded wetlands, the project aims to enhance water retention, support biodiversity, and maintain critical ecosystem services such as groundwater recharge and water purification. These

efforts not only strengthen local communities’ ability to withstand droughts but also contribute to sustainable water management and long-term climate adaptation strategies.

The initial cost of wetland restoration was estimated from the Mekong River Commission’s budget plan, i.e., 500,000 USD for 2 wetlands in Thailand between 2022 and 2026 and 1,000 USD for maintenance. This assumption was used to calculate the initial cost for every five years between 2024 and 2050 and the maintenance cost in the other years for different regions in the country within that period.

3. Detention swales along roads	
Hybrid	5,000,000 USD

Detention swales along roads are a hybrid adaptation strategy combining green and grey infrastructure to mitigate flooding in Thailand’s urban and rural areas. These swales are shallow, vegetated channels designed to slow down and capture stormwater runoff, allowing it to infiltrate the soil and reduce the burden on traditional drainage systems. By integrating green (vegetation) with grey (engineered drainage) infrastructure, detention swales enhance flood resilience, manage peak runoff during heavy rainfall, and reduce surface water accumulation that can cause road flooding. This approach not only helps control water flow but also improves water quality, supports biodiversity, and contributes to a more sustainable and flood-resilient infrastructure network in Thailand.

The cost to develop and implement this initiative is taken from the Mekong River Commission’s budget (Mekong River Commission, 2021), which was 1 million USD from 2022–2026. This reference value was multiplied by 5 to cover the period until 2050 and expand its geographical scope to the full country.

4. Improved solid waste management	
Systemic	4,726,000 USD

Improved solid waste management plays a crucial role as a systemic adaptation measure against flooding in Thailand, particularly by addressing blockages that obstruct water flow during heavy rainfall. Key activities under this initiative include the removal of waste that clogs drainage systems, which is regulated at the municipal level, and clearing invasive species like water hyacinth from water surfaces; both are major contributors to urban flooding. The local adaptation experts in Thailand provided the estimated cost of implementing these activities from the Urban Resilience project led by the International Union for Conservation of Nature (IUCN) in Chiang Rai and Surat

Thani provinces (IUCN, 2023). This was a small-scale project with an initial cost of 10,000 USD. However, it provided a basis for estimating what such efforts would cost at a national scale, adding to a budget of 4.7 million USD. Maintenance costs are estimated to be 1,000 USD per year until 2050.

5. Retention reservoirs

Hybrid	5,027,925 USD
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Retention reservoirs are artificial lakes surrounded by vegetation and designed with a permanent pool of water to provide temporary water storage. These reservoirs play a crucial role in flood mitigation by reducing peak water flows and lowering the risk of flooding during heavy rainfall events. In addition to flood control, they capture and settle sediments at the bottom, helping to filter and treat contaminated stormwater runoff. An example of this project in Thailand is the Bueng Monkey Cheek Project, which addresses the water shortage problem for water consumption and agriculture with a total area of approximately 470 rai (around 75 hectares) and an average depth of 2-3 meters (Bangkok Business, 2024).

The cost of this project is used to estimate the total implementation for Thailand. In 2020, the project cost was 35 million THB, equivalent to 36,321,728 THB or 1,005,584.95 USD (EIU, 2024). The assumption for this measure was that, based on the exposed area, five projects of this kind would need to be implemented at this scale to keep the benefits until 2050 nationally.

6. Training for agricultural topics for adaptation

Systemic	1,620,000 USD
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Training on agricultural practices for climate change adaptation is a key systemic measure to raise awareness and strengthen flood resilience in Thailand. Local experts have highlighted the urgent need for such capacity-building initiatives to help farmers and communities better cope with the impacts of flooding. The Mekong River Commission's Master Plan also underscores the importance of building regional capacity for the rehabilitation and maintenance of the basin using nature-based and hybrid solutions (Mekong River Commission, 2021). The cost estimation for these initiatives includes the design and implementation of tailored training programs, along with detailed field-based training sessions for local stakeholders. These programs aim to equip farmers with practical knowledge and techniques to adapt their agricultural practices to climate variability, enhancing their ability to manage water resources, reduce flood risks, and ensure long-term sustainability in the face of climate change.

The cost estimation for this measure was based on the Master Plan's budget of 60,000 USD between 2022 and 2026 (Mekong River Commission, 2021), which was assumed to be annual and multiplied by the number of years between 2024 and 2050, assuming it would reach a 5-fold increase in the population trained in the Mekong area.

7. Dredging of canals

Grey	50,800,807 USD
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Stormwater drainage systems are essential for managing urban floods, especially with the increasing risks posed by climate change. However, irregular maintenance can lead to blockages and sediment buildup, reducing the system's effectiveness. The term dredging covers a range of activities, from the removal of sedimentation in open drainage canals or pipes to the whole straightening (canalization) and deepening of watercourses. Dredging is a key method for restoring water flow and improving efficiency and capacity to convey water. The cost of dredging canals was estimated from the short-term plan for Flood Mitigation and Management in the Bangkok Metropolitan Area in 2011, which was then transformed to 2024 net present value, considering the average annual percentage change of GDP deflator from the IMF (Phamornpol, 2011).

The cost originally reported was 1.587 billion THB, equivalent to 1,834,925,160 THB in 2024 (EIU, 2024) or 50,800,807 USD for a total of 861 canals.

8. Early warning system

Systemic	12,690,000 USD
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The IPCC's Sixth Assessment Report on Impacts, Adaptation, and Vulnerability highlights early warning systems (EWS) as a key adaptation strategy. According to the 2019 Global Commission on Adaptation's flagship report, *Adapt Now*, EWS delivers the highest return on investment of any adaptation measure, providing more than tenfold benefits. EWS aims to alert communities of impending hazardous weather or climate events, such as floods or droughts, and guide them on how to minimize the impacts. The Mekong River Commission specifies the need to strengthen the hydrometeorology network and flood and drought warning by expanding existing communication and knowledge management tools and technologies for early warning (Mekong River Commission, 2021).

The cost provided by the Mekong River Commission was 470,000 USD between 2022 and 2026, which was assumed to be annual and multiplied by the number of years from 2024 to 2050, assuming that such a budget would be required to expand and maintain the EWS nationally until 2050.

9. Retention furrows

Hybrid

30,674,921 USD

Infiltration ponds are vegetated depressions designed to capture runoff from impervious surfaces, allowing sediments and pollutants to settle while water infiltrates into the soil and groundwater. Typically, dry except during heavy rainfall, these basins provide temporary storage and flow control as part of Sustainable Urban Drainage Systems (SuDS). They may also function as bioretention areas, using engineered soils and vegetation to filter runoff and remove pollutants. Infiltration ponds can serve as recreational spaces or public parks, offering visual appeal and wildlife habitats. They also increase soil moisture, recharge groundwater, and help mitigate low river flows.

The implementation costs for this measure were taken from a study from the IHE Delft Institute for Water Education, the Asian Institute of Technology, and the Hydro Informatics Institute in Thailand (Watkin et al., 2019). This study aimed to expand and deepen the network of furrows on farmland in southern Thailand. The cost of all sources of irrigation for six farmlands, including electricity, equipment, fuel, labour, and all operational costs, was determined through interviews. The average annual cost per rai in 2019 was 777 THB, equivalent to 815 THB or 22.56 USD per rai in 2024, using GDP Deflator conversion from The Economist Intelligence Unit (EIU, 2024). The total rice harvested area for Thailand reached 10,719,700 ha or 66,998,125 rai (FAS, 2023), and the target area of implementation was assumed to be 2 per cent out of the total area, which was 1,359,928 rai, with the assumption that most rice fields already have retention furrows. Therefore, the estimated total cost is 30,674,921 USD.

10. Improved drainage system

Grey

21,895,244 USD

An improved drainage system is one of the grey infrastructure adaptation measures that can be used to address flooding in Thailand, particularly in urban and flood-prone areas. These engineered systems are designed to manage excess stormwater by quickly channelling it away from streets, buildings, and other vulnerable regions, reducing the risk of water accumulation during heavy rains. Upgrading drainage systems involves constructing larger, more efficient pipes, ditches, and storm drains and incorporating advanced technologies such as automated flood gates or pump stations to handle extreme weather events. By enhancing the capacity and efficiency of these drainage networks, Thailand can reduce the frequency

and severity of urban flooding, protect critical infrastructure, and minimize the disruption to daily life caused by rising flood risks due to climate change.

The cost of implementing this measure is estimated from the long-term plan of Flood Mitigation and Management in the Bangkok Metropolitan Area for 2013-2017, which was adjusted for today's value (Phamornpol, 2011). The original cost is 684 million THB, equivalent to 836,119,249 THB in 2024 or 23,148,373 USD (EIU, 2024). This cost was later adjusted to represent national averages, considering cost-benefit ratios from comparable studies and literature reviews.

11. Sandbags

Grey

13,617,110 USD

Sandbags are a simple yet effective grey infrastructure adaptation measure commonly used to mitigate flood risks. As temporary barriers, sandbags are strategically placed along riverbanks, around homes, or across roads to prevent or redirect floodwaters during heavy rainfall or storm surges. While relatively low-cost and easy to deploy, sandbags provide critical short-term protection in emergency flood situations, helping to reduce water infiltration into buildings and infrastructure. In Thailand, where seasonal monsoons and extreme weather can lead to flash floods, sandbags serve as an accessible and rapid response tool, particularly in areas where more permanent flood defence systems may not be in place. Despite their temporary nature, they play a key role in community flood preparedness and resilience, buying valuable time for more long-term solutions to be implemented.

The estimated cost for sandbags was taken from online sandbag costs, and the number of sandbags required was taken from the Bangkok Metropolitan Administration plan to fortify Chao Phraya river banks in 2023 (Bangkok Post, 2023). The online sandbag cost was an average cost of low to high-value sandbags, which is 3,279 THB for 10 Sandbags or 90.78 USD. The Bangkok Metropolitan Administration estimated that 1.5 million sandbags were needed to fortify the Chao Phraya riverbanks, which was taken as an assumption. This brings the total estimated cost to 13,617,110 USD per project.

12. Agricultural zoning

Systemic

13,500,000 USD

Agricultural zoning is an important systemic adaptation measure to reduce flood risks in Thailand by optimizing land use and preventing unsustainable farming practices in flood-prone areas. This approach

involves the development of spatial zoning regulations that control the encroachment of agriculture into sensitive areas, such as reservoir banks, where farming activities can increase soil erosion and water runoff. Additionally, establishing vegetated buffers along drainage systems, transport corridors, and allotment boundaries helps to absorb excess water, slow down surface runoff, and reduce the likelihood of flooding. These buffers also improve soil health and biodiversity, creating natural flood defences.

The Mekong River Commission provides a cost estimation for implementing this activity in Thailand between 2022 and 2026, equivalent to 500,000 USD (Mekong River Commission, 2021). In this study, this cost was used as an annual estimate instead of a 5-year project from 2024 to 2050 to account for national-scale implementation.

13. Water tolerant crops	
Systemic	13,500,000 USD

Water-tolerant crops are one of the systemic adaptation measures to help Thailand’s agricultural sector cope with increasing flood risks. By cultivating crops that can thrive in soggy conditions, farmers can maintain productivity even during periods of excessive rainfall or flooding. This approach often includes plant diversification and intercropping strategies, which involve growing multiple types of crops together or in rotation to enhance resilience. Diversifying crops improves soil health, reduces the risk of total crop failure, and helps manage water more efficiently during floods. Intercropping, on the other hand, can mitigate flood damage by utilizing different plant root systems that absorb water at various depths, stabilizing the soil and reducing erosion. Adopting water-tolerant crops, combined with plant diversification, allows farmers to withstand flood-related disruptions better, ensuring food security and strengthening agricultural resilience.

The estimated cost of this activity was taken from the Mekong River Commission budget planning 2022-2026, equivalent to 500,000 USD (Mekong River Commission, 2021). This cost was used as an annual cost for water-tolerant crops from 2024 to 2050 to account for the whole country.

14. Flood wall	
Grey	382,421,959 USD

Flood walls are designed to protect flood-prone regions like the Bangkok Metropolitan Area. These structures serve as physical barriers that prevent floodwaters from inundating vulnerable zones during

periods of heavy rainfall or storm surges. According to the long-term Flood Mitigation and Management Plan for Bangkok (2013-2017), investments were made to construct new flood walls and elevate existing ones along the Chao Phraya River, Bangkok Noi Canal, and Mahasawat Canal to enhance the city’s resilience to rising water levels (Phamornpol, 2011).

The cost estimates for these projects included engineering, construction, and maintenance of the flood defences to ensure they could withstand increasingly intense flood events. The total was 67,800,000,000 THB in 2011, equivalent to 82,878,486,990 THB in 2024, using GDP Deflator conversion from The Economist Intelligence Unit (EIU, 2024). However, as this is a long-term plan to construct and elevate flood walls, dikes, retention ponds, and develop canal capacities, drainage systems, and other flood protection, the final cost was divided by six to take only the flood wall portion. The one-time estimated cost in 2024 ended up being 382,421,959 USD per project.

15. Flood index insurance	
Insurance	92,345,330 USD

Flood index insurance, such as Thailand’s National Rice Insurance Scheme, is a crucial adaptation measure that helps safeguard rice farmers from the impacts of climate-related disasters like floods and droughts. As one of the world’s leading rice producers, Thailand relies heavily on rice farming for both livelihoods and economic stability. However, the sector is highly vulnerable to extreme weather events. To mitigate these risks, the Thai General Insurance Association (TGIA) launched the rice insurance scheme around 2006 in collaboration with the government’s Disaster Relief Programme. This program provides financial support to farmers whose crops are damaged by destructive weather, ensuring that they receive timely compensation. One of the challenges faced by traditional crop insurance schemes is the high administrative costs in the early stages when the number of policies is insufficient to achieve economic viability. To address this, the Thai government allocated a milestone budget of THB 3 billion (approximately USD 90 million) in 2016 to expand coverage to two million rice farmers (Swiss Re, 2016). This study used this cost to estimate the 2024 net present value of implementing flood index insurance in Thailand using GDP Deflator conversion from The Economist Intelligence Unit (EIU, 2024). The final estimated cost in 2024 was 92,345,330 USD for a similar number of beneficiaries.

16. Soil, water, and pest management

Nbs

6,616,533 USD

Soil, water, and pest management are critical nature-based solutions to help Thailand adapt to the increasing threat of drought, particularly in agriculture. This approach aims to improve soil quality, enhance water retention, and manage pests in a way that reduces environmental impact. Techniques include using organic fertilizers like manure and compost, along with nitrogen-fixing plants and cover crops, which boost soil fertility and minimize nutrient loss. These practices also increase the soil's ability to retain water, making it more drought-resistant. Pest and disease control methods focus on reducing harm to both people and the environment. By adopting these strategies, Thailand can improve agricultural resilience and ensure more sustainable farming in the face of climate challenges.

The costs for these measures are drawn from the Mekong River Commission's budget planning (Mekong River Commission, 2021) and WOCAT (World Overview of Conservation Approaches and Technologies, 2022) estimates per hectare. The budget indicated a 500,000 USD cost for the whole of Thailand between 2022 and 2026. WOCAT database provides initial and maintenance cost estimates, which were used to estimate the total target area. The estimated initial cost was 69.68 USD/ha, and the estimated maintenance cost was 24 USD/ha. The calculated target area was 7,175.66 ha nationally. The assumption was that the initial cost would be repeated every five years, and the maintenance cost of 172,216 USD would be incurred in the years between 2024 and 2050.

17. Legume seed production and propagation

Nbs

3,777,900 USD

Legume seed production and propagation are among the measures for adapting to drought in Thailand, particularly in regions facing water shortages. This program focuses on producing, propagating, and distributing peanut and mung bean seeds, which are more drought-tolerant and require less water compared to other crops. These legumes can be grown after rice harvests, providing farmers with an alternative during dry periods. The initiative aims to distribute seeds to drought-affected land, helping to reduce the negative impacts of income and yield loss. In addition, the project strengthens networks of legume farmers through the Department of Agricultural Extension (DOAE). It offers financial support for seed production and capacity-building efforts within farmer groups and community enterprises.

Cost estimates for the project have been provided by local experts, ensuring it effectively addresses the needs of farmers impacted by drought. A demand of 150,000 kg of seeds every 2 years was identified as an appropriate amount by the experts consulted, with a cost of 1,799 USD/kg. Therefore, the total estimated cost was 269,850 USD every 2 years from 2024 to 2050.

18. Climate-smart agriculture

Hybrid

12,870,472 USD

Climate-smart agriculture plays a key role in helping Thailand adapt to drought by making farming systems more resilient to water shortages and high temperatures. The strategy includes several key activities, such as implementing water-saving irrigation systems and deploying water pumps in off-grid areas to secure a steady water supply for farmers. Additionally, the introduction of heat-tolerant and water-efficient crop varieties ensures productivity in dry conditions. Other important practices are adjusting sowing dates, intercropping, and using low-cost plant nutrient supplementation, all of which help optimize land and water use. An annual crop planning system is also introduced to help farmers better manage their resources.

Cost estimates for these measures were drawn from the Mekong River Commission's budget planning (Mekong River Commission, 2021) and the WOCAT (World Overview of Conservation Approaches and Technologies, 2022) for establishing and maintaining the above activities on a per-hectare basis. The total budget from 2022 to 2026 for the whole of Thailand for climate-smart agricultural practices was 1,560,000 USD. WOCAT database provides initial and maintenance cost estimates, which were used to estimate the total target area. The estimated initial cost was 1,488 USD/ha, and the estimated maintenance cost was 159 USD/ha. The calculated target area was 1,048.39 ha based on the total exposed crops. The assumption was that the initial cost would be repeated every five years, and the maintenance cost of 167,165 USD would be incurred for the years between 2024 and 2050.

19. Management of protected environmental areas

Systemic

13,233,065 USD

The management of protected areas is an important adaptation measure to help Thailand cope with drought by preserving ecosystems and ensuring they continue to provide essential services. One approach

involves the use of rotating enclosures, which allow areas of public rangelands to recover naturally, helping to maintain vegetation and soil health. Additionally, effective management of protected areas plays a key role in maintaining vital ecosystem services like water retention, carbon storage, and biodiversity protection. By focusing on these strategies, Thailand enhances the resilience of its ecosystems while supporting long-term sustainability and biodiversity conservation.

The cost estimates for these measures were drawn from the Mekong River Commission's budget planning and the IUCN's case studies on target protected areas (Mekatitam, 2021). The project budget was to develop and implement three interventions for the management of protected areas for the whole of Thailand, with 1 million USD from 2022 to 2026. The maintenance cost was estimated to be 34 per cent of the initial cost, following the percentage of maintenance cost of soil, water, and pest management measures, which was equal to 344,432 USD. Therefore, from 2024 to 2050, the initial cost of 1 million USD was assumed every five years, and the maintenance costs were assumed for the other years.

20. Improvement of water storage systems

Grey	21,420,000 USD
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Improvement of water storage systems is a crucial grey infrastructure measure aimed at helping rural communities and small-scale farmers in Thailand better manage drought conditions. This measure includes setting up new rainwater storage tanks and maintaining existing ones to ensure a steady water supply during dry seasons. The newly built tanks feature practical elements such as water level gauges, scour drains for removing sediment from the reservoir base, domed roofs, and sturdy steel or galvanized walls for durability. With capacities ranging from 100,000 to 500,000 litres, these tanks provide essential water storage for small communities. By investing in improved water storage, Thailand can strengthen its resilience to drought in vulnerable areas.

The costs for implementing these systems are based on budget allocations from the Ministry of Agriculture calibrated with relevant assets, with ongoing maintenance costs informed by the WOCAT database (World Overview of Conservation Approaches and Technologies, 2022). The Ministry of Agriculture allocated 765 million THB (21,420,000 USD) to develop water storage systems in the Northeast of Thailand (Bangkok Business, 2024). This was used as a one-time cost estimate for the water storage

system in Thailand. The WOCAT database provides initial and maintenance cost estimates, which were used to estimate the total target area. The estimated initial cost was 159.6 USD/ha, and the estimated maintenance cost was 40 USD/ha. The calculated target area was 134,211 ha. The assumption was to have a one-time initial cost in 2024 and a maintenance cost of 5,355,000 USD from 2025 until 2050. This cost was later adjusted to represent national averages, considering cost-benefit ratios from comparable studies and literature review.

21. Improvement of water distribution facilities

Grey	105,000,000 USD
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Improvement of water distribution facilities is an important measure to help Thailand manage drought conditions more effectively. This option includes rehabilitating existing water distribution systems, such as water channels. One major initiative involves transferring water from the Mae-Taeng Dam to the Mae-Ngad and Mae-Kuang Dams over 47 kilometres, aiming to maximize their storage capacities. This project is designed to tackle both drought and flooding issues, particularly benefiting agriculture in Chiang Mai and nearby areas. By boosting the Mae-Kuang Dam's storage by 160 million cubic meters per year, the project will increase water availability for 12,180 hectares of farmland, as well as for urban areas in Chiang Mai and the Lamphun industrial complex (North Public News, 2022).

The total cost for this project reached 15 billion THB (420 million USD), which was used to estimate the initial cost for the whole of Thailand. The WOCAT database provides initial cost estimates (0.16 USD/ha), which were used to estimate the total target area, which is 2.625 billion ha. The assumption was to have a one-time initial cost in 2024 and a maintenance cost of 45,006,048.39 USD from 2025 until 2050. This cost was later adjusted to represent national averages, considering cost-benefit ratios from comparable studies and literature review.

22. Green roofs

NbS	1,493,891 USD
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Green roofs are systems where vegetation is grown on a layer of soil placed over a waterproof membrane on flat rooftops. Green roofs offer a wide range of environmental, economic, and social benefits. They reduce greenhouse gas emissions, mitigate the urban heat island effect, and improve air quality. Additionally, green roofs enhance the aesthetic appeal of metropolitan areas and improve residents' quality

of life by providing recreational spaces. They also boost energy efficiency, optimize electrical supply strategies, and improve the thermal performance of buildings, making them an ideal adaptation measure for heatwaves. The average initial cost and maintenance cost for green roofs were taken from an online source, and the target area was estimated from the Thammasat University Urban Rooftop Farm project (HomeAdvisor, 2022; Urban Nature Atlas, 2021).

The average initial cost was between 10-30 USD per square foot, and the maximum value of 30 USD per square foot was taken. Similarly, the annual maintenance cost is between 0.75 and 1.50 USD per square foot, and the maximum value was taken. However, as these cost estimates were from the USA,

they needed to be adjusted to Thailand's value using the World Bank's Purchasing Power Parity conversion factor of 10.66 THB/USD in 2023 and Thailand versus the USA's GDP factor of 0.01947 (World Bank Group, 2024). The assumed green roof target area was five times larger than the Thammasat University Urban Rooftop Farm project, which was 110,000 square meters or 1,184,040 square feet. The initial cost was calculated with the formula below.

The result was 211,899 USD of initial cost that occurs every 5 years from 2024 to 2050. The maintenance costs were calculated using a formula like the one above but using maintenance cost instead of initial cost. The calculated annual maintenance cost was 10,595 USD, which was applied to all other years.

$$Initial\ cost = \frac{Target\ area\ (sq\ ft) \times Initial\ cost\ (USD/sq\ ft) \times PPP\ factor\ (THB/USD) \times GDP\ factor}{THB\ for\ 1\ USD\ exchange\ rate}$$

2.3 Modelling outputs

This chapter presents the results from CLIMADA, showcasing the expected annual impact for different scenarios and the cost-benefit analysis for selected adaptation measures. In the previous sections, the report presented asset characterization and other climate and socioeconomic scenarios. This information was modelled in CLIMADA to compare the current risk (in 2024) versus the future risk (in 2050) based on two future climate scenarios. The expected annual impact charts show the comparison between current and future risks and the impact of climate change and socioeconomic scenarios.

A list of measures specific to Thailand for minimizing floods, droughts, and heatwaves was also discussed and parametrized into CLIMADA. CLIMADA processed this data against the hazard information. The model quantifies the benefit of the selected adaptation measure as the resulting reduction in the expected impacts. The costs of the adaptation measures are all defined monetarily and, therefore, are comparable. This process identifies a set of “best” measures for a feasibility study before investment.

2.3.1 Expected annual impacts

This chapter presents the Annual expected impacts (AEI), which represent the expected impacts on economic and non-economic assets in Thailand annually. This expected impact is the percentage or absolute value of the economic assets expressed in USD or non-economic assets expressed as the

number of people affected by climate change and socioeconomic scenarios.

The results of this analysis are presented on a waterfall graph with four bars representing current and future risks. The first bar (yellow) represents the expected impact of the modelled hazard today. The second bar (light orange) represents the increase of the expected annual damage over the next 26 years due to population or economic growth for non-economic and economic assets, respectively. Perhaps most important for our purposes is the third bar (dark orange), which represents the expected impact of climate change based on the scenario modelled. It can vary considerably depending on which hazard/asset is being modelled. The final bar (red) is the aggregate of all expected annual impacts. It represents the expected risk under that climate change scenario by the year 2050, when population growth or economic growth and climate change are considered together.

2.3.1.1 Flooding

Flooding has been and will continue to be the most destructive natural hazard in Thailand (Petpongpan et al., 2021; Shrestha & Lohpaisankrit, 2017). In contrast, there is a long history of adaptation to flooding by those living in the country (Daungthima & Kazunori, 2013); as climate change worsens, the frequency, severity, and longevity of these flood events worsen, making the situation untenable (Nair et al., 2014; Thanvisitthpon, 2022). Most regions are affected in some capacity, with the Bangkok Metropolitan Area,

Chao Phraya River Basin, and other major urban areas being the most severely impacted (Thanvisitthpon, 2021). The distribution of this hazard as it relates to both the economic and non-economic assets is problematic due to the widespread nature of flooding throughout Thailand, the population, and associated economic assets, which are mainly located in the nation's many floodplains (Thanvisitthpon, 2022).

As previously alluded to, the impact of flooding in the future is expected to increase significantly in Thailand. The expected enlargement of flood footprints coinciding with urban expansion into flood plains already struggling with insufficient drainage coincide to form a projected scenario of frequent and severe flooding affecting wide swaths of Thai society, severely impacting nearly all assets studied in the project. This future scenario outlined in this report emphasizes the necessity of investing in sectors related to the studied assets, such as education, agriculture, infrastructure, and religious services. By understanding and better anticipating the impacts these sectors will face, preventative measures can be taken to help minimize predicted losses to the Thai people and the economy (Mruksirisuk et al., 2023; Thanvisitthpon, 2021).

1. Economic assets

Figure 14 presents the projected annual impact of flooding on economic assets, including grass (rice, sugarcane, and maize) and tree (durian and rubber) crops and wet markets. The annual expected impact on these economic assets due to flooding is 122.14 million USD, and it will increase dramatically under the RCP 2.6 and 8.5 climate scenarios by the year 2050 due to the combined effects of economic growth and climate change. Despite the predicted decrease in future population by the year 2050, reducing risk slightly, economic growth will still play a sizable role in increasing Thailand's future risk as the country continues its shift from an agrarian society to a more

diverse economy featuring strong manufacturing and tourism sectors in addition to its traditional focus, agriculture (Napasintuwong, 2019). That said, the major factor influencing future risk is climate change. The increasingly frequent and intense flood events in Thailand are predicted to have devastating effects on the country's agricultural sector. This sector still employs a large portion of the population (Pratoomchai et al., 2022). Furthermore, rice, one of Thailand's major exports, and the areas in which it is grown coincide with some of the regions most vulnerable to flooding (Pratoomchai et al., 2022). This issue is also true for the Bangkok Metropolitan Area and its nearby industrial parks, which are making large segments of Thailand's economic future exceedingly vulnerable to flooding in climate scenarios.

2. Non-economic assets

Diarrhoea patients

Figure 15 showcases the increasing impact of flooding on water reservoirs, which in turn increased the percentage of the population that has diarrhoea despite a predicted population decline in Thailand. In 2024, 15,050 people in Thailand are at risk of diarrhoea directly attributed to flooding. Waterborne illnesses, such as diarrhoea, are particularly dangerous to children and remain the leading cause of mortality among children under 5 years old in developing countries (Yazdi et al., 2024; Boschi-Pinto et al., 2008). The predicted decrease in birthrate is a positive when considering this particular asset. As the birthrate decreases, so too does the incidence rate of diarrhoea and other waterborne illnesses. That said, the predicted increase in impact due to climate change negates this, leading to a rise in future diarrhoea under the RCP 8.5 climate change scenario. While particularly deadly to children, diarrhoea can affect anyone exposed to contaminated waters, and under future scenarios, the number of people exposed

Figure 14: Annual expected impact of flooding on all monetary assets combined

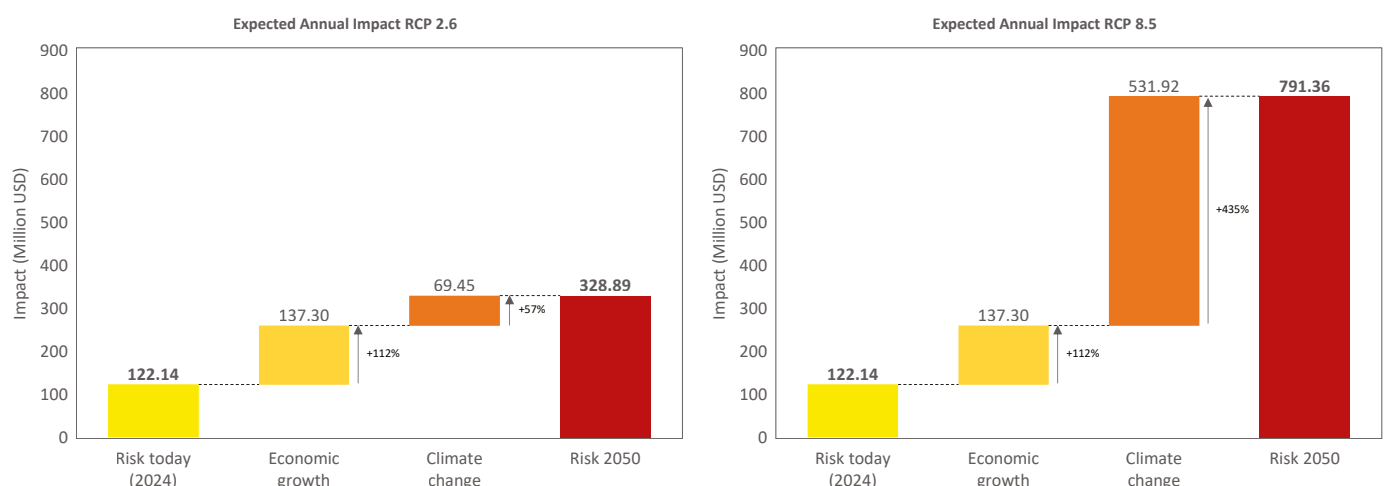
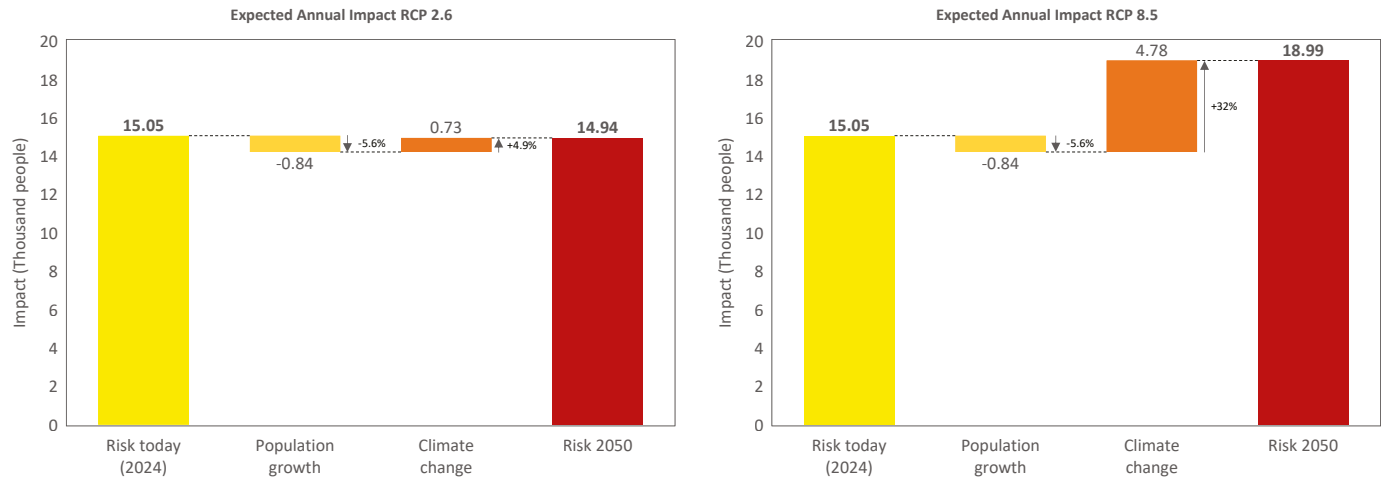


Figure 15: Annual expected impact of flooding on people (diarrhoea patients)



to said waters will increase dramatically (Yazdi et al., 2024).

It is important to expand upon the decrease in Thailand’s future population, an important factor that contributes considerably to most future risk predictions. The decline can be attributed to the reduction in fertility rates over the past few decades, as well as the shift from a traditional agrarian society to a more urban population with higher socioeconomic statuses than previous generations (Srithanaviboonchai et al., 2014).

Students, grass and tree crop farmers, and religious services (Buddhist monks)

Figure 16 indicates the increasing risk of flooding among people (students, grass and tree crop farmers, and Buddhist monks), considering the future population decrease and climate change. In 2024, 1.17 million people are at risk of floods. Under future climate change scenarios, we saw a major increase in people impacted when progressing from RCP 2.6 to the RCP 8.5. Again, this increase in impact is

despite the decreasing total number of people in Thailand, meaning that exposure increases despite decreasing overall population. The difference between the two scenarios is stark, indicating that the future combination of increased flood frequency, longevity, and severity will incur major disruptions for people in diverse aspects of Thai life – educational, economic, and societal.

Students and farmers both belong to two demographic groups that are steadily decreasing in Thailand. The former is due to the decrease in fertility rate (Sasiwonsaraj et al., 2020), while the latter can be attributed to an ageing population not being replaced by the younger generation (Jansuwan & Zander, 2021). Monk populations are more difficult to predict, with their overall population dependent on a large number of factors outside of a raw number of people (McCargo, 2004). Despite all three assets decreasing in population size, the increased flooding due to climate change is expected to affect a wider percentage of people, thus increasing the total impact of flooding on people in Thailand in the future.

Figure 16: Annual expected impact of flooding on students, grass and tree crop farmers, and Buddhist monks

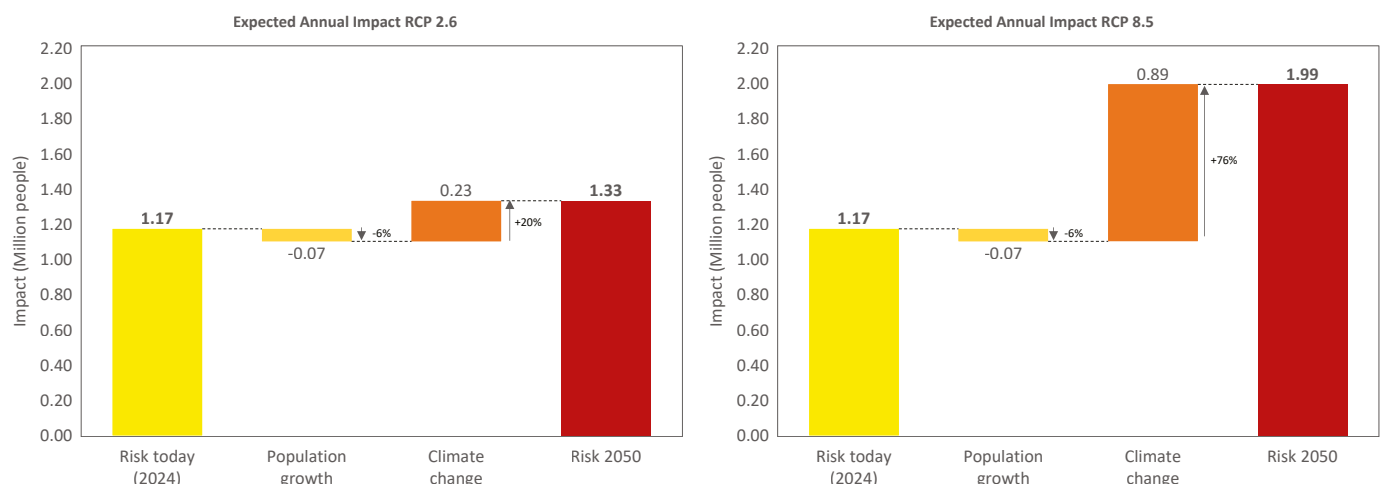
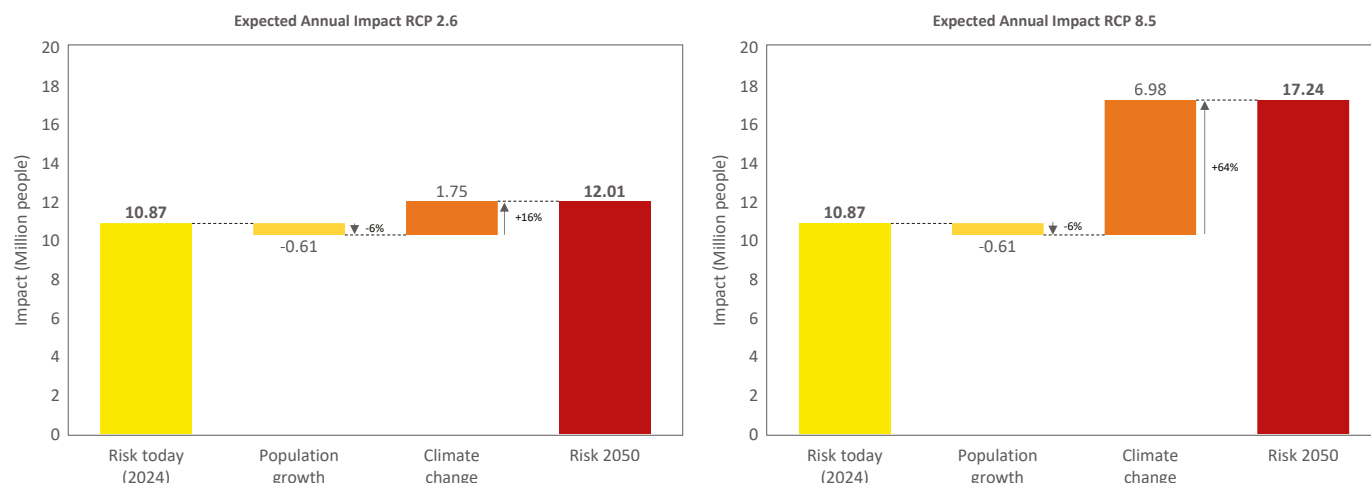


Figure 17: Annual expected impact of flooding on road users



Road users

Figure 17 illustrates the increasing risk that flooding poses to road users, which will be attributed to the effects of climate change by 2050. In 2024, 10.87 million Road Users will be at risk from flooding. As with the previous assets, the total expected impacts of floods on road users are expected to increase dramatically, with the decline in population decreasing the impact slightly and being completely negated by the increased expected effects of flooding on road users due to climate change.

Roadways are vital for supporting economic growth and connecting people and places in Thailand (Assavavipapan & Opananon, 2016; Mungnimit, 2002). Understandably so, most major roadways are located within, near, or connecting the urban centres within the country (Suanmali et al., 2014). Unfortunately, as with the previous assets, this expansion coincides with flood-prone regions, further exposing roadways and the people who use them to future flood impacts (Budhakooncharoen & Dhabhisara, 2014). Urban centres, such as Bangkok, are expanding rapidly, and so are the road networks as people migrate to cities in search of opportunities. This influx of people will cause further stress to an already strained road system, especially in the Bangkok Metropolitan Area (Chamaratana et al., 2010; Thai Rubber Association, 2024).

Roadways and flooding are not limited to the more urban regions within the country, but rather just in their highest concentrations in these areas. As Thailand and its traditional agricultural regions become more interconnected and developed, the impact of flooding on road users is expected to increase in these regions. If the trends continue as expected, these outlying regions will also see urban expansion along waterways and within flood-prone areas (Gullette et al., 2017; Suwanlee & Som-ard, 2020).

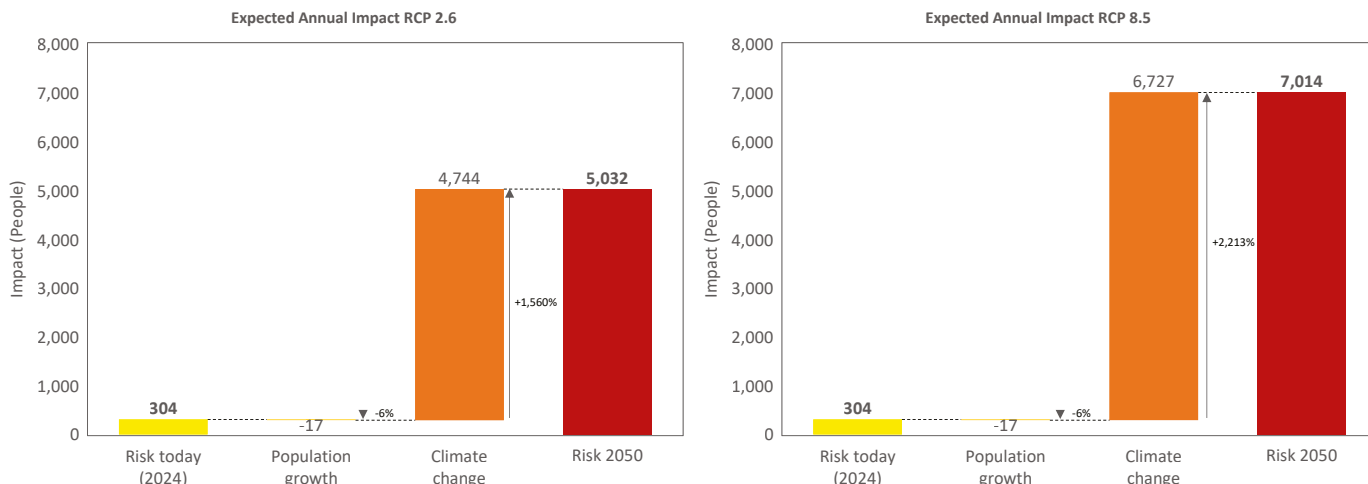
This asset is particularly relevant in Thailand; with the increasing reliance on motor vehicles, it currently and will continue to have a more marked impact on road users than the previous assets (students, access to shelter, and Buddhist monks). This situation is to be expected when considering the numbers associated with each asset, with road users increasing every year as Thailand becomes more car-dependent (Sillaparcharn, 2007). Additionally, there are more road users amongst the Thai population than there are of other assets, considering most people fall under this broad category rather than those with a narrower scope.

People seeking shelter

Figure 18 presents the increasing risk of flooding to people seeking shelter in Thailand. As the name implies, this asset measures the future impact of flooding on people's access to refuge in Thailand after a flood. The effect of flooding on people's ability to access shelter by the year 2050 under both Climate Change Scenarios RCP 2.6 and 8.5 are expected to increase to 5,032 and 7,014 people, respectively, from the current number of 304 people.

Shelter in this context was studied as a religious service in Buddhist Temples. Considering the future climate change, the impact of flooding is expected to increase in Thailand, further exacerbating the situation in an already vulnerable group of people – those needing refuge but unable to reach it during flooding. The inability to access shelter is multifaceted, with housing, roadways, and temples all having a role in determining how many people need shelter and can access it. With that said, flooding's role in people's ability to access shelter and the various factors that influence it creates a group of people less drastically impacted in a raw number of people affected compared to the other assets described above, despite the large percentage increase, as can be seen in the figure below.

Figure 18: Annual expected impact of flooding on access to shelter



2.3.1.2 Droughts

Droughts in Thailand are also expected to increase dramatically in the coming decades, especially in the Northern and Northeastern (Isan) Regions of the country (Chaowiwat, 2016; Khadka et al., 2024). Water demand is also projected to increase, with high-risk water deficit areas including the Ping, Yom, Nan, Chi, and Mun River Basins (Chaowiwat, 2016).

Similarly, water demand in the agricultural sector is rising (Chaowiwat, 2016), which is particularly relevant to the more rural and less developed regions of Thailand, namely the Isan Region. Being the largest and most populated region with the lowest per capita income (Moore & Donaldson, 2016), residents of Isan already struggle to cope with current climate conditions, thus making them highly vulnerable to any hazards further disrupting crop production (Polthanee et al., 2014).

Scenarios like those described above occur throughout Thailand, making this study’s focus on the agricultural sector, water demand, and wet markets particularly

relevant to gauge the country’s vulnerability to droughts in the future. Gaining a better understanding of the severity of current and future challenges will lead to a better understanding of the actions needed to prepare for and address droughts in the future.

1. Economic assets

Wet markets, grass, and tree crops

Figure 19 indicates the projected annual impact of droughts on economic assets (wet markets and grass and tree crops) due to future economic growth and climate change. In 2024, the annual expected impact on the economic assets due to drought is 354.22 million USD, with economic growth as the major contributor when looking at this impact. Both scenarios show a large uptick in predicted impact, but under the RCP 8.5 climate scenario, the climate change in the form of drought increases significantly.

Drought poses a significant risk to the agriculture sector in Thailand, particularly to the country’s main crop, rice. Heavily dependent on irrigation for

Figure 19: Annual expected impact of droughts on all monetary assets combined

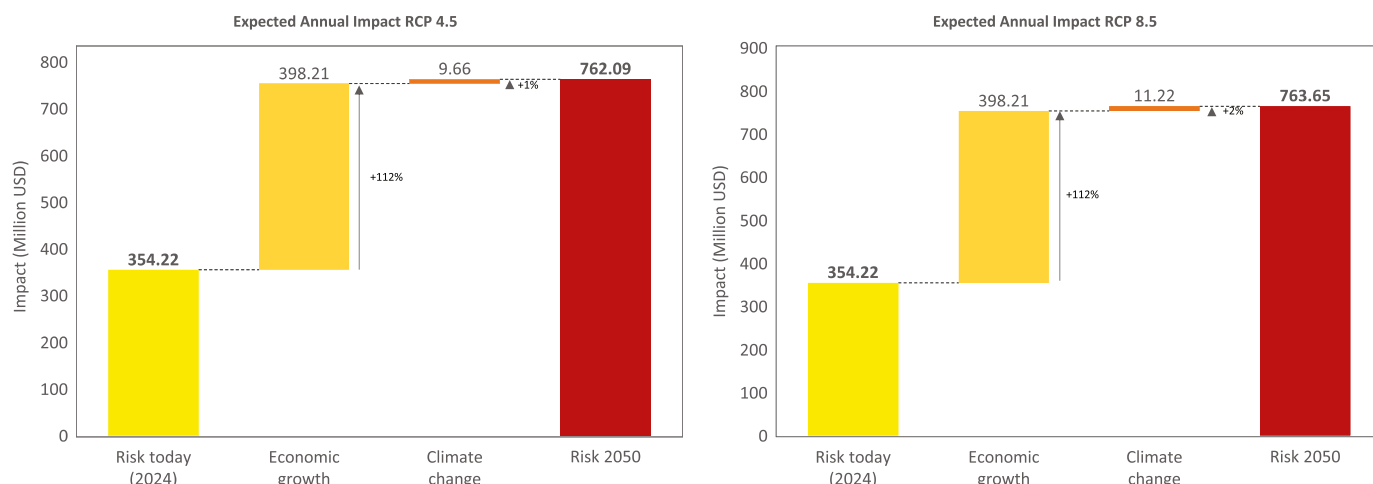
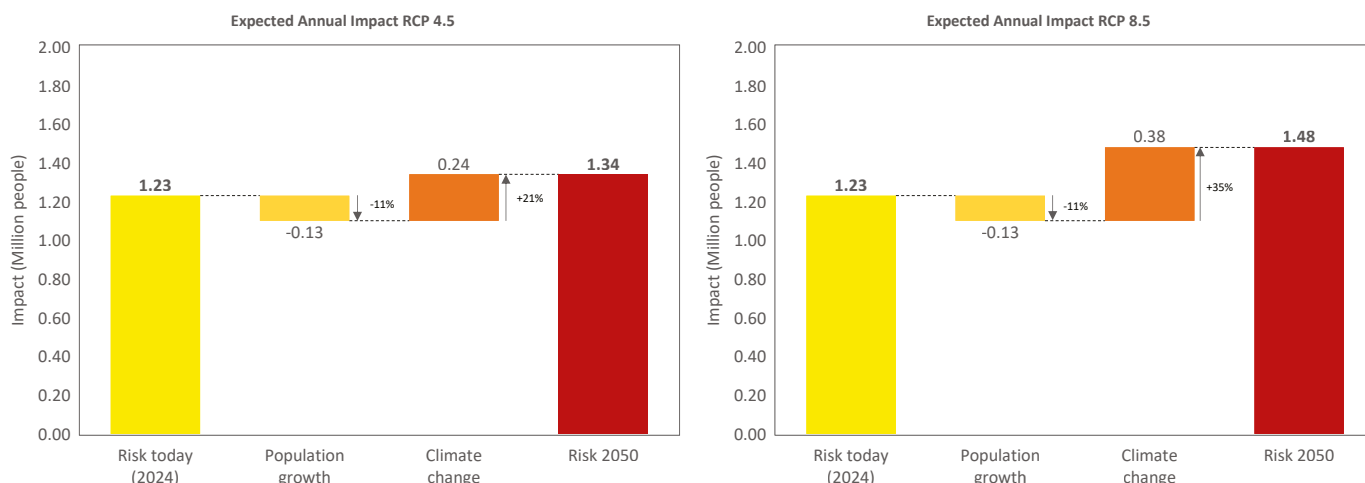


Figure 20: Annual expected impact of droughts on people (Water users and tree and grass crop farmers)



its multiple growing seasons, drought can severely affect rice yields (Polthanee et al., 2014; Yokying, 2024), causing ripple effects throughout Thai society. Other important crops, namely sugar cane, durian, and rubber, are also affected by drought conditions, though less dramatically than rice (Dlamini, 2019; Dlamini & Songsom, 2019; Mangmeechai, 2020).

Wet markets are the traditional location for grocery shopping, with vendors often stocking their stalls with local goods. Wet markets are particularly important in terms of local produce, as they usually offer cheaper and fresher options. Drought will inevitably affect the quantity and quality of the foodstuffs available at these markets, possibly driving up prices for those who shop there and impacting the livelihoods of those who run the shops (Chuechan, 2020; Gorton et al., 2011).

2. Non-economic assets

Water users, grass, and tree crop farmers

Figure 20 highlights the increasing impact on people (water users and grass and tree crop farmers) in Thailand due to climate change, despite the predicted population decline. In 2024, 1.23 million people are projected to be affected by drought. Like previous assets, the decrease in future population will reduce the impact of droughts in Thailand by 2050, albeit by a small margin.

However, water users and crop farmers will be heavily affected by droughts in the future, although the number of people impacted will not vary considerably between the climate scenarios. This result is mainly due to the widespread nature of droughts in Thailand. While the severity of the droughts increases under the RCP 8.5 climate scenario, the number of people affected is only marginally more.

2.3.1.3 Heatwaves

Recent studies highlight the threat of heatwaves in Thailand during the coming decades, with significant increases in frequency and intensity, specifically daytime heatwaves impacting urban and peri-urban areas and nighttime heatwaves impacting the more rural regions (Chongtaku et al., 2024; Huang et al., 2018).

These heatwaves have far-reaching consequences; under future the RCP 8.5 climate scenarios, the predicted temperature increases significantly reduce work performance nationwide. Additionally, crop yields are also severely affected, with estimated reductions of up to 8 per cent for rice (Amnuaylojaroen et al., 2022; Amnuaylojaroen & Parasin, 2022). The negative consequences of future expected impacts affect nearly all aspects of daily life in Thailand and underscore the need for targeted interventions to mitigate the negative impacts of heatwaves throughout the country.

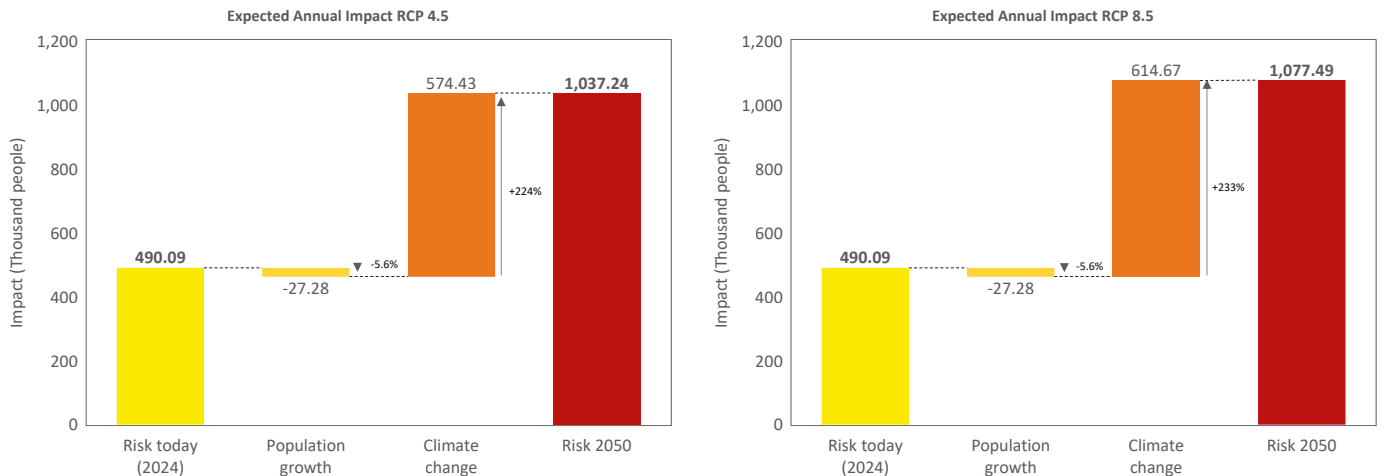
1. Non-economic assets

Students

Figure 21 below illustrates the increasing risk of heatwaves among the student population in Thailand due to climate change, despite the foreseen population decline by 2050. Currently, in 2024, 490.09 thousand students are at risk of heatwaves. However, under RCP 4.5 and 8.5 climate scenarios, projections are that the total expected impacts of heatwaves on students are expected to decrease slightly because of population decline. This slight decline is negated by a significant anticipated increase in impact attributed to climate change in the future, reaching over one million students impacted in both climate change scenarios by 2050.

Identifying where and to what extent students in Thailand will be affected by heatwaves in the future is

Figure 21: Annual expected impact of heatwaves on students



essential for safeguarding educational outcomes and student well-being. Rising temperatures are proven to negatively impact students' health and performance (Somboonwong et al., 2012). With climate change further intensifying heatwaves, understanding the risk allows for implementing adaptive measures like improved school infrastructure or cooling systems to ensure a safe and conducive learning environment for students in Thailand.

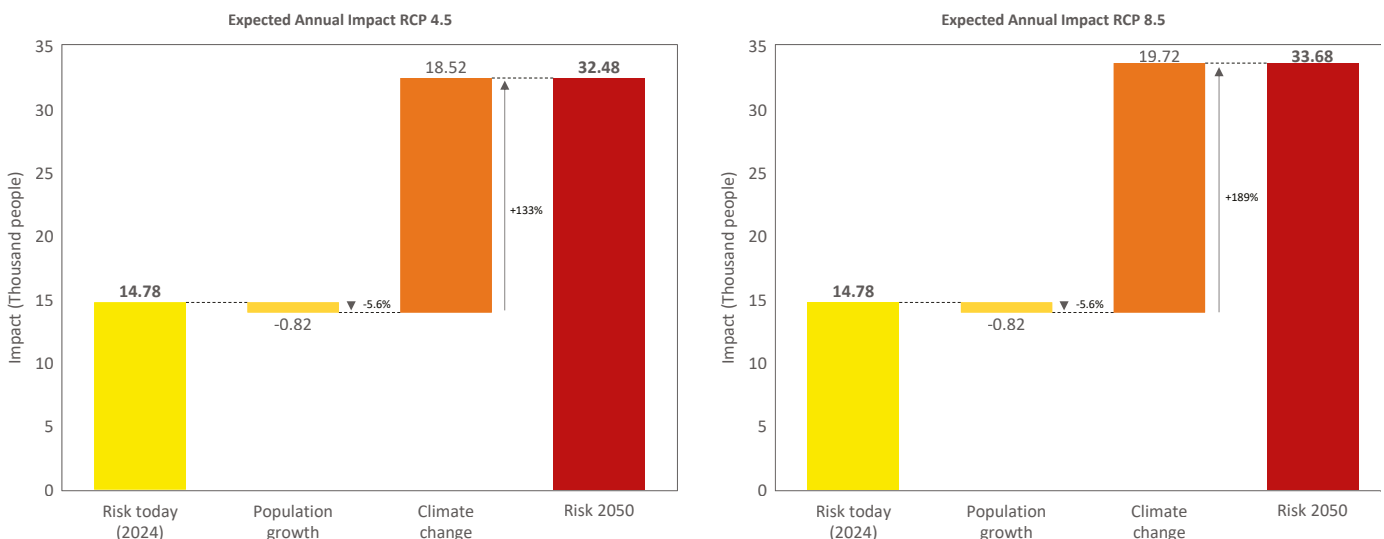
Buddhist monks

Figure 22 indicates the increasing risk of heatwaves among Buddhist monks because of climate change by 2050. Currently, in 2024, 14.78 thousand monks are at risk from heatwaves. This expected impact is of particular note due to monks' unique position in Thai society, acting as spiritual and community leaders yet relying completely on the generosity of the local community to fulfil their duties (Bresnahan, 2019; Preeda, 2017). Similarly, to previous assets, population decline has little impact on how many monks are

affected by heatwaves, while climate change has a significant effect. The difference between RCP 4.5 and 8.5 climate scenarios is minor, again attributable to the large area of impact from heatwaves affecting large portions of the monk population in Thailand.

Rising temperatures have a disproportional impact on the well-being of Buddhist monks, which can be attributed to their lifestyle (Kuramasuwan et al., 2013; Tharika Kamkokgruad, 2019) and the increasingly harsh effects of climate change in terms of heatwave frequency and intensity. Understanding the risks associated with heatwaves and how they affect Buddhist monks and, by extension, the population's access to religious services, allows for an improved approach towards implementing adaptive measures such as cooling systems or improved healthcare, ensuring a safe environment for monks and those who rely on their services in Thailand.

Figure 22: Annual expected impact of heatwaves on Buddhist monks



2.3.2 Cost-benefit analysis

This chapter presents the cost-benefit analysis bar charts showing which adaptation measure has the highest benefit (averted risk) compared to the cost invested for a specific asset and a specific hazard. Each bar represents a particular adaptation measure, with the one on the far left offering the highest benefit or avoided damage per USD invested, progressively decreasing toward the right, where the lowest benefit is shown. The width of each bar reflects the maximum potential avoided damage over the entire time horizon, spanning 27 years from 2024 to 2050. For economic assets, this value is expressed in USD, while for non-economic assets, it is represented by the number of people.

The two red dots in the chart indicate the AAI (Average Annual Impact) and Total Risk. AAI represents the average total annual impact, aligning

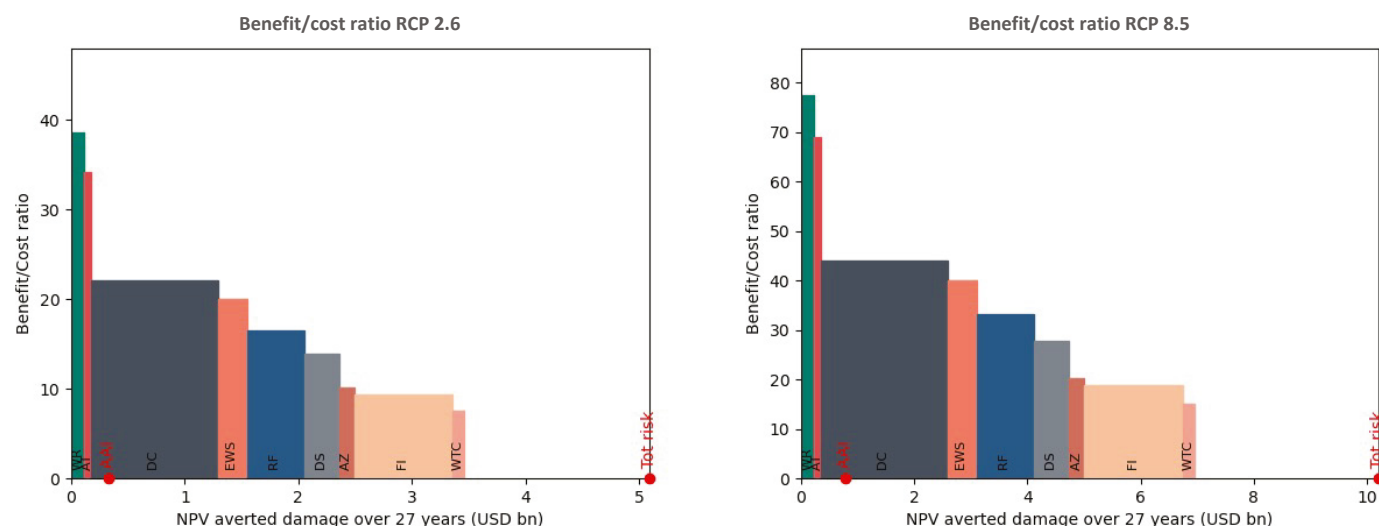
with the Annual expected impact values in 2050 on the waterfall graph. In contrast, the Total risk reflects the accumulated annual expected impact until 2050 for the selected hazard and asset. The width of each column represents the scalability of each measure, with wider columns pointing at solutions that could be more resorted to, while the slimmer ones are measures that make sense for more concrete cases only. Each adaptation measure is allocated a specific colour representing the type of adaptation measures, either NbS, hybrid, systemic, or grey infrastructure. Table 4 shows the abbreviation of each adaptation measure and its colour coding. Additionally, benefit maps will be presented to show the geographical distribution of the benefits from specific adaptation measures and assets throughout the country.

Further, this chapter presents the benefit maps for some measures. These maps showcase the distribution of the benefits in the respective assets.

Table 4: Adaptation measures abbreviation, description and colour coding

Type	No.	Abbreviation	Description
NbS	1	GS	Green spaces
	2	WR	Wetland restoration and rehabilitation
	3	GR	Green roofs
	4	SWP	Soil, water, and pest management
	5	LP	Legume seed production and propagation
Hybrid	6	RF	Retention furrows
	7	DSR	Detention swales along roads
	8	RR	Retention reservoirs
	9	CSA	Climate-smart agriculture
Systemic	7	AT	Training for agricultural topics for adaptation
	8	EWS	Early warning system
	9	AZ	Agricultural zoning
	10	WTC	Water tolerant crops
	11	FI	Flood index insurance
	12	MPA	Management of protected environmental areas
	13	SWM	Improved solid waste management
Grey	14	DC	Dredging of canals
	15	DS	Improved drainage systems
	16	WSS	Improvement of water storage systems
	17	WDF	Improvement of water distribution facilities
	18	FW	Floodwall
	19	SB	Sandbag

Figure 23: Benefit/cost ratio for adaptation measures for economic assets impacted by floods



The maps are presented illustratively for different measures, independently of their ranking on the benefit/cost map, to reflect the sensitivity of the benefits of the measures to the location and the asset.

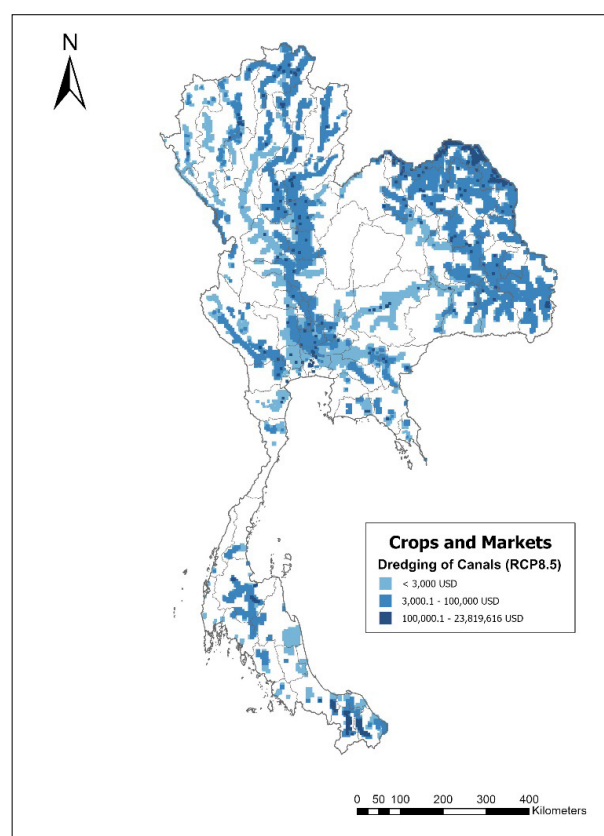
2.3.2.1 Flooding

1. Economic assets

Figure 23 presents the benefit-cost ratio for nine measures evaluated concerning key economic assets, such as tree (durian and rubber) crops, grass (rice, sugar cane, and maize) crops, and wet markets. The ratio reflects the financial return in USD for every 1 USD invested in each measure. Based on the modelling of impacts and costs, wetland restoration and rehabilitation, followed by training for agricultural topics for adaptation, emerge as the most cost-effective strategies for mitigating future flood damage. However, the scaling up of these options is rather limited, and dredging canals will likely be responsible for the largest reduction in risks. Moreover, even with the implementation of all seven studied measures, the total uncovered flood risk remains substantial, leaving more than 1.5 billion USD under the RCP 2.6 scenario and more than 3 billion USD under the RCP 8.5 scenario. This result underscores the need for the Thai government to explore other adaptation measures to reduce flood risks for these assets.

Figure 24 further demonstrates that dredging canals would be of high benefit to tree crops, especially rubber trees, in the Southern region and all grass crops in the Central and Northeastern regions. Wet markets located along the Chao Phraya River Basin and the Mekong River Basin are also observed to get significant benefits.

Figure 24: Benefit map of dredging of canals for economic assets against future flood hazard with the RCP 8.5 climate scenario

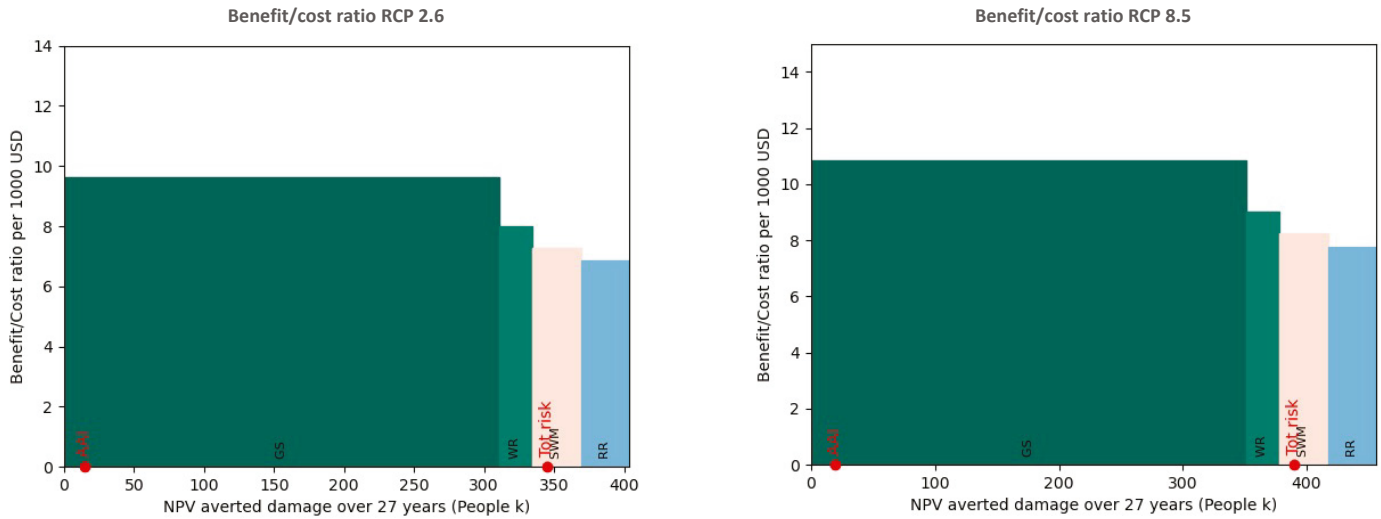


2. Non-economic assets

Diarrhoea patients

Figure 25 presents the benefit-cost ratio for four measures evaluated concerning diarrhoea patients. The ratio indicates the number of diarrhoea cases prevented per 1,000 USD invested in each measure. Based on the modelling of impacts and costs, expanding green spaces, followed by wetland

Figure 25: Benefit/cost ratio for adaptation measures for diarrhoea patients impacted by floods



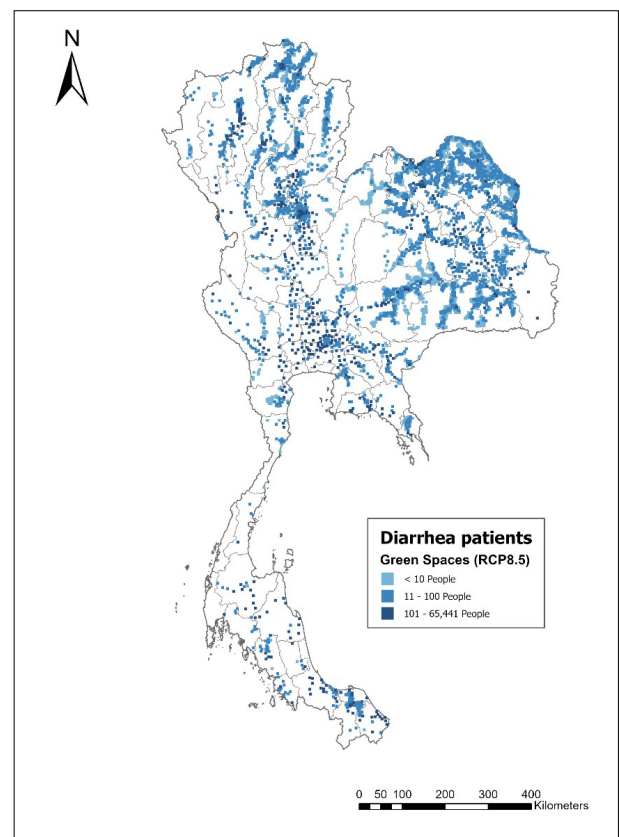
restoration and rehabilitation and improved solid waste management, emerge as the most cost-effective strategies for reducing flood-related health impacts. Research in China has demonstrated that large and dispersed green spaces can significantly reduce flood risk in urban areas with limited green infrastructure (Tian Bai et al., 2018). Additionally, flooding is associated with an increase in diarrhoea cases, particularly among children, due to compromised hygiene and sanitation conditions in flood-affected regions (Léo Heller et al., 2003). Consequently, expanding green space has the potential to not only mitigate flood risks but also reduce the incidence of flood-related diarrhoea cases.

Figure 26 shows the geographical distribution of people who would be prevented from getting diarrhoea due to the expansion of green spaces in the RCP 8.5 scenario. These benefits are spread throughout the country, but especially in the Northern and Northeastern regions along the Mun and Chi rivers, as well as around the Bangkok metropolitan area and along the Chao Phraya river basin going up north in Sukhothai, Phitsanulok, Lampang, Phrae, Chiang Mai, and Chiang Rai provinces.

Buddhist monks and students

Figure 27 indicates the benefit-cost ratio for seven measures evaluated concerning Buddhist monks and students. The ratio represents the number of individuals benefiting per 1,000 USD invested in each measure. According to the modelling of impacts and associated costs, expanding green spaces, followed by the construction of detention swales along roads and retention reservoirs, offers the highest cost-efficiency in mitigating future flood damage. However, even with the implementation of all seven studied measures, the total uncovered flood risk remains substantial, leaving

Figure 26: Benefit map of green spaces that prevent diarrhoea cases due to future flood hazards with the RCP 8.5 climate scenario



more than 12 million people unprotected under the RCP 2.6 scenario and over 17 million under the RCP 8.5 scenario. This result underscores the need for the Thai government to explore other adaptation measures to reduce flood risks for monks and students.

Figure 28 illustrates the geographical distribution of Buddhist monks and students that would avoid future flood hazards in the RCP 8.5 climate scenarios with

Figure 27: Benefit/cost ratio for adaptation measures for Buddhist monks and students impacted by floods

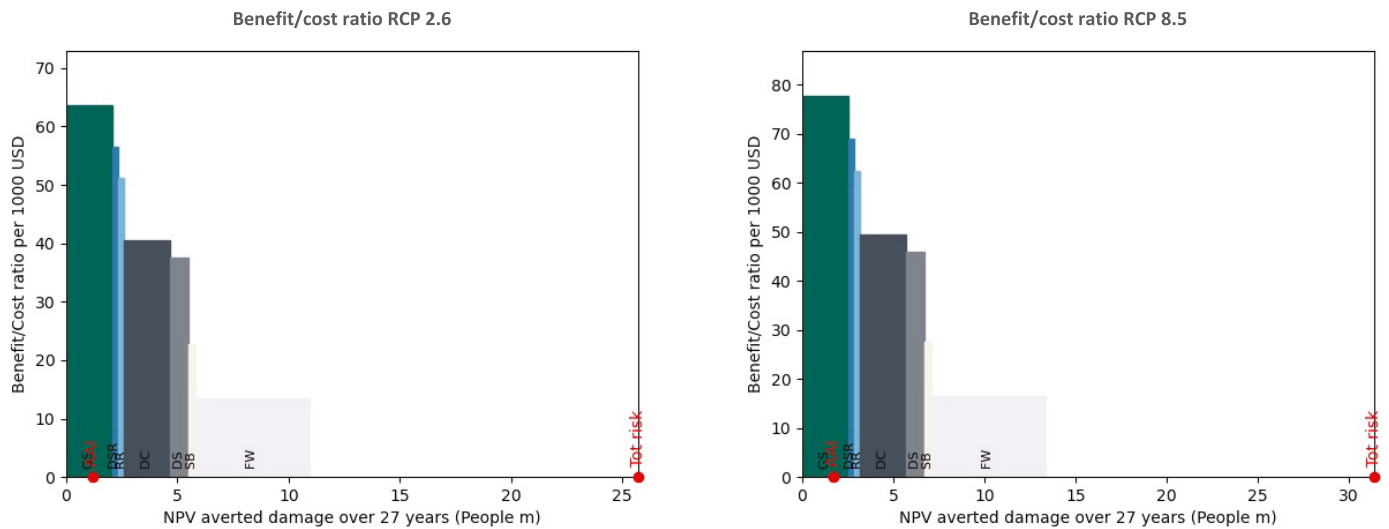
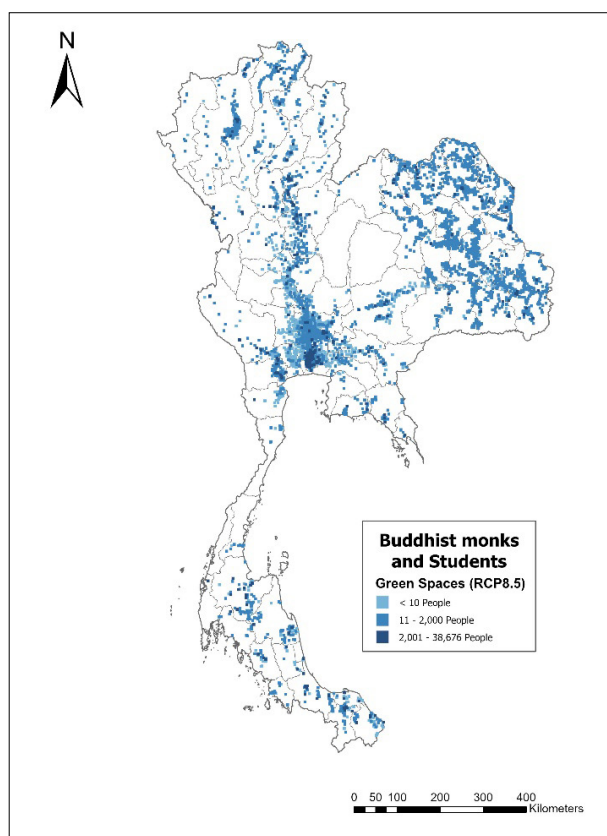


Figure 28: Benefit map of green spaces for Buddhist monks and students against future flood hazards with the RCP 8.5 climate scenario



the expansion of green spaces. They are concentrated along the Chao Phraya river delta, especially in the Bangkok metropolitan area and in the Northeastern region, along the Mun and Chi rivers.

Figure 29 presents the benefit-cost ratio for nine measures assessed concerning people seeking shelter. The measures are meant to reduce the impact on housing that would otherwise be destroyed and leave

inhabitants looking for shelter. The ratio reflects the number of individuals benefiting per 1,000 USD invested in each measure. The projected number of future shelter seekers in Buddhist temples in Thailand remains relatively low (roughly 5,000 during the full study period) and highly concentrated in a few specific areas, namely the BMA. As such, this risk can be comprehensively mitigated with a few adaptation measures, mainly through implementing NbS on green spaces that offer sufficient protection buffers for future exposed homes. Other options include the construction of detention swales along roads and retention reservoirs, which could limit the number of people seeking shelter during flood events.

Tree and grass crop farmers

Figure 30 presents the benefit-cost ratio for nine measures assessed concerning tree and grass crop farmers. The ratio reflects the number of individuals benefiting per 1,000 USD invested in each measure. Like the result for economic assets, the most cost-effective strategies identified were wetland restoration and rehabilitation, training for agricultural topics for adaptation, and canal dredging. This parallel is expected due to the clear connection between the farmers and their crops. In other words, the same measures that reduce the financial impact on the crops also reduce the number of farmers affected, showing consistency in the modelling, including the limited scalability of the first two measures. Further, the portfolio explored was again insufficient to cover the full risk. Under RCP 2.6 and 8.5, around one million farmers would be left unprotected, even if all the measures studied were implemented. This result underscores the need for the Thai government to explore other adaptation measures to reduce flood risks for these assets.

Figure 29: Benefit/cost ratio for adaptation measures for shelter demands due to floods

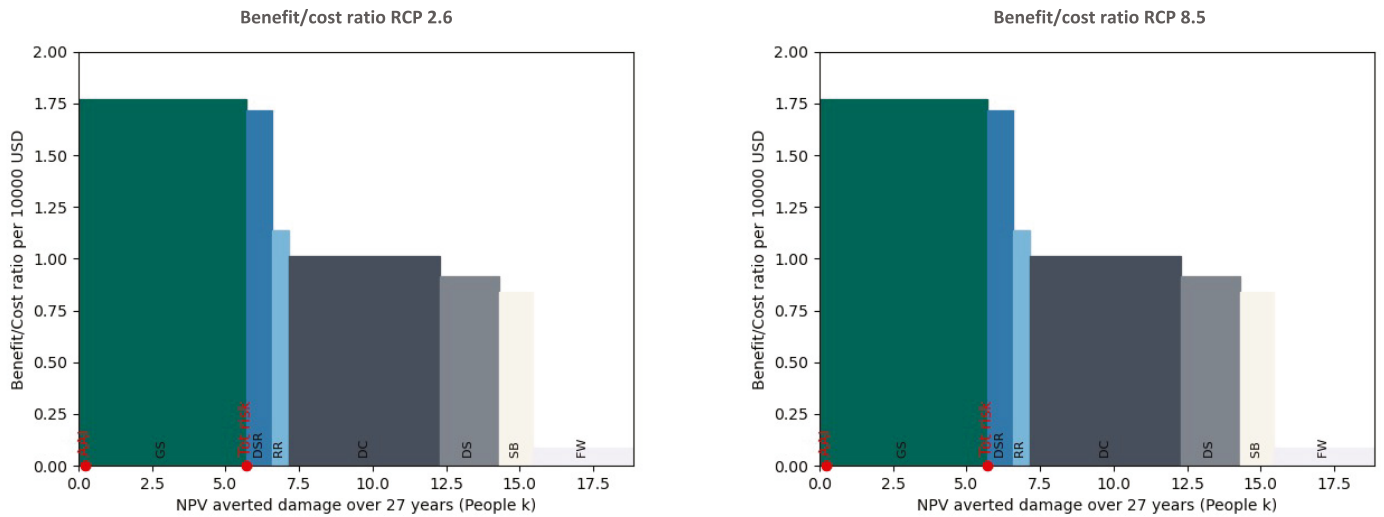


Figure 30: Benefit/cost ratio for adaptation measures for tree and grass crop farmers impacted by floods

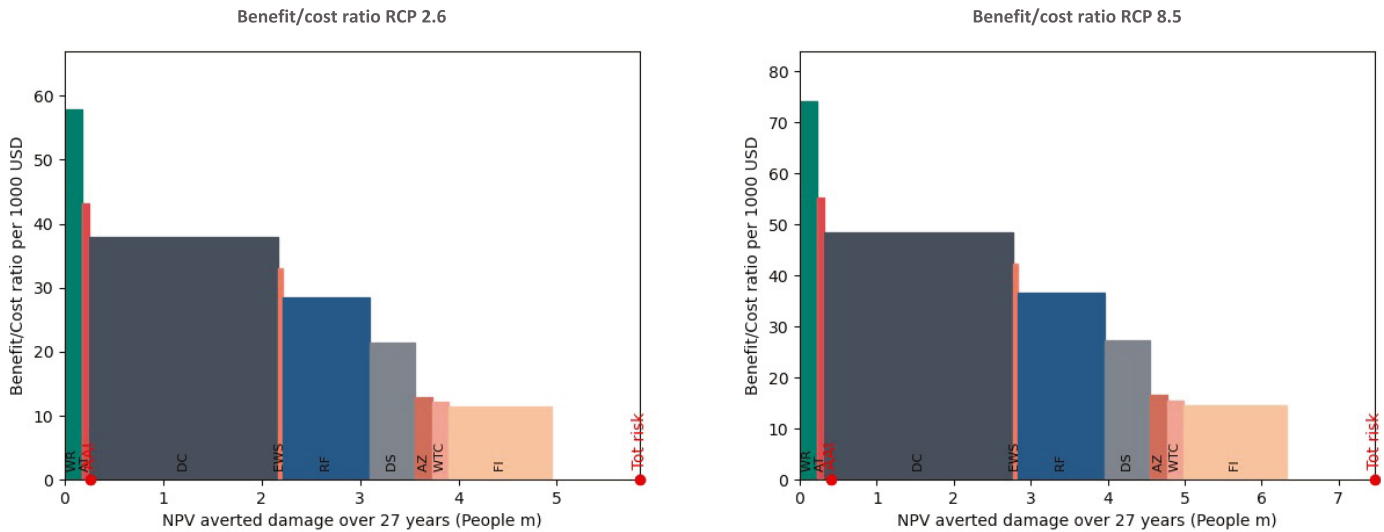


Figure 31 illustrates the geographical distribution of farmers who would be safeguarded from future flood hazards under the RCP 8.5 scenario, with wetland restoration and rehabilitation showing particular benefit in the Chao Phraya River Delta and the Northeastern region, which is part of the Mekong River basin.

Road users

Figure 32 illustrates the benefit-cost ratio for seven measures evaluated concerning road users. The ratio represents the number of road users protected from floods per 1,000 USD invested in each measure. Based on the modelling of impacts and costs, expanding green spaces, followed by wetland restoration and rehabilitation, and the installation of detention swales along roads, are the most cost-effective strategies for minimizing future flood damage. The figure also showcases how the studied portfolio of measures falls short of protecting the total population at risk, leaving over 120 and 200 million people affected until

2050 under RCP 2.6 and 8.5, respectively. The limited scalability potential of the measures partly explains this result, suggesting the Thai government needs to explore various other options to protect road user mobility after flood events.

Figure 33 shows the number and geographical distribution of road users who would benefit most from future flood protection through the expansion of green spaces. Thailand's road infrastructure network is highly developed, reaching people throughout the country. However, most of the road users are in the Central and Northeastern regions.

2.3.2.2 Drought

1. Economic assets

Figure 34 illustrates the benefit-cost ratio for four measures evaluated concerning selected economic assets, such as tree crops, grass crops, and wet markets. The ratio reflects the financial return in USD for every 1 USD invested in each measure. Based

Figure 31: Benefit map of wetland restoration and rehabilitation for tree and grass crop farmers against future flood hazards with the RCP 8.5 climate scenario

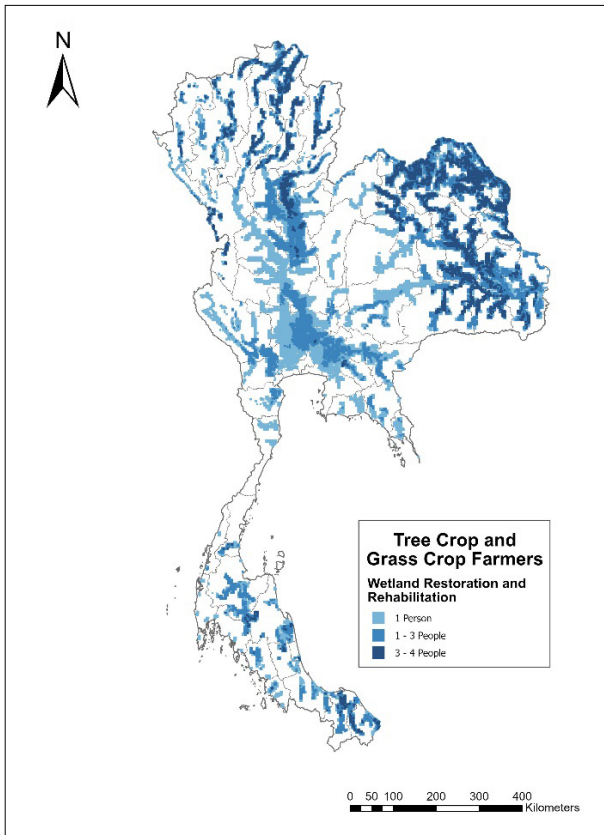


Figure 33: Benefit map of green spaces for road users against future floods with the RCP 8.5 climate scenario

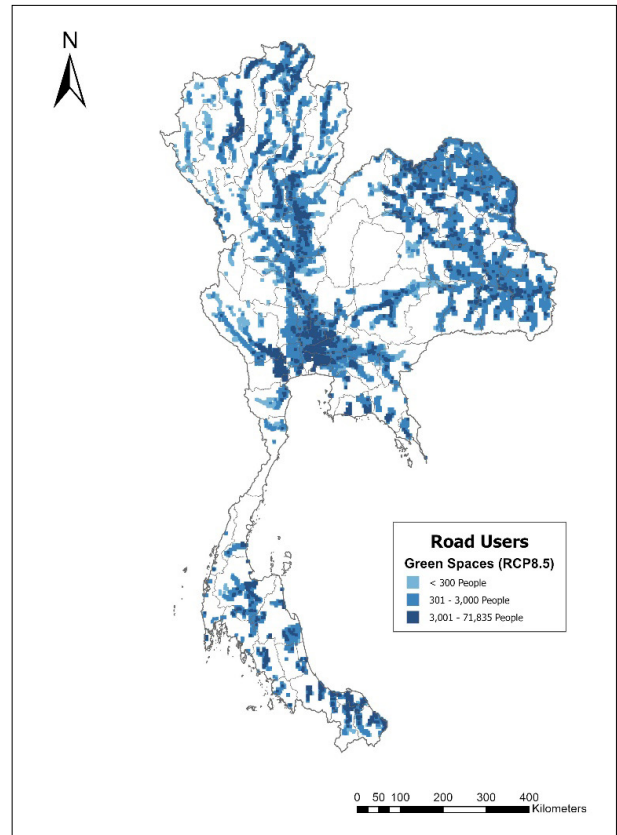
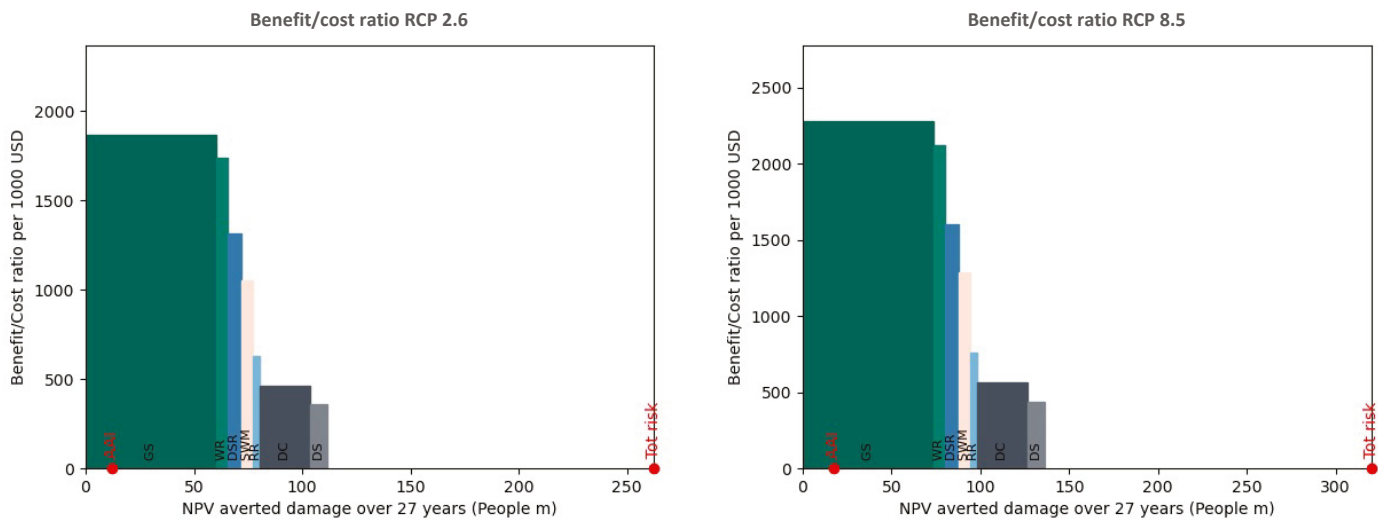


Figure 32: Benefit/cost ratio for adaptation measures for roads impacted by floods



on the modelling of impacts and costs, soil, water, and pest management, followed by implementing climate-smart agriculture practices, improvement of water storage systems, and improvement of water distribution facilities, emerges as the most cost-effective strategy for mitigating future drought damage. That said, the implementation of these four measures does not adequately address the total drought risk for economic assets in Thailand, meaning

additional measures would need to be implemented to cover this gap.

Figure 35 further indicates that soil, water, and pest management would benefit crops mostly in the Northern, Central, and Northeastern regions and wet markets nationwide, particularly around the Bangkok Metropolitan Area. Appropriate soil and water management practices are observed to be

Figure 34: Benefit/cost ratio for adaptation measures for economic assets impacted by drought

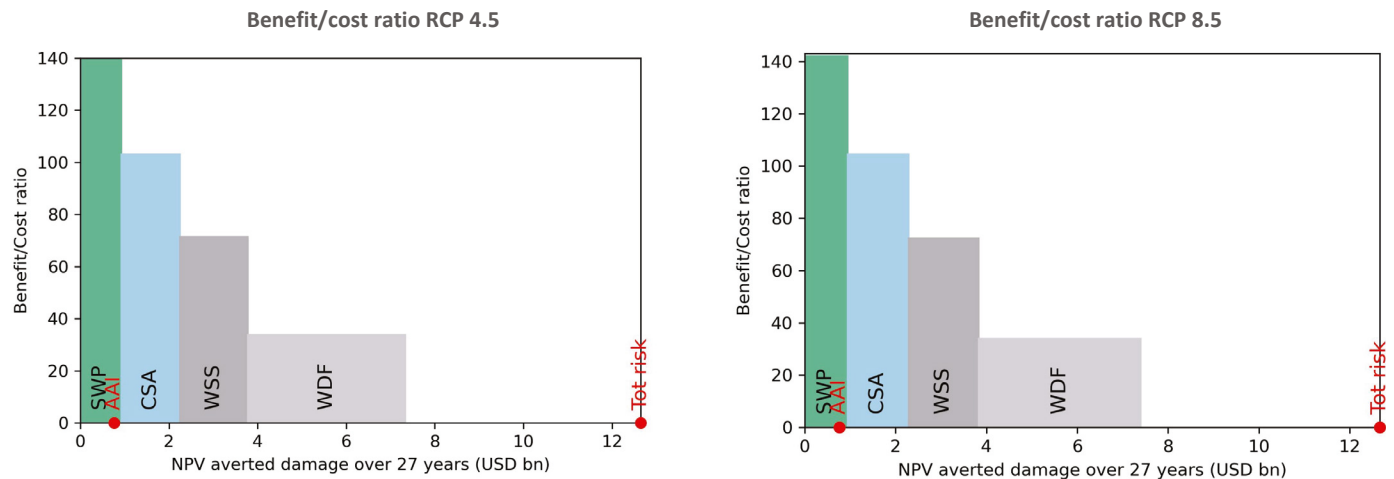
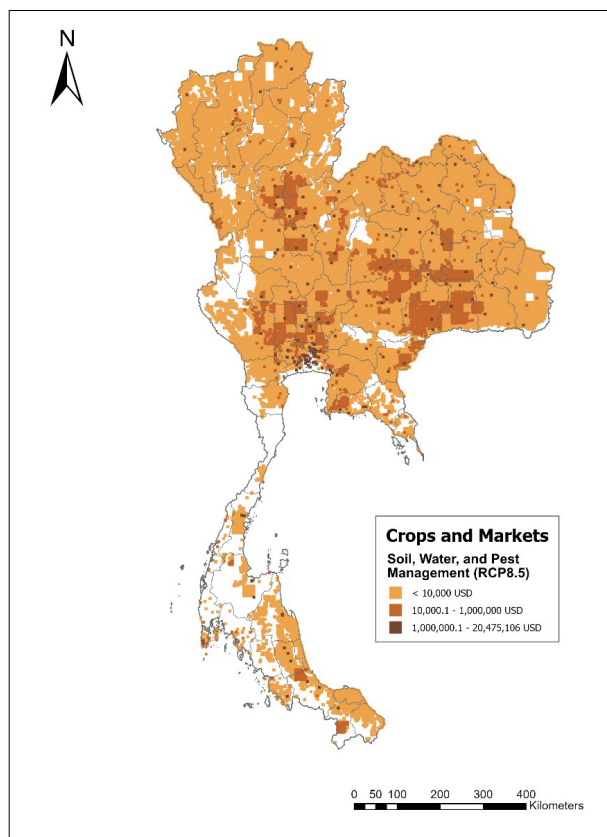


Figure 35: Benefit map of soil, water, and pest management for crops and markets against future drought with the RCP 8.5 climate scenario



the essential first step in building resilience against agricultural droughts by enhancing the quantity and flow of soil water (Cornelis et al., 2019).

2. Non-economic assets

Figure 36 indicates the benefit-cost ratio for seven measures assessed concerning the non-economic assets of tree and grass crop farmers and water users. The ratio reflects the number of people avoiding drought impacts for every 1 USD invested

in each measure. According to the modelling of impacts and associated costs, wetland restoration and rehabilitation, followed by soil, water, and pest management and legume seeds production and propagation, emerge as the most cost-effective strategies for mitigating future drought damage.

Figure 37 illustrates that the population benefitting from wetland restoration and rehabilitation is mostly spread throughout the Northeastern region and concentrated around the Bangkok metropolitan area. Wetland restoration and rehabilitation have the potential to significantly mitigate drought impacts in Thailand by providing various ecosystem services and, therefore, enhance drought resilience (Penny et al., 2023).

2.3.2.3 Heatwave

1. Non-economic assets

Buddhist monks

Figure 38 presents the benefit-cost ratio for two measures evaluated concerning Buddhist monks. The ratio represents the number of monks protected from heatwave impacts per 1 USD invested in each measure. Based on the modelling of impacts and associated costs, expanding green spaces has a higher benefit ratio compared to implementing green roofs. However, these two measures still fall short of addressing the total heatwave risk, leaving around 100 million monks unprotected until 2050 under both studied climate scenarios. Alternative measures should be considered by the Thai authorities to complement the portfolio, with NbS likely offering a high cost-benefit potential.

Figure 39 highlights the number and geographical distribution of monks who would be protected from future heatwaves through expanding green spaces. Several studies suggest that increasing green spaces will effectively mitigate the impact of urban heat

Figure 36: Benefit/cost ratio for adaptation measures for farmers and water users impacted by drought

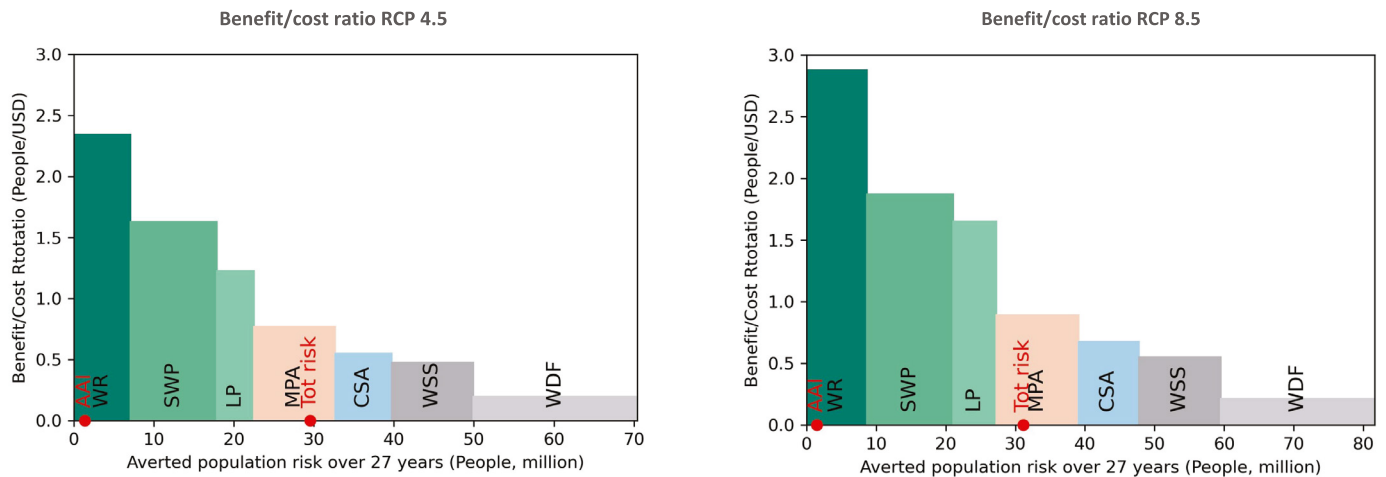
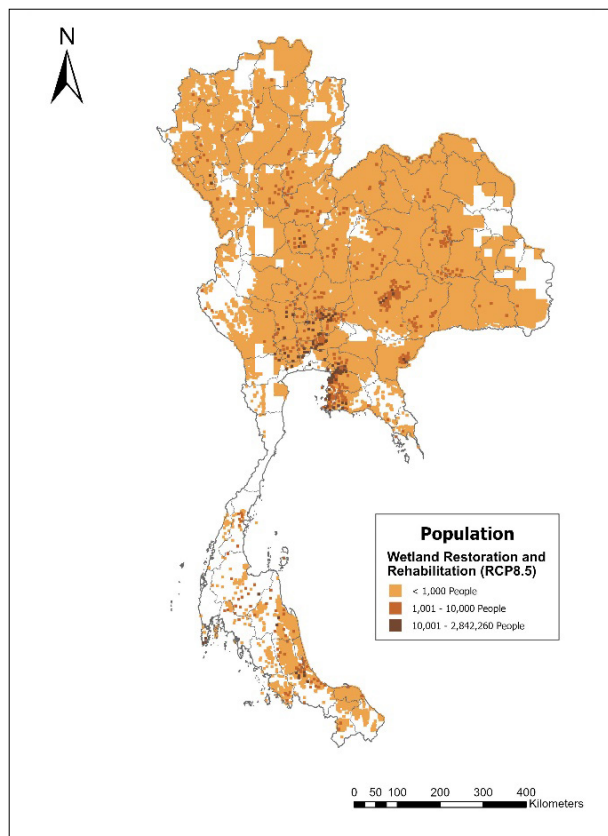


Figure 37: Benefit map of wetland restoration and rehabilitation for the population against future drought with the RCP 8.5 climate scenario



islands in Thailand (Chakriwat, 2024; Itiritiphan et al., 2020; Piyatadsananon & Salakkham, 2023). Moreover, as anticipated, Buddhist monks are spread all over the country. Still, most of the monks who will benefit the most from the expansion of green spaces are situated around the Bangkok metropolitan area.

Students

Figure 40 shows the benefit-cost ratio for two measures assessed concerning students. The ratio indicates the number of students shielded from

heatwave impacts per 1 USD invested in each measure. According to the modelling of impacts and associated costs, expanding green spaces offers a higher benefit ratio compared to installing green roofs. Like monks, the measures cannot cover the full heatwave risk, leaving around 1.5 million students unprotected under both climate scenarios. Again, the Thai authorities could explore other NbS options to increase the protection, as they keep showing the highest cost-effective potential for heatwave management.

Figure 41 further illustrates the number and geographical distribution of students who would benefit from expanded green spaces, with the majority located in the Bangkok metropolitan area, while in Chiang Mai and the Northeastern and Southern regions, the averted damage is less.

2.3.3 Result analysis

This section presents a comprehensive analysis of the climate risk experience in Thailand under the scope set for the study by participants of the different activities of ECA. The analysis covers flooding, drought, and heatwave exposure, as well as the expected impacts and adaptation options for the economic and non-economic assets selected. Where relevant, specific patterns in exposure and impact will be discussed and compared to provide deeper insights, enabling future action. It is important to note that this section should not be considered in isolation. A thorough understanding of the project’s results and the analysis derived from said results requires the reader to recognize the model limitations discussed in Chapter 2.1.2. As such, caution should be exercised when interpreting the findings within those constraints.

Overview of current and future climate risks

In Thailand, both economic and non-economic assets are highly exposed to flooding, drought, and heatwaves.

Figure 38: Benefit/cost ratio for adaptation measures for Buddhist monks impacted by heatwave

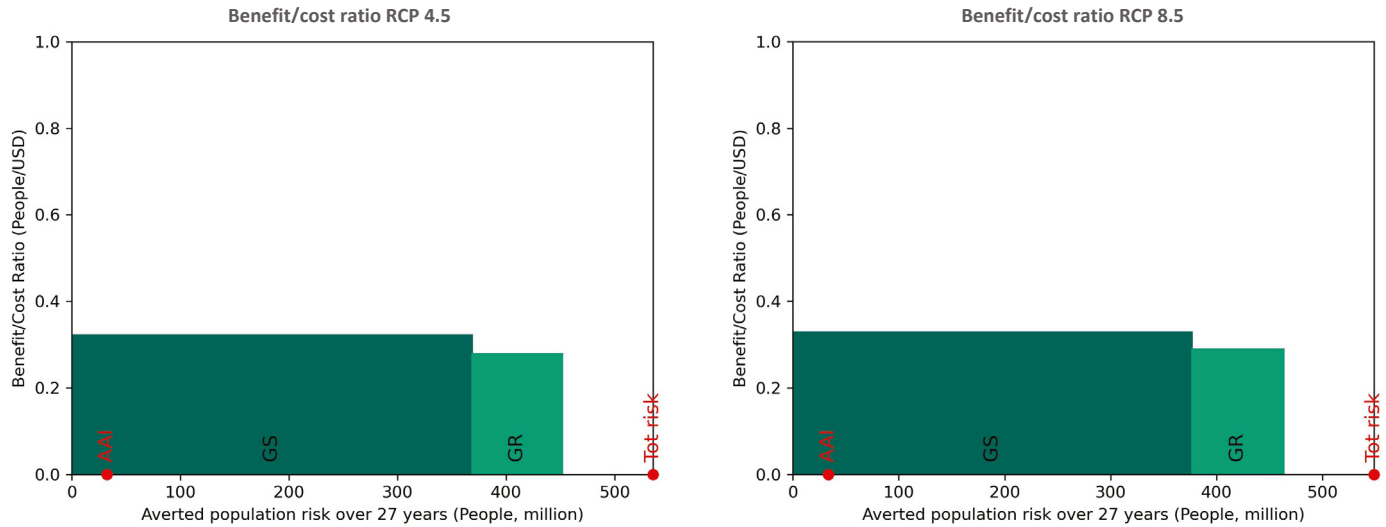
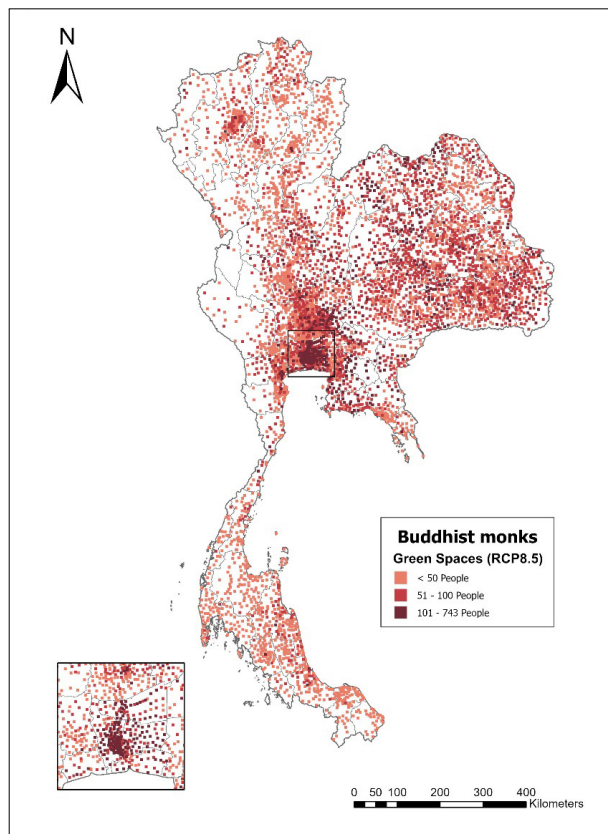


Figure 39: Benefit map of green spaces for Buddhist monks against future heatwave with the RCP 8.5 climate scenario



This reality is particularly present along the country's major river basins: the Mekong, Chi, Mun, and Chao Phraya, where much of the nation's agriculture and population is concentrated, thus exposing all associated with flood risks. In the Chao Phraya River Basin, whose terminus is occupied by the nation's capital and largest city, Bangkok, special attention is required. The Chao Phraya fills many roles in

Thailand, being the country's major manufacturing hub, agricultural heartland, and population centre (Singkran et al., 2019). While flooding is understood as the current and future hazard of greatest concern in Thailand (Satriagasa et al., 2023), the assets affected will always be somewhat limited by the natural geographic extent of flooding. However, both drought and heatwaves are not confined by the same geographic constraints. This lack of limits increases uncertainty in exposure and intensity, affecting wide swaths of both economic and non-economic assets in Thailand.

Droughts have a more widespread impact across the country, in contrast to floods, which are concentrated in the country's river basins. In addition, droughts are predicted to become more prevalent in Thailand despite projections of higher precipitation in parts of the country, with drier dry seasons in some provinces and significantly higher water demands (Kiguchi et al., 2021). The impacts of droughts are also expected in urban areas, such as Bangkok, where social inequalities can lead vulnerable communities to severe water stress, particularly in informal settlements (Danieri & Garschagen, 2019).

Heatwaves are like droughts in their reach across the territory. Their impacts are widespread but are especially felt in urban areas. In the Bangkok Metropolitan Area, for example, the temperatures are exacerbated by different factors such as limited green space, vehicle emissions, and general urban sprawl (Marks & Connell, 2023). Partly due to the rural-to-urban migration (Wuttisorn, 2014) and despite the overall decrease in the Thai population predicted by 2050 (United Nations Department of Economic and Social Affairs, 2024), the urban population is expected to continue increasing, adding further stress to an already strained system.

Figure 40: Benefit/cost ratio for adaptation measures for students impacted by heatwave

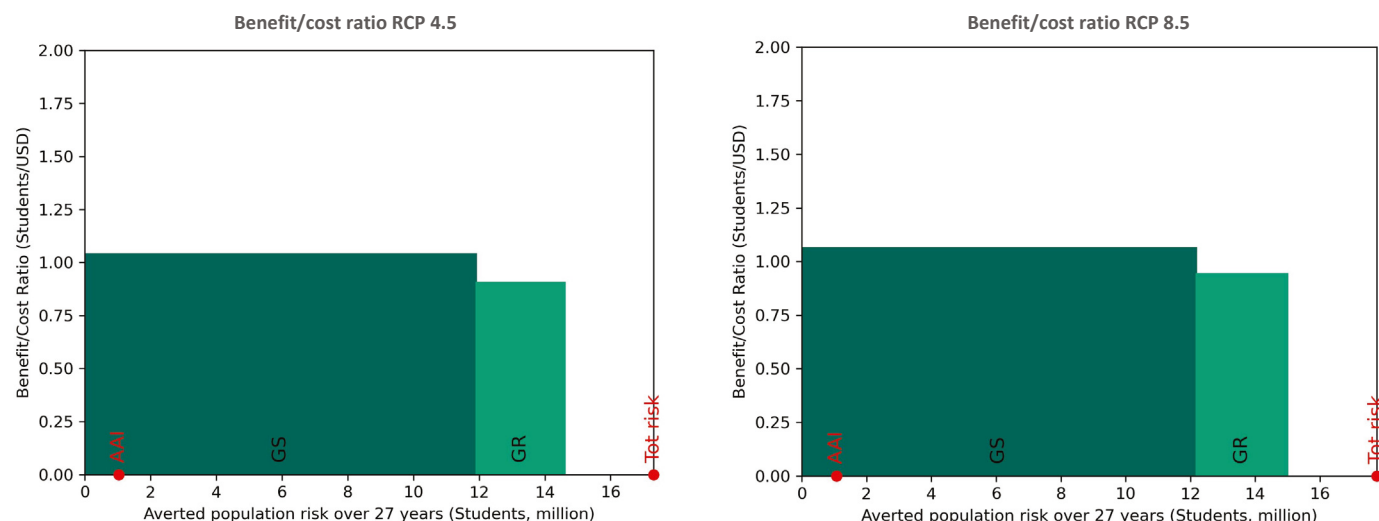
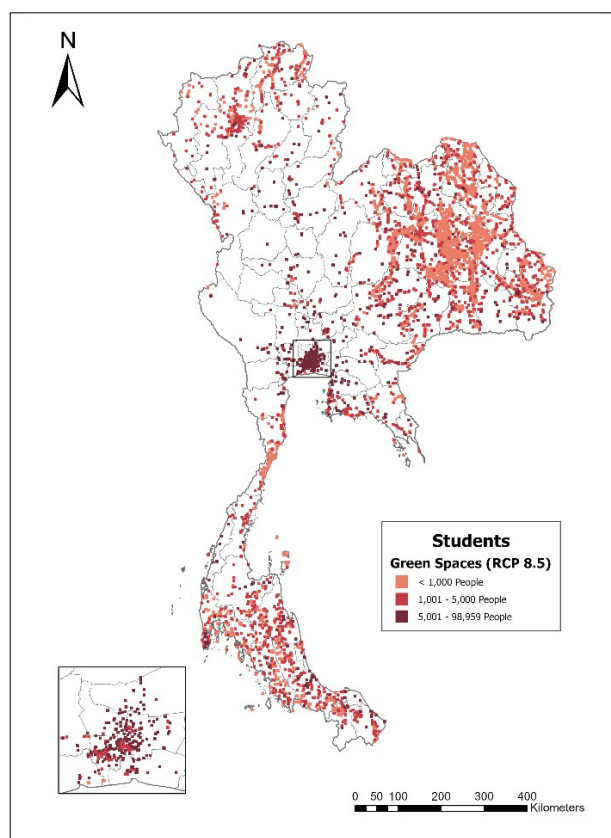


Figure 41: Benefit map of green spaces for students against future heatwave with the RCP 8.5 climate scenario



In Thailand, risk flood-prone areas are expected to grow in size and severity, with climate change contributing to greater impacts on affected populations (Arunyanart et al., 2017; Satriagasa et al., 2023). This situation worsens further since the most populated regions with the greatest density of agricultural output are in floodplains, thus facing significant negative effects on both non-economic and economic assets. Conversely, drought and

heatwaves are not confined by geographic conditions, and, as such, the predicted increase in severity will affect a much larger portion of the modelled assets, albeit to an arguably lesser degree, and, therefore, are often considered as a lesser priority (Kingdom of Thailand, 2024; Supratid & Aribarg, 2022). These two manifestations of exposure are evident in the modelled results and adaptation measures chosen. All three hazards are a clear threat to both economic and non-economic assets throughout the country, though to varying degrees depending upon the local context. Adaptation strategies must account for the more localized impacts of flooding and the more widespread threats posed by droughts and heatwaves to address these two distinct varieties of hazard impact.

Economic and non-economic assets

In Thailand, agricultural economic assets such as trees (i.e., durian and rubber) and grass (i.e., rice, sugarcane, and maize) crops are most exposed to flooding in the Chao Phraya, Chi, Mun, and Mekong River Basins. Grass crops are more widely distributed, with high concentrations in these areas, while tree crops are mainly cultivated in the northeastern (near the Laos border) and the southern regions. Farmers and their livelihoods are often confronted by floods due to this geographic concentration. Future drought conditions will also pose a significant risk to crop production, with the most severe impacts in regions already suffering from water scarcity, such as the upper Chao Phraya River (Lehner et al., 2011).

Non-economic assets, including students, road users, and diarrhoea cases, face varying risks depending on their geographic location. Again, the northeastern Isan region, especially near the Laos border, exhibits the highest exposure to flooding for students and diarrhoea cases due to poor infrastructure and higher

poverty levels. Road users are at significant risk in urban areas, particularly in the BMA, Chiang Mai, and densely populated regions in the Chao Phraya Basin. Buddhist monks, with their unique distribution patterns, show a slightly different exposure trend, being highly concentrated in urban areas like BMA and Chiang Mai but less affected west of the Chao Phraya and along the Myanmar border.

Adaptation options

Nature-based solutions and grey infrastructure measures offer the best cost-effectiveness ratios for floods in Thailand, with NbS being more effective for non-economic assets and grey infrastructure being more effective for economic assets. However, these measures alone are insufficient to cover the total predicted risk, with systemic measures playing an important role in addressing long-term vulnerabilities.

For drought adaptation, a combination of Green, Blue, and Grey Infrastructure, such as soil, water, and pest management, climate-smart agriculture, and water storage systems or distribution facilities, is effective in reducing risks for both economic and non-economic assets. The use of systemic measures and management of protected environmental areas is crucial to prevent severe drought impacts on farmers and counter unmet water demand in urban areas. While most regions experience drought to a moderate degree, reduced streamflow in the dry seasons increases drought risk in areas with high water demand (Kiguchi et al., 2021). The widespread area of effect requires the development of a comprehensive strategy to ensure that the appropriate adaptation measures are adopted in quantities and locations that can meet the varying needs of different regions.

Heatwaves present a unique challenge in Thailand, with limited adaptation measures currently in place that can protect vulnerable assets against this hazard. Green spaces and green roofs have been identified as

cost-effective solutions, though they are insufficient to cover the full risk. The southern region and the northeastern Isan region are particularly exposed to severe heatwave conditions, with large student populations and monks at higher risk. Additional adaptation measures are necessary to protect these vulnerable groups from future heat-related hazards.

Integrating hazard-specific results

Thailand's overlapping climate risks require an integrated adaptation strategy. While floods are more localized to river basins, droughts and heatwaves affect a wider range of assets across the country. Adaptation measures like green spaces and wetland restoration can address all three hazards with varying degrees of cost-effectiveness. However, due to scalability limitations, hazard-specific actions – such as canal dredging for floods, soil, water, and pest management for droughts, and green roofs for heatwaves – are needed to significantly reduce risks, even if they don't offer major co-benefits for other hazards. Additionally, while risk levels differ by region, it is crucial to balance investments to ensure all communities, including those in less populated northern and northeastern provinces, receive adequate protection from future hazards, even if their expected impacts are lower than in major urban areas.

Conclusion

Thailand faces significant challenges from flooding, droughts, and heatwaves. Economic assets, particularly crops and farmers, are concentrated in flood-prone river basins, while non-economic assets, such as students and road users, face varied exposure depending on location. A comprehensive and integrated strategy involving a combination of NbS, Grey, Green, and Systemic Infrastructure will be critical to building long-term resilience for both economic and non-economic assets across the country.



2019

2018

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ECONOMIC

3. Climate Resilient Economic Development (CRED)

Climate Resilient Economic Development (CRED) is a global program implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) to support long-term economic planning with considerations of the impacts of climate change and the benefits of adaptation measures. The approach is used to quantify the socioeconomic impacts of climate change and design specific adaptation measures as part of long-term strategies to mitigate climate change's economic and social risks (Banning et al., 2023).

The CRED program represents a strategic approach designed to address the economic impacts of climate change through innovative planning tools and modelling. The approach enhances the capability of countries to assess and plan for adaptation measures, promoting climate-resilient economic development. Resilient development is essential for mitigating the vulnerabilities faced by different economic sectors and ensuring sustained economic performance to secure income and employment opportunities in participating countries.

The CRED approach involves a multi-step process to integrate climate change considerations into economic planning effectively. In the initial stages, the approach utilizes data from global and/or region-specific climate models tailored to a partner country, in this case, Thailand. Consequently, the damages and potential effects of the adaptation measures are converted into monetary terms, leveraging national and international knowledge. By doing so, the impact of climate change and adaptation measures is best understood as improving long-term economic planning. The approach's emphasis on

sectoral and regional aggregation provides flexibility, accommodating the diverse needs of different countries (Banning et al., 2023).

For CRED, it is essential to incorporate climate data and sectoral model results into macroeconomic models to effectively map climate damages. It addresses the distinct natural and political contexts and data shortcomings of emerging economies for a thorough representation of the impacts of climate change on a range of socio-economic variables. Based on the data availability and existing modelling experience in a country, specific approaches are needed for each country. It considers various inputs covering climate modelling and cost-benefit analysis of different sector-specific adaptation measures (Banning et al., 2023).

The CRED approach supports Thailand in formulating climate-resilient development plans and strategies for economic growth. By establishing a structured framework for climate-resilient economic development, the program contributes to mitigating economic and social risks associated with climate change. This support not only aids in achieving national adaptation goals outlined in climate strategies and adaptation plans but also enhances competitiveness and fosters increased prosperity. Moreover, the CRED program fosters international collaboration and knowledge sharing, contributing to a global understanding and response to climate change. Overall, CRED's efforts are integral to developing robust, climate-resilient economies that can thrive amidst changing environmental conditions (GIZ, 2020, 2022).

3.1 Modelling approach

To support economically informed, climate-resilient decision-making in this project, we introduce a macroeconomic model, the Dynamic General Equilibrium Model for Climate Resilient Economic Development (DGE-CRED).

Dynamic general equilibrium models are complex macroeconomic frameworks that aim to capture the interactions between various economic actors

and sectors over time. These models are built on microeconomic foundations, modelling the large-scale behaviour and interactions of households, firms, and government. Dynamic general equilibrium models are usually characterized by their ability to account for intertemporal decision-making, expectations, and the dynamic evolution of economic variables.

Key features of dynamic equilibrium models include:

- ▶ Microeconomic foundations: The model is based on individual agents optimizing their outcomes.
- ▶ General equilibrium: The model accounts for interactions and feedback between different economic sectors.
- ▶ Dynamic structure: Conditions external to the model (such as frequency and intensity of disasters caused by natural hazards) are specified and can vary over time. Agents can make decisions based on their expectations of the future.
- ▶ Stochastic elements: The model can respond to random shocks and uncertainty.

Macroeconomic models such as this are particularly useful for policy analysis, as they can simultaneously

simulate the effects of various economic shocks or policy interventions on multiple macroeconomic variables.

The DGE-CRED is a model designed to simulate the economic response to the pressures of climate change and explore the benefits of adaptation strategies (Drygalla et al., 2021). The model is free and open source, meaning that its outputs can be inspected and validated by anyone, allowing for more transparent decision-making.

By employing a dynamic general equilibrium framework to model the Thai economy, policymakers can gain insights into the complex interactions between various economic factors, forecast potential outcomes of policy decisions, and develop more effective strategies for resilient economic growth and development.

3.2 Model structure

The DGE-CRED model was built so that it can be adapted to model-specific economies. The user chooses which economic sectors are of interest to their study based on their economic concerns and the data they have available, and they provide the macroeconomic parameters required to describe the economy's behaviour.

Following conversations with stakeholders and based on the available data, DGE-CRED was initialized to model five economic sectors: Agriculture, Energy, Manufacturing, Tourism, and Services. The DGE-CRED team chose appropriate values for the necessary macroeconomic parameters based on their knowledge of economic modelling, literature research, international economic datasets, and Thailand-specific datasets.

The effects of floods, drought, and heatwaves on the modelled economic sectors are described as follows:

- **Agriculture:** As described in the ECA modelling, both floods and drought affect agricultural output with different impacts on tree crops and grass crops. The impacts are combined across crop types to calculate the damage to the agricultural sector. In addition, the sector's capital productivity is affected by floods (due to 'business interruption' caused by infrastructure and asset damage). The impact on capital productivity from floods is assumed to be a percentage shock of the same size as the percentage shock to the sector's assets calculated by CLIMADA. It represents the time taken for a farm to get back to full operation after a flood. Finally, heatwaves are considered

to have an impact on labour productivity, increasing linearly with the length of the event since most agricultural work is outdoor work.

- **Energy:** Drought does not affect energy infrastructure in the modelling setup. Floods affect the energy sector as described in the ECA modelling. In addition, capital productivity loss (business interruption) is estimated using a functional relationship based on the calculated asset loss provided by the Hazus model (US Federal Emergency Management Agency [FEMA], 2024). Heatwaves are considered to have a small impact on labour productivity, increasing linearly with the length of the event.
- **Manufacturing:** Drought does not affect manufacturing in the modelling setup. The effects of the flood on the sector were estimated using the CLIMADA model, combining the ISIMIP flood data used in the ECA study with a global dataset of estimated manufacturing sites based on emission intensity (NCCS-Impacts programme, 2025). As mentioned above, capital productivity loss (business interruption) from flood was calculated using the Hazus relationships. Heatwaves are considered to have a small impact on labour productivity, increasing linearly with the length of the event.
- **Tourism:** Drought does not affect tourism in the modelling setup. Floods affect tourism as described in the ECA modelling. As mentioned above, capital productivity loss (business interruption) from flood was estimated using

the Hazus relationships. Heatwaves are considered to have a small impact on labour productivity, increasing linearly with the length of the event.

- **Services:** Drought does not affect the service sector in the modelling setup. The effects of the flood on the sector were estimated using the CLIMADA model, combining the ISIMIP flood data used in the ECA study with the LitPop global dataset of estimated economic exposure based on population and night light data (Eberenz et al., 2020), which was assumed to have a similar spatial distribution to activities in the service sector. As mentioned above,

capital productivity (business interruption) loss was calculated using the Hazus relationships. Heatwaves were considered to have a small impact on labour productivity, increasing linearly with the length of the event.

- **Housing:** While not an economic sector, DGE-CRED also models housing stock. We allow shocks to housing based on CLIMADA simulations with the ISIMIP flood data and CLIMADA’s population data. Housing is unaffected by drought and heatwaves.

Table 5 presents the key features of the CRED approach with the DGE-CRED model in Thailand.

Table 5: Key features of CRED in Thailand

Features	Description
Available data	<ul style="list-style-type: none"> • Macroeconomic and sectoral data • Labor market data (employment, wages, labour force) • Limited availability for data for climate scenarios, damage data, and CBA of adaptation options • Impact data for disasters in selected hazards and climate scenarios, with impacts offset by adaptation options
Regionalization	<ul style="list-style-type: none"> • Adapted with • Thailand’s economic data, without subregions
Model type	<ul style="list-style-type: none"> • DGE-CRED model
Modelled economic sectors	<ul style="list-style-type: none"> • Agriculture (tree and grass crops) • Energy • Manufacturing • Tourism • Services
Modelling specifics	<p>Macroeconomic dynamic general equilibrium model</p> <ul style="list-style-type: none"> • Originally implemented in MATLAB with Dynare, it can also be run with the open-source alternative Octave. • Wrapped in Python for this project, allowing the model to be called part of a CLIMADA analysis • A simulation model with a mid-to-long-term perspective (until 2050)
Quantified climate change impacts	<ul style="list-style-type: none"> • Drought: impacts on tree and grass crops • Floods: impacts on housing, economic assets in all sectors, and economic productivity in all sectors • Heatwaves: impacts on labour productivity across all sectors
Evaluated adaptation measures	<ul style="list-style-type: none"> • Modelling the economic effects of different percentage levels of adaptation

The modelled economy is shocked by heatwaves, droughts, and floods described in the ECA study between the present day and 2050. Since we don't know exactly when heatwaves and floods will occur, a probabilistic approach was taken to explore the shocks to the economy. The DGE-CRED model was run repeatedly to simulate the period 2014 to 2050 for scenarios with no climate change (historical), an intermediate-emission scenario (RCP 4.5), and a high-emission scenario (RCP 8.5), consistent with the ECA modelling. For years after 2024, each model run was shocked by a different series of disasters caused by natural hazards consistent with the climate change scenario. The disasters were generated by sampling from the return-period impacts simulated for each sector (see below for how impacts were simulated). That is, one in every hundred simulated years would have a 100-year return-period shock, meaning that such a large event would only occur in about a quarter of simulations (since each simulation looks 25 years into the future). Most years in the simulated futures have small or no shocks, with occasional large or very large shocks.

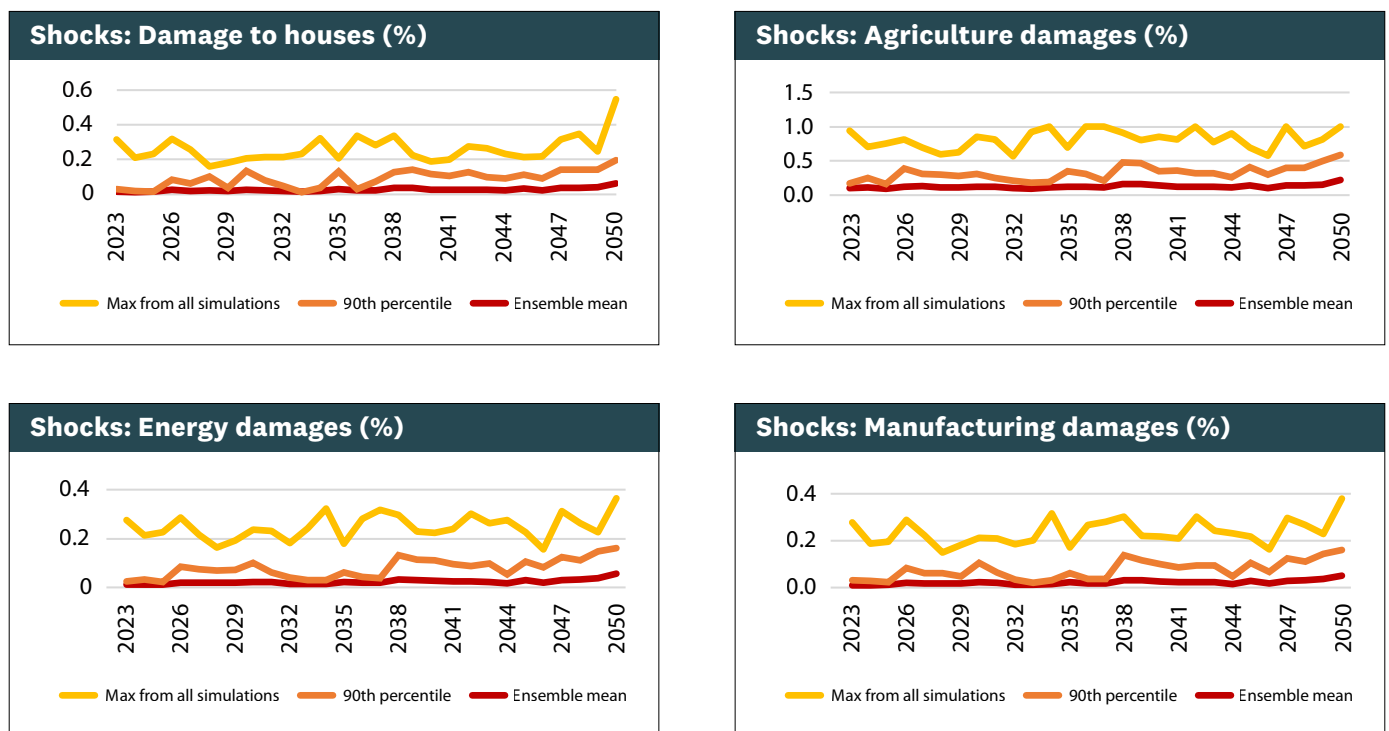
Since the frequency and intensity of impacts increase with climate change, the likelihood of more damaging events also increases towards 2050. This effect was achieved by simulating a year-by-year transition between historical hazards and future hazards: in 2014, every event was sampled from the historical

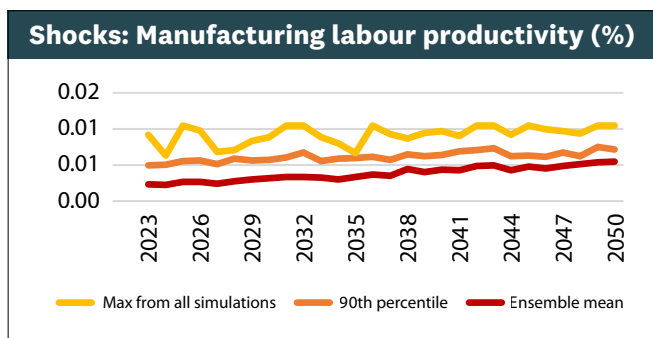
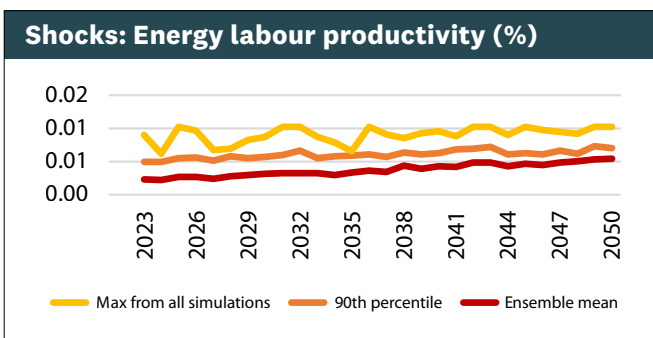
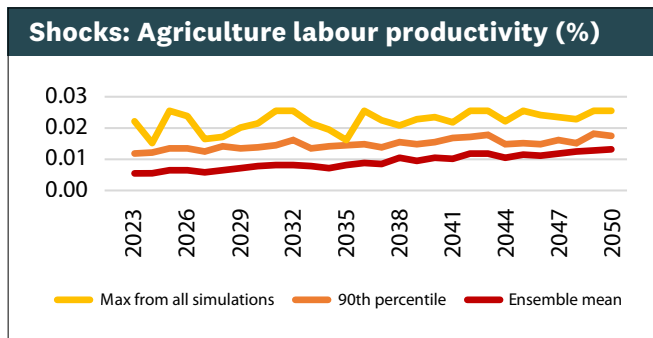
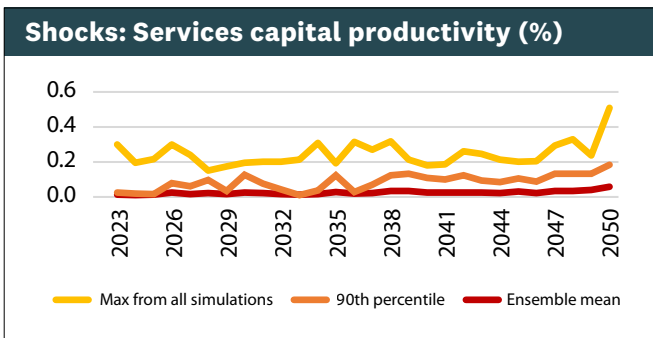
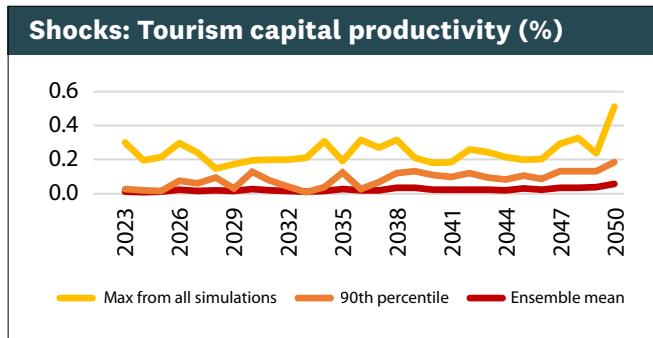
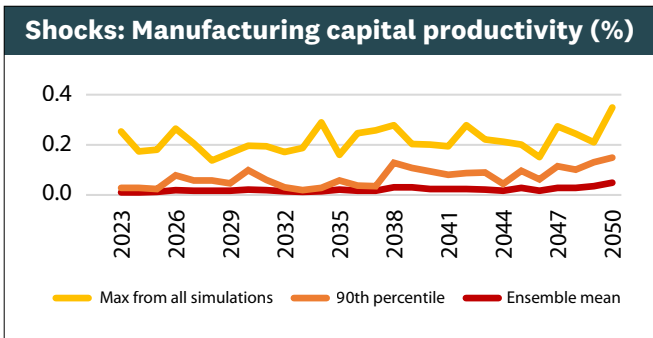
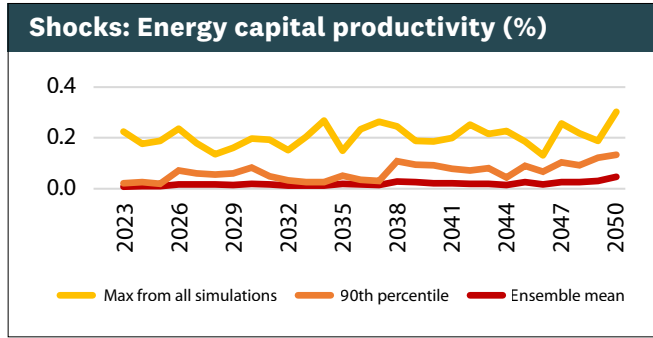
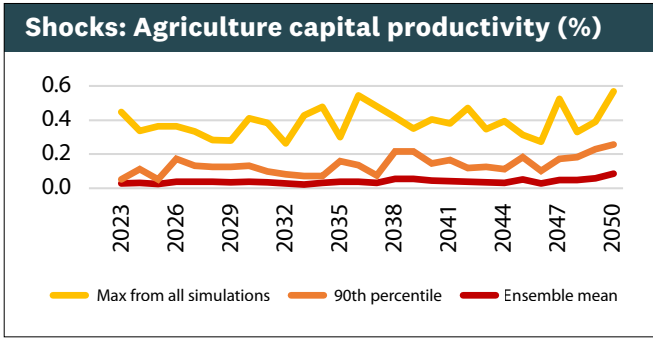
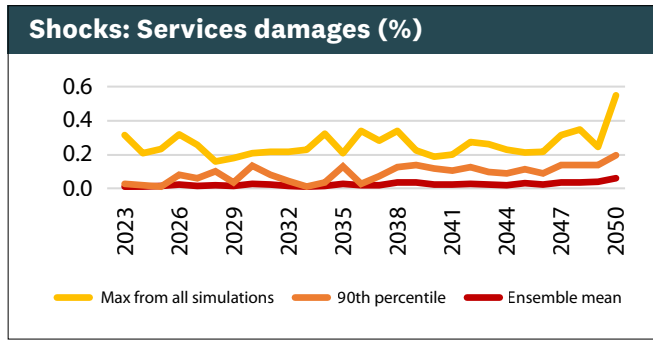
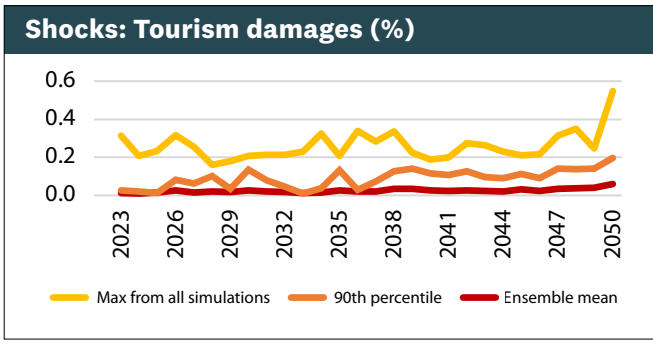
return-period data. By 2050, every event will have been sampled from the 2050 return period data. For the years in between, the sampling transitions smoothly from historical to future risk.

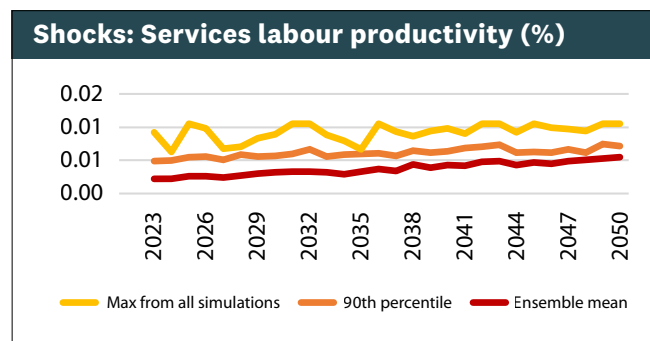
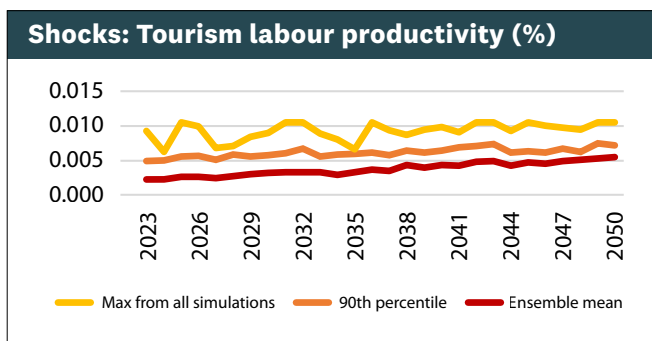
By constructing many plausible timelines for future disasters and simulating each of them with the DGE-CRED model, it is possible to explore the damage that disasters are likely to have on the Thai economy. In each simulated economic sector, shocks are applied to the asset values, capital productivity, and labour productivity following the methods described above. Then, by averaging across the many simulations, it is possible to find the average expected effect on the economy.

An example of the scale and frequency of input shocks used in DGE-CRED is plotted in Figure 42. The shocks are from combined droughts, heatwaves, and floods and are modelled together since their effects on the economy compound. The plot shows the maximum value, the 90th percentile, and the mean value from *all* simulated timelines. The red line indicates the mean size of the shocks. While individual shocks can be quite large, the mean values are much smaller than some individual shocks because larger impacts are rare, and the impacts of climate-related disasters are small in most years of most simulations. The mean shock gradually increases over the simulation period since climate change slowly increases the frequency and intensity of the hazard.

Figure 42: External forcing to DEG-CRED ensemble simulations: the RCP 8.5 scenario







3.3 Modelling limitations

Macroeconomic modelling is inherently complex, requiring numerous assumptions and expert judgments. Simplifying a country's economy into a series of mathematical processes often overlooks important subtleties and potentially critical dynamics. This challenge becomes particularly pronounced when the model is used to analyze an economy's response to significant, and potentially unprecedented, economic shocks.

In interpreting the results of the DGE-CRED model, it is essential to recognize that it is a representation of a complex economic system rather than a perfect replication. As with any model, it is a simplification aimed at providing insights into the system's behaviour.

A critical step in utilizing the model effectively is to acknowledge its key limitations and understand how these constraints might influence the interpretation of its results. Such awareness is crucial for drawing robust and actionable conclusions from the analysis.

Assumptions based on economics and politics

The processes described in DGE-CRED are one valid representation of how the economy works: interacting decisions made by households, businesses, and governments governed by rules specified by economists.

It is nevertheless a simplification that will miss complex processes, including, potentially, important feedback that could lead to large changes in the economy. The rules that describe the model are based on current economic theory and the political opinions encoded within it. The model, therefore, reflects a particular understanding of the economy.

Model uncertainty

CRED describes many economic processes and includes many parameters describing rates, weights,

and constants. Each of these affects how the modelled economy functions. The training data used for these parameters has some limitations. First, it is often very limited, meaning that some parameters are hard to estimate. Second, national economies change constantly, and data from previous years may not represent the economic reality today (or in the future). The model results will always have a measure of uncertainty because of this.

The study here does not attempt to quantify the uncertainty from these parameter selections, to quantify uncertainty in the effects of future climate change (except for comparing different climate change scenarios) or uncertainty in the direct impacts of disasters (as calculated in the ECA phase). Since these are all significant sources of uncertainty, it is important to remember that the economic simulations are also uncertain. It is therefore important to think of these results as indicative: they give a sense of the kind of impacts possible from climate change, not a numerically precise forecast.

When a plot shows “uncertainty” from the DGE-CRED outputs, the uncertainty comes entirely from representing disasters as randomly occurring processes within the model: from running the model many times with different disasters occurring at different times in different runs.

Limits of an equilibrium model

Perhaps the most significant theoretical limitation of DGE-CRED comes from the nature of Dynamic General Equilibrium models. It considers the economy as a series of processes that are constantly adjusting and feeding back on each other. While this is a useful way to describe a slowly changing economy, it is not always appropriate for an economy experiencing sudden shocks, such as from disasters.

DGE-CRED was originally designed to model an economy's responses to the pressures from slow-onset climate impacts, such as changes to crop yield

or labour productivity. In this study, we see how acute climate shocks – through extreme weather – affect the economy.

Economic responses to sudden shocks are much harder to model, and the study decides to stick with the assumptions inherent in general equilibrium modelling. It assumes that every shock to the economy can be absorbed as part of the modelled equilibrium. Some disasters will have enormous structural changes on an economy. Therefore, the actual impacts of disasters on the economy could be more serious and long-lasting than those of simulations.

Perfect foresight

CRED models the economy as a collection of agents (government, businesses, and households) who make decisions, such as how much and what to invest in, how much to work, etc. To make decisions, these agents need to know about the economic reality around them. And to model decisions about climate change, they need some sense of the future impacts of climate change.

This assumption was useful when the future impacts of climate change were modelled as slow onset, but it leads to some odd behaviour when these impacts come through large economic shocks. We see agents start to prepare for *specific* disasters in the years before they strike, which means the impacts of disasters are not as great as they perhaps should be. This condition is clearest in the results for Housing, where we see construction in advance of floods.

The developers of DGE-CRED advise that this can still be thought of as a valid and useful economic process in the model: humans know that climate change is an increasing risk to the economy, and individuals, businesses, and governments will all take preparatory action outside of the adaptation measures specified in the study.

How do we interpret the “positive” impacts of disasters?

Consider the effect of disasters on the construction sector: destruction is very good for construction, and the sector often experiences a boom after a disaster hits, when everything is rebuilt. The corresponding increase in GDP due to this doesn't mean that a disaster is “good” for the economy, and it doesn't reduce its impacts. We can't consider sectors without the larger societal context.

Similarly, in DGE-CRED, some metrics respond “well” to disasters. These can be explained as side effects of loss. For example, if a disaster reduces an industry's ability to operate, the industry may expand, or more people may work longer hours to meet the previous demand. This behaviour shows up in the model as an increase in employment and even GDP but doesn't reflect an increase in quality of life for the people working. Indeed, modelled salaries often drop. GDP and employment are not measures of well-being. We recommend paying attention to the “consumption” indicator that CRED produces. This indicator can be thought of as the available income for households for discretionary spending, something that is necessary for a good quality of life in the economic system and one possible indicator for quality of life.

3.4 Modelling outputs

Floods, droughts, and heatwaves are expected to affect the Thai economy significantly between now and 2050. The plots in this section show how these modelled effects evolve. Each plot shows three climate scenarios: historical, “moderate” climate change (corresponding to the RCP 2.6 scenario for heatwaves and the RCP 4.5 scenario for floods and drought), and “strong” climate change, corresponding to the RCP 8.5 scenario.

Each line in this section's plots shows the mean simulated values from 100 individual model runs, plotted relative to a baseline simulation for a hypothetical economy that wasn't affected by disasters caused by natural hazards. This approach allows us to see how differently an economy evolves due to the shocks of disasters. Taking the mean across many simulations averages out the noise of 100

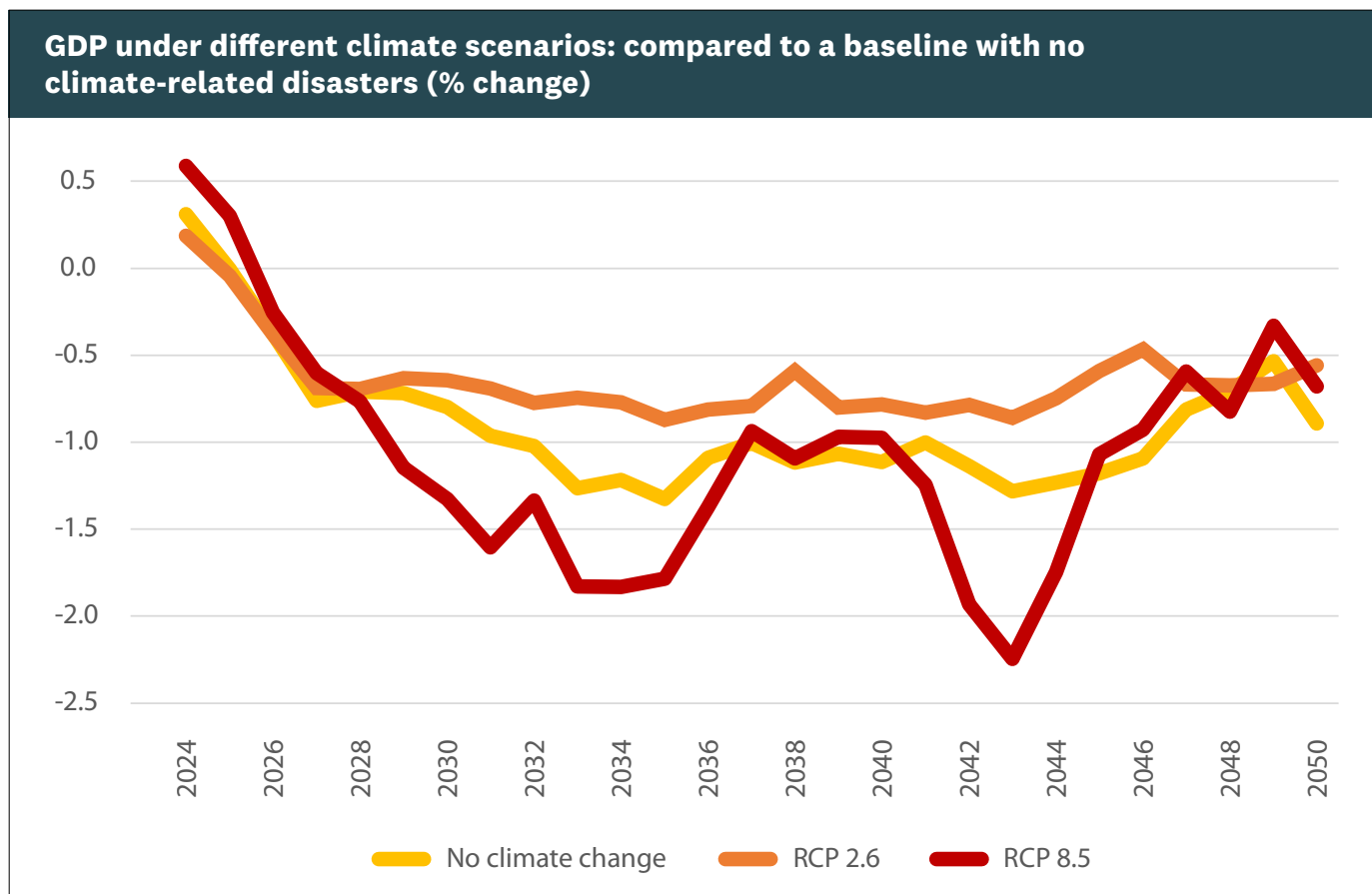
different model runs, each shocking the economy by different amounts in other years.

We plot the economic variables relative to the baseline to isolate the impacts of disasters on the Thai economy from the simulated growth between now and 2050. The following plots do not show the economy shrinking; they show how much smaller the simulated modelled economy is because of heatwaves, drought, and floods.

National GDP projections

Figure 43 shows the timelines of the mean simulated GDP for each climate scenario, averaged across all 100 DGE-CRED simulations, relative to a baseline simulation where the economy was simulated without any disasters.

Figure 43: GDP under different climate scenarios (% change)



The historical scenario shows the impact that disasters would have on the Thai economy without considering the effects of climate change. The two climate change scenarios show how this risk is exacerbated over time, increasing many times over for the RCP 8.5 scenario by 2050.

The key result here is that the economic impacts of disasters extend beyond simple asset damage and business interruption. The impacts here are felt across the entire economy and can potentially be felt years after an event.

While the percentage changes are small, it is important to remember that a 1 per cent impact on an economy with a GDP of USD 500 bn is a loss of USD 5 bn in annual economic activity. As the Thai economy grows beyond 2024, this becomes even larger.

Note that the modelled values here should be taken as indicative. The limited historical data used to train the model means that historically simulated floods likely underestimate the present-day risks. Since the likely impacts of very extreme events (rarer than about 100 years) are unknown, they were excluded from the modelling. That is, we do not include the most catastrophic events in this simulation.

Sectoral GDP projections

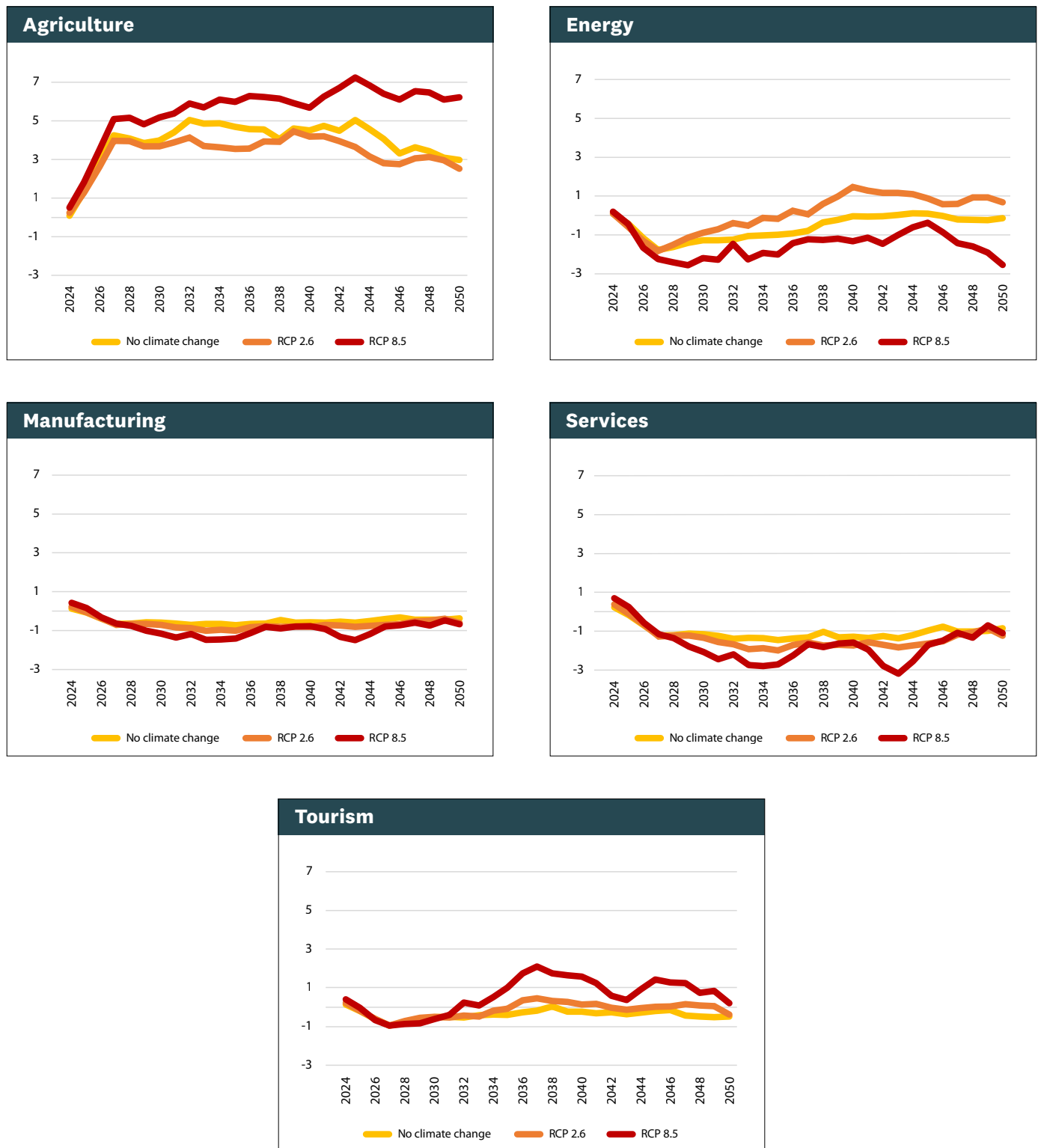
Examining individual economic sectors lets us look at the relative impacts on agriculture, energy, manufacturing, tourism, and the service sector. Figure 44 presents these results.

The GDP projections for the manufacturing and services sectors are very similar to the overall national GDP projections above. In each of these sectors, climate change causes a reduction in economic activity of between 1 and 3 per cent, which will be sustained until 2050. Each of these sectors sees a clear, negative effect from climate change, with the effect stronger in less optimistic climate scenarios.

The signal is less clear in the agriculture, energy, and tourism sectors, where some or all climate scenarios see a *positive* change in GDP relative to the baseline. This rise in GDP presumes a quick and effective response when addressing the impacts of the disasters, leading to temporary employment and significant investments in recovery. However, such presumption is not always the case and should be considered for risk management plans.

Although a positive impact on GDP might seem counterintuitive—especially given that the agricultural sector is heavily affected by all three modelled

Figure 44: Sectoral GDP under climate change scenarios (% change)

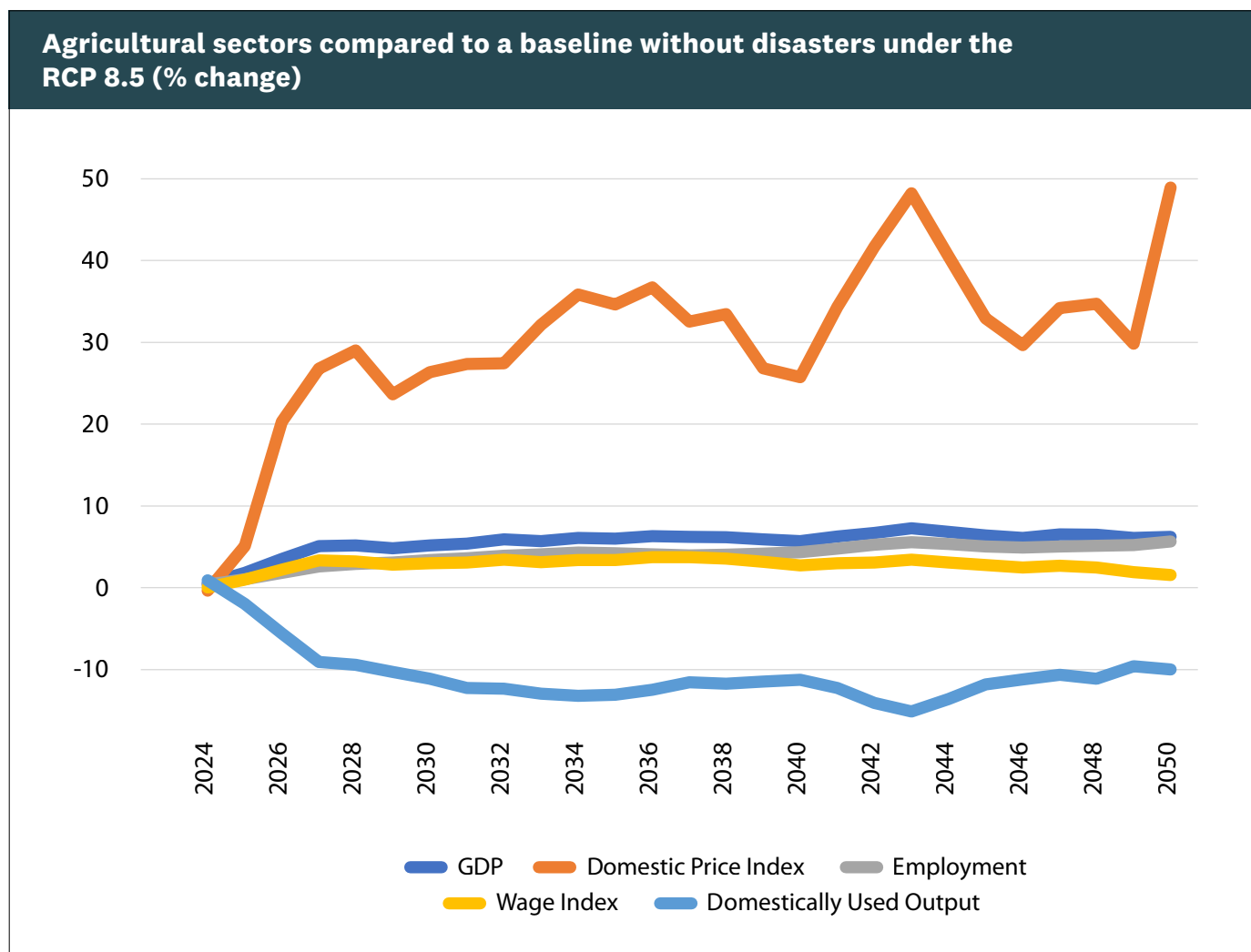


disasters (floods and droughts damage crops and farm infrastructure, while heatwaves reduce labour productivity due to outdoor work)—it’s important to remember that an increase in GDP alone is not always beneficial and does not necessarily reflect a healthier economy. That is the case here. The result can be better understood by looking at other economic variables that the DGE-CRED model simulates in Figure 45.

Consumption projections

GDP is not always a reliable indicator of economic well-being. The DGE-CRED team recommends looking at the Consumption variable as a well-being indicator. It represents the amount of money spent by households and indicates the resources available to individual members of the population. Higher

Figure 45: Agricultural sectors compared to a baseline without disasters under the RCP 8.5 (% change)



consumption means that people have more of their wage left over after the cost of living and, therefore, have more economic choices available to them and can participate in the economy more actively, resulting in a higher quality of life. Lower consumption means that people’s wages are only just enough to pay for the cost of living, resulting in a lower quality of life.

Figure 46 shows the mean modelled change in consumption over time in different climate scenarios. The signal here is clear and strong: the pressure on the economy from drought, heatwaves, and floods results in a strong reduction in the resources available to individuals. This reduction is especially strong in the stronger climate change scenario, reaching a 10 per cent reduction in household consumption by 2050.

Adaptation

The DGE-CRED simulations were repeated with the same shocks from disasters but simulating different levels of climate adaptation in the economy. In these

simulations, adaptation was assumed to start in 2030, and levels were set to give 33 per cent and 67 per cent protection from the direct impacts of disasters. Adaptation was assumed to apply equally to flood, drought, and heat. Figure 47 shows the projected effects of adaptation on GDP and consumption in the RCP8.5 scenario. Other climate scenarios and adaptation levels are not shown here: the effects are very similar in all scenarios, with higher adaptation offering higher protection. The benefits are the largest in the RCP8.5 scenario since the economic shocks to be protected against are larger and more frequent. Therefore, the RCP8.5 scenario is shown here.

In the simulations, adaptations were assumed to come into force in 2030, although the phase-in will be more gradual. The effects on the economy are visible almost immediately: for both GDP and consumption, there is a big change between 2030 and about 2035 as the simulated economies experience smaller average shocks from disasters. The change in GDP is up to 1 per cent and is most strongly observed when the unprotected

Figure 46: Consumption under different climate change scenarios (% change)

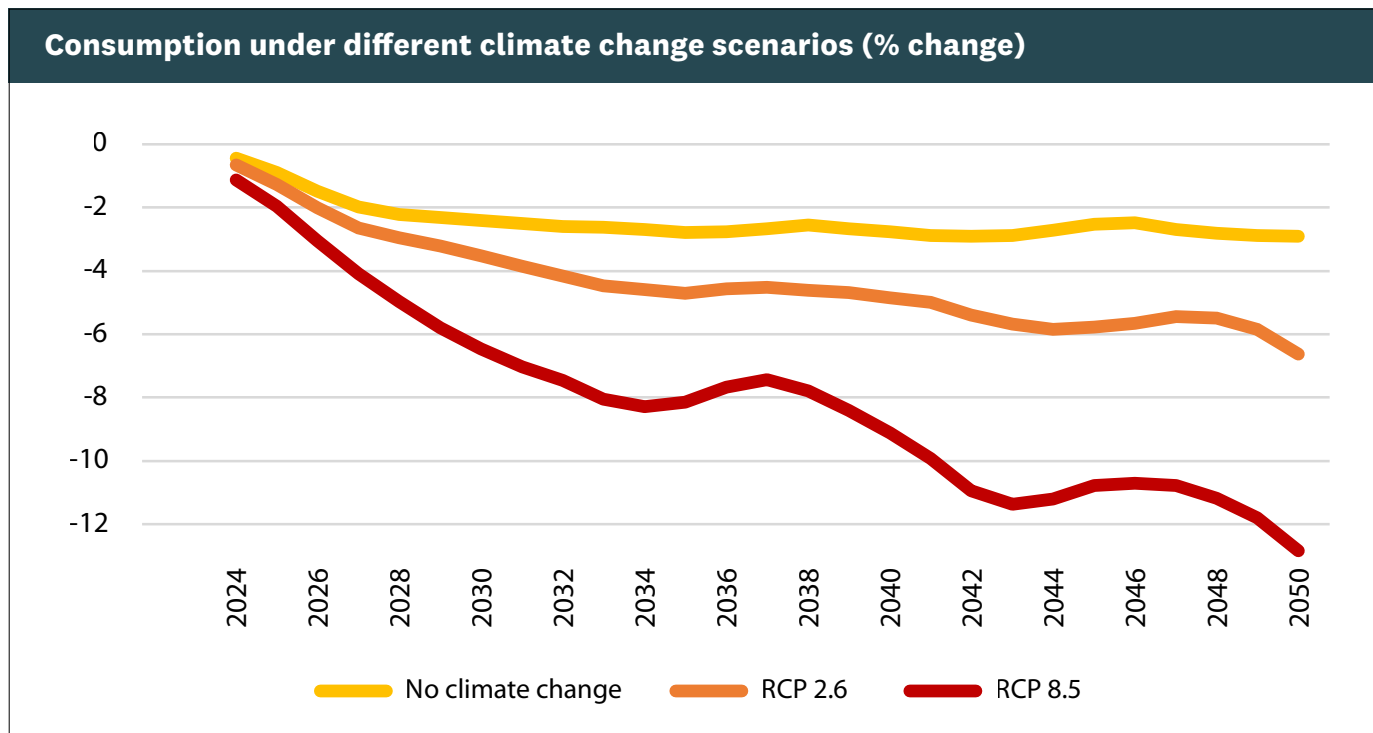
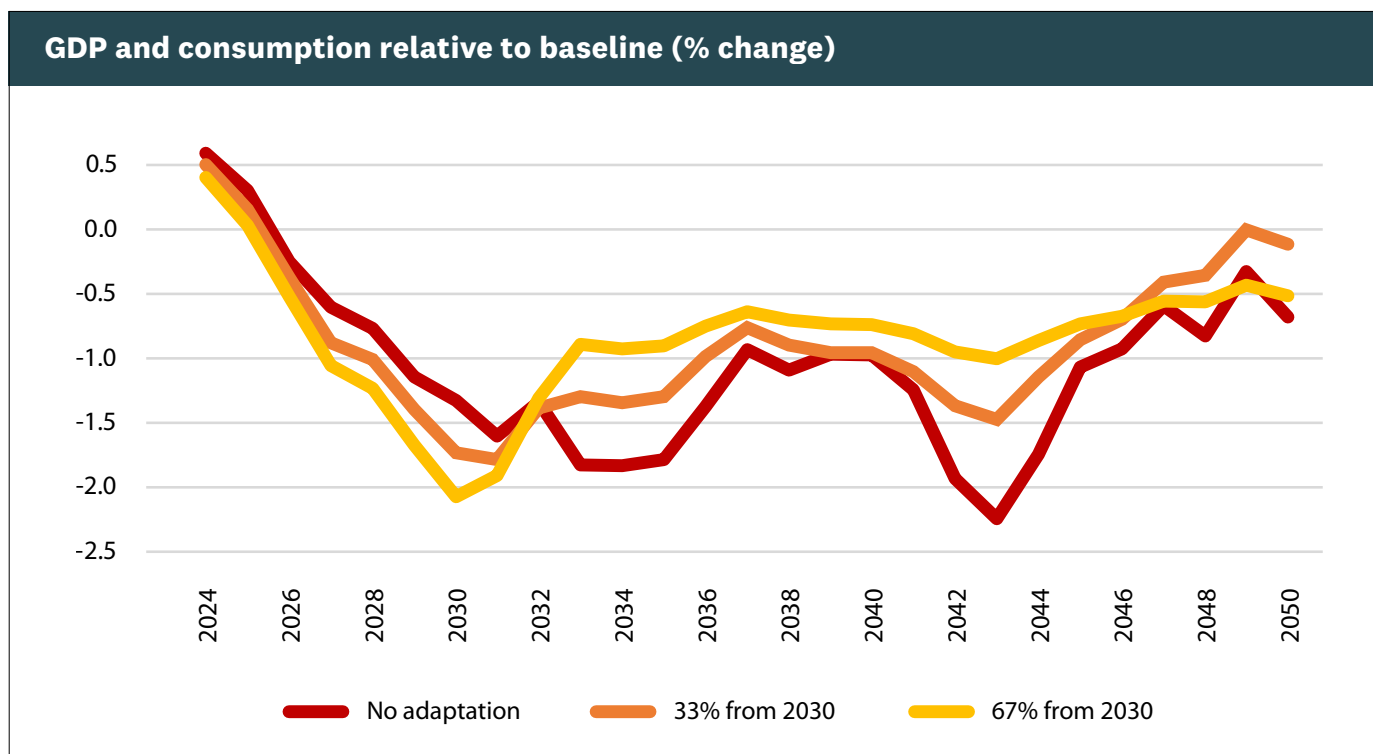


Figure 47: GDP and consumption relative to baseline (% change)



simulations are experiencing worse impacts from catastrophes. The economy with adaptation measures is, therefore, much more resilient. The adaptation measures also serve to reduce the negative effects in other parts of the economy: wage decreases are less, agriculture production is higher, and food prices are lower (not shown).

The effect is most clear in the Consumption variable. With no adaptation, conditions continue to get worse for the average household. With a 67 per cent adaptation, the simulated decline in consumption is stopped.

The plot also demonstrates the importance of early adaptation. In this experiment, climate adaptation

is “switched on” in 2030. If it is introduced later, the negative effects on GDP and consumption before that date will be larger, and it will take longer for the

economy to recover. If adaptation is introduced earlier, the negative effects of climate change are smaller, and the economy can grow faster.

3.5 Results summary

The economy is a complex system, and it is important to understand how it may be affected by disasters in the future. From the project’s ECA modelling, we understand the present and future intensities of floods, drought, and heatwaves in Thailand and how they affect businesses, economic assets, and humans.

The DGE-CRED model allows us to explore the impacts of these hazards on the Thai economy. By running many simulations, each with a different, plausible future timeline of disasters, we can look at the average impacts of these events on the economy under different climate change scenarios.

The DGE-CRED model projections show that natural hazards don’t just affect individual people and businesses: there are significant, persistent, growing impacts on the Thai economy from now to 2050. The impacts compound over time, are worse in stronger climate change scenarios, and are felt in all the modelled economic sectors. By looking at the modelled variable of consumption, which can be taken as an indicator of well-being, we see that the effects on the economy from disasters also strongly impact the population, reducing the funds available to individual households, their consumer choice, their spending, and ultimately their quality of life. Adding climate adaptation measures to the model is an effective way to reduce the modelled impact on the economy. The economic effects of climate adaptation

are visible in the average modelled economy within a few years of introducing the measures and implementing a 67 per cent adaptation level reduces the impacts of disasters on the economy by about 50 per cent in the coming decades.

While the effects on the economy from the modelled events are of the order of a percentage, this is huge in a USD 500 bn economy that is predicted to grow enormously in the next few decades. For sustainable, resilient growth, the impacts of disasters must be reduced since they threaten the rate at which the economy is able to expand. Investment in earlier adaptation is also crucial, as the compounding effects of disaster loss affect economic growth for years after.

The results from DGE-CRED are not an economic forecast. Dynamic general equilibrium models are simplified versions of the complex economic system with accompanying assumptions. The uncertainty from this modelling is represented in the results here. DGE-CRED is likely to underestimate the risks to the Thai economy from climate change: the assumption of economic equilibrium means that most disruptive disasters do not have the massive, system-wide impacts seen in the largest disasters worldwide. Similarly, the short historical period of our modelled hazard data means we underrepresent the largest possible events and, therefore, the largest impacts. See the earlier limitations sections for a full discussion.

4. Graphical User Interface

As described in [Chapter 1](#), the ERA project incorporated a graphical user interface (GUI) to give stakeholders a deeper understanding, autonomy, and ease in exploring the project result. The GUI is named RISK WISE, representing the purpose of the GUI, which is to understand RISK better and support decision-makers in developing WISE policies based on the risk assessment done utilizing the Economics of Climate Adaptation (ECA) framework. This chapter will describe the GUI through a detailed explanation of data input and output for RISK WISE, who can benefit from it, and its limitations.

A GUI is a user interface supporting the interaction between people and machines, such as computers,

tablets, and other devices. A GUI aims to reproduce the code in the backend of a system to be as user-friendly as possible, simplifying its application. It often utilizes symbols and images as they can be understood universally to enable users to communicate with the operating system. Elements of a standard GUI consist of buttons, drop-down menus, navigation fields, search fields, entry fields, text fields, frames, windows, etc. (IONOS, 2020). GUI developers combine visual design with programming functions, prioritizing user-friendliness. Without a GUI, people must master coding languages to type instructions into the command line and thus tell the system what to do.

4.1 Data input

There are two types of data input in developing RISK WISE. The first one is the design and functionality of the GUI itself. It was the first step the GIZ colleague took, taking inspiration from the user interface built by the European Insurance and Occupational Pensions Authority (EIOPA). They created the CLIMADA App, with SWORD Services Greece as the GUI developer, which we also worked with in this project, as an easy-to-use open-source tool powered by CLIMADA for catastrophic modelling⁴. However, the functionality was adapted to the ERA approach, which covers the full impact assessment and cost-benefit analysis we conducted for

all assets and hazards within the project's scope. The second one, as shown in [Figure 1](#) in [Chapter 1.2](#), is the data input displayed in the GUI. All inputs were taken from the modelling inputs explained in [Chapter 2.2](#). [Table 6](#) presents the features offered by RISK WISE.

The tool only runs for one type of selected asset at a time. After all the input parameters are specified, the user clicks the "RUN" button to show the results in [Figure 48](#), which will be explained in the next subchapter.

Table 6: Key features of the GUI in Thailand

Feature	Description
Country	Thailand or Egypt
Hazard	Selected hazard for the study
Scenario	Climate hazard scenarios such as RCP 2.6/RCP 4.5/the RCP 8.5
Time horizon	Fixed from 2024-2050
Exposure of economic assets	selected assets for the study
Exposure of non-economic assets	Selected assets for the study
Annual growth	Fixed input based on economic or non-economic assets selected

⁴ For more information visit: https://www.eiopa.europa.eu/tools-and-data/open-source-tools-modelling-and-management-climate-change-risks_en

Figure 48: Input parameter and selection in RISK WISE

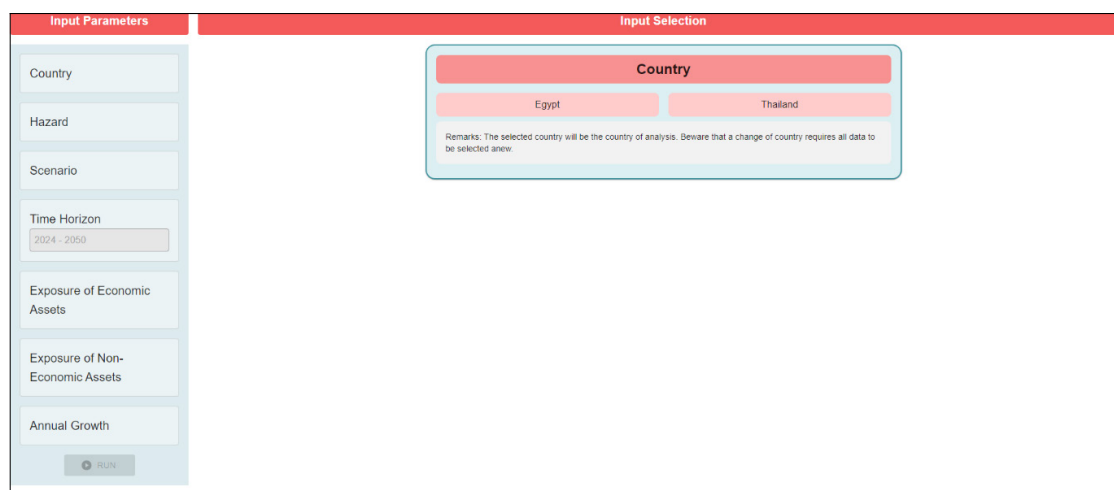


Figure 49: RISK WISE top ribbon



4.2 Data output

Users can navigate several results from the top ribbon of RISK WISE (Figure 49). There are four tabs below the title, from left to right: Parameters, Economic & Non-Economic, Macroeconomic, and Outputs (Reporting). When the Economic and Non-Economic tab is selected, there are additional tabs, i.e., Risk and Adaptation. On the right side, you will also find two red buttons, “+ Add to Output” and “+ Save Map/Chart”, that are useful for capturing Outputs (Reporting). The Parameters tab is for selecting the input parameters that have been explained before. The results from the other tabs will be explained further.

The results are shown in the middle of the page, in the result box, under the Risk tab of the economic and non-economic groups. There are two types of results, which are “Display Map” and “Display Chart”. This figure can be selected below the result box. When “Display Map” is selected, there is a choice to show either Hazard, Values, or Impact maps, which can be selected on the red button on the right side of the page. Users can get more information about the maps or charts on display from the “Result Details” box on the right side of the page. The hazard maps present the hazard intensity for different return periods (for example, RP10, RP25, RP50, RP75, or RP100). Asset values maps present the total assets grouped by total country (ADMIN0), provinces (ADMIN1), or districts (ADMIN2). Impact maps present the total impacted value of assets based on different hazard intensities.

For example, Figure 50, Figure 51, and Figure 52 show the Flood Hazard map with a 10-year return period (RP10), the Wet markets' Economic Asset Values map in billion USD grouped by the second administrative level in Thailand (Provinces), and the Grass Crop's Impact map in for 10-year flood hazard return period.

When “Display Chart” is selected, an impact chart will be shown in the centre. The four bars indicate, from left to right, the total risk in the current year (2024), the increase/decrease of risk due to economic development or population growth, the increase of risk due to climate change, and the total future risk (2050) based on the selected climate hazard scenario. For example, Figure 53 shows the impact chart for grass crops against floods with the RCP 8.5 climate scenario in millions of USD.

Another important result in RISK WISE is the benefit/cost analysis of adaptation measures. This figure is available under the “Adaptation” tab under the “Economic and Non-Economic” tab (see Figure 49). The chart presents short-listed adaptation measures, previously discussed in Chapter 2.2.4, for the selected hazard and asset. Each bar represents a specific adaptation measure, with the one on the far left offering the highest benefit or avoided damage per USD invested, progressively decreasing toward the right, where the lowest benefit is shown. The width of each bar reflects the total avoided damage over the entire time horizon, spanning 27 years from 2024 to

Figure 50: Flood hazard map with a 10-year return period

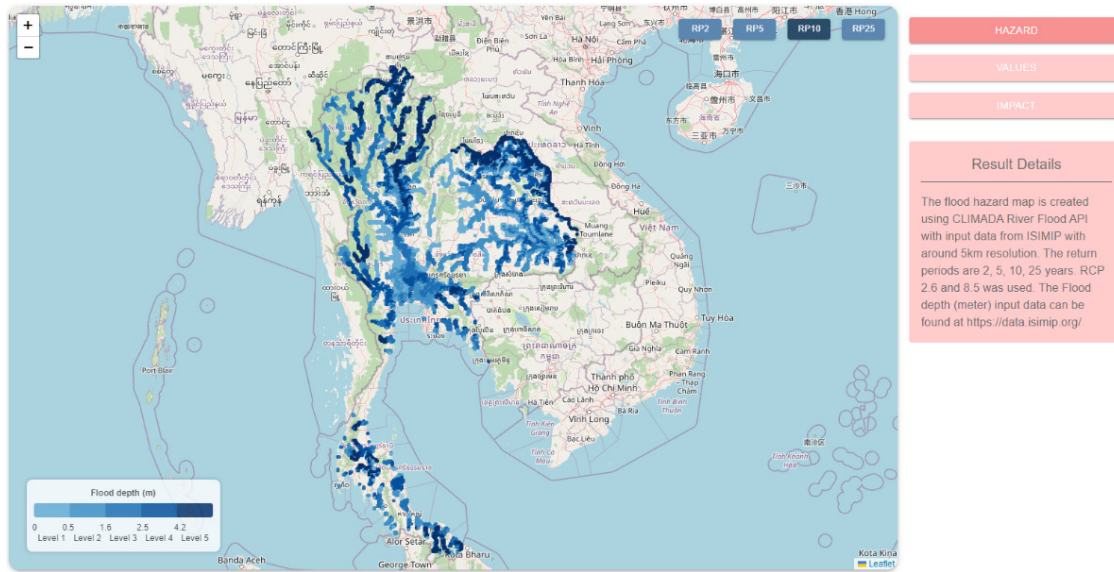


Figure 51: Grass crops' economic asset value in millions of USD grouped by the second administrative level

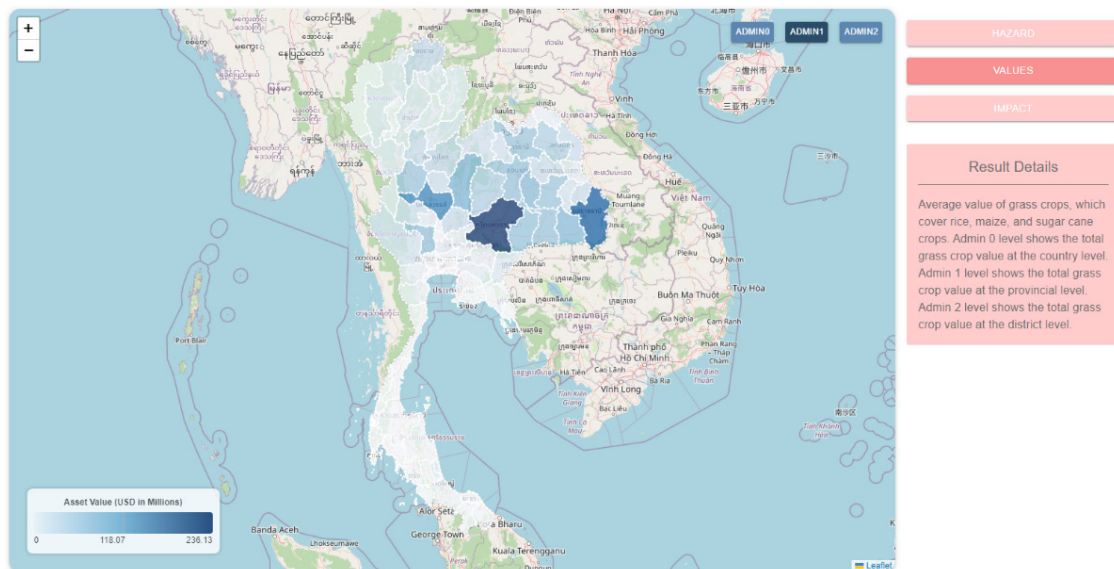


Figure 52: Grass crops impact map in USD

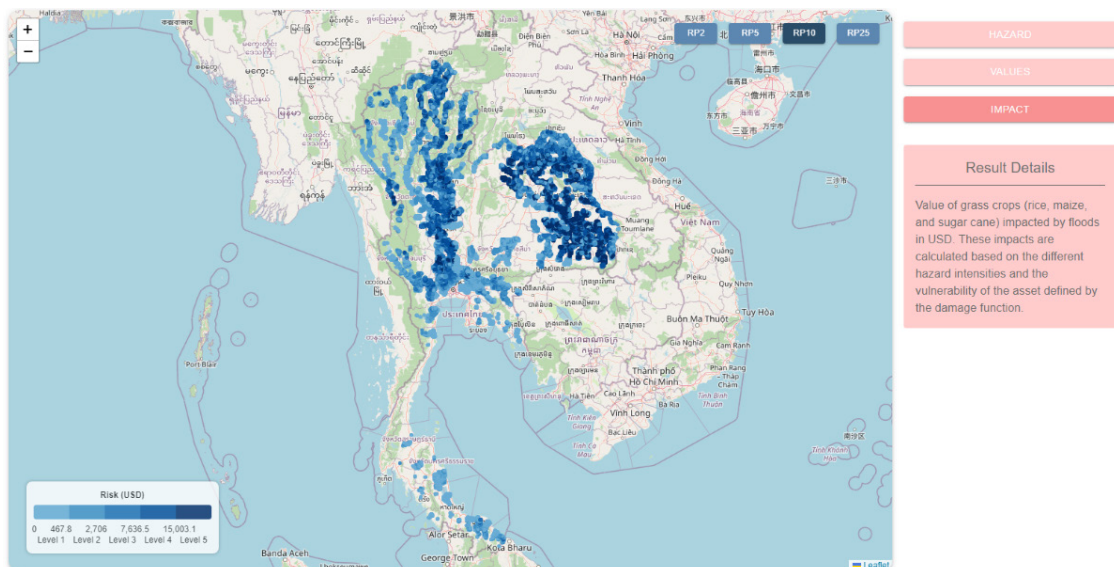


Figure 53: Impact chart for grass crops against flood at the RCP 8.5

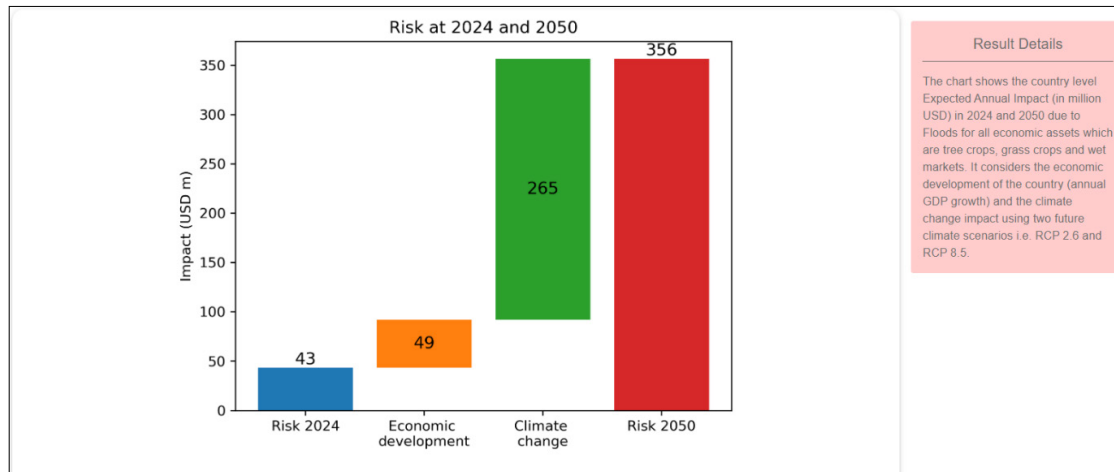
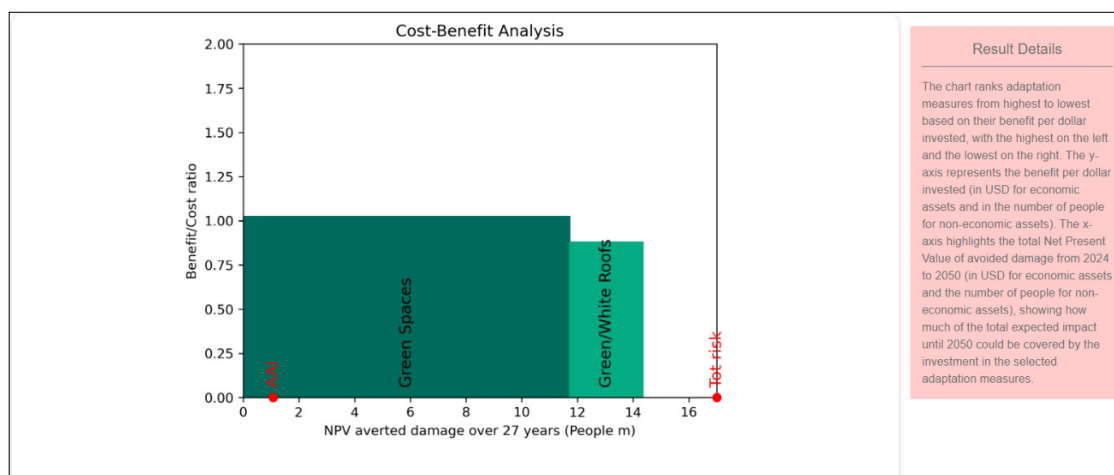


Figure 54: Cost-benefit analysis chart comparing adaptation measures



2050. For economic assets, this value is expressed in USD, while for non-economic assets, it is represented by the number of people. In the chart, the two red dots indicate the AAI (Average Annual Impact) and Total Risk. AAI represents the average total impact per year, while Total risk reflects the total expected impact until 2050 for the selected hazard and asset.

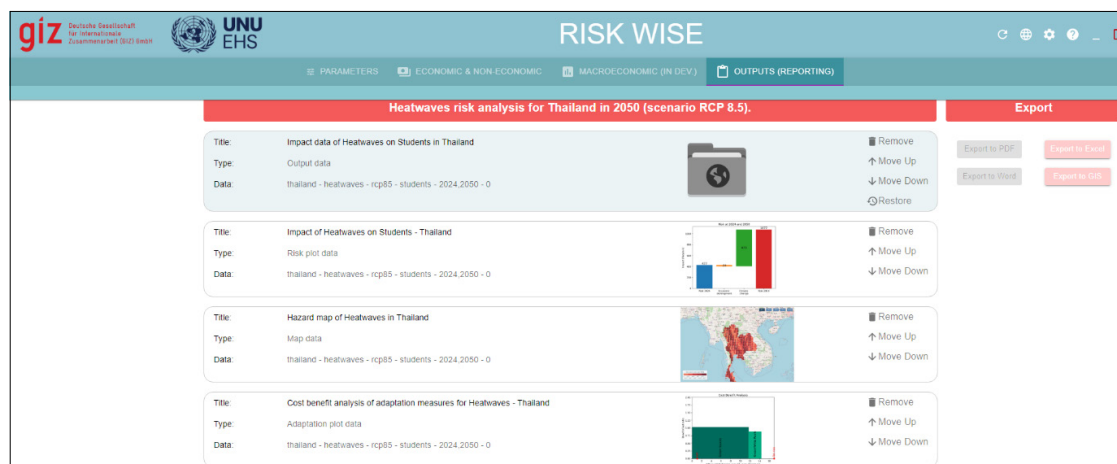
Figure 54 shows the comparison of measures for students against Heatwave with the RCP 8.5. Here, we can see that Green Spaces have the highest benefit/cost, with around 1 student per 1 USD invested in green spaces. While implementing Green Roofs will only benefit 0.8 students per 1 USD invested or 8 students per 10 USD invested.

RISK WISE offers users the ability to download information in various formats and create standard reports, accessible via the “Outputs (Reporting)” tab (see Figure 55). There are two key options: “+ Add to Output” and “+ Save Map/Chart”. The “+ Add to Output” button allows users to save selected input

parameters and their results when viewing the Display Map under the “Risk” tab. These saved selections can then be accessed from the “Outputs (Reporting)” tab, where users have the option to download the data either as an Excel file or as Geographic Information System (GIS) files. The “+ Save Map/Chart” button is used to save the map or chart displayed in the Result window as an image file, also accessible via the “Outputs (Reporting)” tab.

All exported documents are automatically saved in your computer’s reports folder within the RISK WISE directory. For example, C:\RISK_WISE_v_0_6_0\resources\app\data\reports. As shown in Figure 55, the top line represents the selection for “+ Add to Output,” which activates the red “Export to Excel” and “Export to GIS” buttons on the right-hand side. The lines below correspond to selections from “+ Save Map.” When these are selected, only the “Export to PDF” and “Export to Word” buttons become active.

Figure 55: Outputs tab for students and heatwave (RCP 8.5)



4.3 Benefits and limitations

The development of RISK WISE underwent multiple rounds of testing and feedback, including input from local stakeholders. Selected stakeholders were involved in evaluating key aspects of the GUI, such as functionality, usability, visual design, and overall ease of use. Their insights helped identify pain points and areas for improvement, leading to actionable changes that made the interface more intuitive and user-friendly. A video guide was created to support users further, providing a step-by-step tutorial on using RISK WISE, ensuring that stakeholders could easily navigate the GUI during testing and beyond. This guide is included with the application, helping users understand and maximize the benefits of the GUI.

The final version of RISK WISE provides two options at the start of the application. The GUI offers the option to show the results of the ERA project or explore further functionality. Selecting ERA Project Result shows all data input and results that the team

has calibrated. The Explore function allows users to upload their data sets into CLIMADA and run the application for some functionalities. However, the results shown may not be correct as the GUI does not automatically calibrate new inputs.

RISK WISE offers a user-friendly interface that allows stakeholders to seamlessly interact with data and models generated by other components, particularly the ECA framework. Users can easily use specific parameters such as country, hazard type, climate scenarios, and assets at risk to filter ERA results. The GUI then generates visual outputs, such as maps, graphs, and reports, that aid in interpreting and communicating the results of risk assessments. This functionality is especially valuable for translating complex model outputs into actionable insights, empowering decision-makers to make informed, data-driven choices.



5. Conclusions and Recommendations

5.1 Conclusions

The *Enhancing Risk Assessments (ERA) for Improved Country Risk Financing Strategies Project* leveraged two advanced modelling platforms—CLIMADA and DGE-CRED—within the framework of the Economics of Climate Adaptation (ECA) to assess the impacts of heatwaves and floods on Thailand’s economy and society. By integrating these models, the project provided a comprehensive analysis of current and future climate risks, emphasizing both economic and non-economic consequences. To support decision-making and the practical application of these results, a user-friendly Graphical User Interface (GUI), RISK WISE, was developed to enhance the accessibility and usability of the data.

Key outcomes from ECA and CLIMADA

CLIMADA focused on the specific impacts of floods, droughts, and heatwaves on economic assets, including tree (durian and rubber) and grass (rice, maize, and sugar cane) crops and wet markets, as well as non-economic assets, such as access to education, water, health, and mobility. The main conclusions are:

- ▶ Exposure to the different hazards varies throughout the country: Thailand’s climate risks have diverse geographic impacts. Flooding predominantly threatens river basins such as the Chao Phraya, where agricultural and economic activities are concentrated. At the same time, droughts and heatwaves pose broader risks nationwide, with heatwaves particularly affecting urban areas and droughts mostly agriculture-dependent rural regions. These differences underscore the need for targeted, context-specific adaptation strategies to reduce climate vulnerabilities across the country effectively.
- ▶ A multi-hazard adaptation portfolio involves different solutions and approaches. Effective adaptation to climate risks requires a combination of nature-based solutions (NbS), grey, and green infrastructure. While in Thailand, NbS are cost-effective for protecting both economic and non-economic assets

from floods, their scalability is limited for the former and requires a combination with grey infrastructure to cover a significant portion of the risk. For drought, a mix of water management, climate-smart agriculture, and infrastructure is key to mitigating impacts, especially in water-scarce regions. And for heatwaves, particularly in urban and vulnerable areas, expanded green spaces and green roofs are needed to enhance resilience.

- ▶ An integrated strategy is needed for comprehensive climate resilience: While some measures show promising cost-effective potential for various hazards and economic and non-economic assets, the expected benefits are not equally distributed, and the remaining risks require tailored efforts. As precipitations, temperatures, and water demands are projected to increase under both studied climate scenarios, floods, droughts, and heatwaves are expected to worsen, requiring forward-looking strategies that integrate action toward various types of impacts.

Key outcomes from CRED

The DGE-CRED model provided a macroeconomic perspective, assessing how floods and heatwaves could impact Thailand’s economy over time in the Agriculture, Energy, Manufacturing, Tourism, and Services sectors and in housing. The main takeaways include:

- ▶ Significant economic impact: Floods, droughts, and heatwaves are projected to reduce Thailand’s GDP by up to 2 per cent by 2050 compared to a baseline scenario without climate-related disasters. This reduction reflects broader economic disruptions beyond immediate asset damage.
- ▶ Consumption as an Indicator of well-being: While GDP changes may appear modest, the projected decline in household consumption could reach 10 per cent by 2050 under strong climate change scenarios. This indicates a

substantial decrease in individual economic resources and quality of life.

- ▶ Importance of adaptation: Implementing climate adaptation measures can significantly mitigate the economic impacts of climate-related disasters. A 67 per cent adaptation level could reduce disaster-related economic losses by approximately 50 per cent in the coming decades, demonstrating the benefits of early and proactive adaptation strategies.
- ▶ Compounding effects of disasters: The effects of climate-related disasters compound over time, with persistent impacts on all economic sectors. Early investment in adaptation is crucial, as delays could exacerbate negative economic outcomes and hinder long-term growth.

The role of RISK WISE

The RISK WISE GUI plays a crucial role in translating these complex model outputs into actionable information. By offering visualizations and reports tailored to different stakeholders' needs, the tool helps bridge the gap between data analysis and decision-making. While the platform allows for user data inputs, the lack of automatic calibration for new datasets is a key limitation, necessitating caution when using external data. Overall, RISK WISE enhances the accessibility of the study's findings, empowering users to explore risk scenarios and adaptation options more effectively.

5.2 Recommendations

Macro-level recommendations

1. National multi-hazard climate resilience policy: Develop and implement a comprehensive national policy focused on resilience to floods, droughts, and heatwaves, with differentiated adaptation approaches for each sector (e.g., energy, agriculture, and tourism). This policy should guide local governments and prioritize resources toward high-risk areas and vulnerable sectors.
2. Investment in adaptive infrastructure: Increase funding for a blended portfolio of nature-based solutions (NbS), grey, green, and blue infrastructure to bolster national resilience. Grey infrastructure should prioritize high-value economic assets in flood-prone areas, while NbS and climate-smart practices can target non-economic assets and environmental conservation, especially in rural regions.
3. Climate risk data integration and decision support: Deploy RISK WISE and similar decision-support tools across all levels of government to integrate climate risk data into budgeting, policy, and project planning. Training programs on these tools for local officials and policymakers are critical to translating climate risk data into actionable, region-specific adaptation plans.
4. Early climate adaptation investment: Prioritize early investment in adaptation measures, especially in high-exposure sectors like energy and agriculture. An early adaptation phase-in plan can leverage predicted GDP savings, strengthening the Thai economy's ability to absorb shocks while reducing cumulative climate impacts.

Micro-level recommendations

1. Implement targeted flood management in river basins: In flood-prone areas, especially along the Chao Phraya, Mekong, and Mun basins, localized flood risk measures like canal dredging and riverbank reinforcement should be adopted. These should be supplemented with grey infrastructure where NbS alone are insufficient. Community-level flood preparedness and early warning systems can further strengthen resilience among at-risk populations.
2. Promote climate-smart agriculture in drought-susceptible regions: Deploy drought-resilient practices integrating soil, water, and pest management in agriculture-dependent regions such as the Isan area. These practices should be adapted to local crop needs and water scarcity conditions, reducing farmers' vulnerability to prolonged dry seasons and supporting food security.
3. Expand green infrastructure in urban areas for heat resilience: Prioritize green roofs and urban green spaces in high-density urban areas, especially Bangkok, which faces intensifying heatwaves. However, not all heat-related risks can be covered through these measures, requiring additional options to be explored.

Final thoughts

The integration of ECA, CLIMADA, and DGE-CRED in this project provides a nuanced understanding of Thailand's climate vulnerabilities and adaptation needs. This cross-cutting approach enables more comprehensive decision-making by addressing the interconnected impacts of climate risks across economic and non-economic sectors. RISK WISE's accessibility further enhances decision-making by translating complex data into actionable insights, empowering Thailand's stakeholders to build a resilient and climate-adaptive future.



Annex I. Economic and non-economic assets

Economic assets

1. Grass and tree crops

This report evaluates the impact of flooding and drought on grass and tree crops in Thailand. Agriculture plays a crucial role in Thailand's economy; one in six individuals, or roughly one-third of the country's workforce, is employed in the agricultural sector, one of the country's main employment sectors. According to data from 2020, almost half (46.54 per cent) of the nation's land use is dedicated to agriculture, with roughly half of that being devoted to rice cultivation specifically (46.04 per cent) (MoNRE, 2024). This sector is crucial for maintaining economic stability and food security. However, climate hazards such as flooding and drought threaten agricultural outputs significantly. These hazards, coupled with the projected decrease in population and ongoing rural-to-urban migration amongst the nation's youth, could further weaken an already strained farm sector and, subsequently, Thailand's economy (Wuttisorn, 2014).

Projections indicate that rice, by far the nation's most important agricultural product, could decline 10 per cent to 13 per cent due to these climate impacts. Combined with a similar reduction in maize yields, these reductions will also cause food availability and food stability dimensions in Thailand to decrease (Attavanich, 2023). The predicted weakness in these areas has many dimensions, derived from non-optimal moisture levels in grain kernels, negative physical changes to the grain kernel, effects on pollination, or changes in planting and harvest schedules due to disruptions in weather patterns, along with many other factors (Yokying, 2024). As such, it is essential to understand the impact of climate hazards such as flooding and heatwaves in Thailand.

Asset location

To determine the location of crops in Thailand, we utilized the Land Use Land Cover Database in all provinces from the Land Development Department in Thailand (LDD, 2019), which includes detailed landcover classifications, key crops such as rice, maize, sugarcane, durian, and latex rubber. The latitude and longitude coordinates were extracted by projecting the shapefile and filtering the attribute

table based on the relevant landcover codes within the dataset. The centroid of each polygon representing crop areas was calculated to pinpoint the exact location for further analysis.

Asset valuation

Because of the varied effects that floods and droughts have on different types of crops, we chose crop types that are representative of Thailand's major agricultural outputs and have data available at a resolution suitable for input into CLIMADA. We divided crops into two major categories: grass crop, which includes rice, maize, and sugarcane, and tree crops, which include durian and latex rubber. To estimate the values of the crop, the area of each crop type was calculated within the polygons from the landcover dataset in hectares. The crop yields were determined from USDA sources, Local Market Values, and online databases (CEIC, 2018; FAS, 2022, 2023; Thai Rubber Association, 2024). Yield data was calibrated with a five-year average yield using the listed sources and crop prices.

The damage functions displaying the effect of floods or droughts on each crop type were based upon previous ECA studies and calibrated to fit the Thailand context – Drought Risk: Ethiopia and Flood Risk: Vietnam specifically (UNU-EHS & Frankfurt School of Finance & Management, 2021a, 2021b). Each study created damage functions for similar crop types studied in our project and, as such, were seen as an accurate baseline for the newly created damage functions. The final asset value for each location was computed and summed to get the total crop value per location in Thailand, valued at USD 1.60 billion and USD 1.33 billion for trees and grass crops, respectively, for flood hazards. When discussing drought, the total crop value per location in Thailand was valued at USD 47.9 billion and USD 39.9 billion for tree and grass crops, respectively.

2. Markets

This report evaluates the impact of flooding and drought on Traditional Markets (which include Wet or fresh markets) in Thailand. Despite the recent increase in modern supermarkets in Thailand, Traditional

Markets still hold a large percentage of the market share – roughly half as of 2016 (Poapongsakorn et al., 2019). These Traditional Markets play an important role in Thai society; until recently, these markets were visited multiple times a week and, as such, were a social and economic hub. Additionally, modern supermarkets target the urban and, often, wealthier Thai population who value a “one-stop-shop” philosophy and the convenience of supermarkets or hypermarkets. On the other end of the spectrum, Traditional Markets, which often focus on fresh produce and prepared food, can keep prices low for consumers by cutting out costs associated with the packaging and sorting/grading of the products related to modern retailers (Gorton et al., 2011).

The loss of Traditional Markets affects not only those who rely on said markets for foodstuffs but also the individuals who sell the goods. The vendors operate on thinner margins than modern supermarkets and cater to a clientele that is more sensitive to price increases. Any disruption in business, including loss of sales from the unavailable product, has a disproportionately negative effect on all parties when compared to modern supermarkets (Gorton et al., 2011). For these reasons, it is important to understand the effect that flooding and drought have on markets, in addition to the physical damage they could incur because of said hazards.

Asset location

To determine the location of markets in Thailand, we utilized the database of fresh market locations from

the Department of Internal Trade of Thailand (DoIT, 2019). This database includes the different varieties of “Fresh Markets” throughout Thailand. GIS was utilized to determine the centroid of each polygon representing each market, calculated to pinpoint the exact location for further analysis. This population assigned to each market acted as the basis on which loss of business damage could be estimated for each location.

Asset valuation

Estimating the value of each market was a multistep process based on an estimated loss of business incurred because of drought or flood events. Firstly, the total volume of sales from traditional grocers was determined, and this value was distributed throughout each Thiessen polygon based on the total population reliant on said market. This approach allowed us to show varying levels of market value depending on the perceived popularity and, therefore, the increased amount of goods in each market. The loss of business value was developed based on the average number of vendors specializing in fresh produce and dried goods and the value of their goods sold each year at Fresh markets in Thailand (Chaiyaphan & Ransikarbum, 2021; Chongtaku et al., 2024; Chuechan, 2020; Poapongsakorn et al., 2019). This function is the estimated sales volume of produce and dried goods at fresh markets and the number of people estimated to rely on said fresh markets. This function determined the estimated total market value at USD 451 billion and 13.5 billion for flooding and drought, respectively.

Non-economic assets

1. Diarrhoea patients

This report seeks to analyze the potential incidence of diarrhoea cases in Thailand because of flooding. Flooding in Thailand severely degrades water quality and compromises the sanitation infrastructure, which in turn leads to an increased incidence of waterborne diseases such as those associated with diarrhoea. Studies have shown a correlation between diarrhoea morbidity rates in flood areas in Southeast Asian Countries, including Thailand. This increased incidence of diarrhoea during flood events can strain healthcare facilities, reduce overall public health, and impede socio-economic development (Cao et al., 2021; Saulnier et al., 2018; Schwartz et al.,

2006; Yomwan et al., 2012; Yomwan et al., 2015). Addressing the vulnerability of diarrhoea patients in the context of flooding is especially important when aiming to develop further effective public health interventions and climate adaptation strategies aimed at safeguarding the vulnerable population. This report aimed to evaluate the number of people affected by diarrhoea due to low-quality water because of flood events in Thailand. By overlaying flooded areas, we can estimate the morbidity rate per 100,000 people in any given area based on the inundation rate of the flood waters and the population of the flooded region using the following equation from the American Center for Disease Control (CDC):

$$\text{Incidence Rate Ratio (IRR)} = \frac{\text{New cases occurring during a given period}}{\text{Size of population during the same period}} \times 10^n$$

By defining the period based on flood duration and letting a constant, the equation transforms the result of the division into a uniform quantity (n), equal to 5, fitting with the number of patients in the study. The resulting weekly IRR (cases per 105 people) was calculated from the weekly report of diarrheal patients from hospitals in the study area.

Asset location

To determine the location of people affected by diarrhoea during flood events in Thailand, we utilized geospatial data from the Land Use Land Cover Database in all provinces from the Land Development Department in Thailand (LDD, 2019), which includes detailed information on reservoirs located within Thailand. Using GIS, we determined the centroid of each reservoir. We applied the Thiessen Polygon tool to determine an estimated “area of reliance” for each reservoir and the number of people who are reliant on each reservoir for their water needs. The centroid acted as the proxy for the location of each asset, and the latitude and longitude determined are based on this point.

Asset valuation

The total population of Thailand in 2020 was available as a raster dataset, with a total of 69,668,998 people (HOTOSM, 2020b). The assumption used in this study is that all populations rely on the closest water reservoir to where they are located. Using the Thiessen polygon method in GIS, we managed to divide the whole of Thailand into smaller areas with one water reservoir inside and then calculate how many people are inside those smaller areas. The asset in this case is the potential number of diarrhoea patients, which is equal to the total population of Thailand.

2. Water users

This report also aims to analyze the potential Water Users because of drought in Thailand. Because of its monsoon climate, Thailand oscillates between periods of intense precipitation and drought/heat. As climate change intensifies, so do periods of drought. Studies have shown a direct correlation between the intensification of drought and an increase in Water Users amongst the Thai population (Ikhwal, 2021). This unmet demand for water puts additional pressure on an already stressed system that must meet the population’s needs at the two extremes: during drought conditions as well as during extreme precipitation and flooding. This report also aims to analyze the potential Water Users because of drought in Thailand. Because of its monsoon climate, Thailand oscillates between periods of intense precipitation and drought/heat. As climate change intensifies, so

do periods of drought. Studies have shown a direct correlation between the intensification of drought and an increase in Water Users amongst the Thai population (Ikhwal, 2021). This unmet demand for water puts additional pressure on an already stressed system that must meet the population’s needs at the two extremes: during drought conditions as well as during extreme precipitation and flooding.

Asset location

To assess the impact of droughts on Water Users in Thailand, we utilized geospatial data from the Land Use Land Cover Database in all provinces from the Land Development Department in Thailand (LDD, 2019), which includes detailed information on reservoirs located within Thailand. Using GIS, we determined the centroid of each reservoir. We applied the Thiessen Polygon tool to determine an estimated “area of reliance” for each reservoir and the number of people who are reliant on each reservoir for their water needs. The centroid acted as the proxy for the location of each asset, and the latitude and longitude determined are based on this point.

Asset valuation

The total asset value or total potential water users in this case is equal to the total population of Thailand in 2020, 69,668,998 people, who were assigned to each “area of reliance” using the Thiessen polygon method. The development of Water Users’ damage function during droughts was a two-step process. From previous studies, we have known the ratio of demand and unmet demand from a certain population within a reservoir for over a year in Thailand. To apply this ratio to the rest of Thailand, we calculated each year within the span’s SPI (representing drought) using historical precipitation data (POWER, 2024) in conjunction with historical population data (NSO, 2010) to change the ratio to a specific value – in this case, total people with unmet water demands. The damage curve shown below shows this relationship: unmet water needs per 100,000 people and SPI. Using the reservoir data described above, their “area of reliance,” and modern population data (HOTOSM, 2020b), we were able to create the damage function shown below.

3. Religious services (Buddhist monks)

The ERA-ECA report also evaluates religious services during floods and heatwaves. Buddhism is the predominant religion in Thailand, with over 95 per cent of the population – meaning roughly 64 million people within Thailand follow Buddhism as of 2015 (NSO, 2015). Additionally, a large proportion of young men become Buddhist monks temporarily – these monks rely on the charity of others, seeking food from the surrounding population and residing in

temples interspersed throughout the country and, in return, provide the local community with spiritual guidance and other religious services (Cassaniti, 2023; Tharika Kamkokgruad, 2019). During times of extreme heat or flood, monks are unable to collect their daily sustenance and go about their daily duties. Practitioners are unable to seek guidance or visit temples, thereby severing this important and symbolic aspect of Thai culture temporarily.

The population of Buddhist monks is uniquely vulnerable to the increase in flood and heatwave frequency and severity. Relying on the charity of a vulnerable population suffering from the same conditions creates a difficult dynamic for the local community providing for the monks, as well as the monks who themselves are representatives of Buddhism and hold a leadership role within the community. This give-and-take social contract will only become more strained as the negative effects of climate change worsen within Thailand. As such, it is important to understand how access to religious services, represented here by access to the monks as well as temples for shelter, is affected by flooding and heatwaves in Thailand.

Asset location

A multi-step process was undertaken to determine the location of monks throughout Thailand. Firstly, the National Office of Buddhism and Open Government Data of Thailand list of Buddhist temples (NOB, 2024) was used to determine the geolocation of over 43,000 temples in Thailand, which was later input into GIS. Then, monks were assigned to each temple based on their zip code to estimate the total monk population within each province, accounting for the possibility of zip codes having multiple assets, each with unique latitude and longitude data.

Additionally, to assess access to temples for shelter, we used the same geolocation for temple locations throughout Thailand as described above. To estimate the number of people who seek refuge at a particular temple, it was necessary to estimate the number of houses affected by flooding. To do this, we used data from HOTOSM to determine the latitude and longitude of houses throughout Thailand. What we considered houses in this study were places of residence listed as apartments, houses, condominiums, dormitories, and residential within the database.

Asset valuation

The relationship between flood events and religious services is a relatively straightforward one; as inundation rates increase, the ability of monks to reside within the temple structures is compromised, thereby not allowing the monks to participate in their portion of the social contract nor allowing easy access

to tithing. While the temples vary substantially in size and structure, we estimated a 1.5 m inundation rate would severely limit the habitability within the temples, thereby compromising their ability to provide religious services to the community. This 1.5 m threshold is based on previous research by the EU Joint Research Commission and provided the best estimate for damage to various structures as a function of inundation levels (Moel et al., 2016).

When estimating the number of people seeking shelter in temples, we first assumed that the damage was 80 per cent or more and that people would be forced to seek shelter. Using the JRC report on global damage curves, it was determined that 80 per cent of damage occurs at roughly 2.5 m inundation.

Similar to the assumptions made concerning flooding, heatwaves affect a monk's ability to provide religious services to the local community by severely compromising the monk's well-being during times of extreme heat (Karlsson & Ziebarth, 2018; Tawatsupa et al., 2012). Monks have a much higher obesity rate than the rest of the Thai population (Kuramasuwan et al., 2013); this can be attributed to their sedentary lifestyle and unhealthy diet (Bresnahan, 2019). As a result, monks are much more susceptible to heat-related illnesses associated with obesity (Chung & Pin, 1996; Thawillarp et al., 2015). For this study, heatwave data from a previous ECA study in Vietnam was applied to the Buddhist monk context, thereby displaying the increased susceptibility to heat-related illnesses described above (UNU-EHS & Frankfurt School of Finance & Management, 2021a). To plot this estimated Monk Mean Damage Degree, the WSDI data from the Vietnam study was also used due to the similarity in climate between the two countries. Again, the assumption is that heatwaves do not necessarily damage the religious site itself but rather limit the population's ability to interact with the Buddhist monks in one form or another.

When considering both flooding and heatwaves as they affect religious services, we consider Buddhist monks rather than the temples when assigning a valuation, and as such, for both hazards, the valuation is equal to the total population of monks in Thailand, which is 205,823.

4. People seeking shelter

During periods of extreme flooding, such as the case in 2011, people often evacuate their homes to designated shelters throughout the country, the closest suitable public space (Chanta & Sangsawang, 2012). Schools, multi-purpose facilities, and Buddhist Temples make up the bulk of shelter locations for people to take refuge, with Temples being particularly desirable

due to their importance in Thai society, their ability to be used day and night, and their unique design enabling high capacity – in the case of large temples the complex is often composed of a large compound with multiple, sometimes stone buildings and open spaces (Manawongcharoen & Panbamrungkij, 2021). It is understood that under conditions necessitating evacuation from their homes, people have a preference to seek shelter in Temple compounds (Alam, 2024; Andrew et al., 2013). This does not necessarily mean that shelter is always available at these sites. Due to their importance, temples are often more resistant to flooding because of their design and building type, but they are still not completely impervious to flooding. Additionally, people seeking shelter are not only limited to the availability of the shelter but also people's ability to travel to the shelter to seek aid, thus adding another factor to the evaluation of this asset as an extension of the religious services asset described above, it sought to incorporate people's inability to access shelter, with shelter, in this case, being limited to people seeking shelter in Temples.

Asset location

To determine the location of assets, it was necessary to decide on the houses that people fled from and the temples that they attempted to escape to. To do so, we utilized the National Office of Buddhism and Open Government Data of Thailand's Buddhist temples (NOB, 2024) to determine the location of said assets. For houses, we utilized the HOTOSM database of buildings within Thailand, specifying the places of dwelling as houses, apartments, attached housing, condos, condominiums, dormitories, homes, houses, residential, semi-detached houses, and detached (HOTOSM, 2024a) . For the roadways that people use to access shelter sites, we again utilized the HOTOSM database (HOTOSM, 2024c).

Asset valuation

Using the location of houses in conjunction with the average number of people per household in Thailand (ESRI, 2022), we determined the number of people needing shelter during flooding. We assigned them to the closest temple, which acts as a shelter. Flooding along roads was also factored into this, with the assumption being that any inundation rate over 0.3 m would not allow people to access shelters (Pregolato et al., 2017). With all factors considered, we determined that the number of people not receiving shelter in temples during flooding despite needing so is 304 people.

5. Education

Students represent an important non-economic asset as they represent the nation's future potential and socio-economic development. That said, students in Thailand face significant climate-related risks affecting their education, health, and overall well-being. Different student groups exhibit distinct vulnerabilities to climate risks. Children are more vulnerable and less able to withstand climate hazards such as floods, droughts, and severe heatwaves (UNICEF, 2022). During floods, schools may become inaccessible to teachers and students and are often repurposed as shelters, thereby disrupting normal learning activities (Akello, 2014).

Additionally, extreme heat can significantly impact education, with students showing lower levels of achievement during hotter school years. Research indicates that a one-degree Fahrenheit increase in temperature can reduce the amount learned in the school year by 1 per cent (Goodman et al., 2018). Heat exposure can exacerbate educational inequalities, as students from lower-income homes are more likely to live in areas impacted and less likely to have access to air conditioning. In 2022, it was estimated over 10 million children were exposed to heatwaves (UNICEF, 2024). Against such climate impacts, the report recognizes students as a key asset. It explores the effects of flooding and heat waves to ensure that the climate adaptation measures are effectively designed to protect them.

Asset location

To evaluate the impact of flooding and heatwaves on students in Thailand, we utilized data from the HOTOSM Database of education facilities within Thailand (HOTOSM, 2024b). Like other assets, we used Thiessen Polygons to establish an area around each facility location and assigned the estimated student population within each polygon to the associated education facility.

Asset valuation

To estimate the student population within each education facility polygon, the approach was two-fold. Using Thailand's Population raster data from 2020 (HOTOSM, 2020a) and Thai Census data from the year 2020 (BOPP, 2020), we applied zonal statistics to assign students to the appropriate education facility's latitude and longitude value.

When considering the student population affected by flooding, we determined that the inability of students to attend school because of impassible roads was the best estimation for damage to education by flooding. Roads are considered impassible by passenger cars when inundation rates surpass 0.3 m (Pregolato et

al., 2017). As such, when this threshold is reached, 100 per cent of students are unable to attend school.

After this student value was determined, the same ECA Report Heatwave damage function was used as the proxy for the Thai population affected by heatwaves. Using this as the baseline, we calculated the student incidence rate for heatwave hospitalizations (Thawillarp et al., 2015), on which we based our Students affected by heatwave damage function. To apply the Vietnam data to the Thai student context, we used the calculated student incidence rate to the Vietnam damage function to estimate the Mean Damage Degree of Thai students during heatwaves (MoE, 2008; UNICEF, 2019).

Because we are assessing the damage from heatwaves and flooding to the Thai student population in its entirety, the estimated total valuation for students between the ages of 3–17 in 2020 was 6,600,745 people in Thailand. This data provides a baseline for assessing the impact of flash floods and heatwaves on the educational sector in Thailand.

6. Grass and tree crop farmers

In addition to the grass and tree crops discussed previously, the study also explored the non-economic impact of floods and droughts on grass and tree crop farmers throughout Thailand. The arguments made regarding crops affected by these hazards can be applied here – as climate change increasingly affects the agricultural sector in Thailand, the individuals relying on said crops for their livelihood and sustenance are also negatively affected. As stated previously, one in six individuals, or roughly one-third of the country's workforce, are employed in the agricultural sector – making it one of the country's main employment sectors (MoNRE 2024). Coupled with the ongoing rural-to-urban migration among the nation's youth, the ageing rural farmers in Thailand are becoming increasingly vulnerable as climate change continues to intensify instances of flood and drought throughout the country (Wuttisorn 2014).

Asset location

To determine the location of farmers throughout Thailand, we utilized the Land Use Land Cover Database in all provinces from the Land Development Department in Thailand (LDD, 2019), which includes detailed landcover classifications, key crops such as rice, maize, sugarcane (referred to as grass crops), durian, and latex rubber (referred to as tree crops). The latitude and longitude coordinates were extracted by projecting the shapefile and then filtering the attribute table based on the relevant landcover codes within the dataset. The centroid of each polygon

representing crop areas was calculated to pinpoint the exact location for further analysis.

Asset valuation

To determine the value of this particular asset, it was necessary to estimate the number of farmers at each location specified above. To do so, we utilized farmer population counts by type in each province (DoAE, 2021). If one household equates to one farmer, we assigned farmers based on their crop designation (grass or tree) and the estimated number of farmers per province based on the amount of land dedicated to each crop type.

The damage functions displaying the effect of floods or droughts on each crop type were based upon previous ECA studies and calibrated to fit the Thailand context – Drought Risk: Ethiopia and Flood Risk: Vietnam specifically (UNU-EHS & Frankfurt School of Finance & Management, 2021a, 2021b). Each study created damage functions for similar crop types studied in our project and, as such, were seen as an accurate baseline for the newly created damage functions. The total valuation for grass crop farmers and tree crop farmers is based on the total number of farmers for each crop designation throughout the country, meaning the estimation for each is 1,050,658 tree crop farmers and 5,365,577 grass crop farmers in Thailand.

7. Road users

This report also aims to evaluate how flooding affects road users. Flash floods significantly impact road users and mobility in Thailand by disrupting transportation infrastructure and posing immediate safety hazards. During flooding, inundated roadways are rendered impassable, increasing congestion in unaffected roads and increasing the risk of accidents. Floodwaters can cause road surfaces to erode more quickly, undermine bridges, and wash out critical infrastructure, leading to traffic delays, detours, and road closures, further complicating emergency response and evacuation efforts. The disruption to transportation networks affects not only daily commutes but also emergency services and the delivery of goods and services, highlighting the need for robust flood management and infrastructure resilience to protect road users and maintain mobility during extreme weather events.

Asset location

Road network datasets were acquired from HOTOSM to assess the impact of flooding on road users (HOTOSM, 2024c). From this dataset, we selected attributes such as busway, motorway, primary, raceway, residential, road, secondary, service, tertiary,

trunk, and track. For analysis, we created a 2km x 2km grid across Thailand, ensuring comprehensive coverage. The road network was then buffered by 10km to account for the area most likely to be affected by the flooding near the road. Following this, we clipped the grid using the buffered road areas to focus on regions directly adjacent to the road network, allowing us to map and analyze precisely the areas where road users are most vulnerable to the effect of flash floods.

Asset valuation

To estimate the number of road users potentially impacted by flooding, we integrated population data with the road network. Using the raster population data for Thailand, we polygonized the population count. Then, we intersected these population polygons with the clipped grids from the road buffer

zones, enabling us to determine the population density within each grid that overlaps with the road network, offering a clear picture of the number of people who could be affected by disruptions in transportation during a flood event. The damage function created to assess this asset is based upon the assumption that passenger vehicles are unable to operate safely when inundation rates exceed 0.3 m. Additionally, we also assume that most roads are built up to some degree, with an estimated base height of 1 m applied to take this into account. When considering this information, the threshold is set at 1.3 m (OIP, 2014; Pregnotato et al., 2017). By combining the road infrastructure with population data, the value of road users was quantified, reflecting the total 69,971,472 estimated road users in Thailand.

Annex II. Methodology for adaptation measures selection

The methodology for selecting adaptation measures to address flood, drought, and heatwave risks in Thailand involves a systematic four-step process. First, a comprehensive long list of potential adaptation measures is defined, drawing on existing knowledge and expert input. Next, this list undergoes validation and refinement through the weighing of selection criteria, ensuring that the most relevant and effective measures are prioritized. The third step employs a multi-criteria decision analysis (MCDA) to narrow down the long list to a short list of high-priority adaptation measures, considering various factors such as cost-effectiveness, stakeholder acceptance, and potential maladaptation. Finally, the cost of implementing and maintaining these short-listed measures across the entire country is estimated, providing a good basis to analyze the cost-benefit of implementing these measures.

A. Defining a long list of adaptation measures

The initial phase of identifying adaptation measures begins with a comprehensive literature review and consultation with local experts and project partners.

Several key aspects guide this process: incorporating international best practices in flood and heatwave mitigation and adaptation, aligning with local and national strategies or master plans on climate adaptation, sustainable development, or regional action plans, and including existing practices from local experts, as well as additional measures proposed by them for implementation in Thailand. Before the adaptation workshop, the literature review focused on the first two aspects, ensuring that global standards and national strategies were thoroughly considered. During the workshop, input from local experts was gathered to address the third and fourth aspects, allowing for a contextually relevant and locally endorsed list of adaptation measures.

As a result, Table 7 below shows the list of flood and heatwave measures categorized into five measure types. The categorization of adaptation measures into grey, nature-based, hybrid, systemic, and insurance types provides a structured approach to addressing climate risks like floods and heatwaves. Grey measures involve conventional engineering solutions, such as dams, levees, and urban drainage systems, that rely on infrastructure to mitigate impacts.

Table 7: Long list of identified flood and heatwave adaptation measures for Thailand

Hazard	Adaptation measures		Types
Flood	1	Embankment walls	Grey
	2	Mobile flood embankments	Grey
	3	Sluice gates	Grey
	4	Ground (building) elevation	Grey
	5	Elevation of electricity substations	Grey
	6	Dry floodproofing	Grey
	7	Flood walls	Grey
	8	Reinforced electricity poles	Grey
	9	Improved drainage system	Grey
	10	Dredging of canals	Grey

Hazard	Adaptation measures		Types	
Flood	11	Pump stations	Grey	
	12	Rain collection tanks for existing buildings	Grey	
	13	Permeable pavements	Grey	
	14	Modular water retention systems	Grey	
	15	Wet floodproofing	Grey	
	16	Small dams	Grey	
	17	Water diversion system	Grey	
	18	Green spaces	NbS	
	19	Recharge parks with bio-filtration	NbS	
	20	Infiltration ponds	NbS	
	21	Wetland restoration and rehabilitation	NbS	
	22	Road spillways	Hybrid	
	23	Detention swales along roads	Hybrid	
	24	Constructed wetlands	Hybrid	
	25	Retention reservoirs	Hybrid	
	26	Retention furrows	Hybrid	
	27	Sandbags	Hybrid	
	28	Flood awareness campaign	Systemic	
	29	Smart-city data hub development	Systemic	
	30	Hydrological and meteorological monitoring	Systemic	
	31	Flood protection storage facilities	Systemic	
	32	Improved solid waste management	Systemic	
	33	Early warning system	Systemic	
	34	Agricultural zoning	Systemic	
	35	Training for Agricultural topics for adaptation	Systemic	
	36	Water tolerant crop	Systemic	
	37	Flood index insurance	Insurance	
	Drought	1	Boreholes	Grey
		2	Construction of cisterns	Grey
		3	Watering ponds/wells	Grey
		4	Portable water treatment plants	Grey
		5	Motorized solar pumps	Grey
		6	Improvement of water storage systems	Grey
		7	Improvement of water distribution facilities	Grey
		8	Small and medium-sized irrigation systems	Grey
		9	Forage storage facilities	Grey
		10	Wetland restoration and rehabilitation	NbS

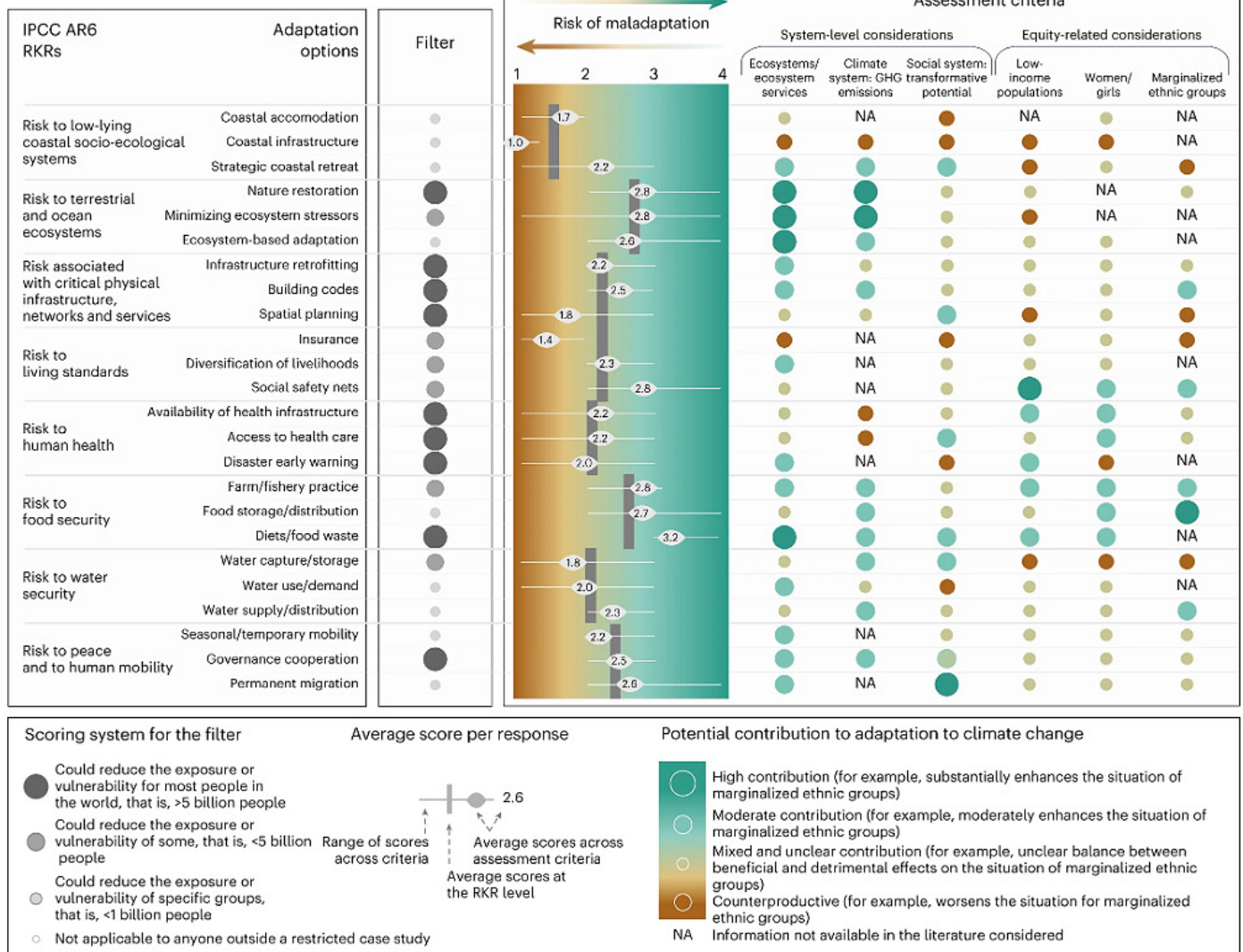
Hazard	Adaptation measures		Types
Drought	11	Management of protected environmental areas	NbS
	12	Replanting Indigenous varieties	NbS
	13	Livestock enclosures	NbS
	14	Crop switching	NbS
	15	Watershed protection with bunds	Hybrid
	16	Micro-reservoirs in riverbeds	Hybrid
	17	Establishment of fodder tree and grass nursery sites	Hybrid
	18	Community-based rangeland management	Systemic
	19	Improved veterinary health support	Systemic
	20	Rehabilitation of rural market and trade	Systemic
	21	Water information system	Systemic
	22	Promotion of alternative farm and non-farm activities	Systemic
	23	Capitalization	Systemic
	24	Crop insurance	Insurance
	25	Livestock insurance	Insurance
Heatwave	1	Agricultural wastewater treatment plant	Grey
	2	Seawater cooling system	Grey
	3	White roofs	Grey
	4	Shaded walkways	Grey
	5	Climate-proofed standard for road design	Grey
	6	Cooling centres	Grey
	7	Green spaces	NbS
	8	Urban farming	NbS
	9	Urban Forestry	NbS
	10	Green roofs	NbS
	11	Cooling by water spray	Hybrid
	12	Climate-smart agriculture	Systemic
	13	Research and monitoring	Systemic
	14	Early warning system	Systemic
	15	Training on adaptation agricultural practices	Systemic
	16	Water-saving cultivation and production practices	Systemic
	17	Green building codes	Systemic
	18	Integrated fertilizer management	Systemic
	19	SMART hotels	Systemic
	20	Working hour policy	Systemic

Nature-based solutions (NbS) harness natural processes and ecosystems, like restoring wetlands or planting urban forests, to enhance resilience. Hybrid measures combine elements of grey and nature-based solutions, integrating infrastructure with ecological enhancements, such as using constructed wetlands. Systematic measures focus on policies, governance frameworks, and community-based strategies that improve overall adaptive capacity, such as early warning systems or improved solid waste management. Insurance provides financial protection against the economic impact of climate-related disasters, serves as a risk transfer mechanism within climate disaster risk financing and insurance (CDRFI), and complements other adaptation approaches by providing crucial financial support and facilitating recovery. This comprehensive categorization balances immediate protective needs with long-term sustainability and resilience.

B. Validation and weighing of selection criteria

After compiling a long list of 37 measures for flood, 25 for drought, and 20 for heatwave, the most promising adaptation measures must be selected to be parameterized within CLIMADA. To do so, it is best practice to reduce the long list to a shortlist based on specific selection criteria. Selection criteria are attributes or characteristics needed to address risk while effectively meeting sustainability and economic relevance requirements. Our long list utilized (Reckien et al., 2023) the Adaptation–Maladaptation Continuum (see Figure 56 below), which is helpful when promoting successful adaptation or the risk of maladaptation. The following selection criteria, validated by key stakeholders, were used to ensure that the shortlisted measures are both impactful and feasible:

Figure 56: Location of adaptation options along the adaptation–maladaptation continuum, contributing to potentially successful adaptation or the risk of maladaptation



1. **Cost-effectiveness:** It is a crucial selection criterion that evaluates how well an adaptation measure achieves its objectives relative to its cost. It estimates whether the chosen measures provide a high, medium, or low benefit for the total expense. This is assessed and validated by local key stakeholders, experts, and data where available.
2. **Upscaling potential:** It considers how much further potential for different adaptation measures can be exploited in the country, i.e., how to increase the usage of adaptation measures or implement them in another location. This is assessed and validated by experts and data where available.
3. **No-regret options (risk gradient):** Risk-independent vs. risk-specific: adaptation strategies can be useful even in the absence of climate change or in case of uncertainty regarding future climate change impacts (= risk-independent) or they can be risk-specific, where their implementation is only sensible when risk is present (e.g., insurances). This is assessed and validated by experts and data where available.
4. **Co-benefits (for SDGs):** Many adaptation strategies not only adjust systems to cope with climate risk but also have the potential to contribute to other development benefits. It is indicated by estimating whether an adaptation measure has a high, medium, or low relevance to other sustainable development goals (SDGs) that it could also address. This is assessed and validated by experts and data where available.
5. **Potential for maladaptation:** Adaptation interventions may also produce undesired effects or maladaptive outcomes (e.g., biodiversity losses, increased energy demand, etc.), which must be considered for each adaptation strategy. The IPCC 6th Assessment Report graph below was mainly used to guide whether an adaptation measure has a potential for high, medium, or low maladaptation. This is assessed and validated by experts and data where available.
6. **Stakeholder interest (social acceptance):** Another indicator for assessing adaptation strategies is the interest that stakeholders show in a plan, as this determines future uptake/ acceptance and implementation. It estimates whether an adaptation measure has a high, medium, or low stakeholder acceptance. This is assessed and validated by local key stakeholders, experts, and data, where available.
7. **Institutional support requirements:** Institution-led vs. autonomous: While most adaptation strategies can be initiated and implemented by different actors, depending on their concrete design, a distinction can be made between strategies that require generally high institutional support and those that can be initiated by (agro) pastoralists/ smallholders themselves, thus requires low institutional support. This is assessed and validated by experts and data where available.
8. **Nature-based solutions (NbS):** The International Union for Conservation of Nature and Natural Resources (IUCN) defines NbS as “actions to protect, sustainably manage, and restore natural and modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits”. Prioritizing NbS ensures that adaptation measures enhance resilience to floods and heatwaves and promote biodiversity and landscape protection. This is assessed and validated by experts and data where available.

These eight selection criteria were presented to and validated by key stakeholders during the Adaptation workshop. Then, key stakeholders were asked to weigh each criterion used in a Multi-Criteria Decision Analysis. Stakeholders ranked the validated criteria by assigning a score from 8 (most important) to 1 (least important). The average value of all assigned scores represents the weight for each criterion. The results of the ranking and the resulting weight of each criterion are shown in Table 8.

C. Multi-Criteria Decision Analysis – Defining a short list of adaptation measures

Multi-Criteria Decision Analysis (MCDA) is a structured approach used to prioritize adaptation measures by evaluating how well they meet multiple objectives. In the context of climate change adaptation, MCDA helps determine overall preferences among various measures by systematically comparing each measure against a set of predefined selection criteria, listed in Table 8. This method allows for a balanced assessment of different measures, ensuring that those selected address the immediate risks of floods and heatwaves and align with broader goals like economic viability, environmental stewardship, and the SDGs. Through MCDA, decision-makers can transparently and objectively identify the most suitable adaptation measures for implementation.

MCDA was applied to the long list of measures to get the short list of measures by estimating the value

Table 8: Weight of selection criteria. Ranked from 8 (most important) to 1 (least important)

Criterion	Average points	Weight
Cost-effectiveness	6.79	18.57%
Stakeholder interest (social acceptance)	5.79	15.84%
Co-benefits (for SDGs)	5.50	15.05%
Nature-based solutions	4.46	12.21%
Institutional support requirements	4.31	11.79%
Upscaling potential	3.85	10.53%
Potential for maladaptation	3.23	8.84%
No-regret options (risk gradient)	2.62	7.16%

for each selection criterion for each measure and then averaging the value based on the weight of each criterion. The total score is between 0 and 1, with 1 being the highest score and priority. The short-listed measures are presented in Table 9 below.

D. Costing of short-listed adaptation measures

The shortlisted adaptation measures were parameterized and input into CLIMADA. Another important piece of information to include is the estimated total implementation and maintenance

costs for the country from 2024 to 2050. This cost information was sourced from available and accessible literature, plans, or roadmaps, such as the Flood and Drought Master Plan 2021 from the Mekong River Commission and relevant news articles. Costs from the available years were then adjusted to reflect 2024 values by applying the local currency GDP Deflator. It goes through a calibration phase based on historical data. Finally, these costs were converted to USD using the projected 2024 exchange rate, providing a standardized and consistent financial framework for evaluating the adaptation measures.

Table 9: Short-listed adaptation measures

Hazard	Adaptation measures		Types	Score
Flood	1	Green spaces	NbS	1.00
	2	Wetland restoration and rehabilitation	NbS	0.94
	3	Detention swales along roads	Hybrid	0.86
	4	Improved solid waste management	Systemic	0.83
	5	Retention reservoirs	Hybrid	0.77
	6	Training for agricultural topics for adaptation	Systemic	0.73
	7	Dredging of canals	Grey	0.70
	8	Early warning system	Systemic	0.68
	9	Retention furrows	Hybrid	0.67
	10	Improved drainage system	Grey	0.55
	11	Sandbags	Grey	0.52
	12	Agricultural zoning	Systemic	0.47
	13	Water tolerant crops	Systemic	0.41
	14	Flood wall	Grey	0.40
	15	Flood index insurance	Systemic	0.35

Hazard	Adaptation measures		Types	Score
Drought	1	Wetland restoration and rehabilitation	NbS	1.00
	2	Soil, water, and pest management	NbS	0.96
	3	Legume seed production and propagation	NbS	0.89
	4	Climate-smart agriculture	Hybrid	0.78
	5	Management of protected environmental areas	Systemic	0.78
	6	Improvement of water storage systems	Grey	0.63
	7	Improvement of water distribution facilities	Grey	0.63
Heatwave	1	Green spaces	NbS	1.00
	2	Green roofs	NbS	0.85

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