United Nations University
Institute for Environment and Human Security

Enhancing risk assessments for improved country risk financing strategies

FINAL REPORT:
EGYPT

UNU EHS

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List of acronyms

AEI	Annual Expected Impacts
AR5/6	5th/6th Assessment Report
BMA	Bangkok Metropolitan Area
BMZ	German Federal Ministry for Economic Cooperation and Development
CCA	Climate Change Adaptation
CDRFI	Climate and Disaster Risk Finance and Insurance
CLIMADA	CLIMate ADAptation
CMIP6	Coupled Model Intercomparison Project Phase 6
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRED	Climate Resilient Economic Development
DGE-CRED	Dynamic General Equilibrium model for Climate Resilient Economic Development
ECA	Economics of Climate Adaptation
EIOPA	European Insurance and Occupational Pensions Authority
EIU	Economist Intelligence Unit
ERA	Enhancing Risk Assessment
ETCCDI	Expert Team on Climate Change Detection and Indices
FRA	Financial Regulatory Authority
GCM	Global Circulation Models
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GUI	Graphical User Interface
HOTOSM	Humanitarian OpenStreetMap Team
ICRM	Integrated Climate Risk Management
IPCC	Intergovernmental Panel on Climate Change
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
IUCN	International Union for Conservation of Nature and Natural Resources
MCDA	Multi-Criteria Decision Analysis
MCII	Munich Climate Insurance Initiative
NAPs	National Adaptation Plans
NbS	Nature-based solutions
NDCs	Nationally Determined Contributions
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
UNU-EHS	United Nations University Institute for Environment and Human Security
WCRP	World Climate Research Programme
WSDI	Warm Spell Duration Index

Foreword from the Financial Regulatory Authority

As the Financial Regulatory Authority (FRA), we are pleased to present the findings of the “Enhancing Risk Assessments (ERA) Project for Improved Country Risk Financing Strategies” for Egypt. This project addresses the pressing climate challenges Egypt faces, particularly the severe impacts of flash floods (and riverine floods in future scenarios) and heatwaves on our agricultural sector, the tourism industry, but also on energy generation, as well as non-economic effects such as education, mobility, and health effects on the population.

With the support of the ERA Project, we, as the different government organizations, have a more precise, data-driven understanding of the areas most exposed to these risks. Through the Economics of Climate Adaptation (ECA) framework, we have identified the regions, assets, and communities most vulnerable to climate impacts. This detailed understanding enables us to design targeted interventions, deploy resources efficiently, and prioritize the adaptation measures that deliver the greatest benefit and enhance our national resilience.

The insights derived from this project provide a foundation for developing robust risk financing strategies essential to reinforcing the socio-economic resilience of the different economic sectors and ensuring their sustainability. As we move forward, these findings will guide strategic decisions that offer meaningful support to Egyptian farmers, businesses, and local populations, equipping them to meet current and future challenges with greater confidence and resilience!

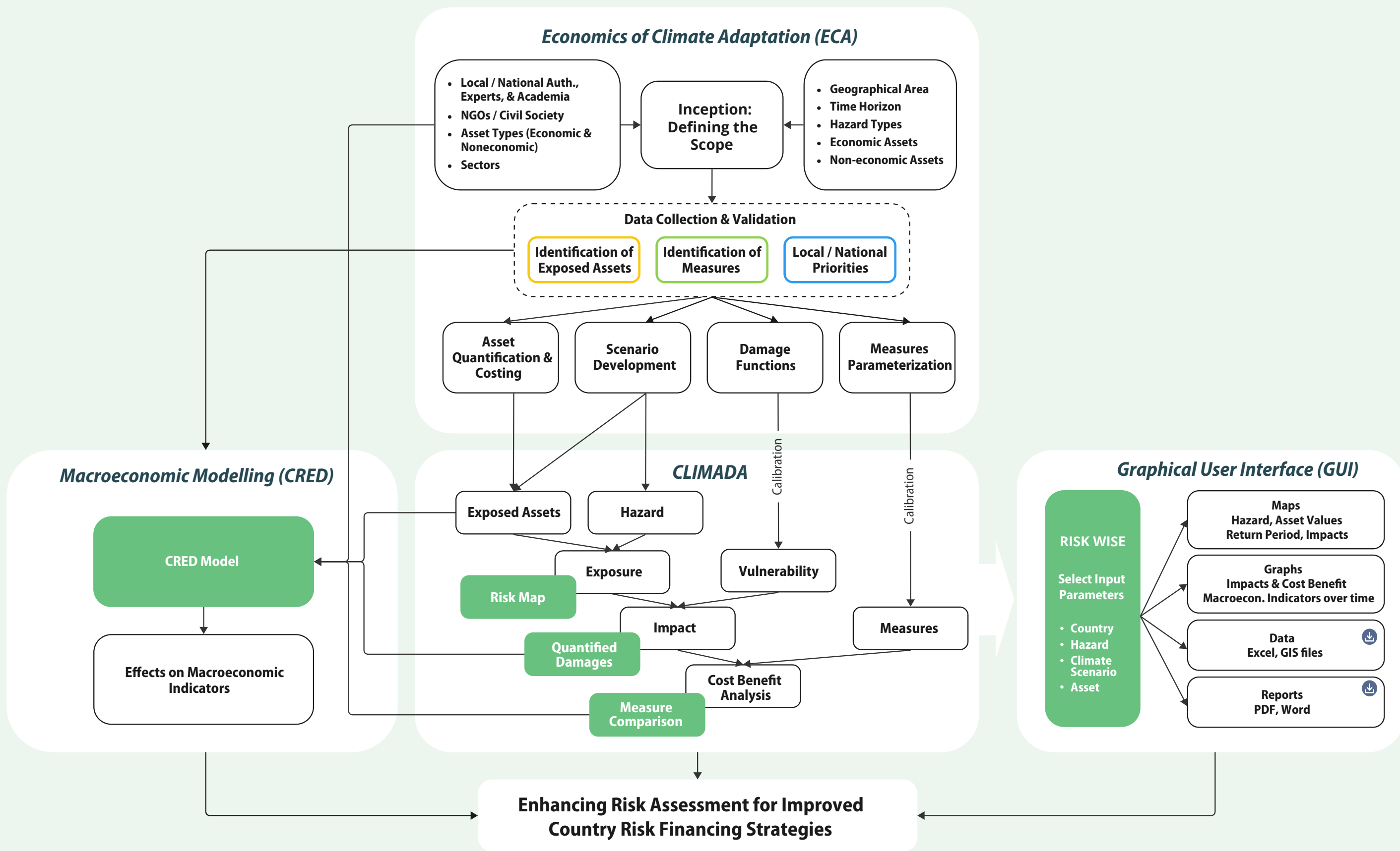
We hope these insights can accelerate the discussions between the different governmental bodies and beyond, encouraging them to join us in our commitment to a resilient, sustainable future for Egypt and its communities.

Office of the Deputy Assistant to the Chairman
Financial Regulatory Authority

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 economic effects of climate change. However, estimating climate and disaster risks and their impacts on macroeconomic indicators (e.g., GDP, employment) and non-monetary indicators (e.g., access to health, education, and cultural loss) remains challenging, making developing comprehensive financial protection strategies difficult (Nasr Ahmed et al., 2021).

The *Enhancing Risk Assessments (ERA) for Improved Country Risk Financing Strategies* project provides the Egyptian Government partners with a new generation of risk assessments for developing their climate change adaptation, which can inform their climate and disaster risk financing strategies. 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.



Scope

Through stakeholder consultation, the project defined the hazards, assets, and other parameters of the study, 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 Egypt.

Table: Scoping parameters of the study

Key elements	Selected components
Hazards	Heatwaves & heavy and sudden precipitation (flash floods)
Time horizon	2050
Climate scenarios	RCP-4.5 (intermediate GHG emission with estimated warming of 2°C between 2041-2060) and RCP-8.5 (very high GHG emission with estimated warming of 2.4°C between 2041-2060)
Economic assets	Agriculture (water bodies, crops, livestock), tourism (hotels), energy (power plants)
Non-economic assets	Mobility (transportation means), water access (water bodies), health (hospitals), education (schools)
Sectors for macro-economic impacts	Agriculture, tourism, real estate, financial sector, manufacturing, energy, health

Key findings

Exposure to heatwaves and floods

- Egypt is highly exposed to heatwaves and floods, with assets along the Nile River particularly likely to be affected.
- Heatwaves are an immediate threat, especially to agriculture, livestock, and urban infrastructure. Projected population growth and urbanization will exacerbate these risks, increasing energy demand and pressure on public services.
- Flood risk, although less severe in the near term, is expected to rise significantly, with riverine floods becoming more frequent and severe, particularly affecting agriculture and rural infrastructure.

Economic and non-economic impacts

- Economic Assets: Key sectors like agriculture (notably wheat production in regions like Asyut), tourism (hotels), and power generation are highly vulnerable to heatwaves and floods. Annual average damage estimates by 2050 range from $28.7 million under moderate climate scenarios (RCP 2.6) to $66.2 million under more extreme scenarios (RCP 8.5).
- Non-Economic Assets: Education, health, and transportation systems are at significant risk, particularly in urban areas. Students and road users face heightened risks from both hazards and health vulnerabilities, which are expected to increase, particularly due to the spread of climate-sensitive diseases.

Macroeconomic impacts

- The DGE-CRED model projections indicate that climate hazards could slow Egypt's economic growth over the next few decades, with the compounded effects of disasters having long-lasting impacts. The economic losses could be mitigated by up to 50 per cent through the timely implementation of adaptation measures.
- The findings emphasize the importance of early adaptation to avoid compounding economic losses that could persist long after individual events.

Adaptation strategies

- A mix of nature-based solutions (such as afforestation and flood retention reservoirs) and early warning systems (EWS) are key adaptation strategies. These approaches help mitigate flood risks, reduce energy demands, and protect vulnerable populations.
- For heatwaves, measures such as green roofs and urban tree planting are cost-effective solutions that can reduce energy use in buildings and mitigate health risks.
- Adaptation efforts should be integrated to address overlapping risks, with trade-offs carefully managed to ensure that both economic and non-economic sectors benefit equitably.

Recommendations

National-level adaptation

- Egypt must develop and implement a comprehensive national adaptation strategy, incorporating nature-based solutions, infrastructure upgrades, and early warning systems.
- Priority should be given to safeguarding key economic sectors like agriculture, energy, and tourism, which are vital for national development and are particularly vulnerable to climate hazards.

Investment in resilience

- Proactive adaptation investments will protect Egypt's assets from climate risks and ensure long-term economic resilience. Early investments in infrastructure, EWS, and ecosystem-based solutions can prevent significant economic losses over time.

Support for vulnerable populations

- Education, healthcare, and transportation systems need targeted interventions to protect vulnerable groups, especially in urban areas where climate risks and population densities intersect.

Leveraging RISK WISE for decision-making

- RISK WISE should be utilized by local authorities and national policymakers to explore risk scenarios and develop localized adaptation plans. Future upgrades of the tool should focus on expanding its functionality to include automatic data calibration, enhancing its reliability for broader user-generated inputs.

Conclusion

The report underscores the pressing need for Egypt to strengthen its climate resilience by integrating adaptation into both national policy and sector-specific strategies. The findings from this study provide a robust foundation for guiding these efforts, offering actionable insights through the CLIMADA and DGE-CRED models and practical tools like RISK WISE to support decision-makers. Climate adaptation is necessary to mitigate risks, ensure sustainable economic growth, and protect Egypt's most vulnerable populations.

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1. Introduction

1.1 Context

Climate change leads to increased frequency and severity of extreme weather events, conflicts, and global instabilities, disrupting supply chains, causing economic downturns, and reducing food security and socioeconomic stability. Developing countries are hardest hit due to extreme poverty and harsh geographic conditions (Lalthapersad-Pillay & Udjo, 2014). There are significant impacts on vulnerable populations and countries after the far-reaching consequences of macroeconomic shocks. Agricultural production in Egypt is expected to decrease by 10-18 per cent by 2030, with consumer prices rising by 7 per cent to 24 per cent and producer prices rising by 12-22 per cent in a worst-case climate scenario, considering lower yields and higher water demand (Nasr Ahmed et al., 2021).

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 economic effects of climate change. However, estimating climate and disaster risks and their impacts on macroeconomic indicators (e.g., GDP, employment) and non-monetary indicators (e.g., access to health, education, and cultural loss) remains challenging, making developing comprehensive financial protection strategies difficult (Nasr Ahmed et al., 2021).

Considering the difficulties outlined above, the *Enhancing Risk Assessments (ERA) for Improved Country Risk Financing Strategies* project provides the Egyptian Government partners with a new generation of risk assessments for developing their climate change adaptation, which can 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 Egypt. Overall, the project aimed to answer three guiding questions:

i. What is the potential climate-related damage over the coming decades?

ii. How much of that damage can be averted, and what type of Climate Change Adaptation (CCA) measures can be used?

iii. 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 comprehensively present the Enhancing Risk Assessment (ERA) approach. 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 Egypt. 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 enhanced risk assessments (ERA)

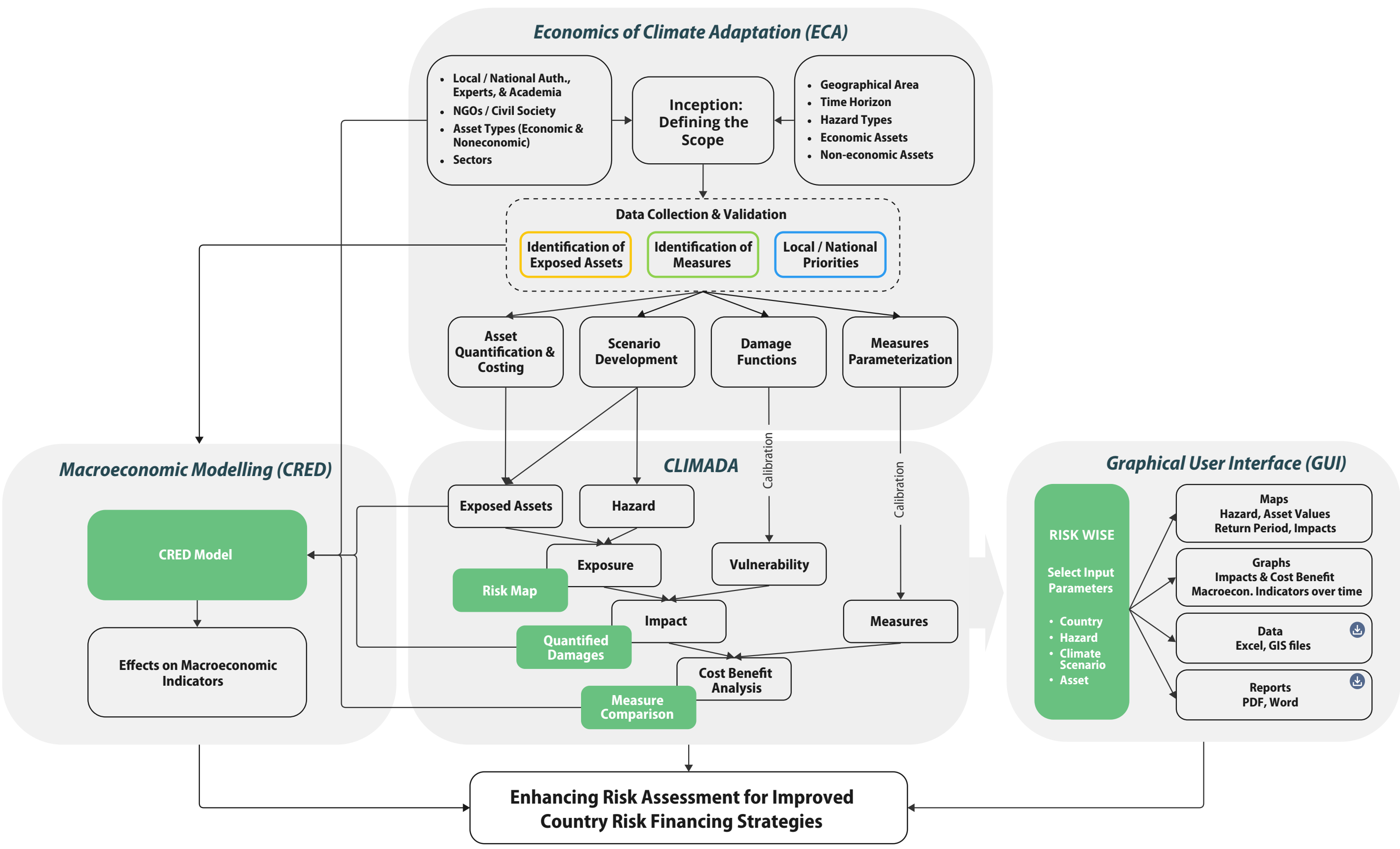
As the name implies, the overall objective of the ERA project was to provide the partners in the Egyptian government with an enhanced risk assessment for developing climate change adaptation and informing climate and disaster risk financing strategies. To accomplish this, the *Economics of Climate Adaptation* (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 basic 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 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. 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, 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 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 programme-based insurance solutions 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

CLIMate ADAptation (CLIMADA) is a modelling platform that enables probabilistic climate risk modelling and estimates the averted damages (benefits) of different adaptation measures. It involves several steps: geospatial asset localization, asset valuation, and scenario development to simulate different climate risks, damage 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)

iii. enable dynamic application by partner institutions through a simple Graphical User Interface (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. We use the Dynamic General Equilibrium model for Climate Resilient Economic Development (DGE-CRED) to extend the ECA insights to a country-wide socioeconomic scale. 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 full economic system and how they 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 Egypt 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 Egypt and climate change

Located in the northeastern corner of Africa, Egypt is surrounded to the west by Libya, to the south by Sudan, to the east by Palestine, and Israel along the Mediterranean Sea in the north. Egypt’s topography is characterized by the vast and arid Sahara Desert, which occupies most of the country, the fertile Nile River Valley and Delta, and the Sinai Peninsula’s rugged mountainous region. Egypt experiences a desert climate with a mild winter from November to April and a hot summer from May to October, with temperatures varying from 140C in winter and 30°C in summer in the coastal regions. The inland desert area experiences temperature fluctuation, ranging from 43°C during the day in summer, 7°C at night in summer, and 18°C during the day and 0°C at night in winter (World Bank, 2021a). Egypt is one of the most populous countries in the Middle East and North Africa (MENA), with approximately 92.1 million people, most of whom are concentrated along the Nile River and its delta (CAPMAS, 2017). The country’s GDP is estimated at USD 395.9 billion in 2023, with key contributions from agriculture, industry, and services (Kamal, 2018; World Bank, 2024).

The impact of climate change in Egypt is significant due to its geographical location, population growth, and reliance on agriculture (Devaux, 2023). The situation will exacerbate Egypt’s vulnerabilities, increasing human development challenges and uneven distribution of resources and opportunities across different geographical areas. Climate change will increase uncertainty in water availability, intensify heatwaves and desertification, and threaten biodiversity and food security. Sea-level rise could lead to saltwater intrusion, inundation, and erosion in coastal regions such as Alexandria, further impacting water quality for agriculture and drinking (World Bank, 2022). The agricultural land within the Nile Delta is already under threat due to higher temperatures (Smith et al., 2014).

Further, according to the World Bank (2022), there is high uncertainty around the timing and volume of Nile River water, which accounts for about 97 per cent of freshwater resources in Egypt, available to Egypt due to climate change impacts. The cumulating impacts of climate change can result in a total economic loss estimated at USD 36 billion to USD 64 billion. Estimates for Egypt suggested that by 2060, the combined impact of climate change will represent between 2 per cent and 6 per cent of Egypt’s GDP (Smith et al., 2014; World Bank, 2022).

1.3.1 Flash floods

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 (CRED, 2024). Flash floods have become one of the major disasters in arid regions, bringing severe damage. These floods can be caused by rainfall from intense thunderstorms or the sudden release of water from reservoirs. They develop quickly with high flow velocities, often within hours of heavy rain (Shao-Hong et al., 2012). Flash floods have undeniable impacts on Egypt’s economy and environment. The country has been subjected to several flash floods over the past decade, affecting many parts of Upper Egypt, the Red Sea, and the Sinai regions. Severe flash floods were recorded in 1987, 1997, 2010, and 2016, resulting in significant loss of life and property damage (Cools et al., 2012; Prama et al., 2020). More recently, heavy rains caused severe flooding in Egypt, affecting cities like Cairo, Giza, South Sinai, and the Red Sea regions in 2020. The catastrophic event caused 40 fatalities, with 400 people injured, and affected 20,000 people or 4,000 families (IFRC, 2020).

Multiple factors aggravate vulnerability to flash floods in Egypt. Climate change, rapid population growth in flood-prone areas, and inadequate management exacerbate flood risk (Saber et al., 2020). Managing flash floods becomes increasingly critical as the country faces challenges implementing sustainable development plans. Improved understanding, prediction, and mitigation of these events are essential for reducing their devastating impacts and ensuring the safety and well-being of Egypt’s population. The government addresses climate change challenges by improving its flash flood assessment and prediction capabilities. Integrating GIS and hydrological simulation models in identifying high-risk areas and providing warnings for evacuation and emergency response have become crucial for risk assessment and early warning systems (El Gohary, 2020). To mitigate the impacts of flash floods, the Egyptian government has invested in structural measures such as storage dams and artificial lakes to control floodwaters. However, implementing these strategies faces challenges due to water scarcity issues in arid countries.

1.3.2 Heatwaves

Climate change is expected to increase mean temperatures and extreme heat in dry, arid environments. Egypt’s already hot climate is becoming even more extreme, with average temperatures rising in the 2000s. Projections indicate an increase in the temperature by 0.53°C per decade (World Bank, 2021b). Moreover, extreme weather events such as heatwaves are becoming more frequent and intense. The escalating temperatures pose severe risks to public health, agriculture, water resources, and the economy. Studies have indicated that increasing heatwaves in Cairo lead to higher indoor overheating risk and health impacts, especially for elderly residents with limited access to cooling (Bayomi et al., 2021). For instance, the 2015 heatwave in Egypt resulted in over 90 deaths, primarily affecting the elderly and those in cramped living conditions (Mitchell, 2016).

Heatwave significantly impacts Egypt’s energy sector, particularly in big cities such as Cairo. During the peak summer months, up to 50 per cent of the city’s electricity is used for air conditioning to cope with extreme heat (IEA, 2023). Heatwaves can cause severe water shortages as higher temperatures lead to increased evapotranspiration. Researchers have analyzed historical data and predicted rising temperatures will accelerate evapotranspiration, leading to water shortages (Badr et al., 2023). This issue is critical in a country where water scarcity is already a pressing issue.

Heat stress caused by extreme temperatures can negatively impact Egypt’s economy by reducing agricultural productivity. The high temperatures are expected to disrupt the country’s domestic food supply chains as elevated temperatures influence the duration of crop-growing periods and even alter the areas where certain crops can be cultivated, making it more challenging for sustainable food production (Gamal et al., 2021). Sudden temperatures have negatively affected the growth and productivity of crops such as wheat across different regions in Egypt (Khalil et al., 2021). These extreme temperature fluctuations threaten millions of Egyptians’ food security and livelihood.

2. Economics of Climate Adaptation (ECA)

2.1 Further on the ECA framework

The ECA framework is applied in this report 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 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 places 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 socio-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 not only the impacts on the physical assets but also on the services provided by some of them.

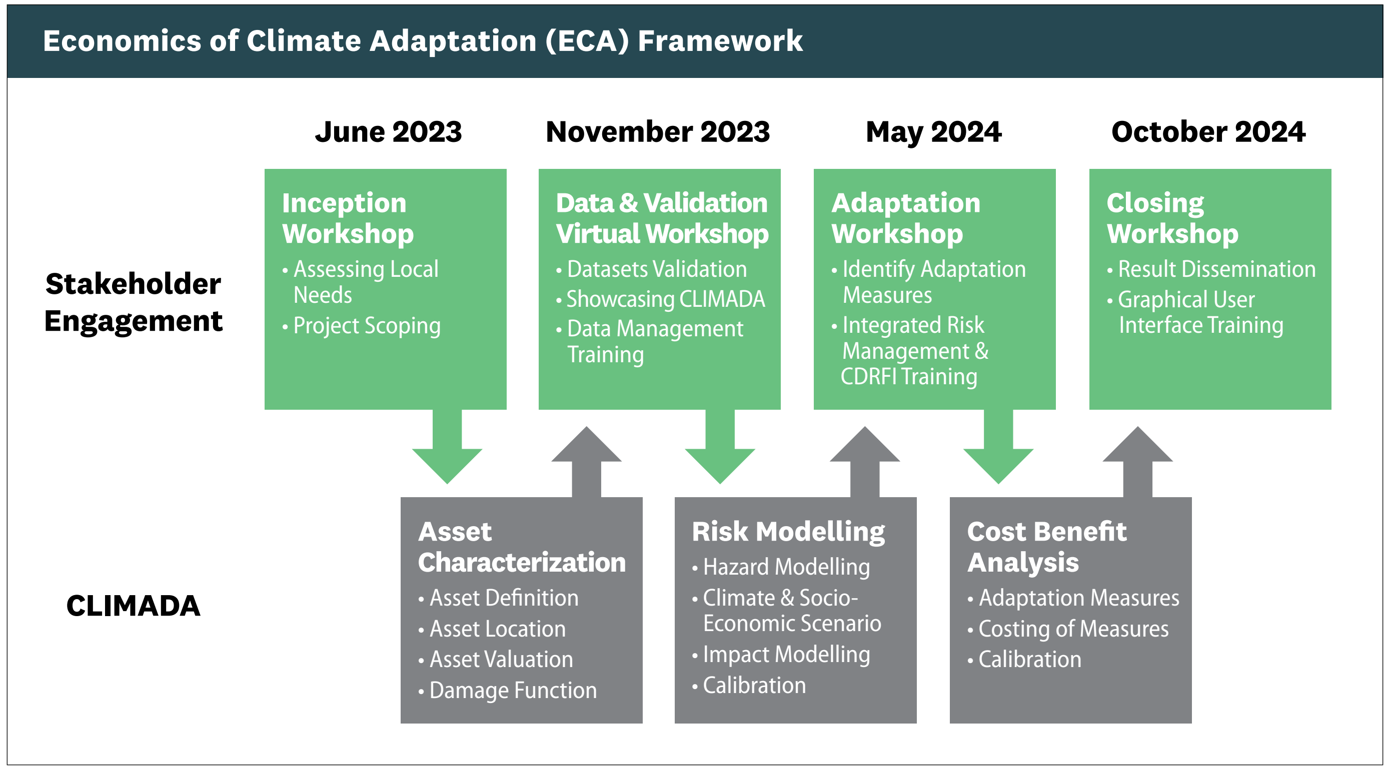
A plethora of approaches have already been designed to respond to the complexity of climate change-related projects. Regarding the development of climate change adaptation strategies, they range from climate vulnerability assessments, risk assessments, and economic and/or sustainability impact assessments 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 and the linked open-source modelling platform CLIMADA. The latter uses available data to calculate the potential impact of current and future hazards on several selected assets, including the costs/benefits of selected measures.

However, there's still a need to include non-economic assets and macroeconomic impacts in ECA and CLIMADA. The steps ERA followed to integrate these assets, CRED for macroeconomic assessments, and the GUI for enhanced access to the project results into the ECA framework are presented in Figure 2, including the series of stakeholder engagement workshops implemented in cooperation with GIZ and local partners, UNU-EHS and MCII, focusing on integrated climate risk management.

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 approach, ensuring the accuracy and relevance of the project's data and assumptions. Below is a brief

Figure 2: ERA approach for the ECA framework



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 Financial Regulatory Authority (FRA) and GIZ. The workshop discussed the needs and expectations of local stakeholders and collaboratively defined the scope of the risk assessment. 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 to:

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 Egypt.

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 1.

As presented in Table 1, the initial hazard identified during the inception workshop included heatwaves and heavy and sudden precipitation. While the heatwaves remained unchanged, heavy, sudden precipitation was revised to flash floods as a direct result of heavy, sudden precipitation, which has, more evident, immediate effects.

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 flash floods and heatwaves were collected. Further, specific indicators and the quantification methodology were developed for the economic and non-economic assets,

Table 1: Key elements for the risk assessment

Key elements	Selected components
Hazards	Heatwaves & heavy and sudden precipitation
Time horizon	2050
Climate scenarios	RCP-4.5 (intermediate GHG emission with estimated warming of 2°C between 2041-2060) and RCP-8.5 (very high GHG emission with estimated warming of 2.4°C between 2041-2060)
Economic assets	Agriculture (water bodies, crops, livestock), tourism (hotels), energy (power plants)
Non-economic assets	Mobility (transportation means), water access (water bodies), health (hospitals), education (schools)
Sectors for macro-economic impacts	Agriculture, tourism, real estate, financial sector, manufacturing, energy, health

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.

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	11
6. Non-economic assets	14
7. Mobility	12
Total	68

After the inception workshop, data collection was carried out. The Egyptian government provided several data required for modelling. The remaining data was supplemented with open databases. A simultaneous and extensive literature review was conducted 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 collected data as best available.

3. To present the identified indicators to assess non-economic impacts.

4. To discuss the data usage for CLIMADA in depth.

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 Data Validation workshop concluded, 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 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 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 knowledge with the organizers as possible. The different activities inquired about 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 Egyptian 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 offers further details on the methodology for selecting adaptation measures. A detailed overview of the Methodology for Adaptation Measure Selection can be found in Annex 2.

4. Closing workshop

The closing workshop aims to deliver the project results to participants and discuss the follow-up opportunities with them 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 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, various sources were utilized to construct and validate assumptions on the vulnerability of assets to different intensities of events, 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 identified 13 shortlisted adaptation measures (5 for floods, 6 for heatwaves, and 2 shared), including grey infrastructures, nature-based solutions, hybrid and systemic measures, and insurance.

Briefly summarized below are the steps taken for the CLIMADA platform, which are aligned with the Stakeholder Engagement activities from ECA. These activities provided CLIMADA with the most accurate data possible. Broadly speaking, the information gathered from stakeholders was analyzed further via the processes summarized in the following sections.

1. Asset characterization

After the conclusion of the Inception workshop, the data collection phase fully commenced. The Egyptian partners of the project strongly supported this phase, facilitating access to existing data. When necessary, the required data was supplemented with open-access 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 assets, at which rate the damage occurred, and where exactly these assets were located within Egypt. Lastly, an estimated valuation of the total assets was created using information gathered during the various workshops and by our literature review. More detailed explanations of the process with specific examples can be found in Annex 1.

2. Risk modelling and calibration

CLIMADA requires two major driving pieces of information to characterize the risks in any given region. This specific information is consolidated through two data inputs: the hazard and the entity files. The hazard files contain information on the type, intensity, and frequency of the hazard under consideration for current and future conditions. These files were developed based on the best available and accessible data sources at that time, considering the availability of future hazard projections under climate change. 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 costs) and the net averted damage of a set of measures, thereby presenting a measure-specific prediction of worthwhile investments. 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 and heatwave risks in Egypt, which involves a systematic four-step process:

1. First, a comprehensive 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 selecting and weighing the criteria 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 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 and heatwaves, which, in the case of ERA, offers valuable insights for national-level decision-making. While the hazard models rely on secondary data and global projections that were downscaled to local contexts, this approach is common in probabilistic assessments (Chokkavarapu & Mandla, 2019; Giorgi & Gutowski, 2015). It allows for the comparison of risk trends across regions. The lower 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 reasonable for guiding resilience-building actions, even as they may not capture the granularity of localized events.

Another consideration is that the damage functions derived from a thorough literature review have not yet been fully validated with ground-level data. Limitations of data availability in the Egyptian context led to challenges in verifying and calibrating these functions. However, expert consultations during stakeholder workshops were used to validate these and other inputs, assumptions, and results throughout the project. The damage functions used in ERA ultimately offer a credible starting point for estimating potential impacts across different scenarios. While uncertainties are inherent to all models of this nature, they do not diminish the value of the insights gained, particularly when recommendations are intended to inform national-level adaptation strategies (Ylhäisi et al., 2014).

The results of our analysis should be seen as a foundational layer upon which future work can build. While using these results for decision-making at more localized levels introduces challenges and is therefore discouraged, the national-level analysis provides a strong baseline for comparing regions and guiding broad-scale interventions. Further research and validation at the local level are needed to refine these findings and enhance their applicability. This iterative approach ensures that the model's outputs remain a powerful tool for resilience planning while acknowledging the need for continued refinement as more localized data becomes available.

2.2 Modelling inputs

2.2.1 Hazard models

1. Flash floods

Due to limited data availability on flash floods, the flood hazard map was generated using the CLIMADA River Flood API, an open-source platform designed for probabilistic multi-hazard risk modelling. This hazard map served as a proxy for flash flood modelling. A notable strength of the CLIMADA River Flood API is its seamless integration with other components of the broader CLIMADA framework. It enables users to combine flood hazard data with exposure and vulnerability information to assess flood impacts comprehensively (Riedel et al., 2024). The platform is designed for accessibility and computational efficiency, leveraging freely available data to promote widespread adoption of flood risk assessment and management (Riedel et al., 2024).

CLIMADA estimates economic damage to measure the risk, which involves translating flood depth into potential damages (ETH Zürich, 2024; Riedel et al., 2024). The CLIMADA River Flood API requires input data, including spatial flood depth and fraction. This study used data from the ISIMIP2a and ISIMIP2b simulations of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP)[1], featuring a resolution of 150 arcseconds (~5 km) (Sven Willner et al., 2024). These simulations provided outputs from the CaMa-Flood river routing model, driven by runoff data from various global hydrological models (GHMs) under different climate scenarios (ETH Zürich, 2017). Flash floods have a distinct spatial distribution compared to the modelled river floods that we used, since flood losses will tend to be along rivers rather than, for example, the Sinai Peninsula. Therefore, some at-risk exposures will not be well-modelled in this study.

In this study, flood hazards were assessed for different return periods (RP2, RP5, RP10, and RP25) across two scenarios: present (2024) and future (2050). The results illustrate the increasing impact of flood hazards on vulnerable regions in Egypt over time.

2. Heatwaves

The heatwave hazard information, as an input for CLIMADA, was modelled in a standalone manner outside the CLIMADA environment. The Warm Spell Duration Index (WSDI) was selected to characterize the heatwave conditions in Egypt. This climate indicator measures persisting warm spells as a robust proxy for heatwaves based on the daily maximum temperature information and is mainly based 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 a better indicator for Egypt. Since 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.

For the WSDI-based heatwave hazard modelling in Egypt, the CORDEX Regional Climate Model (RCM) projections tailored for the Africa domain were opted for. 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 of 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 from RCA4 RCM runs driven by the Had-CGCM2-ES GCM based on IPCC AR5 future projection scenarios, namely RCP 4.5 (intermediate scenario) and RCP 8.5 (high-emission scenario), were selected. The daily maximum temperature data for current baseline conditions from 1979-2005 and future projected scenarios (2025-2050) were acquired from the CORDEX Africa domain at a resolution of 0.22x0.22 degrees (roughly ~25km) to calculate the WSDI intensities and the corresponding frequencies. Using the daily RCM data, the WSDI was calculated as the total count of days that are a part of a heatwave/warm spell. The sequence of 6 or more consecutive days when the daily maximum temperature exceeded the 90*th* percentile of the baseline normal period (~30 years, typically used and adopted in this study) was considered the duration of unusually warm periods.

Given the pertinent information on heatwave signals, albeit the computational simplicity, there are 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 in most regions with ungauged catchments, several assumptions are necessary to represent physical processes. Despite the limitations, the WSDI generously provides a robust 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, prioritising ample historical and future projections at a reasonably sound spatial detail, which was provided by the higher resolution (0.22 degrees) products of CORDEX AFRICA.

3. Climate scenarios

This report recommends using the Regional Climate Models (RCM) offered by the CORDEX, a global coordination effort for developing high-resolution climate projections and precipitation models by downscaling GCMs to RCMs (Pinto et al., 2018; Pinto et al., 2016). Particularly, the Coordinated Regional Climate Downscaling Experiment proved more accurate and outperformed any other simulation independently from the data used over countries. However, RCM models with biases within the observation values are known for overestimating extreme precipitation numbers on rainy days (Samuel et al., 2023).

For this study, the climate change emission scenarios based on the IPCC Fifth Assessment Report (AR5) were considered for the climate change assessment. The sixth Assessment Report from the IPCC (AR6) and the Coupled Model Intercomparison Project Phase 6 (CMIP6) include over 100 GCM models from over 50 modelling centres. However, applying the raw data of GCMs at a local scale without downscaling due to their relatively coarse resolution is a rigorous task. Due to the unavailability of the current CMIP6 CORDEX data for the African region, the CMIP5 CORDEX data available at higher resolution were selected. Regarding the AR5 scenarios, there is no consensus on which of the four Representative Concentration Pathways (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. 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 specific regions, and precipitation and temperature 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.

As part of the Inception Workshop, participants were asked to select the scenarios for which the future impacts should be projected. RCP4.5 and RCP8.5 were chosen to provide a range of possible effects and consider a less optimistic scenario in the Heatwave modelling. However, RCP 2.6 (weak climate change signal) was used instead of the requested 4.5 in the case of floods because the accessed projections were of better quality and more consistent with other studies.

2.2.2 Asset characterization (Economic and non-economic)

The report evaluates the impact of floods 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 1 presents further details on this process.

Data for this analysis were sourced from online research centres, databases, and Egyptian authorities. Given the limited availability of historical damage data, additional sources were utilized to confirm and refine the assumptions made, 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. Therefore, all assets are geo-located and partitioned where necessary. Similarly, the model requires numerical values for all assets to assess an initial and a post-

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

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 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 flash floods 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 with current events. 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 in CLIMADA to reflect historical data before they can be used for future projections. We used existing damage functions on different assets with the intensity parameter of depth and WSDI for floods and heatwaves, respectively, supplemented with historical data from Egypt 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 flash floods 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 Egyptian 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 seven asset groups for floods: in the case of non-economic assets, the addressed impacts are related to health (diarrhoea patients), mobility (road users), and education (students). Regarding economic impacts, the assets were crops, livestock, hotels, and power plants. Five asset groups were included for heatwaves: heat-related patients and students for non-economic impacts, and crops, livestock, and hotels for the economic ones. As presented before, for non-economic assets, the quantification is based on population counts at a specific resolution, representing the distribution of these assets across Egypt.

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. Table 3 summarizes the hazards analyzed, the related economic and non-economic assets, and the total

Table 3: Summary of hazards and the value of their economic and non-economic assets

Hazard	Asset type	Impact	Asset	Total value	Value unit
Floods	**Non-economic**	Education	Students	17,240,136	People
		Health	General population	95,944,315	People
		Mobility	Road users	721,643	People
	Economic	Crops	Crop (Cash crops)	10,931,742,102	USD
		Livestock	Livestock (Cattle / buffalo)	9,064,750,597	USD
		Hotel	Hotels	775,845,545	USD
		Power plants	Power plants	19,802,999	USD
Heatwaves	**Non-economic**	Education	Students	17,240,136	People
		Health	General population	95,944,315	People
	Economic	Crops	Crop (Cash crops)	10,931,742,102	USD
		Livestock	Livestock (Cattle / buffalo)	9,064,750,597	USD
		Hotel	Hotels' electricity bill	138,357,384	USD

value of assets. The detailed methodology for asset valuation for economic and non-economic assets is given in Annex 1. As explained in Chapter 2.1.2, the values of the assets are used to quantify the expected impacts of the studied hazards on the assets and the benefits of the adaptation measures.

2.2.2.1 Economic assets

1. Crops

Agriculture plays a crucial role in Egypt's economy, contributing 14.5 per cent to the country's GDP and employing 28 per cent of the workforce (MOIC). This sector is essential for maintaining economic stability and food security, especially given Egypt's rapidly growing population. However, climate hazards such as floods and heatwaves threaten agricultural outputs significantly. Projections indicate that agricultural production in Egypt could decline by 8 per cent to 47 per cent by 2060 due to these climate impacts, exacerbating food scarcity, driving up prices, and increasing reliance on food imports, which could further strain the economy (UNDP, 2013).

The increasing intensity and frequency of floods due to climate change can result in crop failures by physically damaging canopies or negatively affecting soil conditions, limiting root and plant function. Further, highly wet conditions due to flooding can also delay key field operations, such as planting and harvesting, affecting agricultural yield (Khalil et al., 2021; van der Velde et al., 2012).

Figure 3 illustrates the agricultural areas at risk due to floods in Egypt. The map shows the significant impact of floods on Egypt's agriculture, with the most vulnerable areas concentrated along the Nile River. Flood exposure to crops is mostly seen along the Nile River around the densely cultivated regions. Under the future climate scenario (RCP 2.6 and RCP 8.5), flood risk is particularly high in the densely cultivated regions of northern Egypt, including major areas like Cairo, Giza, and the Nile Delta governorates such as Beheira, Qalyubia, and Kafr el-Sheikh. These areas are susceptible to current and projected future flood events, potentially leading to significant economic losses in Egypt's agriculture sector. It is crucial to note that Egypt's agriculture heavily relies on the Nile-adjacent regions, making these areas particularly vulnerable to the increasing floods due to climate change.

Figure 3: Exposed crop areas to floods

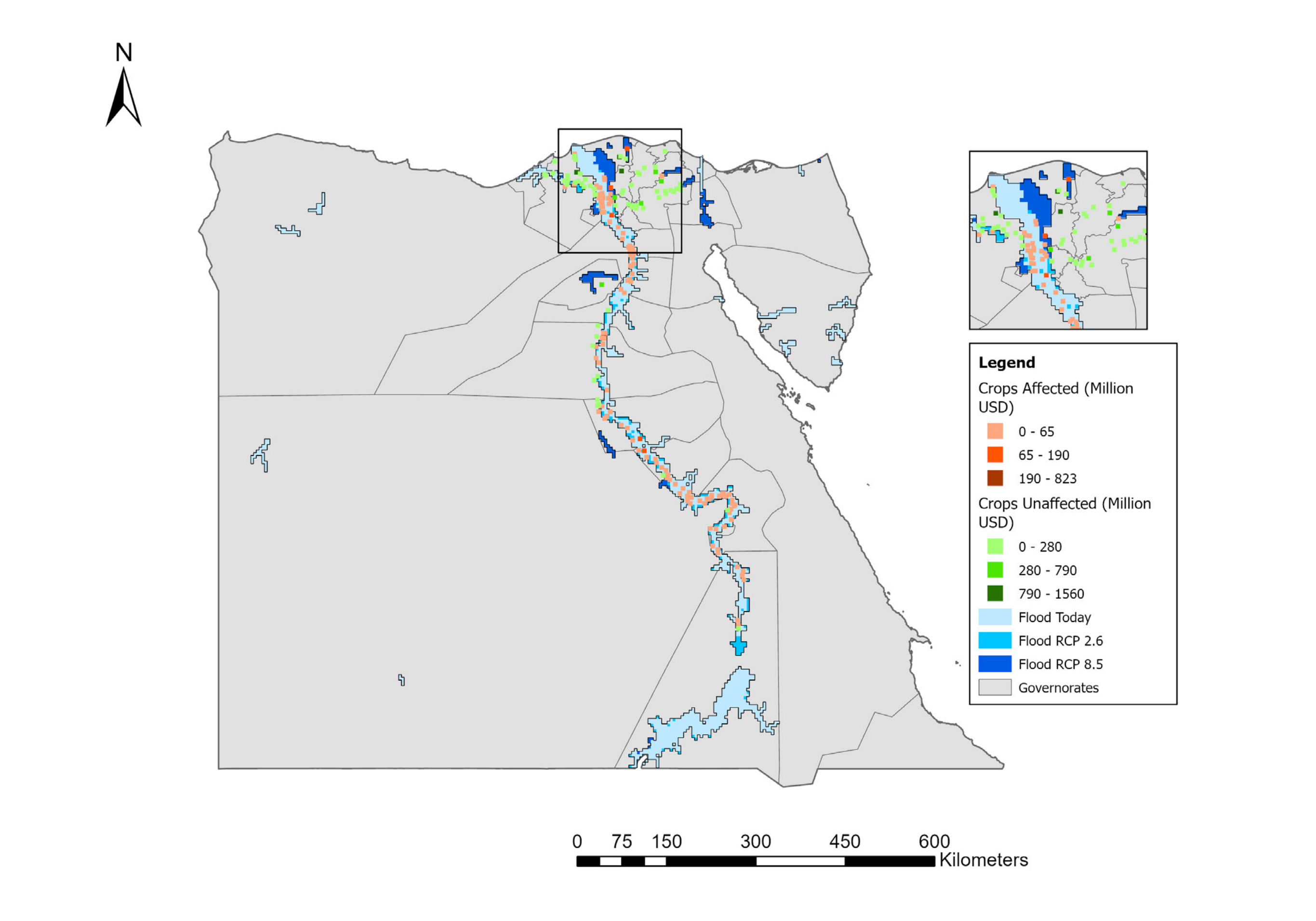


Figure 4: Exposed crop areas to heatwaves under RCP 8.5

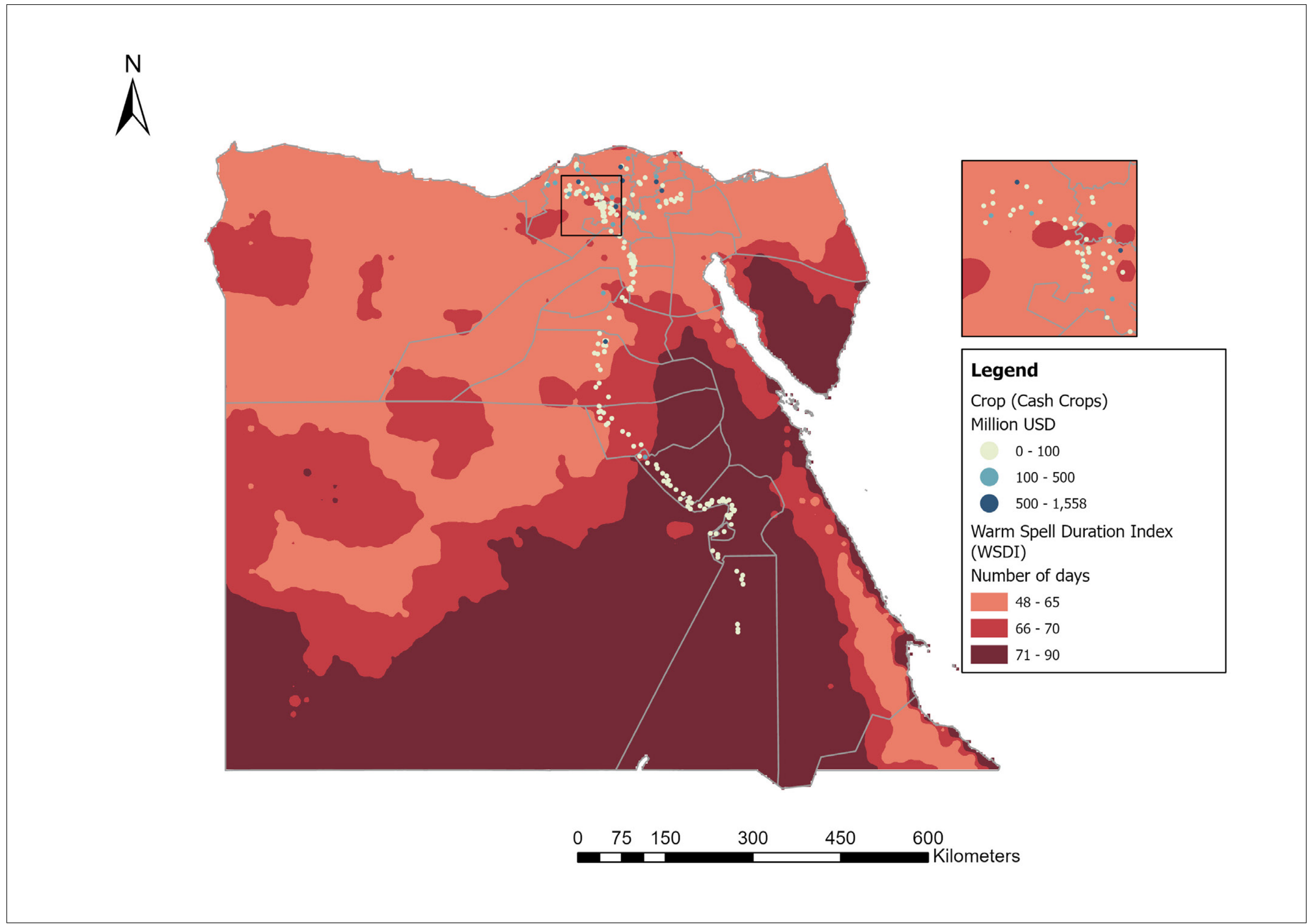
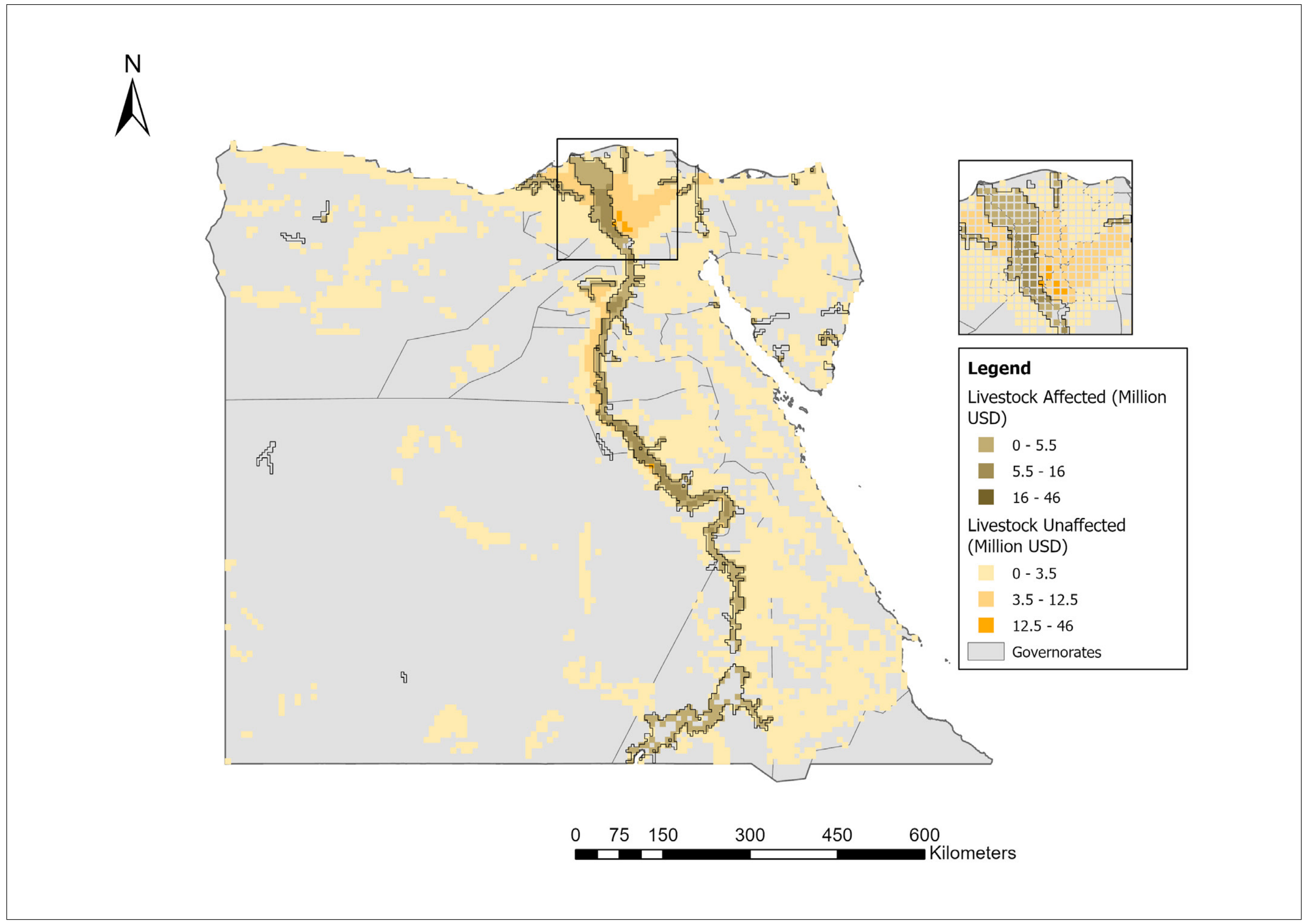


Figure 5: Exposed livestock areas to floods



Similarly, heatwaves can result in heat stress and reduce crop growth and development, particularly on heat-sensitive crops, thereby damaging crops and reducing yield, productivity, and quality (Maksoud, Tharwat Diab Abd El, 2022). Figure 4 illustrates Egypt's crop exposure to heatwave under an RCP 8.5 scenario for 2050. Southern Egypt, especially near Asyut, Sohag, Qena, and Luxor, are the most vulnerable regions, experiencing longer warm spells (71-90 days) on average than other parts of the country. The crops in these regions are more exposed to extreme heatwaves, while regions in the north, specifically the Nile Delta region, are exposed to more moderate heatwaves. That said, the number of crops grown in the latter Delta region is much greater, potentially leading to significant economic losses, which could be as high as 1.56 billion USD in some areas, as depicted in the figure below.

2. Livestock

The livestock sector in Egypt is predominantly composed of cattle, goats, sheep, and water buffalo. Livestock is a crucial component of the country's agricultural economy, contributing to the sector's output, with livestock products representing 40 per cent of the value-added agriculture (Ahmed et al., 2020). In 2021, livestock accounted for 24.5 per cent of Egypt's agricultural GDP (World Bank, 2021b). However, climate hazards threaten livestock health and productivity. Floods can result in direct livestock losses by drowning, disease outbreaks, and damage to infrastructure such as barns, feed storage, and transportation routes. Additionally, livestock greatly suffers from heatwaves due to heat stress, resulting in decreased milk production and affecting an essential source of food and income in Egypt (World Bank, 2021b).

Figure 5 presents the exposure of Egypt's livestock to floods. The most affected area is concentrated in Northern Egypt, adjacent to the Nile Delta region, which includes major cities such as Cairo, Giza, and Alexandria and the Nile Delta governorates such as Beheira, Qalyubia, and Kafr el-Sheikh, where the potential economic losses in livestock reach comparatively higher levels. It is important to note that the central and southern parts of Egypt along the Nile River, including the Asyut, Sohag, Qena, Luxor, and Aswan, while also exposed to floods, have a relatively low exposure.

Heatwaves significantly impact livestock in Egypt, particularly in summer when the temperature is higher, affecting their health and productivity. High temperatures often suppress food intake, leading to lower feed, reduced weight, and lower milk yield (Goma & Phillips, 2021). Further, prolonged exposure to heat can cause heat exhaustion or heat stroke, which can be fatal to the livestock if not appropriately managed (Goma & Phillips, 2022). These challenges can result in economic losses for farmers and the country's economy.

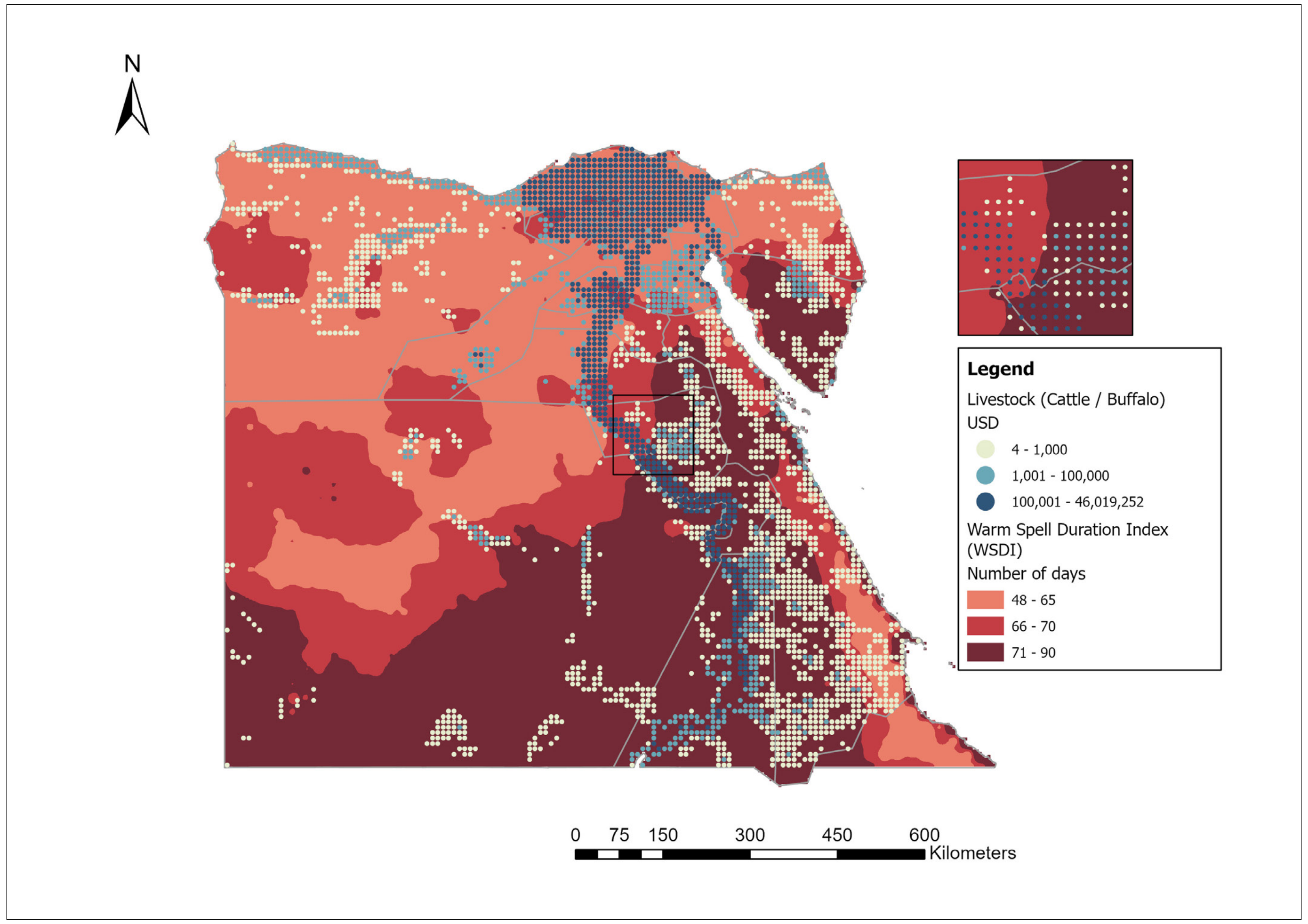
Figure 6 illustrates Egypt's livestock exposure to heatwaves under an extreme climate scenario. The figure shows that the livestock population is most concentrated in areas like the Nile Delta along the Nile River, particularly in regions near major cities such as Cairo and Alexandria. These areas are characterized by higher livestock density and moderate exposure to heat waves. Further, central Egypt in regions such as Minya, Asyut, and Sohag are substantially affected by heatwaves, with some areas experiencing 71-90 days of extreme heat. The prolonged exposure to heatwaves makes the region critical regarding livestock exposure to heatwave.

3. Hotels and power plants

Tourism significantly contributes to the Egyptian economy with a projected revenue of USD 2.78 billion by 2024 (Statista, 2024b). However, this key industry faces increasing challenges due to extreme weather events. Floods have caused extensive damage to hotel infrastructure and disrupted operations in certain areas (UNDRR, 2014). This hazard can cause significant damage to hotel buildings, foundations, walls, and electrical systems. Further, floods can lead to power outages, affect water supply, and disrupt hotel services, affecting the comfort and safety of the guests. These impacts can result in substantial financial loss to hotel owners due to increased cost of repairs and loss of business during floods (Negm, 2020; Saber et al., 2020).

Many hotels are located along the Nile River. These areas are critical to Egypt's tourism sector and are particularly vulnerable to current and future flood events. Floods could severely impact the hotel infrastructure in the country's northern region, especially in Cairo, Qalyubia, Monufia, and Al Sharqi, where the tourism industry is highly concentrated. The exposure map presents a substantial risk to the

Figure 6: Exposed livestock areas to heatwaves under RCP 8.5



country's tourism sector and local economies, which are essential for the country's revenue.

Similarly, power plants are critical infrastructure in Egypt, providing electricity to support the country's growing population and industrial development. Increasing floods in Egypt can cause significant damage to power plants, causing operational disruptions. The exposure of power plants along the Nile River, especially in Cairo, Qalyubia, Monufia, and Al Sharqi, is of particular concern, as floods in these areas could disrupt the energy supply to most of the regions in the country.

Figure 7 illustrates the exposure of hotels and power plants to floods in Egypt.

Heatwaves significantly affect hotels by increasing the cost of energy, considering the high demand for cooling, especially during the summer months (IEA, 2023). Guest comfort is a primary concern for hotels, and with the increasing temperature, hotels are highly dependent on cooling infrastructures. The higher the use of air conditioning to keep the guests comfortable, the higher the energy bills for the hotels. The direct impacts of heatwaves on power plants were not calculated, as limited literature and historical effects were reported.

Figure 8 presents the exposure map for hotels in Egypt under RCP 8.5, indicating varying heatwave risks. The regions of greater concern are again in southern Egypt, mainly along the coast of the Red Sea and along the Nile, with another notable area of exposure along the south coast of the Sinai Peninsula. Cairo, on the other hand, also has a high density of hotels, but the expected heatwave exposure level is comparatively low. However, it is important to note that in big cities such as Cairo, impervious surfaces such as roads can increase the temperatures, adding heat stress (Abutaleb et al., 2015; Myint et al., 2013). Regardless, the exposure significantly increases from current scenarios and might lead to substantial raises in energy consumption and costs. In contrast, the western Mediterranean coast region may experience low levels of heatwaves, but its hotel infrastructure is lower, which means this is less of a concern.

Figure 7: Exposed hotels and power plants to floods

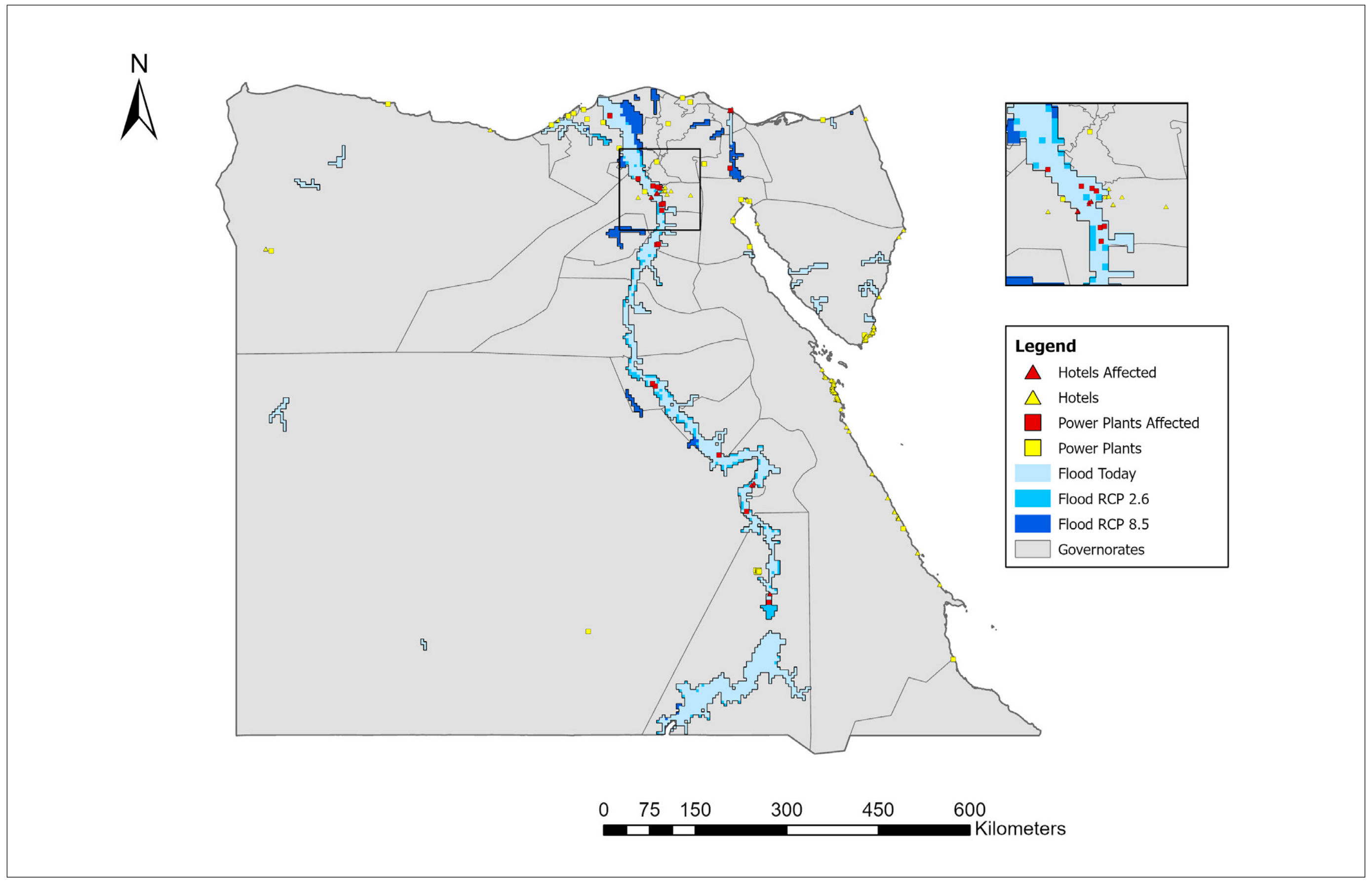


Figure 8: Exposed hotels to heatwaves under RCP 8.5

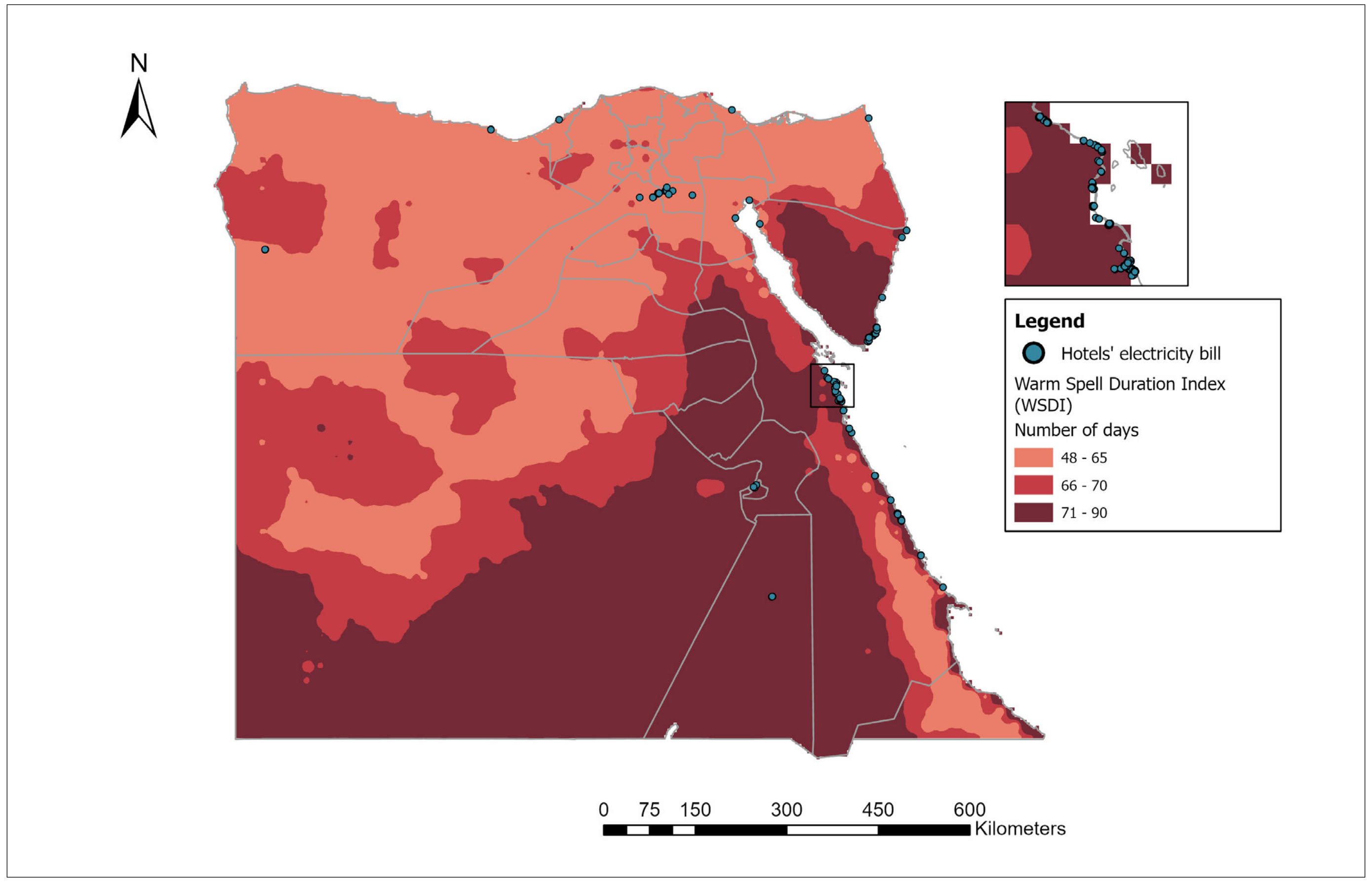
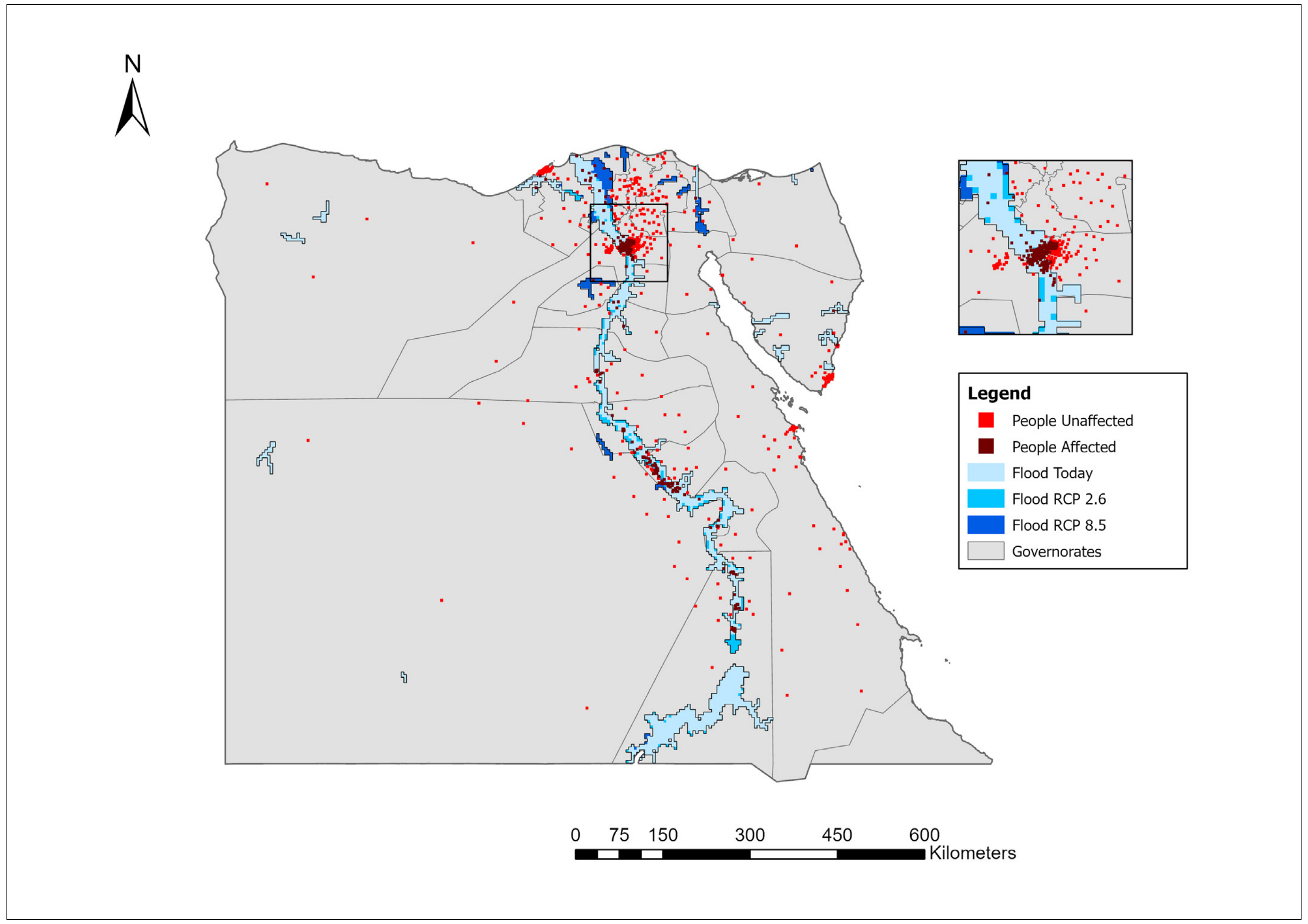


Figure 9: People exposed to floods



2.2.2.2 Non-economic assets

1. Health (Diarrhoea patients)

Floods in Egypt can severely degrade water quality and compromise sanitation infrastructure, increasing the incidence of waterborne diseases such as diarrhoea. Studies have shown a clear correlation between diarrhoea morbidity rates and changes in precipitation patterns, with extreme rainfall events exacerbating the spread of diarrhoeal diseases in Egyptian Governorates (Saad-Hussein et al., 2023). The increased impact of diarrhoea during flood events can strain healthcare facilities, reduce overall public health, and impede socio-economic development. Addressing the vulnerability of diarrhoea patients in the context of floods is crucial for developing effective public health interventions and climate adaptation strategies to safeguard the vulnerable population.

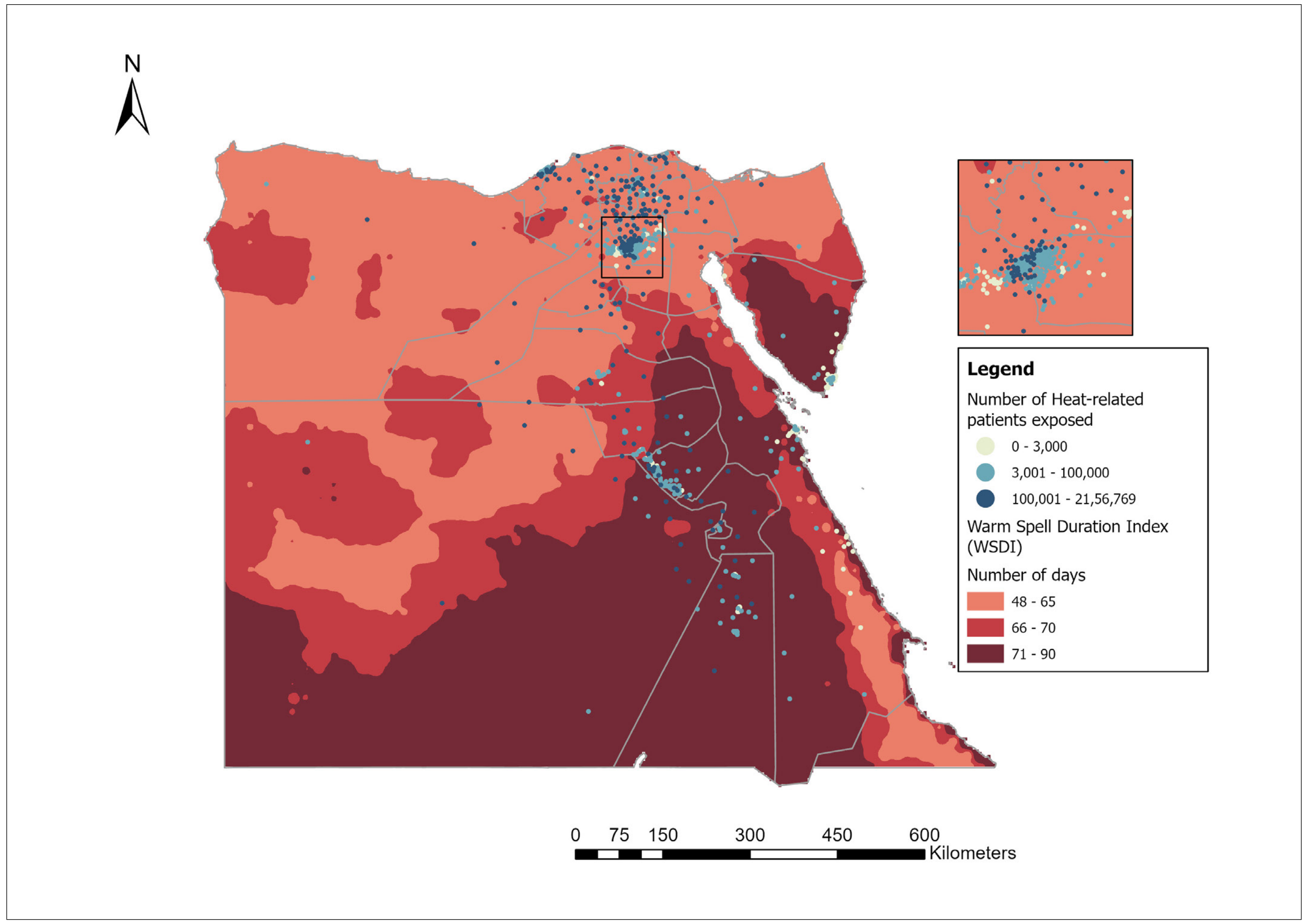
Figure 9 presents the exposure of Egypt's population to floods, potentially leading to diarrhoea outbreaks. Population-dense urban areas like Cairo and Sohag are located around large rivers facing the highest levels of exposure. As is the case for people in Ismailia, future scenarios complicate the conditions for cities and communities close to other water bodies, such as the Great Bitter Lake. Forward-looking solutions will be needed to address this issue, especially in regions not used to facing floods.

2. Health (Heat-related patients)

Heatwaves significantly increase the number of hospitalizations in Egypt by exacerbating heat-related health issues. Prolonged high temperatures can lead to a rise in conditions such as heatstroke, dehydration, and cardiovascular complications (WHO, 2015). These health problems often necessitate urgent medical attention, resulting in higher hospitalization rates.

Figure 10 illustrates the exposure of Egypt's population to heatwave. The map shows that northern Egypt, including cities such as Cairo and Giza, is more densely populated but exposed to heatwaves to a lesser degree than the comparatively sparsely populated southern governorates. The people residing in these northern regions will still be exposed to up to 65 heatwave days annually, which can still lead to heat-related illnesses such as heatstroke, especially in as densely populated a city as Cairo. As in previous assets, southern regions, specifically

Figure 10: People exposed to heatwaves under RCP 8.5



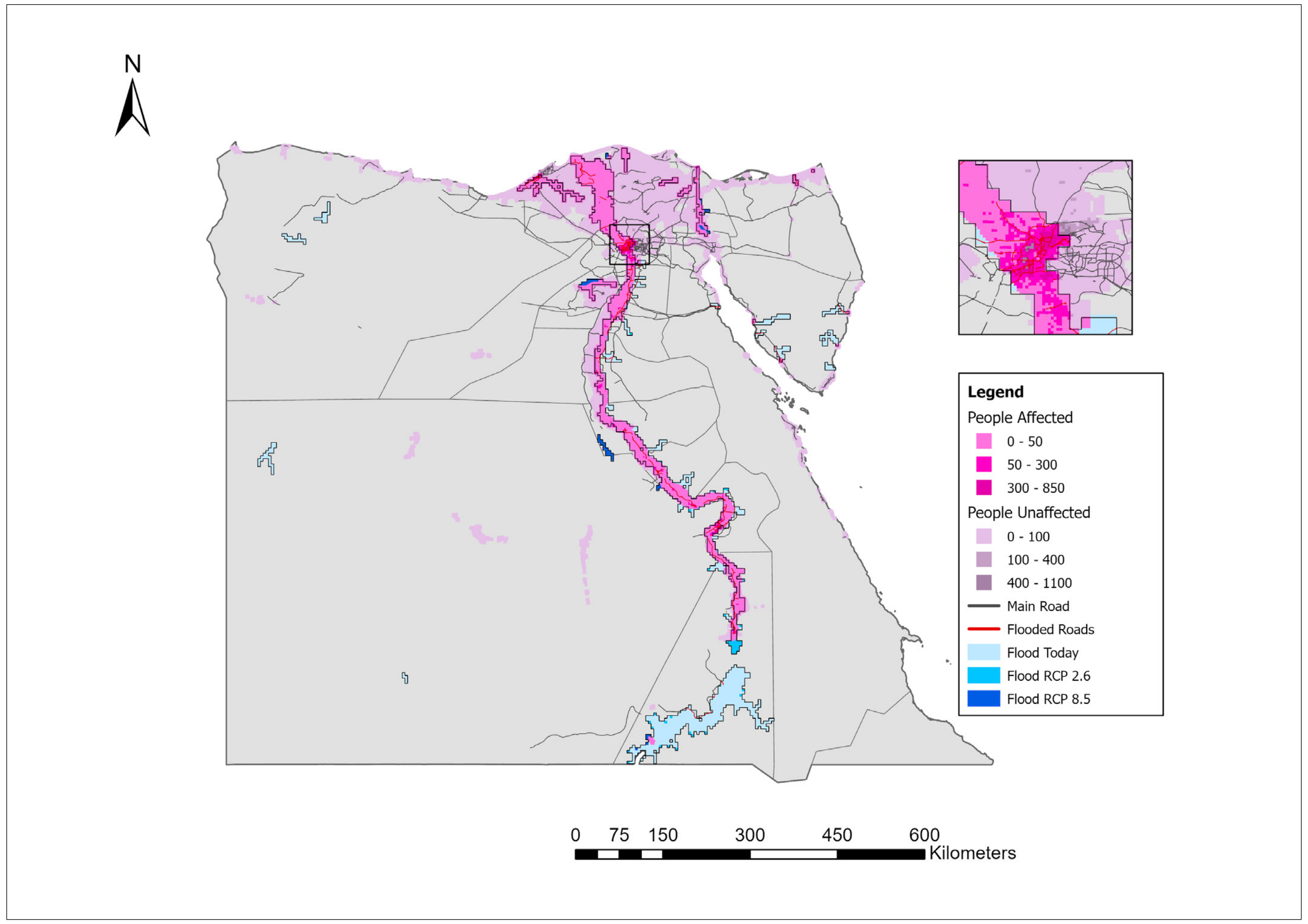
in communities along the Nile, also have high concentrations of people but much higher exposure to extreme heatwave conditions than the north. Sohag and Assyut governorates are areas of great concern. Overall, heatwaves in Egypt can be intense and prolonged, and healthcare facilities frequently experience surges in patient numbers during extreme heat events. Vulnerable populations, including the elderly and those with preexisting health conditions, are particularly affected (Katzan & Owsianowski, 2017). The increased demand for medical services during heatwaves underscores the need for effective public health measures, such as improved hospital cooling systems and enhanced heatwave preparedness strategies, to mitigate the impact on the healthcare system.

3. Mobility (Road users)

Floods significantly impact road users and mobility by disrupting transportation infrastructure and posing immediate safety hazards. Heavy rainfall can rapidly inundate roadways, rendering them impassable and increasing the risk of accidents. Floodwater can cause road surfaces to erode, undermine bridges, and wash out critical infrastructure, leading to traffic delays, detours, and road closures. Additionally, the reduced visibility and slippery conditions during heavy rains heighten the risk of vehicular collisions and accidents. Flash floods' sudden and unpredictable nature exacerbates these risks, 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.

Figure 11 presents road users' exposure to floods in Egypt. Given the higher density of cities and settlements along the Nile River compared to other areas in the country, this region experiences high exposure to riverine flooding. The northern region of Egypt, especially in the parts of Cairo, Giza, and Qalyubia, is particularly exposed to the impacts of floods, and roads in these areas are at risk of being disrupted, hindering transportation and emergency response. Under future climate scenarios, the frequency and intensity of these events are projected to worsen, increasing the expected number of impacted communities.

Figure 11: Roads exposed to floods



The impacts of heatwaves on road mobility are much less studied than those of floods, and even less literature has focused on regions with conditions comparable to Egypt's. Some research is available on heat-related road crashes and the consequential fatalities (Blondin, 2022; Wu, 2022; Wu et al., 2018), but it was insufficient to build reliable damage functions that could be validated in the Egyptian context. Therefore, this report does not include risk assessments for mobility and heatwaves.

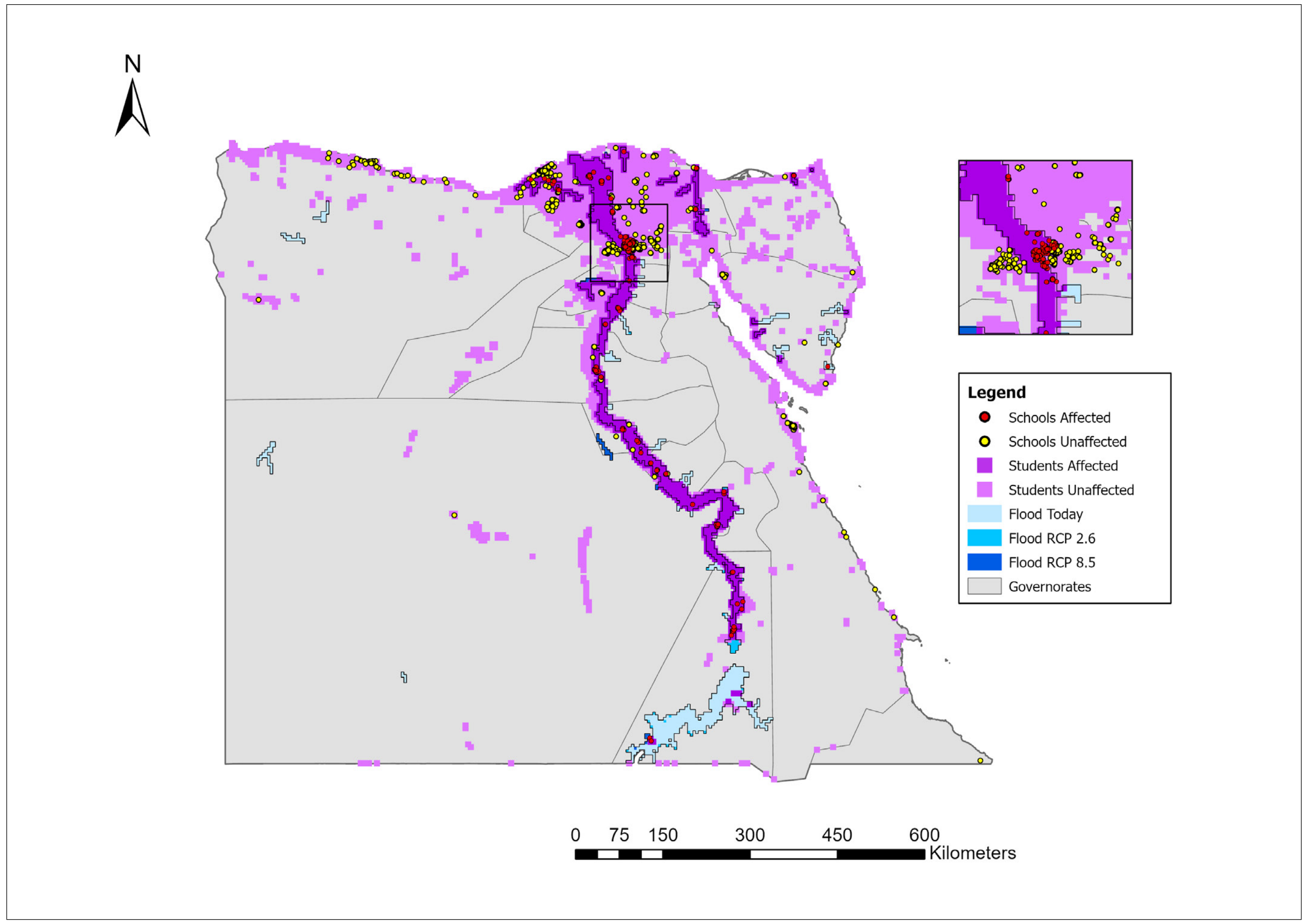
4. Education (Students)

The impacts of extreme events on access and quality of education are well understood globally. Destruction of school infrastructure, health complications for students, and reduced teacher contributions are just a few examples of education being vulnerable to floods and heatwaves (Jeev T, 2024; Leal Filho et al., 2023; Venegas Marin et al., 2024). Unfortunately, Egypt is no exception; students 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). Schools may become inaccessible to teachers and students during floods or repurposed as shelters, 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 5.3 million children were exposed to heatwaves worldwide (UNICEF, 2022).

Figure 12 presents the exposure of students to floods in Egypt. In this study, we assessed the number of impacted students as the number of people of school age who live within a flooded area, limiting their mobility to an education facility. The map showcases the highest potential impact of floods along the Nile River. The country's northern region,

Figure 12: Students exposed to floods



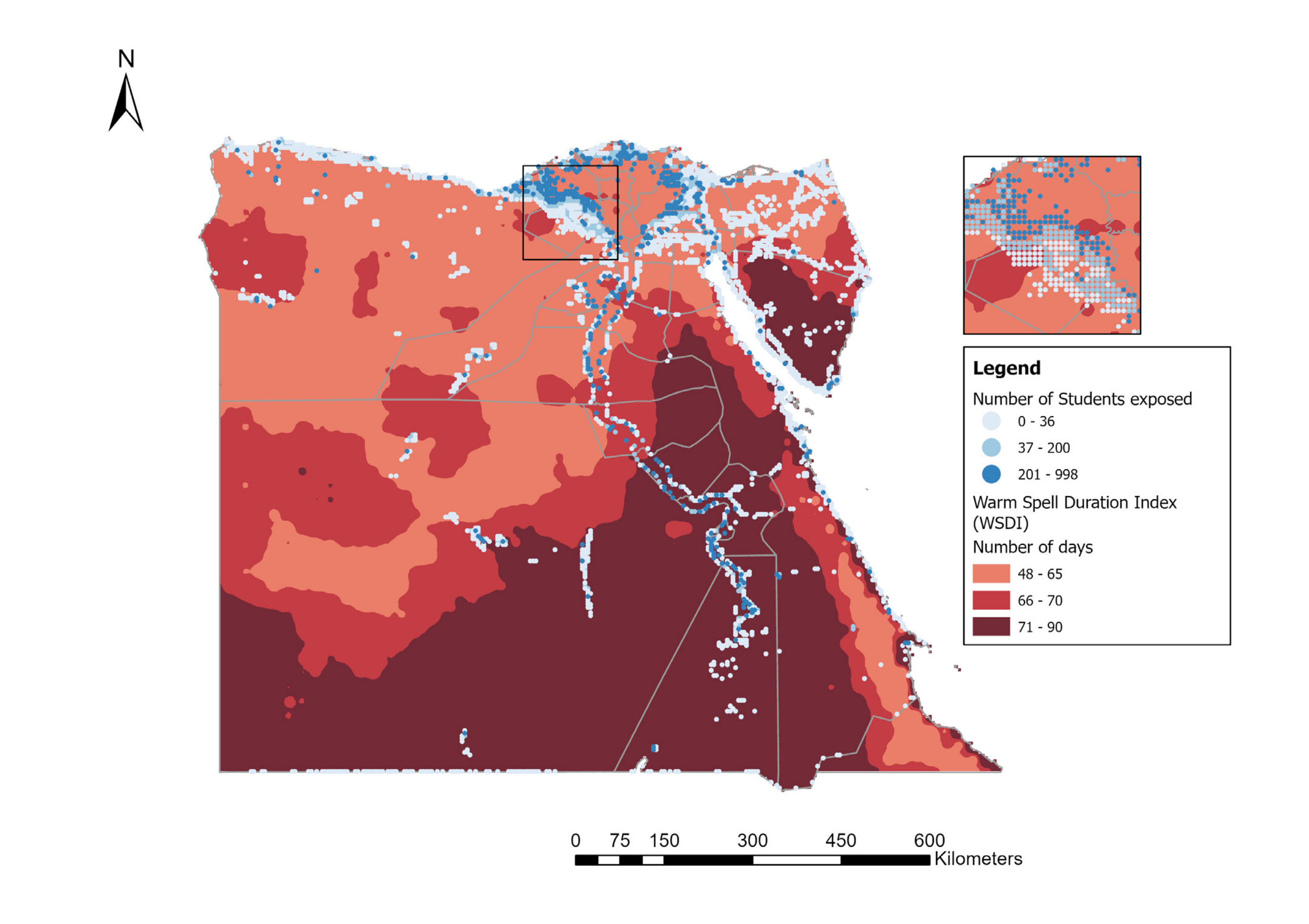
in major cities like Cairo, Giza, Qalyubia, Monufia, and Alexandria, is densely populated, making the schools and students more exposed to flash floods. Under future climate change scenarios, the impacts of floods in Egypt are projected to increase. Therefore, current and future flood risks will impact schools and students, making infrastructure and safety measures crucial. Considering the extreme scenario of the high population in Northern Egypt, adaptation measures have become essential as many students may face increased disruption due to flooding.

Extreme heat can also 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). Figure 13 illustrates the number of students exposed to heatwave in Egypt. The country's northern regions, especially in Giza, Alexandria, and Beheira, again have a highly dense population, and as a result, the student population is also extremely concentrated in this region. This high density of students extends south along the Nile, where heatwave intensity is more extreme, particularly in the Luxor, Qena, and Aswan Governates, where heatwave length can reach up to 90 days. This high level of exposure amongst students is particularly troubling, where heatwaves 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 (UNICEF, 2022).

2.2.3 Socio-economic scenarios

As outlined in Chapter 1.2, ECA and CLIMADA utilize socio-economic development indicators, including population growth, GDP growth, and discount rate, to project economic and non-economic impacts under future scenarios such as RCP 2.6, RCP 4.5, and RCP 8.5. These indicators are essential for modelling how Egypt's economic and demographic dynamics will evolve, in addition to the 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 RCP 8.5, a high-emission trajectory with potentially rapid population increases and

Figure 13: Students exposed to heatwaves



economic strain. By considering socio-economic factors, the models help to assess Egypt's potential vulnerabilities and adaptive capacity under different climate conditions.

1. Population growth

The average annual population growth rate of 1.29 per cent until 2050, published by the UN Department of Economic and Social Affairs, is considered in this study (United Nations Department of Economic and Social Affairs, 2024). As of 2015, the population of Egypt accounted for over 20 per cent of the total population in the Arab world and was the third most populous country in Africa, increasing by more than 1.5 times during the past 30 years from roughly 48 million to over 90 million in 2016 (CIA, 2024). That said, replacement rates have been falling steadily, and projections predict Egypt's fertility rates will be approximately the same as France, Germany, Japan, and Italy by 2100 (Aboukorin, 2024).

2. Economic growth

Trends were analyzed to estimate future growth, and the Economist Intelligence Unit (EIU) projected an average annual growth rate of 4 per cent in Egypt until 2050 (EIU, 2024a). Egypt's economy is dominated by services (51 per cent of GDP) and Industries (34 per cent), while agriculture makes up only 19 per cent of the country's GDP. Despite being the most highly industrialized country on the African continent after South Africa, the manufacturing base makes up only 16 per cent of the country's GDP (AFDB, 2024). In previous years, the Egyptian economy experienced growth rates of 4-5 per cent. However, the COVID-19 pandemic decreased this growth, bringing it down to 3.6 per cent in 2020 (BMZ, 2023). Despite the significant impact on tourism, one of the country's key revenue sources, Egypt managed to navigate the crisis relatively well compared to other countries in the region.

3. Discount rate

The discount rate data, derived from the projected yearly average percentage change of the GDP Deflator provided by the EIU, averaged 6.89 per cent between 2024 and 2050 (EIU, 2024a). 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

Table 4: Overview of flood and heatwave adaptation measures for Egypt

Hazard	Adaptation measures		Types	Cost Est. (2024 USD)
Flood	1	Tree planting	NbS	69,156,293
	2	Retention reservoirs	Hybrid	10,653,600
	3	Dredging of canals	Grey	40,341,171
	4	Infiltration ponds	Hybrid	52,523,956
	5	Recharging wells	Hybrid	77,706,469
	6	Early warning system	Systemic	2,556,657
	7	Small dams	Grey	168,148,056
Heatwave	1	Tree planting	NbS	69,156,293
	2	Green roofs	NbS	11,397,873
	3	Early warning system	Systemic	22,370,745
	4	Training on adaptation agricultural practices	Systemic	79,895,517
	5	Water-saving cultivation and production practices	Systemic	75,634,423
	6	Research and monitoring	Systemic	14,221,402
	7	Climate-smart agriculture	Hybrid	251,404,561
	8	Green building codes	Systemic	436,762,161

by determining the present value of future costs and benefits. In 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).

2.2.4 Adaptation measures

This chapter presents Egypt's shortlisted flood and heatwave adaptation measures. These measures aim to reduce the disaster impact on selected assets and population groups by lowering the intensity or the frequency of the effect, the vulnerability of the assets, the number of assets expected to be affected, or a combination of these. The cost-benefit analysis of implementing these measures was calculated according to the potential averted damage. The result will be presented in Chapter 2.4.2.

The adaptation measures were selected based on a literature review and consultation with local experts, partner organizations, and government representatives. Initially, a total of 29 flood adaptation measures and 20 heat wave adaptation measures were identified (referred to as a long list). This list was then reduced to seven flood and eight heat wave adaptation measures (referred to as a short list), which were then introduced to CLIMADA. A detailed methodology for this participative measures selection procedure can be found in Chapter 2.2. Table 4 presents an overview of Egypt's adaptation measures for floods and heatwaves.

The measures were 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. 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 negative economic impact of climate-related disasters. It serves as a risk transfer mechanism within Climate Disaster Risk Financing and Insurance (CDRFI), complementing other adaptation approaches by providing crucial financial support and facilitating recovery. This comprehensive categorization balances immediate protective needs with long-term resilience.

This chapter presents a detailed description and cost estimation for each flood and heatwave adaptation measure presented in Table 4. Most of the cost assumptions were taken from planned budgets for Egypt. However, some cost estimates were hard to find; therefore, they had to be adjusted from available cost estimates to represent the national average, considering cost-benefit ratios from comparable studies and literature reviews. 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 from 2024 to 2050.

1. Tree planting	
NbS	**69,156,293 USD**

Planting trees in urban areas is essential for flood and heatwave adaptation and mitigation in cities. Increasing green spaces through tree planting helps lower ambient temperatures, reduce the impact of heatwaves, and enhance stormwater management by regulating surface runoff and decreasing the risk of flash floods. Tree canopies intercept rainfall, slowing water flow, and their root systems absorb water, reducing stormwater runoff and nutrient pollution in waterways. Urban forests offer essential ecosystem services, including air and water purification, shade, habitat creation, carbon sequestration, and nutrient cycling. Moreover, urban forests also provide a connection to nature that is often perceived as missing in urban areas.

In response to climate change, Egypt has launched the "100 million trees" campaign, targeting 9,900 locations and converting 6,600 acres into forested areas and gardens utilizing treated wastewater (Mohamed, 2024). The tree planting cost was estimated from this project budget, which was 3 billion EGP or 69,156,293 USD. The target was to plant 1.5 million trees in Cairo, 585,000 in Giza, 404,000 in Sohag, and 393,900 in Sharqia.

2. Retention reservoirs	
Hybrid	**10,653,600 USD**

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. Recognizing the flood risks in the South Sinai Governorate, one of the region's most vulnerable to torrential rains in Egypt, the government has prioritized the construction of 307 artificial lakes with a storage capacity of 53,268,000 cubic meters to protect the area from potential flood disasters (al-Kady, 2022). The estimated investment cost of retention reservoirs or lakes was taken from a World Bank report on small dam safety, which showed 0.2 USD per cubic meter, bringing the total cost of retention reservoirs in Egypt to 10,653,600 USD.

3. Dredging of canals	
Grey	**40,341,171 USD**

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 removing sedimentation in open drainage canals or pipes to the whole straightening (canalization) or deepening of watercourses. Dredging is a crucial method for restoring water flow and improving efficiency and capacity to convey water. As part of Egypt's large-scale poverty reduction and rural development program, Haya Karima, 5 per cent of the first phase budget has been allocated to canal rehabilitation, emphasizing the importance of maintaining these vital systems (Raouf et al., 2023). This included bridge rehabilitation and protection against all hazards.

The cost of this measure was estimated by dividing by ten the 5 per cent budget of Haya Karima as an assumption for the canal dredging against flood hazards, for a sum of 40,341,171 USD.

4. Infiltration ponds	
Hybrid	**52,523,956 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. A European Commission paper provides detailed cost estimates for these systems' construction and maintenance (OIEau et al., 2013).

The initial capital expenditure in 2015 was 20 USD per cubic meter, and the maintenance cost was 0.15 USD per cubic meter. This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit and converted to USD (EIU, 2024b) to 60.9 USD and 0.5 USD, respectively. Considering the exposed areas, a demand for five ponds across Egypt was estimated, with a detention volume of 75,000 cubic meters and a detention area of 500,000 square meters. Such projects would lead to a one-time investment of 22.8 million USD and an annual maintenance cost of 1.14 million USD from 2025 to 2050.

5. Recharging wells	
Hybrid	**77,706,469 USD**

Recharging wells is a cost-effective rainwater harvesting technique that directs water into local aquifers beneath urban areas. In urban hydrology, reduced rainfall infiltration poses significant concerns, as it decreases groundwater recharge, increases flood risks, and accelerates pollutant transport. A 2021 study by the Faculty of Engineering at Port Said University estimated recharging wells' capital and maintenance costs in five coastal Egyptian cities, such as Marsa Marouh, Dabaa, Zaheria region in Alexandria, Baltim, and Al-Arish (Gabr et al., 2022). These cities often experience heavy rainfall during storms, leading to flash floods and inundation. By implementing rainwater harvesting (RWH), the collected water can help alleviate flood risks and be used to narrow the growing gap between water supply and demand caused by population growth.

The estimated cost for recharging wells from the 2021 study was used as the estimated cost of this measure. The average investment cost per well was 78,030 EGP, and the repair and maintenance cost was 20,000 EGP. This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit and converted to USD (EIU, 2024b). The study proposed the implementation of 78 wells. The assumption for the whole of Egypt was 50 times, considering the 56 prominent cities in Egypt. The final investment and maintenance costs in 2024 were 10.14 million USD and 2.6 million USD, respectively.

6. Early warning system	
Systemic	**2,556,657–22,370,745 USD**

The Intergovernmental Panel on Climate Change'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 heatwaves, and guide them on minimizing the impacts. Egypt's National Strategy for Adaptation to Climate Change (2011) outlines the estimated long-term investment costs for developing and implementing these systems (Government of Egypt, 2011). This cost is then transformed to the 2024 net present value, considering the average annual percentage change of the GDP deflator from the IMF.

Heatwave early warning systems (EWS) tend to be costlier than flood EWS due to the broader geographic areas they must cover, as heatwaves affect entire urban and rural regions. These systems require a denser network for metrological measurement instruments, satellite data monitoring expertise, and widespread communication and cross-sector collaboration, including healthcare, to protect vulnerable populations, adding to the overall costs. In contrast, flood EWS focuses on specific areas like floodplains and relies on hydrological models, with costs influenced by the length of rivers, local conditions, and the sophistication of monitoring technology (Golding, 2022). The Intergovernmental Panel on Climate Change'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 heatwaves, and guide them on minimizing the impacts.

Egypt's National Strategy for Adaptation to Climate Change (2011) outlines the estimated long-term investment costs for developing and implementing these systems (Government of Egypt, 2011). In 2011, the investment cost was estimated to be 20 million EGP, and the maintenance cost was estimated at 1 million EGP. These investment and maintenance costs are then transformed to the 2024 net present value, considering the average annual percentage change of GDP deflator from the IMF to be 2,130,547 USD and 106,527 USD, respectively. From 2024 to 2050, the assumption for the flood EWS was to have two initial investment costs and four maintenance costs. The flood early warning system has been utilized in the Nile region for a long time, so the mentioned cost complements the existing EWS infrastructure. However, heatwave frequency has been increasing in recent trends. It requires a denser network for metrological measurement instruments and data expertise for satellite data monitoring, forecasting, and dissemination, which leads to higher investment costs needed for a heatwave. The cost for heatwave was adjusted from the flood early warning cost to represent national averages, considering cost-benefit ratios from comparable studies and literature reviews.

7. Small dams

Grey	168,148,056 USD

The World Bank defines small dams as all retention structures that do not meet the criteria for large dams. According to the Environmental and Social Framework, large dams are those with a height of 15 meters or more, or between 5 and 15 meters, if they impound over 3 million cubic meters of water (The World Bank Group, 2021). Small dams provide benefits such as drinking and irrigation water, flood control, and small-scale hydropower generation, particularly in rural and agricultural regions. The Egyptian government has prioritized the construction of small dams in the South Sinai Governorate, an area highly vulnerable to torrential rains and flood risks (al-Kady, 2022).

The estimated cost for building small dams was taken from the National Water Resources Plan 2017 in 2005, with a 631 million EGP investment budget and a 12 million EGP annual maintenance cost for small reservoirs (Arab Republic of Egypt, 2005). This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit and converted to USD (EIU, 2024b). The one-time investment cost in 2024 reached 118.55 million USD, with an annual 2.25 million USD maintenance cost from 2029 to 2050.

8. Green roofs

NbS	11,397,873 USD

Green roofs are systems where vegetation is grown on a layer of soil placed over a waterproof membrane on flat rooftops. Green roofs offer various 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. A study by universities in Egypt and the United Arab Emirates assessed the feasibility of green roof systems in Egypt, providing average costs for three systems: NFT, DWC, and SB (Desouki et al., 2024).

The initial cost for setting up the green roof system in 2024 was taken from the average cost of those three systems, which was 400 EGP per square meter in 2011. This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit to be 1,850 EGP per square meter (EIU, 2024b). The cost estimation was based on the potential implementation of green roofs on top of the 798 hotels identified across Egypt. The hotel rooftop area for green roofs was estimated at 100 square meters per hotel. The maintenance cost for 2025 until 2050 was estimated to be 9 per cent of the initial cost, which was 36 EGP per square meter in 2011 and equal to 167 EGP per square meter in 2024.

9. Training on adaptation agricultural practices

Systemic	79,895,517 USD

Training farmers in climate adaptation practices, particularly in response to heatwaves, is crucial for safeguarding their livelihoods and income. By equipping smallholder farmers with the knowledge and tools to adapt to extreme heat, they can better protect their crops from damage, ensuring more stable yields. Heatwaves pose a significant threat to agricultural productivity; adaptation training enables farmers to implement strategies such as adjusting planting schedules, selecting heat-resistant crop varieties, and improving irrigation techniques. This training is also known as climate farmer field schools, which is one of the key components of the Sustainable Agriculture Investments and Livelihoods project. This initiative is designed to help smallholder farmers increase their income, enhance profitability, and diversify their livelihoods while preparing them for climate hazards like heatwaves. Egypt's National Strategy for Adaptation to Climate Change (2011) includes an estimated cost to train small farmers in adapting to climate change, aiming to empower rural communities to implement projects that enhance resilience to disasters and crises.

The budget for this strategy was used as an estimated cost for the whole of Egypt. The investment costs for these trainings vary every year of the five-year plan, starting with 40 million EGP, followed by 180 million EGP, 350 million EGP, and 180 million EGP in 2011. This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit and converted to USD (EIU, 2024b) to 4.26 million USD, 19.17 million USD, 37.28 million USD, and 19.17 million USD to replicate the strategy.

10. Water-saving cultivation and production practices

Systemic	75,634,423 USD

Water-saving cultivation and production practices are important adaptation measures against heatwaves, which can exacerbate water scarcity and threaten agricultural productivity. Optimizing water use through modern irrigation techniques and careful demand planning helps farmers maintain crop yields during extreme heat conditions. These practices are particularly important in regions like Egypt, where water scarcity is a significant concern. Farmers can better protect their livelihoods and sustain agricultural production in the face of heatwaves by adopting water-saving methods. Egypt's National Strategy for Adaptation to Climate Change (2011) includes the estimated costs to improve irrigation efficiency, maintain crop productivity, and protect land from degradation.

The budget for this strategy was used as an estimated cost for the whole of Egypt. The investment costs for these practices vary every year of the five-year plan, starting with 5 million EGP, followed by 125 million EGP, 330 million EGP, and 250 million EGP in 2011. This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit and converted to USD (EIU, 2024b). The final cost estimates are 532,000 USD, 13.31 million USD, 35.15 million USD, and 26.63 million USD for an equivalent five-year plan in 2024.

11. Research and monitoring

Systemic	14,221,402 USD

Research and monitoring are essential adaptation measures against heatwaves, especially for predicting and managing crop diseases influenced by climate conditions. Scientists can forecast potential diseases by analyzing climate and weather data and recommend mitigating their impact. Building a knowledge base that links weather patterns to crop vulnerabilities is crucial for effective adaptation. Egypt's National Strategy for Adaptation to Climate Change (2011) highlights several key research areas, including the effects of climate change on public health, identifying the most vulnerable sectors, and studying its impact on crop productivity. The strategy also calls for a national database of climate data, adaptation plans, risk-reduction measures, and coordination across ministries. Specific initiatives include creating heat maps for agro-climate zones, conducting climatic studies in collaboration with the health sector, and developing a system to predict insect and disease outbreaks based on climate data. Other priorities include mapping crop varieties and disease prevalence and exploring crossbreeding to enhance resilience.

The estimated cost for Egypt was taken from the National Strategy for Adaptation to Climate Change in 2011. The investment costs for these activities vary every year of the five-year plan, starting with 80.5 million EGP, followed by 22 million EGP, 14 million EGP, and 13 million EGP in 2011. This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit and converted to USD (EIU, 2024b). The final cost estimates are 8.57 million USD, 2.34 million USD, 1.49 million USD, and 1.38 million USD for an equivalent five-year plan in 2024.

12. Climate-smart agriculture

Hybrid	251,404,561 USD

In Egypt, climate-smart agriculture (CSA) measures focus on enhancing resilience to heatwaves and ensuring food security. Key practices include water-saving and modern irrigation techniques, off-grid water pumping, and the cultivation of heat-tolerant, water-efficient crop varieties. Additional strategies involve piloting and promoting adjusted sowing dates, intercropping, low-cost nutrient supplements, and agrovoltaics for irrigation and designing livestock shelters. These CSA initiatives aim to create climate-resilient agricultural systems. The cost of implementing CSA in Egypt is outlined in the National Strategy for Adaptation to Climate Change (2011), which also emphasizes building genetic diversity in plant varieties and species to optimize productivity despite changing climate conditions.

The estimated cost for Egypt was taken from the National Strategy for Adaptation to Climate Change in 2011. The investment costs for these agricultural practices vary every year of the five-year plan, starting with 400 million EGP, followed by 560 million EGP, 670 million EGP, and 730 million EGP in 2011. This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit and converted to USD (EIU, 2024b). The final cost estimates are 42.61 million USD, 59.65 million USD, 71.37 million USD, and 77.76 million USD for an equivalent five-year plan in 2024.

13. Green building codes

Systemic	436,762,161 USD

Green building code is an adaptation measure against heatwaves, enhancing building design for better ventilation, air circulation, and heat management. These codes recommend increasing the spacing between buildings and reducing building heights to improve airflow and reduce heat accumulation. Egypt's National Strategy for Adaptation to Climate Change (2011) provides a detailed cost assessment for evaluating existing homes' condition and ability to withstand climate impacts. The strategy also calls for reviewing and updating current construction codes, ensuring they align with climate resilience standards and incorporate the latest innovations in green building practices.

This cost was used as an estimated cost for the whole of Egypt. The investment cost for implementing the codes was 1.1 billion EGP for the first five-year plan and 1 billion EGP for the second to the fourth five-year plan in 2011. This was then adjusted to the 2024 cost using the GDP Deflator conversion factor from the Economist Intelligence Unit and converted to USD (EIU, 2024b). The final cost estimates are 117.18 million USD for the first five-year plan and 106.53 million USD for the second to the fourth equivalent five-year plan in 2024.

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 and described the inputs for the model. CLIMADA used these inputs to compare the current risk (in 2024) versus the future risk (in 2050) based on two future climate scenarios. The expected annual impact charts compare current and future risks, climate change impact, and socioeconomic scenarios.

A list of measures specific to Egypt for minimizing floods and heatwaves was also discussed and parametrized into CLIMADA. CLIMADA processed this data against the flood and heatwave 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 Egypt 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, economic growth and climate change are considered together.

2.3.1.1 Floods

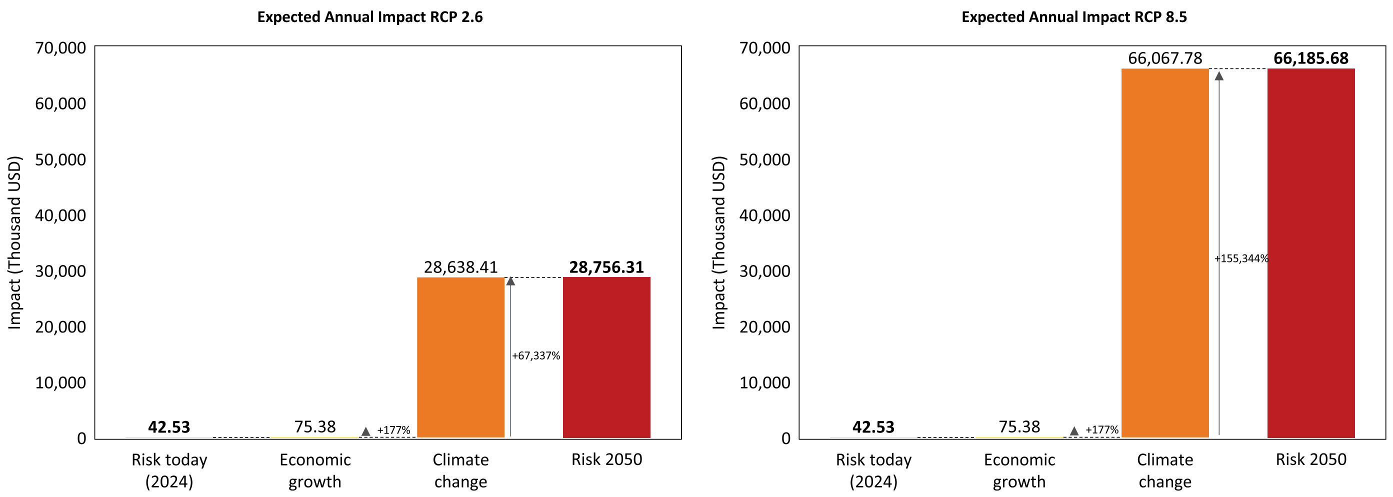
Even though floods in Egypt are a major concern, with losses reaching hundreds of billions of USD in the last decades, most impacts are experienced in urban areas and their related assets (Esmaiel et al., 2022). Given that this study mainly covered economic assets common in rural parts of the country, such as crops and livestock, the current estimated impacts were relatively low. Assets also common in cities, such as hotels and power plants, can be found in locations currently with low exposure or low vulnerability to the expected intensity of these hazardous events.

However, rainfall is expected to decrease in many regions, reducing the risk of flash floods. In contrast, riverine floods are expected to increase, leading to a considerable growth in flood depth and duration growth in the exposed areas (He et al., 2022; Mostafa et al., 2019). Even though the footprints of the floods will not drastically expand, the overall damages are projected to be higher because the assets will be submerged under larger amounts of water, which will also take longer to be drained. This growth in expected impacts underscores the urgency of investments in safeguarding sectors related to the studied assets, such as agriculture, tourism, and energy generation. By anticipating these impacts and taking proactive measures, Egypt can minimize losses and protect its economy against the adverse effects of climate change (Mahmoud & Gan, 2018).

1. Economic assets

Figure 14 presents the average annual impact of floods on economic assets, which in 2024 are estimated at 42,530 USD. These impacts will rise significantly due to economic growth and climate change under RCP 2.6 and 8.5 climate scenarios by 2050. The nature of the damages is the main factor expected to change, with smaller and quickly solvable effects on the infrastructure of hotels, for example, turning into permanent damages and losses. Similarly, temporary and manageable impacts on crops and livestock are projected to become more intense and persistent, particularly for those located on the borders of rivers, which for crops are the large majority.

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



2. Non-economic assets

Diarrhoea patients

Figure 15 highlights the increasing impact of floods on diarrhoea patients due to population growth and climate change in Egypt. In 2024, 109,05 people in Egypt are at risk of flood-related diarrhoea. The diarrhoea cases are expected to rise significantly due to population growth and climate change under RCP 2.6 and 8.5 climate scenarios by 2050.

While relatively low, studies have shown a strong increase in diarrhoeal morbidity in specific geographical locations in Egypt during floods (Saad-Hussein et al., 2023). Our results indicate a significant rise in potential diarrhoea patients across different climate scenarios, highlighting the need for further monitoring or action. These findings are particularly relevant in the Egyptian context because kids and youth are often the groups with higher rates of diarrhoea (Wang et al., 2023), and a large share of the country's population is within these groups. While population growth is predicted to slow in the coming decades, the impact of increased flooding due to climate change and the potential associated water contamination will continue to affect Egyptian vulnerable populations at an increasing rate.

Students

Figure 16 highlights the increasing risk to school access for students due to floods, considering the future population growth and climate change. In 2024, the average annual number of students at risk

Figure 15: Annual expected impact of floods on the general population (diarrhoea patients)

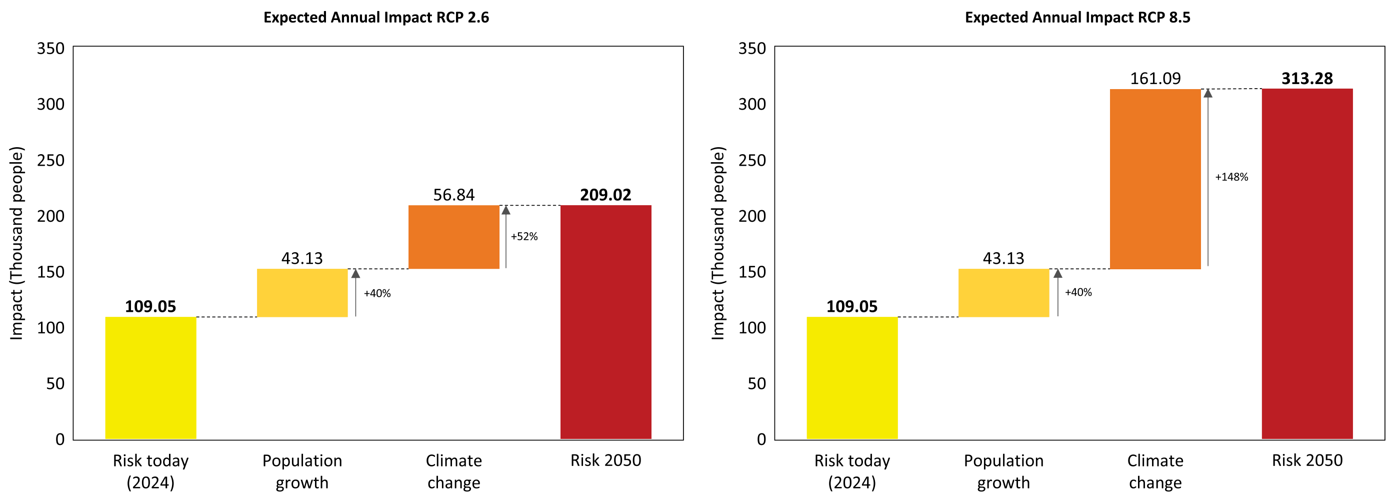
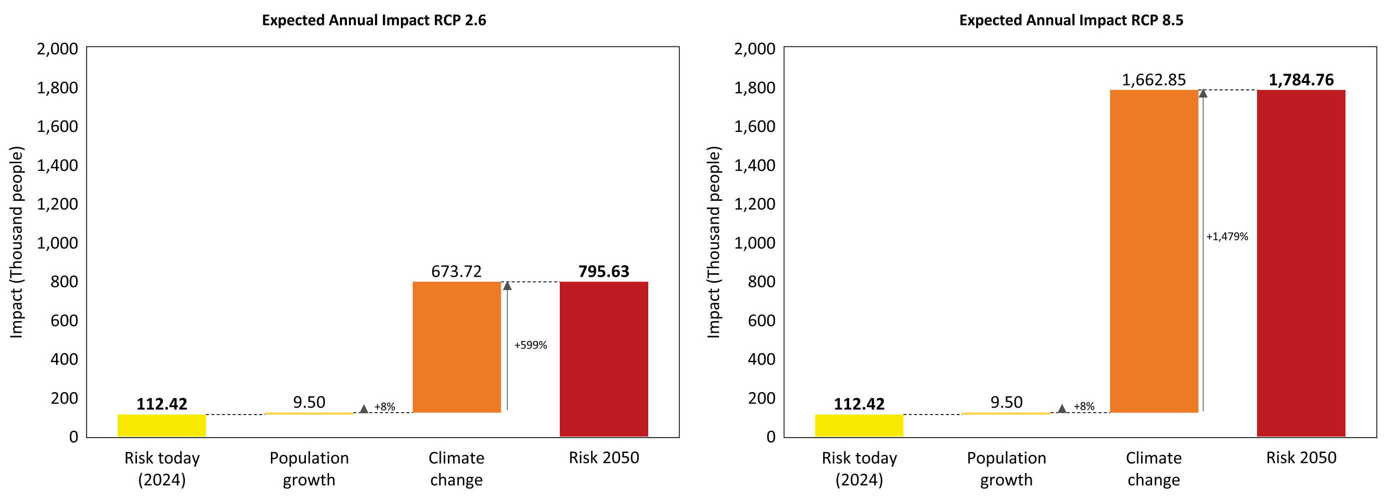


Figure 16: Annual Expected Impact of floods on students



is relatively low. This number is expected to rise due to population growth, but a significant spike due to climate change under RCP 2.6 and RCP 8.5 by 2050. Severe flood events due to climate change disrupt and damage educational facilities, complicating the ability of students to attend school regularly. Similarly to the case of economic assets, the rise in impacted students is linked to the increased depth of floods exacerbated by climate change in areas that usually would not experience conditions that could limit the mobility of students into education facilities.

Road users

Figure 17 illustrates the increasing risk of floods among road users, considering the population growth and climate change. In 2024, the mobility of 183,420 road users is at risk of floods. The risk is expected to increase by 2050 to 210,240 road users under RCP 2.6 and 253,690 under RCP 8.5.

As discussed earlier, population growth is expected in the coastal regions and the Nile Delta. The expressways and highways, essential for the country's rapid urban expansion, often face higher risks of damage during floods, making road users even more vulnerable (Neumann et al., 2015; Saber et al., 2020). The impacts on overall mobility are less marked than those on student access to schools, even though the latter are also related to their ability to reach schools. The difference in vulnerability between the general population and school students explains this difference. Figure 17 refers to non-student mobility.

2.3.1.2 Heatwaves

Heatwaves in Egypt are expected to increase significantly by the end of the century. In all climate scenarios, warmer maximum temperatures and more extended periods of elevated heat are projected, while cold spells and low night temperatures will become scarcer (Hamed et al., 2022). Recent events, such as the heatwave of 2015, left behind high social and economic tolls, including fatalities, particularly among the elderly (Mitchell, 2016). Economic impacts in urban and rural areas are a major concern, with

Figure 17: Annual expected impact of floods on road users

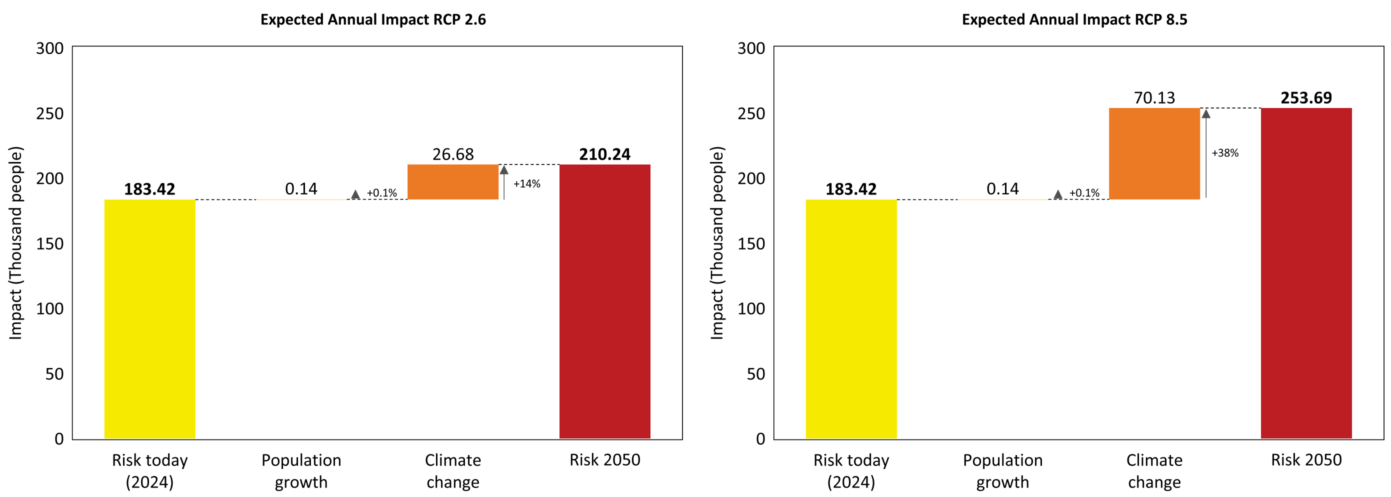
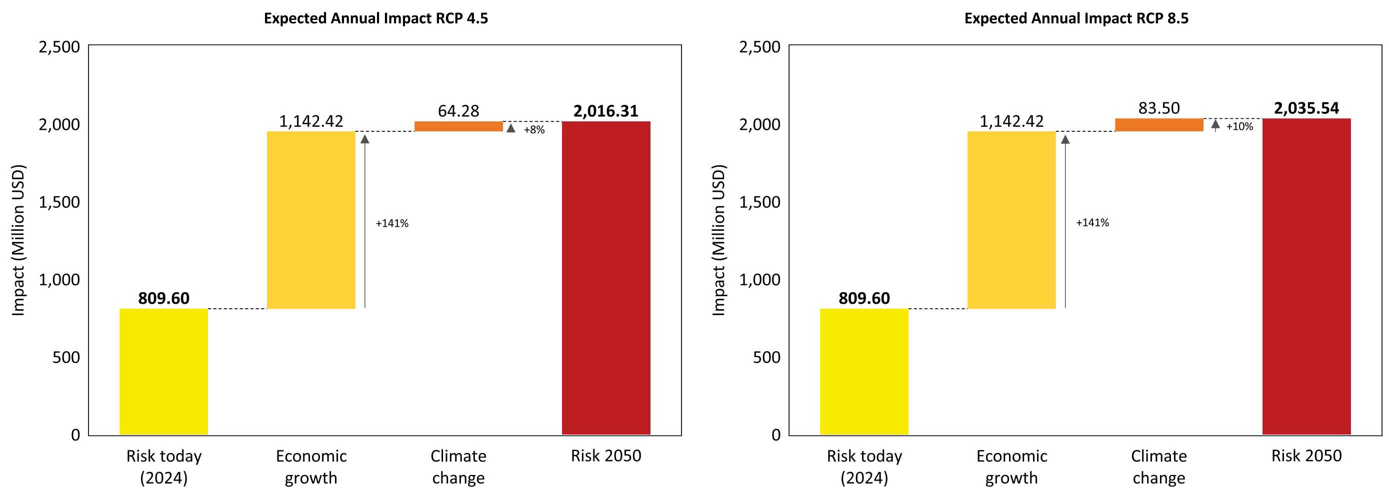


Figure 18: Annual expected impact of heatwaves on all studied economic assets combined



energy consumption in cities and losses in livestock production due to heat stress expected to rise by 2050 (Abdrabo et al., 2018; Goma & Phillips, 2022).

This study focuses on direct losses on crops and livestock for agriculture and increases in energy consumption in hotels, as selected by participants of the scoping workshops. The economic and non-economic impacts associated with heatwaves were quantified and analyzed, and how they are important to understanding the severity of current and future challenges and appropriately preparing to address them were analyzed.

1. Economic assets

Figure 18 presents the projected average annual impact of heatwaves on economic assets (crops, livestock, and hotels) due to future economic growth and climate change. In 2024, the average risk on these assets due to heatwaves is 809.60 million USD. These impacts are expected to increase significantly due to economic growth and relatively low due to climate change under RCP 4.5 and RCP 8.5. This result suggests that even though this hazard is expected to worsen in the coming decade, the economic boost projected due to, among others, infrastructure investments will lead to higher demands on the agriculture and tourism sectors, which will result in more exposure to assets (Abdrabo et al., 2018; Statista, 2024a). As explained, this analysis does not involve indirect agricultural production, such as eggs and dairy, which will likely cause additional economic losses due to heatwaves (Abdrabo et al., 2018; Goma & Phillips, 2022).

2. Non-economic assets

Heat-related patients

Figure 19 highlights the increasing impact on heat-related patients due to population growth and climate change in Egypt. In 2024, an average of 4,120 people will become heat-related patients. The projection is anticipated to rise significantly due to population growth and climate change, with cumulative heat-

Figure 19: Annual expected impact of heatwaves on total population (heat-related patients)

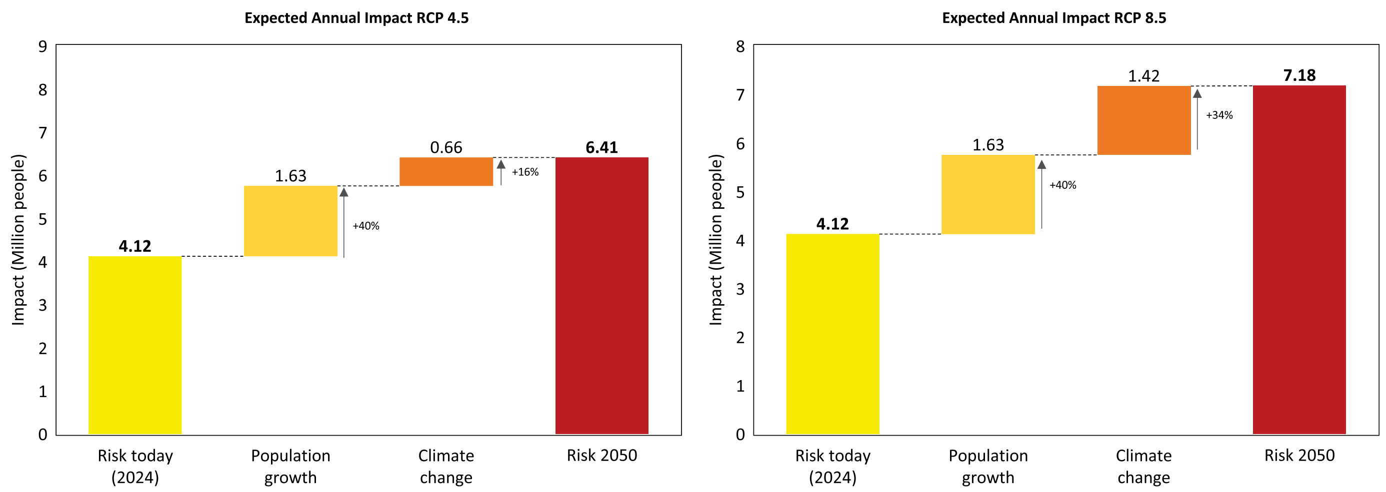
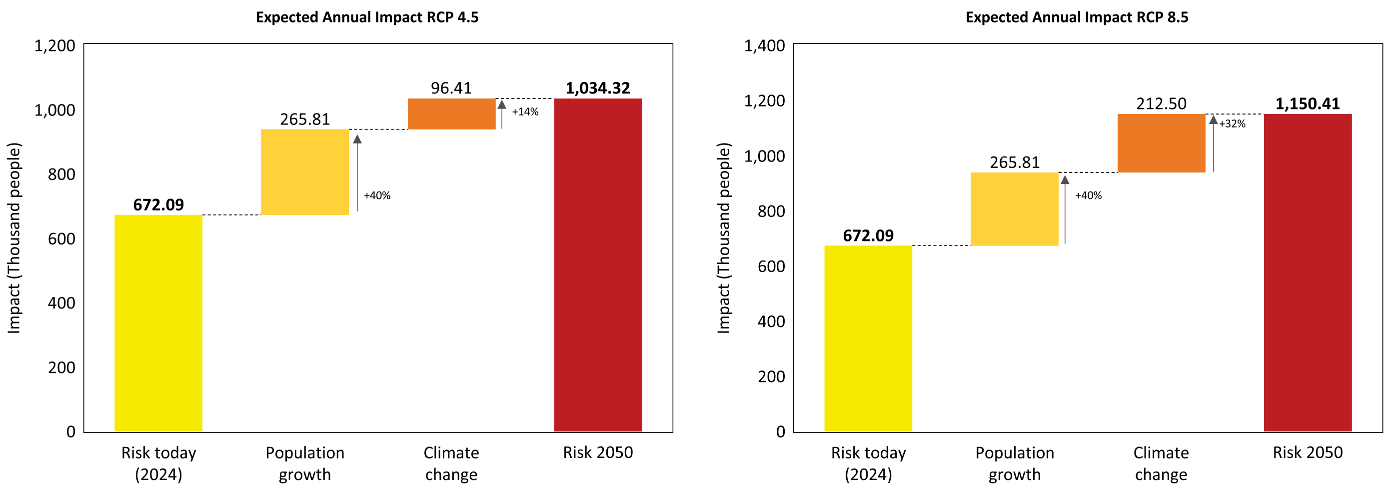


Figure 20: Annual expected impact of heatwaves on students



related patients at 6,410 under the RCP 4.5 climate scenario and 7,180 under the RCP 8.5 by 2050.

With the decline in mortality, demographic changes are expected, with an increase in the proportion of older adults. As life expectancy increases, the growing elderly population, particularly vulnerable to extreme heat, faces higher health risks. With a rapidly growing population, with more people moving to cities and an ageing population, more people are expected to be affected by extreme conditions (Abyad, 2021; Bayomi et al., 2021). The strain on the healthcare system is expected to rise, leading to more hospitalizations. Our results also show that population growth and climate change increase hospitalizations due to heatwaves.

Students

Figure 20 illustrates the increasing risk of heatwaves among students, considering the population growth and climate change. In 2024, the average number of annually affected students is estimated at 672,090. This number is projected to rise due to population growth and climate change, with 1,034,320 people affected under RCP 4.5 and 1,150.41 people affected under RCP 8.5 by 2050.

The growing population in Egypt can lead to overcrowded schools (*Emerald Expert Briefings*, 2019; Khalifa et al., 2000), potentially intensifying the heatwave's effects on children's health, academic performance, and daily lives. As the population grows, more students will require adequate classroom cooling to address the intensifying heat-related issues affecting education quality.

2.3.2 Cost-benefit analysis

This chapter presents the benefit-cost bar charts resulting from CLIMADA. These charts show which adaptation measure has the highest benefit (averted risk) compared to the investments for a given asset and hazard. 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 maximum possible avoided damage over the entire time horizon, spanning 27 years from 2024-2050. 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 (AEI) values in 2050 on the waterfall graph. In contrast, the Total risk reflects the accumulated AEI until 2050 for the selected hazard and asset. Each column's width represents each measure's scalability, with wider columns pointing at solutions that are more apt to be resorted to, while the slimmer columns are measures that make sense for more concrete or specific cases only. Each adaptation measure is allocated a specific colour representing the type of adaptation measures, either NbS, hybrid, systemic, or grey infrastructure. Table 5 shows the abbreviations of each adaptation measure and their 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. 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.

Table 5: Adaptation measures abbreviation, description, and colour coding

Type	No.	Abbreviation	Description
NbS	1	GR	Green roofs
	2	TP	Tree planting
Hybrid	3	RR	Retention reservoirs
	4	IP	Infiltration ponds
	5	RW	Recharging wells
	6	CSA	Climate-smart agriculture
Systemic	7	EWS	Early warning system
	8	AT	Training on adaptation agricultural practices
	9	WSP	Water-saving cultivation and production practices
	10	RM	Research and monitoring
	11	GBC	Green building codes
Grey	12	DC	Dredging of canals
	13	SD	Small dams

2.3.2.1 Floods

1. Economic assets

Figure 21 presents the benefit-cost ratio for six measures evaluated on selected economic assets, such as crops, livestock, hotels, and power plants. The ratio reflects the financial return in USD for every 1 USD invested in each measure. Based on modelling impacts and costs, tree planting, followed by the construction of retention reservoirs and the dredging of canals, emerges as the most cost-effective strategy for mitigating future flood damage. Implementing these three measures would effectively address Egypt's total flood risk for economic assets.

The benefit map in Figure 22 further demonstrates that dredging canals would significantly enhance resilience in crops, livestock, hotels, and power plants, particularly in the regions of Aswan, Qena-Luxor, and along the borders of the Beheira, Monufia, Qalyubia, Giza, and Cairo governorates. Although dredging canals can improve water conveyance, their effectiveness in reducing flood damage depends on proper implementation and careful adaptation to local conditions (Talaat ElGamal et al., 2019). Therefore, adopting a balanced approach that integrates nature-based solutions, grey infrastructure, and systemic measures is essential to effectively mitigate future flood risks in Egypt.

Figure 21: Benefit/cost ratio for adaptation measures for economic assets impacted by flood

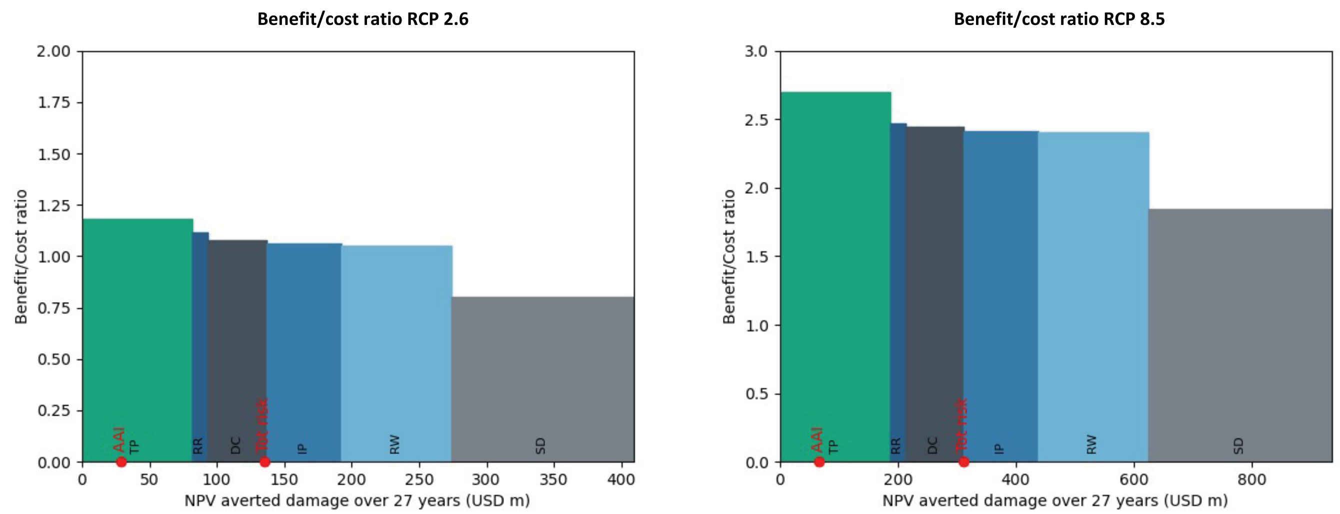


Figure 22: Benefit map of dredging of canals for economic assets against future floods with RCP 8.5 climate scenario

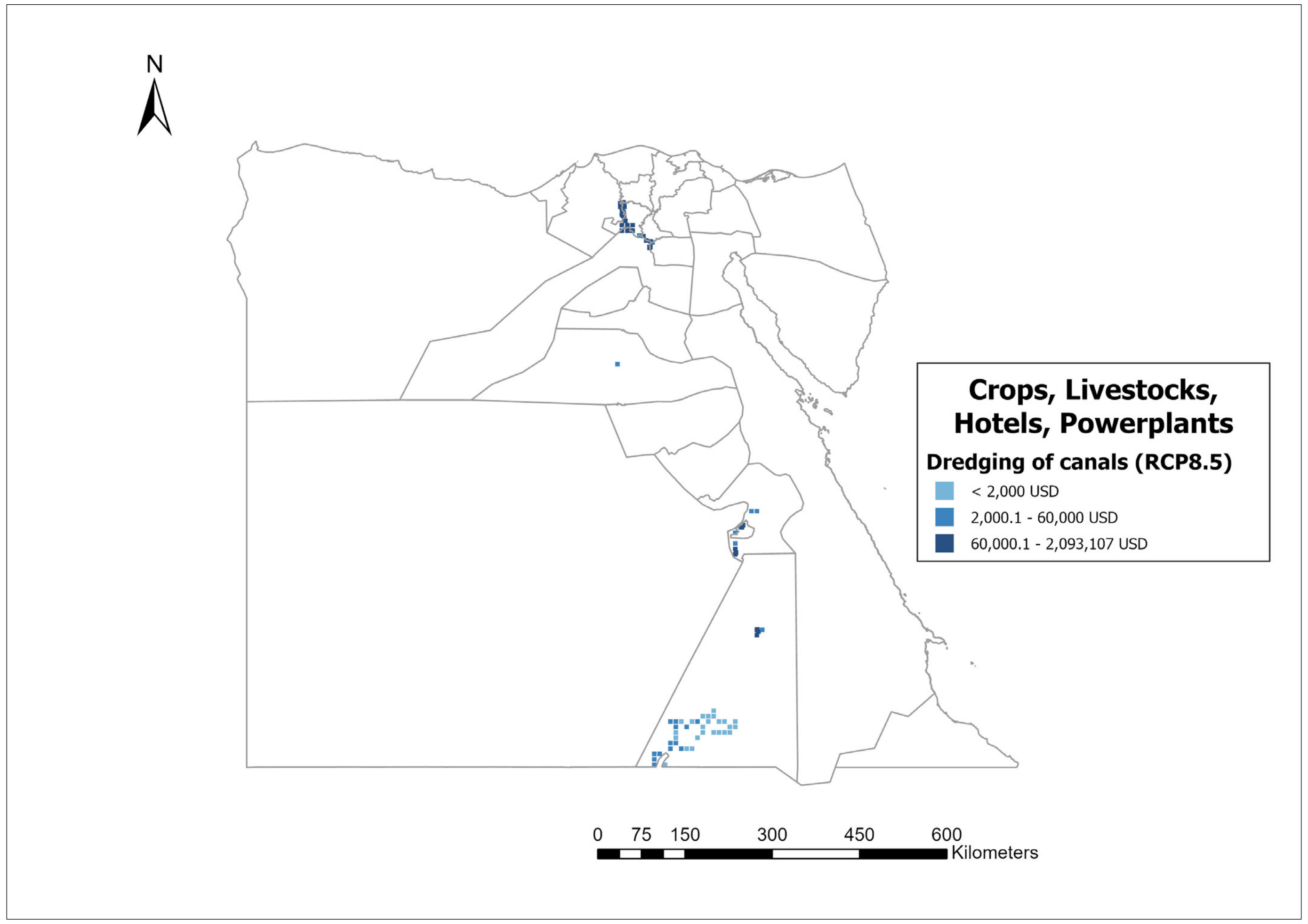
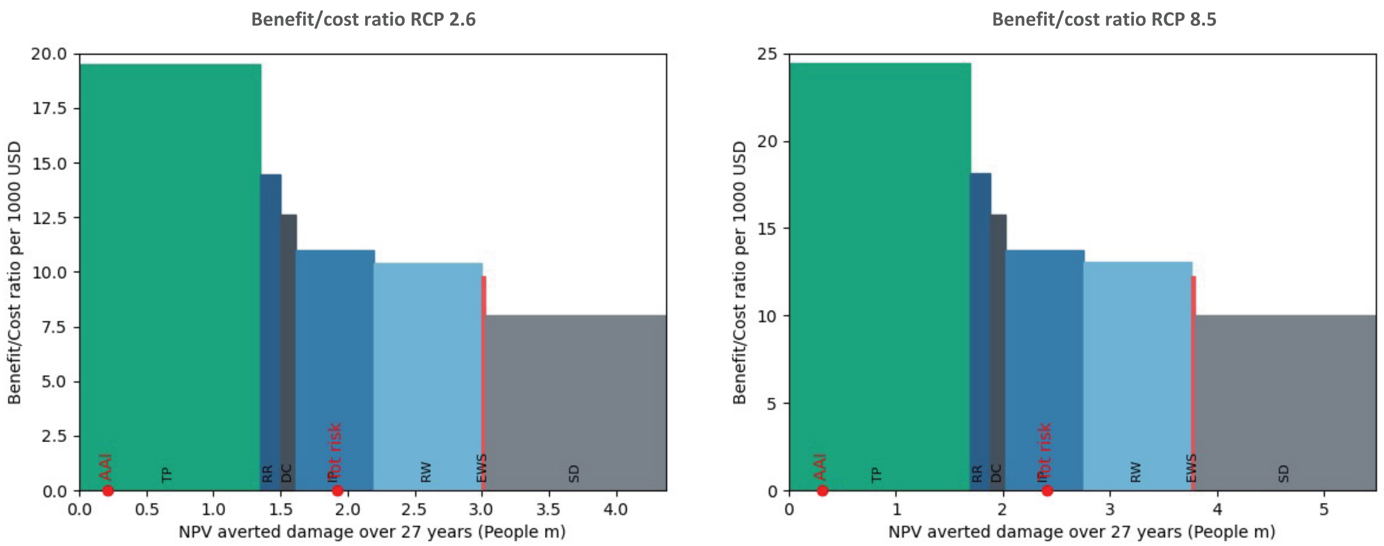


Figure 23: Benefit/cost ratio for adaptation measures for diarrhoea patients impacted by floods

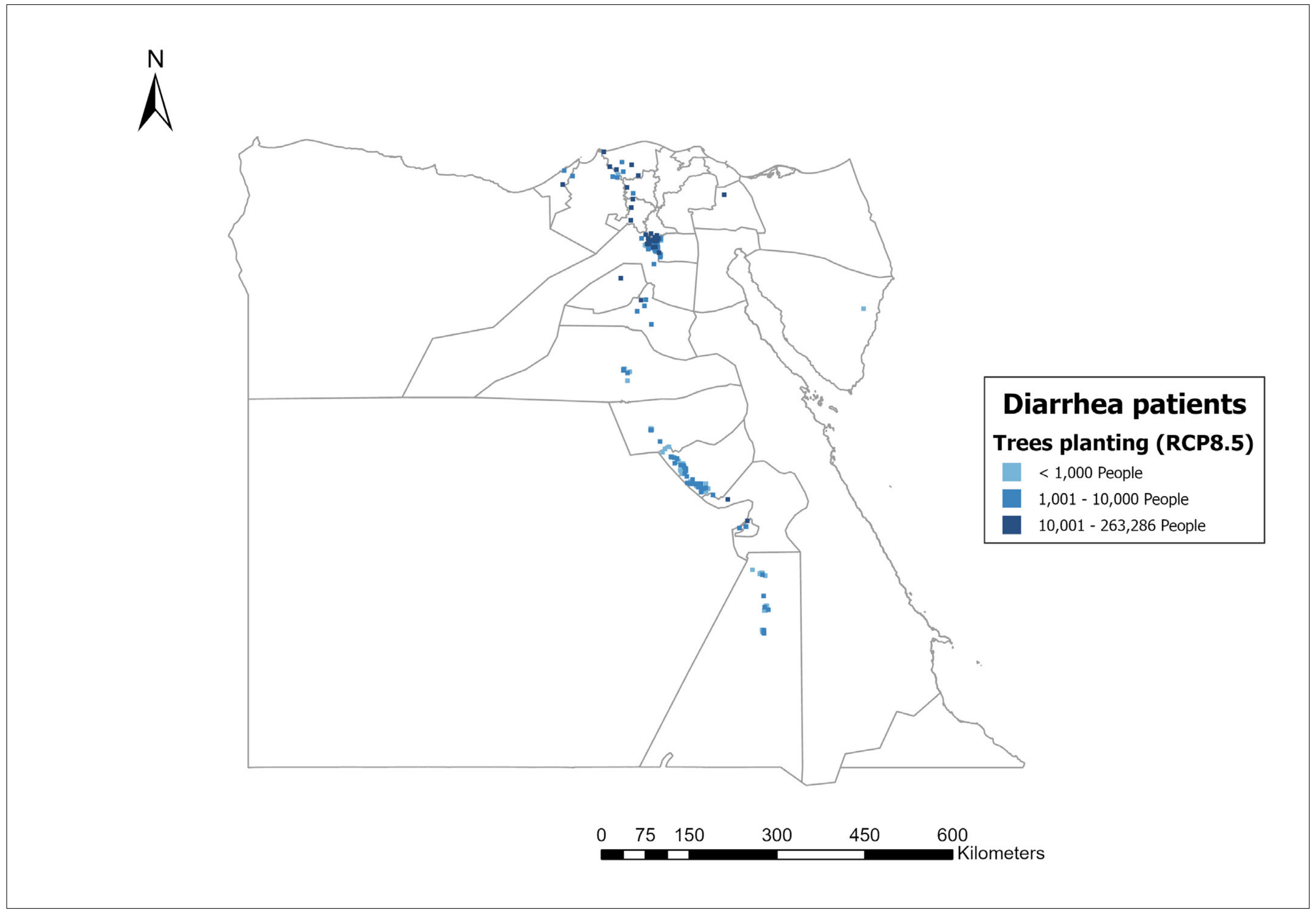


2. Non-economic assets

Diarrhoea patients

Figure 23 shows the benefit-cost ratio for seven measures evaluated for diarrhoea patients. The ratio represents the number of diarrhoea patients that would benefit per 1,000 USD invested in each measure. Based on modelling impacts and costs, tree planting, followed by the construction of retention reservoirs and the dredging of canals, demonstrates the highest cost-efficiency in mitigating future flood-related impacts.

Figure 24: Benefit map of tree planting that prevents diarrhoea cases due to future flood hazards with RCP 8.5 climate scenario



For example, if we look at the benefit/cost ratio for RCP 8.5, investing 1000 USD in tree planting will potentially reduce almost 25 diarrhoea patients due to flooding.

Figure 24 further illustrates the geographical distribution of the population that would avoid diarrhoea due to planting trees in the RCP 8.5 scenario. They are primarily located in the Greater Cairo metropolitan area, including Cairo Governorate, Giza, and Imbaba cities in Giza Governorate, and Shubra El Kheima in Qalyubia Governorate. The Greater Cairo region is the largest metropolitan area in Egypt, with a population of more than 20 million people (Thomas Brinkhoff, 2022).

Students

Figure 25 illustrates the benefit-cost ratio for seven measures evaluated in relation to students. The ratio represents the number of students protected from flood impacts per 1,000 USD invested in each measure. Based on modelling impacts and associated costs, tree planting, followed by the construction of retention reservoirs and the dredging of canals, emerges as the most cost-effective strategy for mitigating future flood damage. However, even if all seven measures are implemented, they would still fall short of addressing the total flood risk, which is projected to affect nearly five million students under the RCP 2.6 scenario and up to nine million under the RCP 8.5 scenario.

This result underscores the need for the Egyptian government to further explore the adaptation requirements of children of school age to protect their access to education during and after flood events. Figure 26 highlights the number and geographical distribution of students who would be protected from future flood impacts through tree planting. As anticipated, most are situated along the Nile, where the flood risk is highest in Egypt.

Road users

Figure 27 indicates the benefit-cost ratio for seven measures evaluated for road users. According to modelling impacts and costs, tree planting, followed by the construction of retention reservoirs and the dredging of canals, shows the highest cost-efficiency in mitigating future flood damage. However, even with the implementation of all seven measures, it would still be insufficient to address the total flood risk, which could affect over 2.5 million people under the

Figure 25: Benefit/cost ratio for adaptation measures for students impacted by floods.

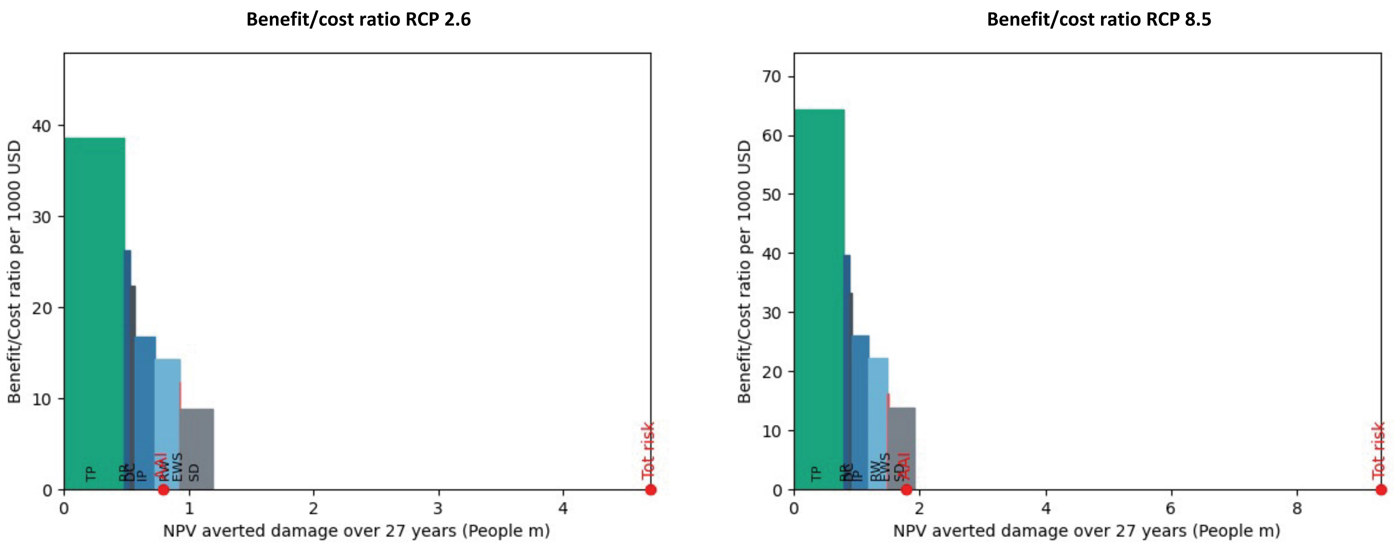
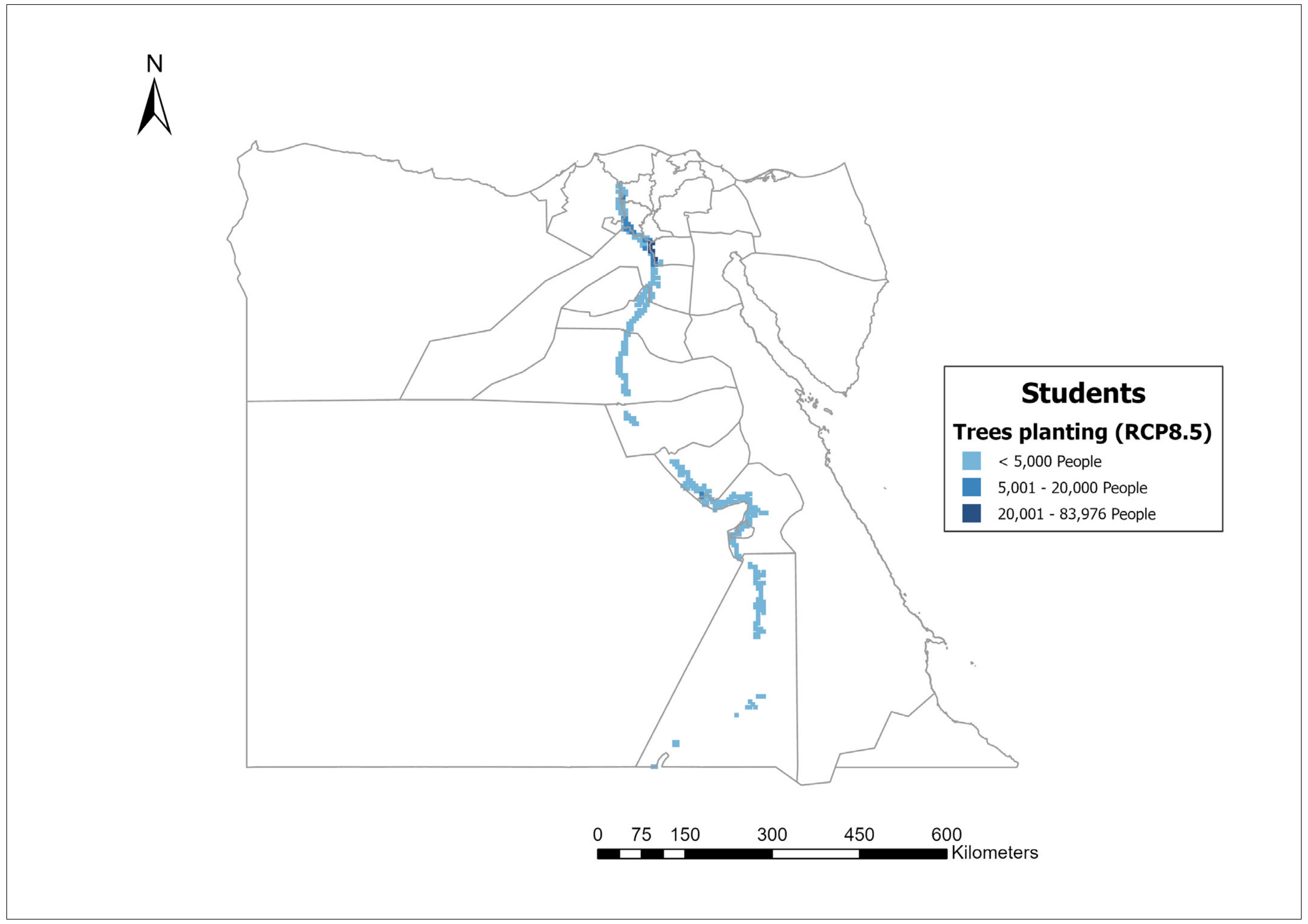


Figure 26: Benefit map of planting trees for students against future floods with RCP 8.5 climate scenario



RCP 2.6 scenario and nearly three million under the RCP 8.5 scenario. This result underscores the need for the Egyptian government to explore other adaptation measures to reduce flood risks for road users.

Figure 28 further illustrates the geographical distribution of people who would still have access to roads due to the planting of trees in the RCP 8.5 scenario. They are mostly located along the Nile River, towards the Rosetta branch. However, the highest concentration of people is observed in the Greater Cairo region and the city of Luxor.

Figure 27: Benefit/cost ratio for adaptation measures for road users impacted by floods

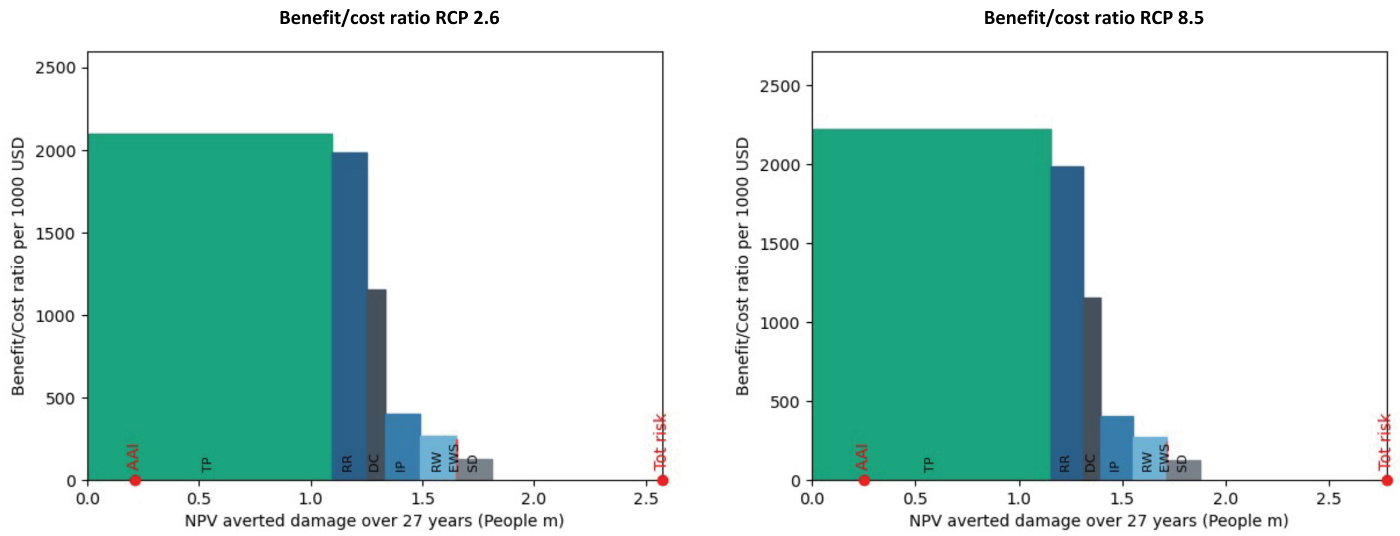
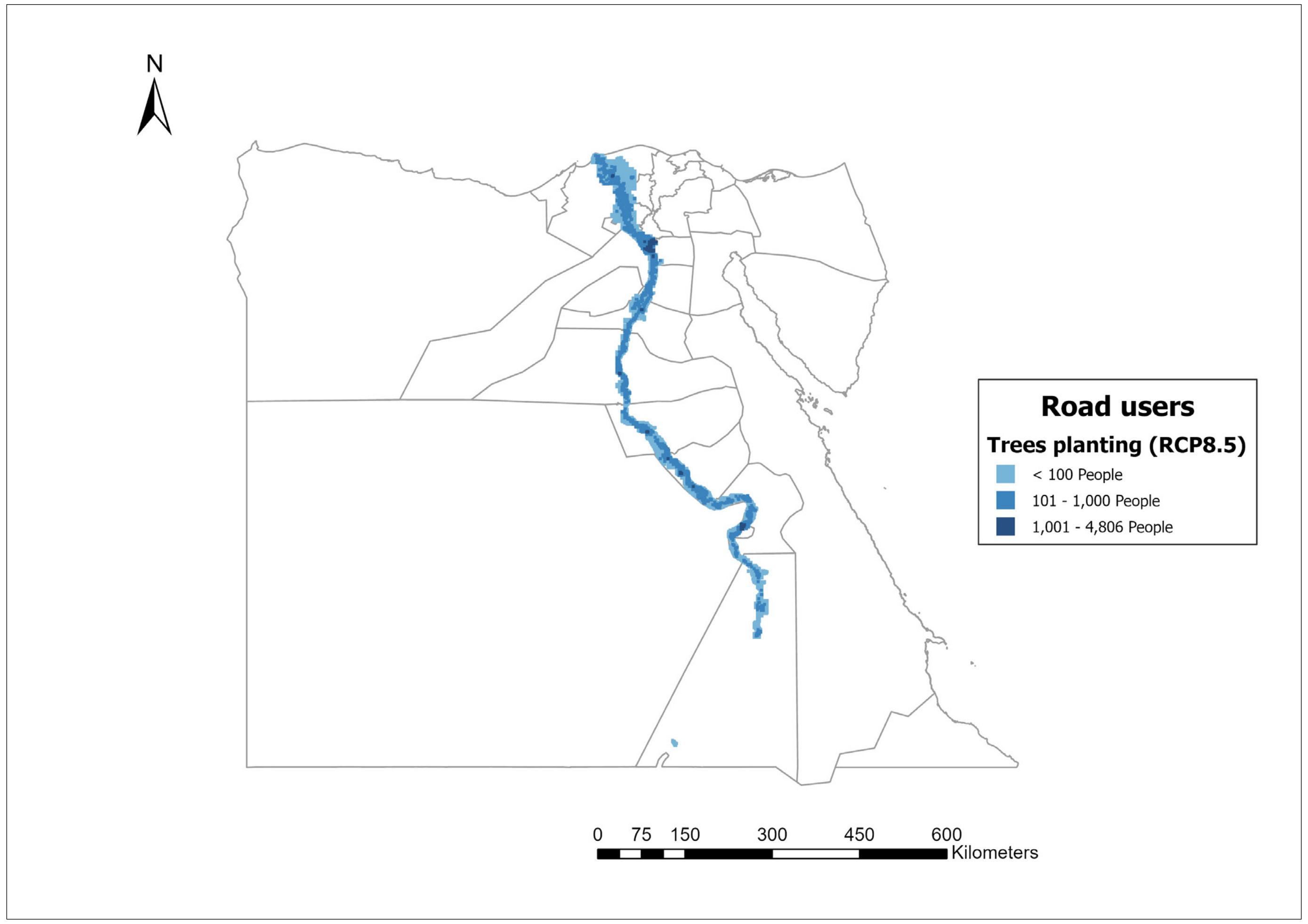


Figure 28: Benefit map of tree planting for road users against future floods with RCP 8.5 climate scenario



2.3.2.2 Heatwaves

1. Economic assets

Crops and livestock

Figure 29 presents the benefit-cost ratio for five measures assessed for crops and livestock. The ratio represents the financial return in USD for every 1 USD invested in each measure. Based on modelling impacts and costs, Early Warning Systems (EWS) emerged as the most cost-effective strategies for mitigating future heatwave damage, followed by research, monitoring, and agricultural training. The significant benefits of EWS

Figure 29: Benefit/cost ratio for adaptation measures for crops and livestock impacted by heatwave

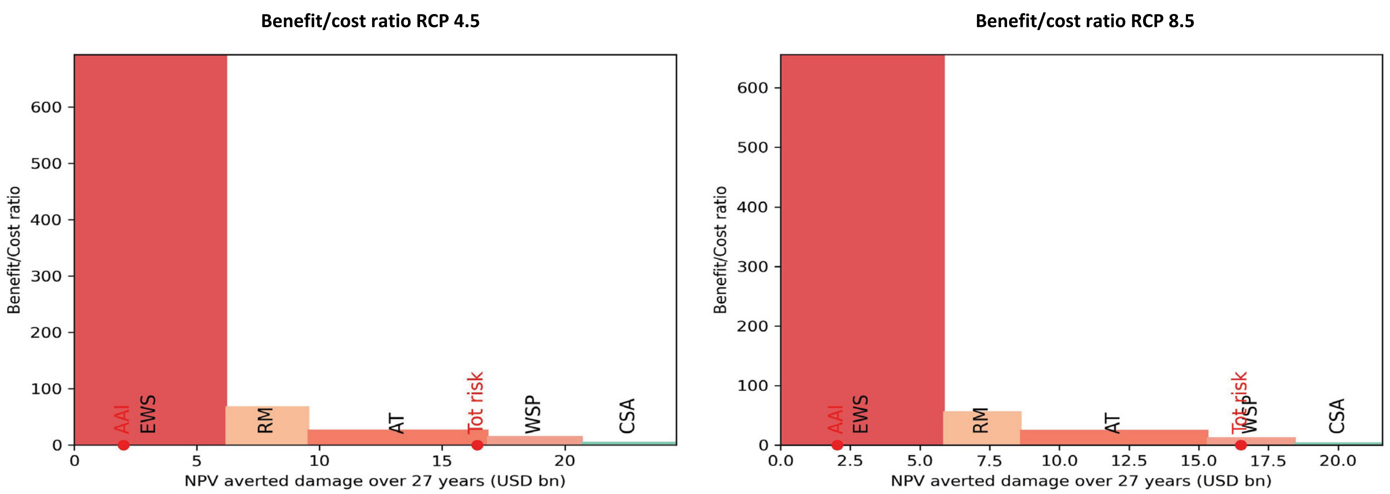
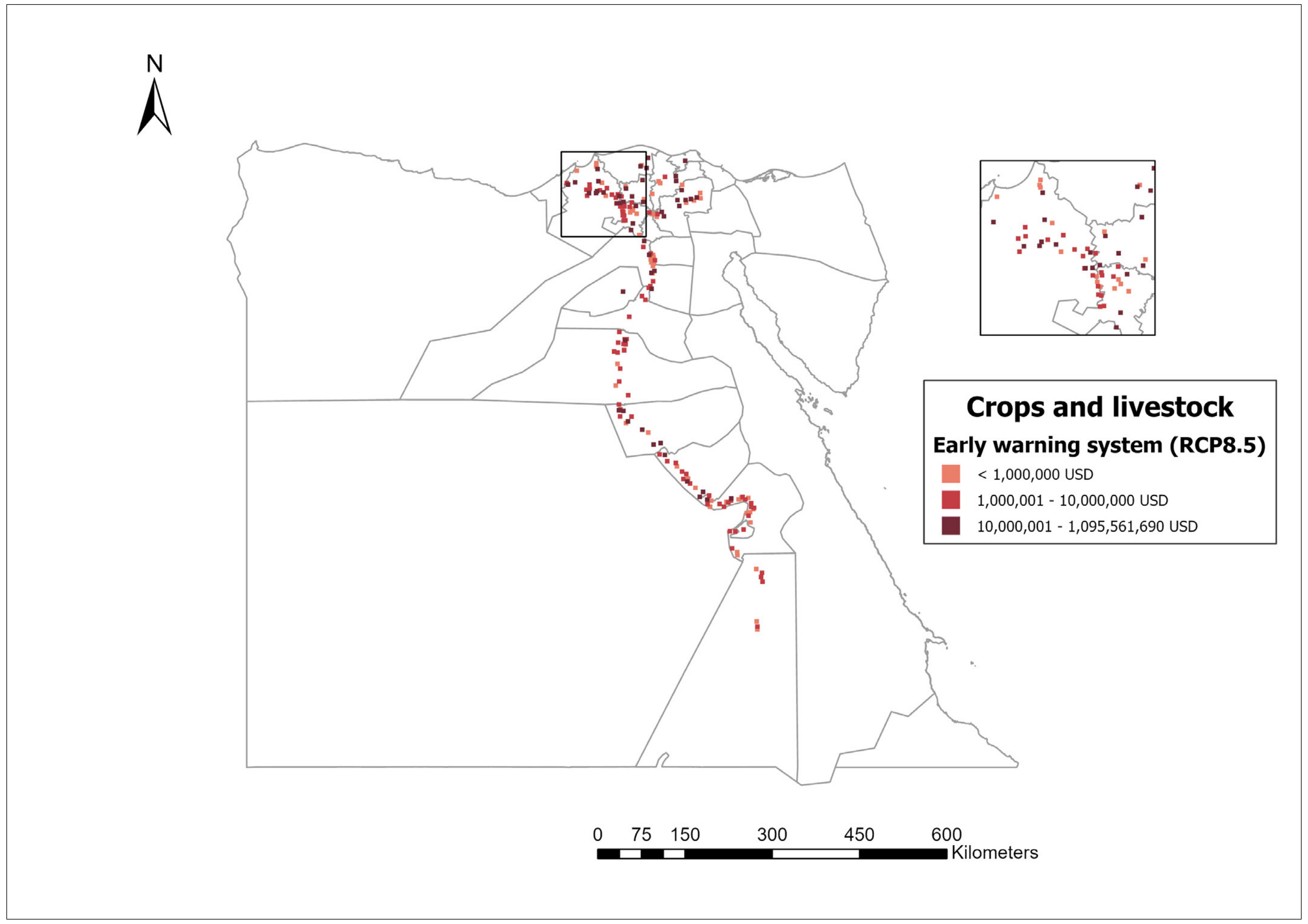


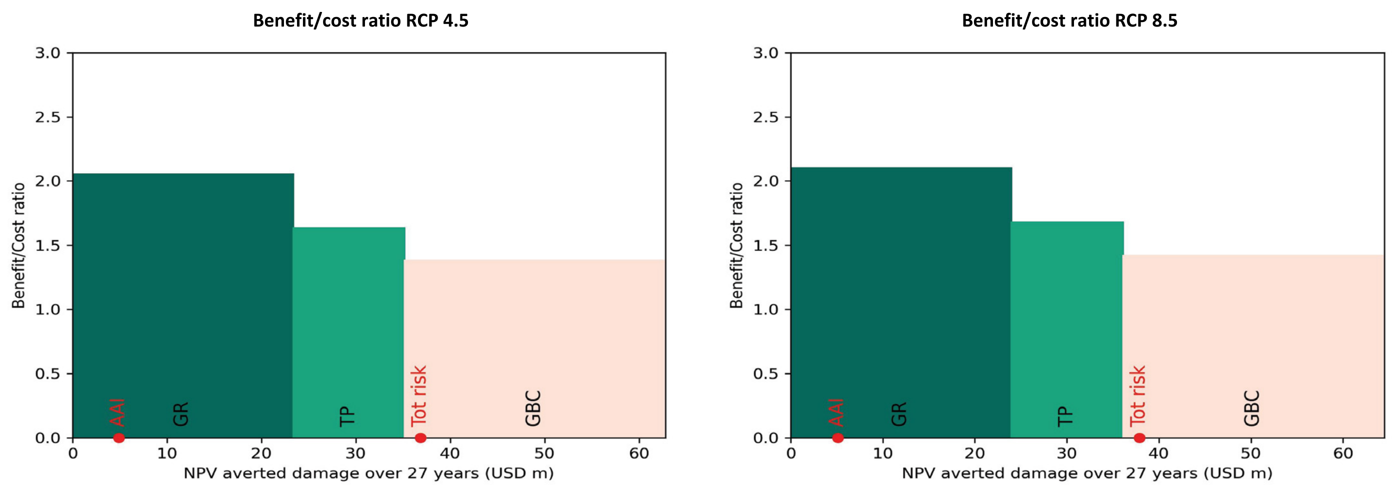
Figure 30: Benefit map of EWS for crops and livestock against future heatwaves with RCP 8.5 climate scenario



align with findings from a study in East and Southern Africa, which concluded that early warning systems offer a high benefit-to-cost ratio in reducing disaster risks, particularly for food insecurity (Ademola K. Braimoh et al., 2018). This can be attributed to their relatively low cost to implement, widespread applicability, and a high number of people/assets positively affected by said implementation. In this particular case, one can envision a scenario where early warning for flash flooding allows livestock herders to take the necessary precautions to protect their herd from the event.

Figure 30 highlights the geographical distribution of crops and livestock that would avoid heatwave impact due to the early warning system in the RCP 8.5 scenario. They are observed along the Nile River delta, between Alexandria and Baheria.

Figure 31: Benefit/cost ratio for adaptation measures for a hotel's electricity bill impacted by a heatwave



Hotels

Figure 31 shows the benefit-cost ratio for three measures evaluated for the hotels' electricity bills. The ratio reflects the financial return in USD for every 1 USD invested in each measure. Based on modelling impacts and costs, green roofs, followed by tree planting and green building codes, emerge as the most cost-effective strategy for mitigating future heatwave damage. Green roofs have demonstrated substantial potential for reducing energy consumption in cooling Egyptian buildings. Studies conducted in various climatic regions of Egypt have reported energy savings between 15-32 per cent compared to conventional roofs (Basil Kamel et al., 2012), with some research indicating savings as high as 31-39 per cent (Ayman Ragab & Ahmed Abdelrady, 2020).

Figure 32 presents the geographical distribution of hotels that would benefit from implementing green roofs under the future heatwave scenario based on the RCP 8.5 climate model. Most of these hotels are located along the Red Sea coast, Sharm El-Sheikh, and the Cairo governorate – Egypt's key tourist regions.

2. Non-economic assets

Heat-related patients

Figure 33 illustrates the benefit-cost ratio for eight measures evaluated for heat-related patients. The ratio represents the number of individuals protected from heatwave impacts for every 1 USD invested in each measure. Based on modelling impacts and associated costs, green roofs, followed by tree planting and early warning systems, emerge as the most cost-effective strategies for mitigating future heatwave damage. Among NbS, green roofs play a crucial role in regulating building temperatures and mitigating the harmful effects of heatwaves on human health. The research, conducted across 15 European cities, highlighted the significant impact of green roofs in reducing indoor heat and lowering the risk of heatwave-related mortality (Antonino Marvuglia et al., 2020).

Figure 34 indicates the geographical distribution of people who would avoid future heatwave impact in the RCP 8.5 scenario by tree planting. They are spread nationwide, with a concentration in the Greater Cairo region, Qalyubia, Monufia, Gharbia, Dakahlia, Al Sharqia, Alexandria, and Sohag governorates. Research on tree planting in Egypt highlights its effectiveness in alleviating heat stress and enhancing thermal comfort. Studies from Assiut University in Cairo reveal that increasing tree density and greenery in outdoor areas can significantly lower air temperatures and improve thermal comfort (Amr Sayed Hassan Abdallah, 2022; Amr Sayed Hassan Abdallah et al., 2020):

Students

Figure 35 indicates the benefit-cost ratio for four measures assessed for students. The ratio reflects the number of students shielded from heatwave impacts for every 1 USD invested in each measure. According to modelling impacts and associated costs, green roofs, followed by tree planting and early warning systems, emerge as the most cost-effective strategies for reducing future heatwave damage. Figure 36 further shows where green roofs would decrease the number of students affected by heatwaves across Egypt.

Figure 36 illustrates the geographical distribution of students who would avoid future heatwave impacts in the RCP 8.5 scenario by green roof implementation. They are spread along the Nile River delta and

Figure 32: Benefit map of green roofs for hotel electricity bills against future heatwaves with RCP 8.5 climate scenario

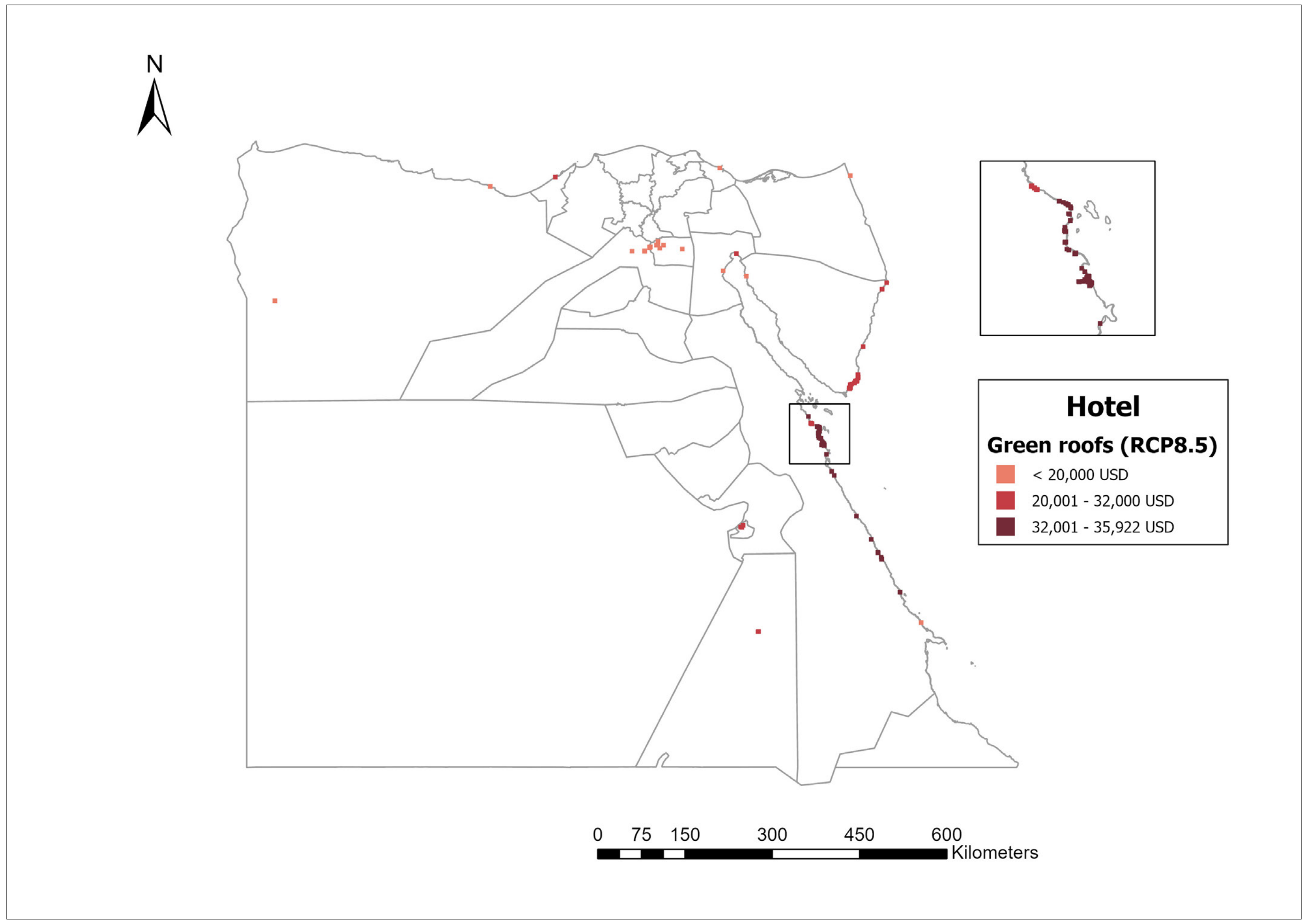
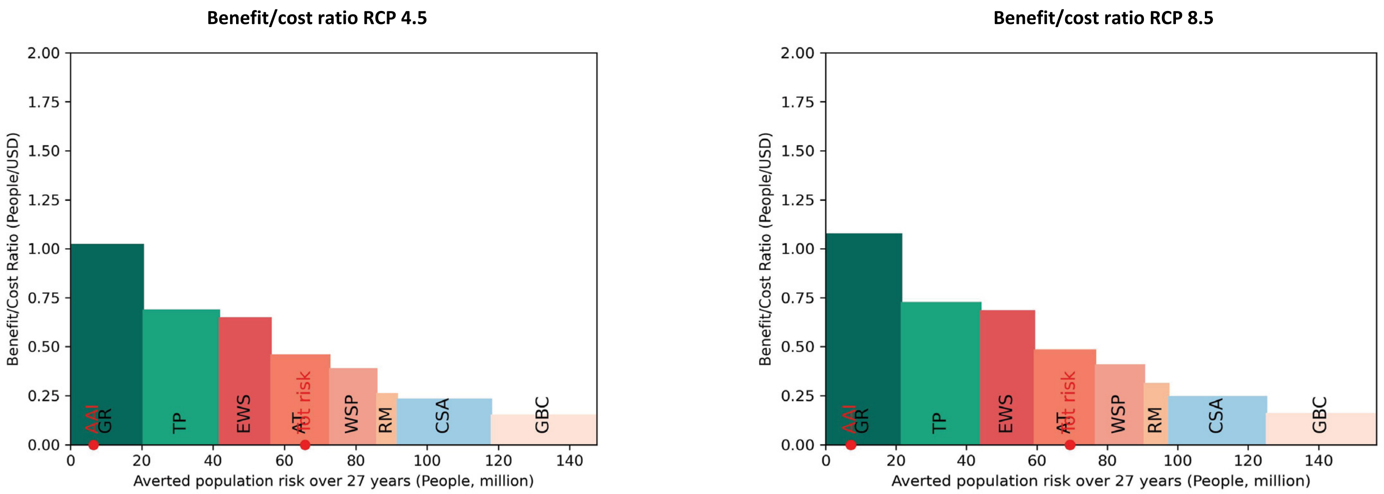


Figure 33: Benefit/cost ratio for adaptation measures for heat-related patients impacted by heatwave



the coasts, with a concentration in the Greater Cairo region.

Green roofs have been shown to reduce indoor temperatures compared to conventional roofs, thus enhancing the thermal comfort of students (Su & Huang, 2015). A study conducted at an elementary school in Taipei revealed that green roofs not only have a cooling effect on the interior but also positively impact the perception and satisfaction of students and teachers. They reported feeling cleaner air and enjoyed being able to play in the area covered by the green roof, which improved their overall well-being (Su & Huang, 2015).

Figure 34: Benefit map of tree planting for heat-related patients against future heatwave with RCP 8.5 climate scenario

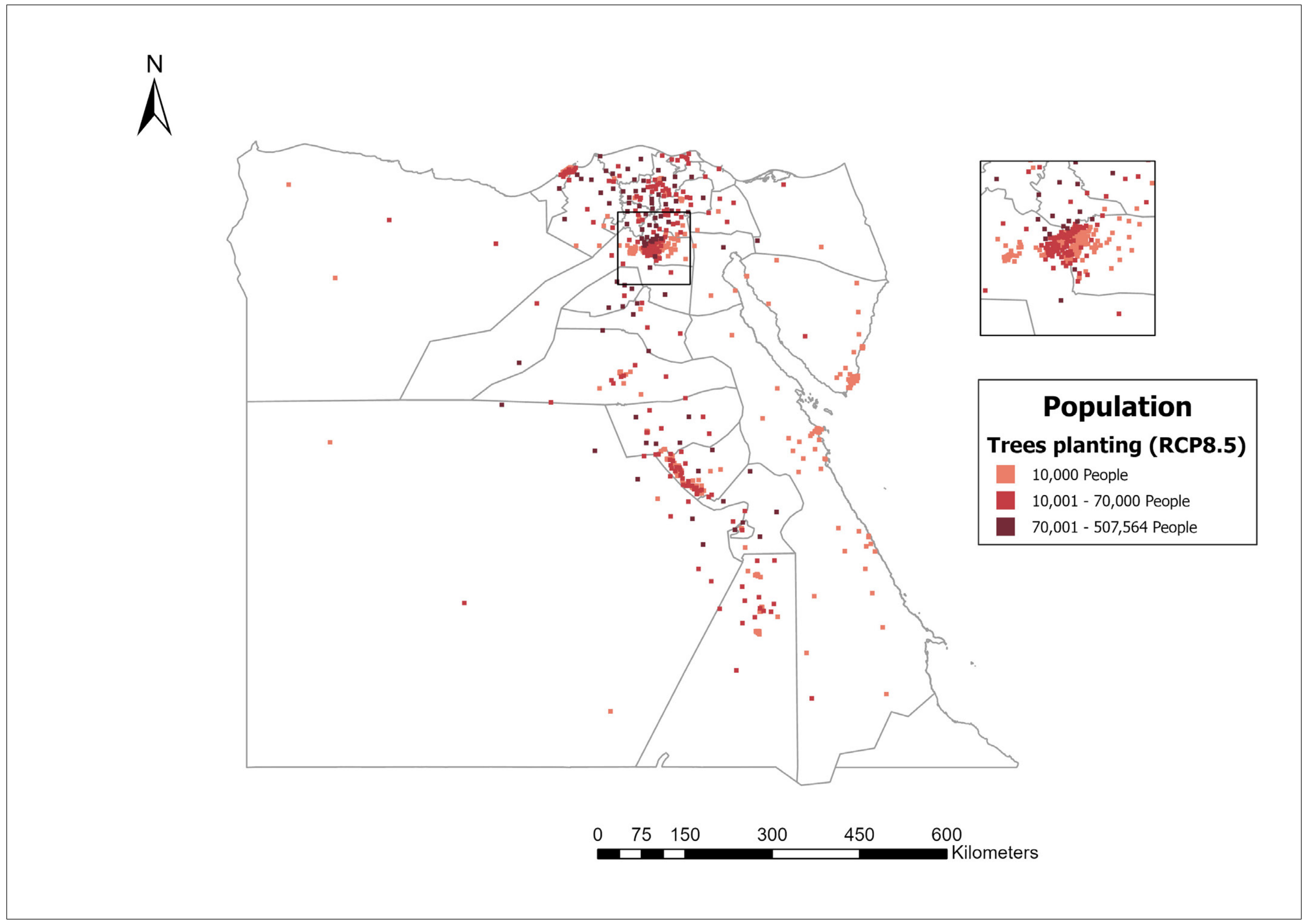
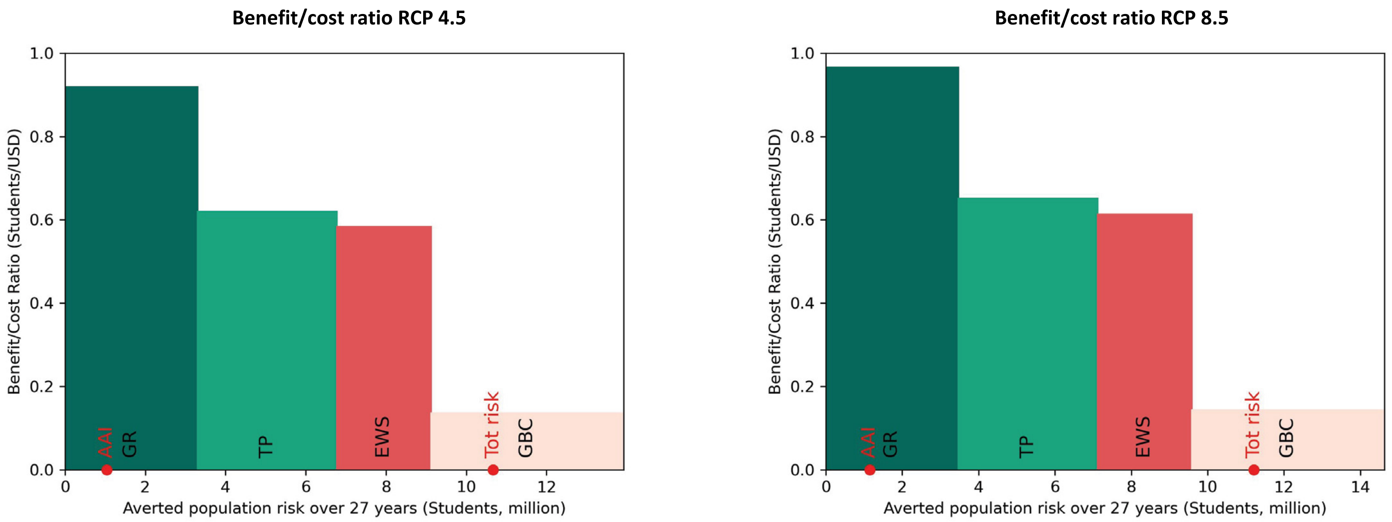


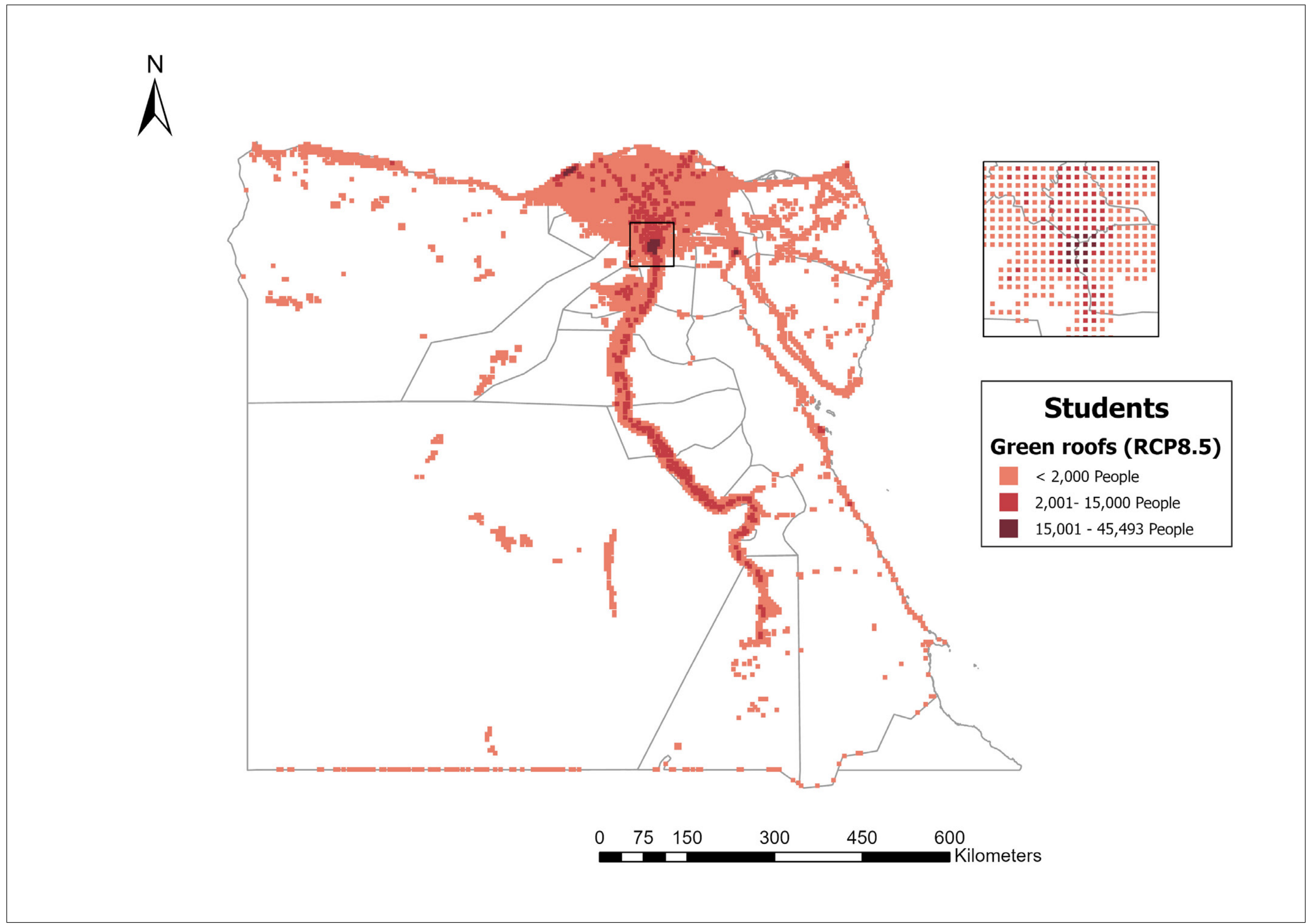
Figure 35: Benefit/cost ratio for adaptation measures for students impacted by heatwave



2.3.1 Results analysis

This section presents a comprehensive analysis of the climate risk experience in Egypt under the scope set for the study by participants of the different activities of ECA. The analysis covers heatwave and flood exposure, and the expected impacts and adaptation options of the economic and non-economic assets selected. Where relevant, specific patterns in exposure and impact will be discussed and compared to provide deeper insights. It is important to note that this section should not be considered in isolation. A thorough understanding requires recognizing the model limitations discussed in Chapter 2.1.2, and

Figure 36: Benefit map of green roofs for students against future heatwave with RCP 8.5 climate scenario



caution should be exercised when interpreting the findings within those constraints.

Overview of current and future climate risks

Economic and non-economic assets in Egypt face high exposure to flooding and heatwaves, particularly along the Nile River. Heatwaves present a more immediate threat than riverine flooding for most of Egypt's assets. However, future scenarios indicate a shift, with flood risks projected to increase, particularly along the Nile River. As such, adaptation strategies must address both present-day heatwave risks and anticipated future flood impacts.

Future heatwave risk in Egypt is significantly affected by high economic growth projections (Statista, 2024a). Although the population growth rate stabilizes at 1.5 per cent annually, longer life expectancy and urbanization will strain infrastructure, especially in densely populated cities where cooling demands will rise (Abu-Hatab et al., 2022). Economic growth will increase energy consumption as tourism and agriculture expose more people, livestock, and crops to extreme heat. As heatwaves intensify in urban and economically active areas, Egypt's population and expanding economy will put more significant pressure on energy, infrastructure, and agriculture, necessitating more robust adaptation strategies to mitigate climate risks.

In contrast, even though floods are currently a significant challenge in the country, the impacts are mostly related to sudden extreme precipitation and are experienced in urban contexts (Esmaiel et al., 2022). However, climate projections point to decreased rainfall in many regions, reducing the risk of flash floods. In contrast, riverine floods are expected to become a major problem in previously unexposed areas (He et al., 2022; Mostafa et al., 2019). Our results project total damages of 28.7 million under RCP 2.6 and 66.2 million under RCP 8.5 by 2050. These estimates focus mainly on rural assets, and the overall cost rises significantly when buildings, such as hotels, face severe damage.

Economic and non-economic assets

Economic assets such as crops and power plants are most exposed to flooding, especially in the Nile Delta and areas like Asyut and Sohag, which are key agricultural regions. For instance, Asyut is a critical hub for wheat production, accounting for 7 per cent of Egypt's total wheat area in recent years (G. A. EL-Sagheer et al., 2021). This geographic concentration underscores the vulnerability of Egypt's agricultural sector, which is vital for national food security and economic stability. Targeted adaptation measures are, therefore, essential to protect these crucial economic assets from future flood damage.

Conversely, livestock and hotels, though more exposed to heatwaves, are less likely to be collectively affected by flooding due to their broader spatial distribution. Livestock is highly vulnerable to heat stress, which negatively affects growth rates, milk production, and reproductive health, especially as temperatures regularly exceed 40°C in the summer (Goma & Phillips, 2021, 2022). As heatwaves intensify, livestock adaptation measures will become increasingly critical to ensure the sector's resilience, particularly in the country's south.

Non-economic assets, especially students and road users, face different challenges. The projected increase in flood risks and temperatures in urban areas, particularly for students, who constitute nearly 18 per cent of the population (GAR, 2015), calls for urgent action to protect educational and transportation infrastructure and ensure the safety of this vulnerable group. Additionally, recent research highlights the correlation between flooding and increased cases of infectious diseases, such as diarrhoea, further compounding the health risks associated with climate hazards (Mohammad Shirmohammadi Yazdi et al., 2024).

Adaptation options

The study identifies a variety of adaptation measures to address the specific risks. Hybrid and nature-based solutions (NbS) such as afforestation and retention reservoirs are highly effective for flooding. These measures can reduce flood intensity and provide additional environmental benefits, such as improved biodiversity (Omer et al., 2023). Furthermore, Early Warning Systems (EWS) have been identified as effective for non-economic assets like students and road users; however, their overall impact on averted damages for these population groups over the coming 27 years is relatively low compared to other adaptation options.

For heatwaves, EWS showed the highest potential to protect crop production and livestock, which is in line with other studies in the scientific literature (Ademola K. Braimoh et al., 2018). Regarding addressing the expected increase in energy demand from hotels due to the high temperatures, green roofs were identified as the most cost-efficient option, with a significant reduction in the need for cooling in buildings (Ayman Ragab & Ahmed Abdelrady, 2020). Similarly, green roofs and tree planting were the best investments to reduce this health risk for impacts on non-economic assets related to heat stress in the overall population and school-age children.

Integrating hazard-specific results

Given the overlapping nature of climate risks in Egypt, an integrated approach to adaptation is crucial. While heatwaves and riverine flooding pose distinct challenges, there are opportunities to develop synergies between adaptation measures for both hazards. For example, NbS, like tree planting, can reduce flood risks while providing shade and cooling during heatwaves, benefiting economic and non-economic assets. However, trade-offs must also be considered, particularly when prioritizing investments with uneven benefits for different assets and hazards, requiring balancing efforts to avoid widening gaps in climate resilience. For instance, EWS can be very effective for economic assets during heatwaves but offer sub-optimal benefits for non-economic impacts related to floods.

The role of economic growth and climate change in flood and heatwave risks is also an important difference between hazards, which should be reflected in adaptation strategies. While flood management will need to incorporate an important change in regimes, from fast to riverine, affecting different areas and assets, the main challenge with heatwaves is the projected increase in cooling demands related to economic growth. This difference in risk drivers should not lead to investments that primarily benefit the interests of those experiencing increased financial wealth over those whose livelihoods are endangered.

Finally, the results in this report also suggested that some of the explored measures would be insufficient to cover the full risk in cases like floods for road users and students. This outcome underscores the need to consider financial solutions such as risk transfer, which can also reduce the need for investment in some of the costliest and least efficient measures for heatwaves and floods.

Conclusion

In summary, Egypt faces significant challenges from climate hazards. The exposure of economic and non-economic assets to these hazards is expected to increase in the coming decades, driven by economic growth, urbanization, and climate change. While current adaptation measures provide some protection, they are insufficient to address future risks. A comprehensive adaptation strategy integrating diverse solutions will safeguard Egypt's assets and ensure long-term resilience. By balancing localized adaptation efforts with broader, nationwide initiatives, Egypt can mitigate the socio-economic impacts of climate change and protect its people and economy.

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3. Climate Resilient Economic Development (CRED)

Climate Resilient Economic Development (CRED) is a global programme 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 programme 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 different economic sectors face 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, Egypt. 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 Egypt in formulating climate-resilient development plans and strategies for economic growth. By establishing a structured framework for climate-resilient economic development, the programme 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 programme 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:

1. Microeconomic foundations: the model is based on individual agents optimizing their outcomes.
2. General equilibrium: the model accounts for interactions and feedback between different economic sectors.
3. 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.
4. 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 anyone can inspect and validate its outputs, allowing for more transparent decision-making.

By employing a dynamic general equilibrium framework to model the Egyptian 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 Modelling structure

The DGE-CRED model was built to 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 available data, 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 four economic sectors: Agriculture, Energy, Manufacturing, and Tourism. 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 Egypt-specific datasets.

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

- As described in the ECA modelling, heatwaves affect farm livestock, while floods affect crops and livestock. These impacts are combined to cause damage to the agricultural sector. In addition, the sector's capital productivity is affected (consider this to be a 'business interruption'). 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. 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.
- Heatwaves do not affect energy infrastructure. Floods affect the energy sector as described in the ECA modelling. In addition, capital productivity loss (business interruption) is estimated using a functional relationship provided by Hazus' model (US Federal Emergency Management Agency [FEMA], 2024).
- Heatwaves do not affect manufacturing. 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). In addition, capital productivity loss was calculated using the Hazus' relationships.
- Heatwaves do not affect tourism. Floods affect tourism as described in the ECA modelling. In addition, capital productivity loss (business interruption) was estimated using the Hazu's relationships.
- 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.

Table 6 presents the key features of the CRED approach with the DGE-CRED model in Egypt.

Table 6: Key features of CRED in Egypt

Features	Description
Available data	• Macroeconomic and sectoral data • Labor market data (employment, wages, labour force) • Energy balances • Impact data for climate-related disasters in selected hazards and climate scenarios, with impacts offset by adaptation options
Regionalization	• Adapted for Egypt (without subregions)
Model type	• DGE-CRED model
Modelled economic sectors	• Agriculture (crops, livestock) • Energy • Manufacturing • Tourism (Hotels)
Modelling specifics	• Macroeconomic dynamic general equilibrium model • 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	• Heatwaves: impacts on livestock and labour productivity • Floods: impacts on housing, crops, livestock, energy assets, energy economic productivity, manufacturing assets, manufacturing economic productivity, tourism assets, tourism economic productivity
Evaluated adaptation measures	Adaptation in the agriculture sector: • Investing in rehabilitating and expanding irrigation systems Adaptation in the tourism and infrastructure sector: • Investing in climate-resilient roads and bridges

The modelled economy is shocked by heatwaves 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.

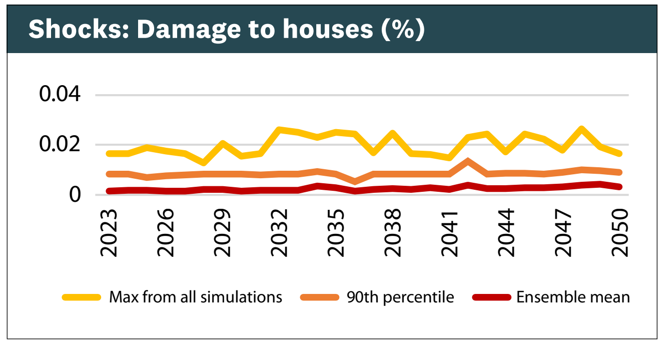
Since the frequency and intensity of impacts increase with climate change, the likelihood of more damaging events also increases towards 2050. This effect was achieved by simulating a year-by-year transition between historical hazards and future hazards: in 2014, every event was sampled from the historical return-period data. By 2050 every event is sampled from the 2050 return-period data. For the years between, the sampling transitions smoothly from historical to future risk.

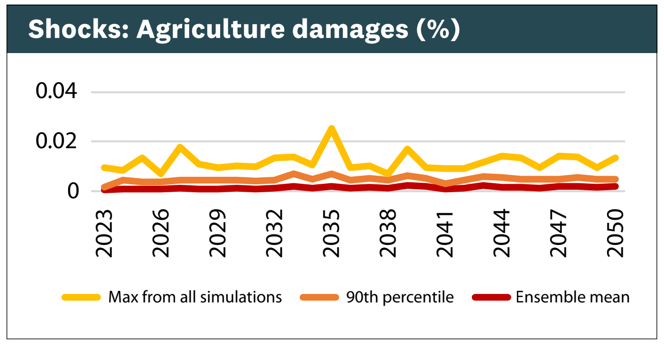
By constructing many of these plausible timelines of future disasters and running the DGE-CRED model with their economic shocks, it is possible to simulate the damage that disasters have on the Egyptian economy. In each economic sector, shocks are applied to the asset values, capital productivity, and labour productivity following the methods described above.

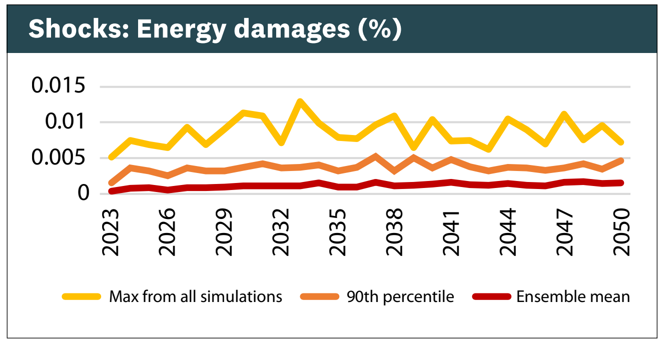
Then, by averaging across the many simulations, it is possible to find the average expected effect on the economy.

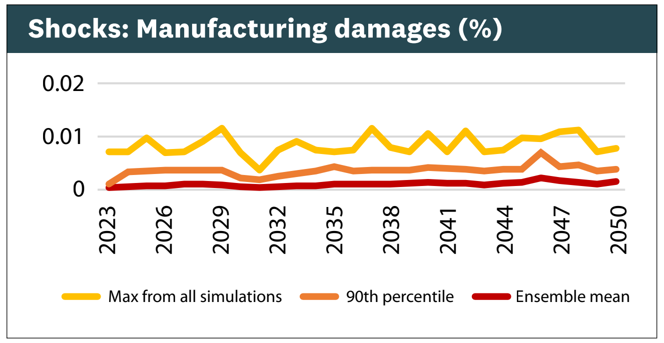
An example of the scale and frequency of input shocks used in DGE-CRED is plotted in Figure 37. The shocks are from combined both heatwaves and floods and are modelled together since their effects on the economy compound. The plot shows the maximum value, the 90th percentile, and the mean value from *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.

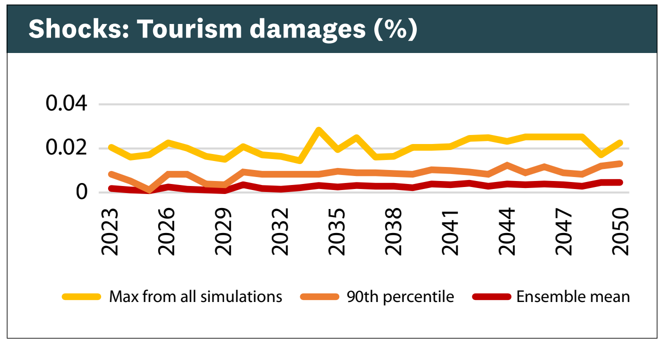
Figure 37: External forcing to DEG-CRED ensemble simulation: RCP 8.5 (% annual sectoral shocks)

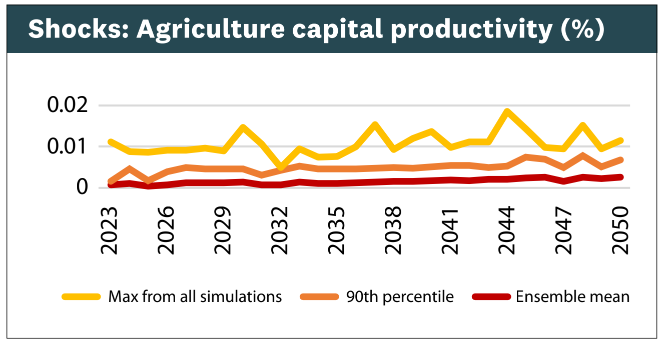


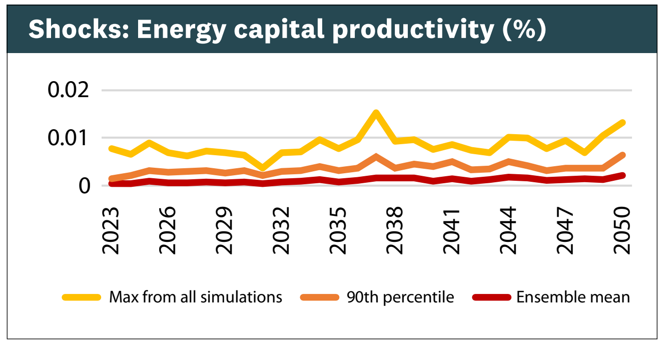


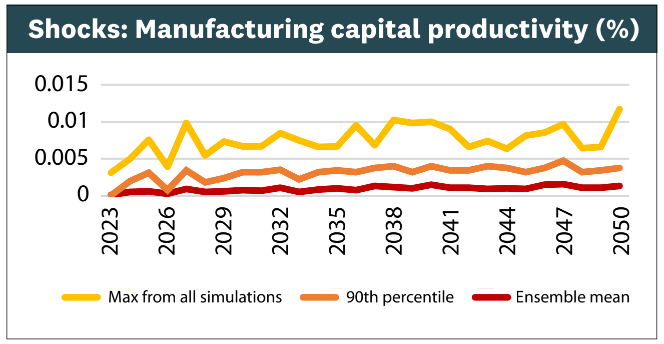


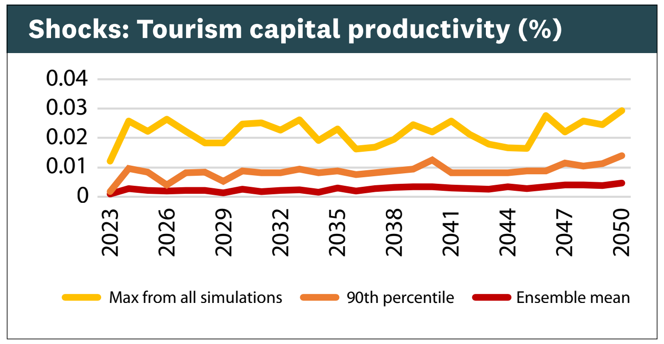


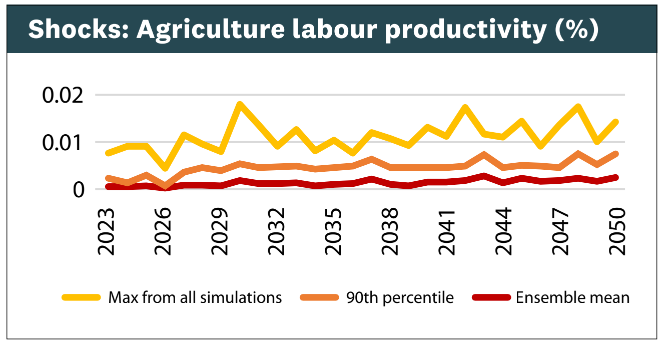


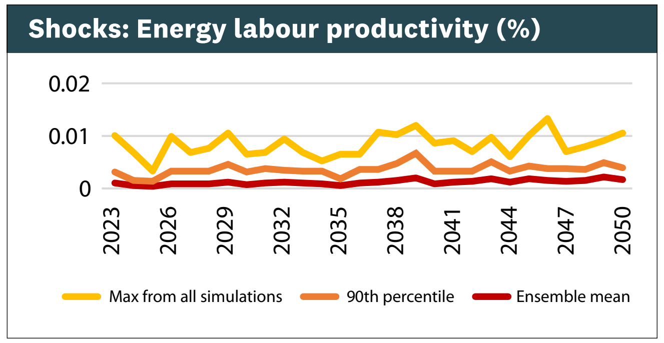


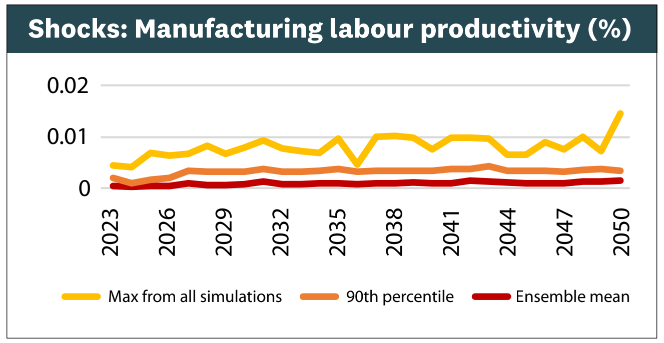


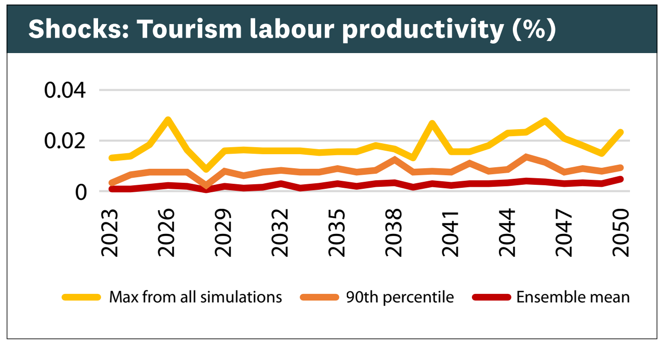












3.3 Modelling limitations

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 climate-related 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 to invest in, what, 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 while everything is rebuilt. The corresponding increase in GDP due to this doesn't mean that a climate-related 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

Heatwaves and floods are expected to significantly affect Egypt's economy between now and 2050. The plots in this section show how these modelled effects evolve over time. Each plot shows three climate scenarios: historical, 'moderate' climate change, corresponding to the RCP2.6 scenario for heatwaves; the RCP 4.5 scenario for floods; and 'strong' climate change, corresponding to the RCP 8.5 scenario.

Each line on the plots in this section shows the mean simulated values from 100 individual model runs, plotted relative to a baseline simulation for an 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 serves to average out the noise of 100 different mode runs, each shocking the economy by different amounts in different years.

We plot the economic variables relative to the baseline so that we can isolate the impacts of climate-relatedl disasters on the Egyptian economy from the simulated growth between now and 2050. That is, the following plots do not show the economy shrinking; they show how much smaller the simulated modelled economy is due to the effects of heatwaves and floods.

National GDP projections

Figure 38 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.

The historical scenario shows the impact that climate-related disasters already have on the Egyptian economy. The two climate change scenarios show how this risk is exacerbated over time, increasing many times over for the RCP8.5 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 later.

While the percentage changes are small, it is important to remember that a 1 per cent impact on an economy of USD 350 bn is a loss of over USD 3 bn in annual economic activity. As the 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

Figure 38: GDP under different climate scenarios compared to a baseline without disasters (% change)

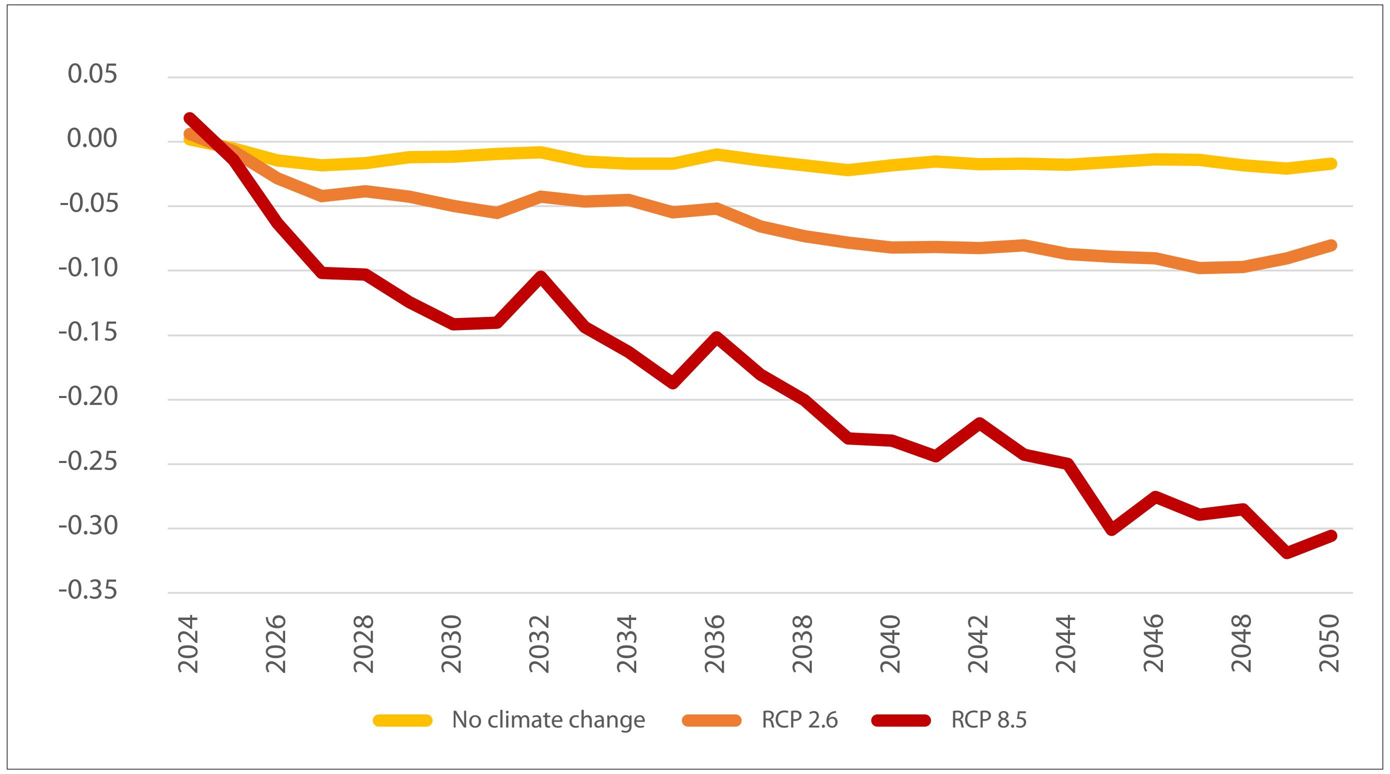
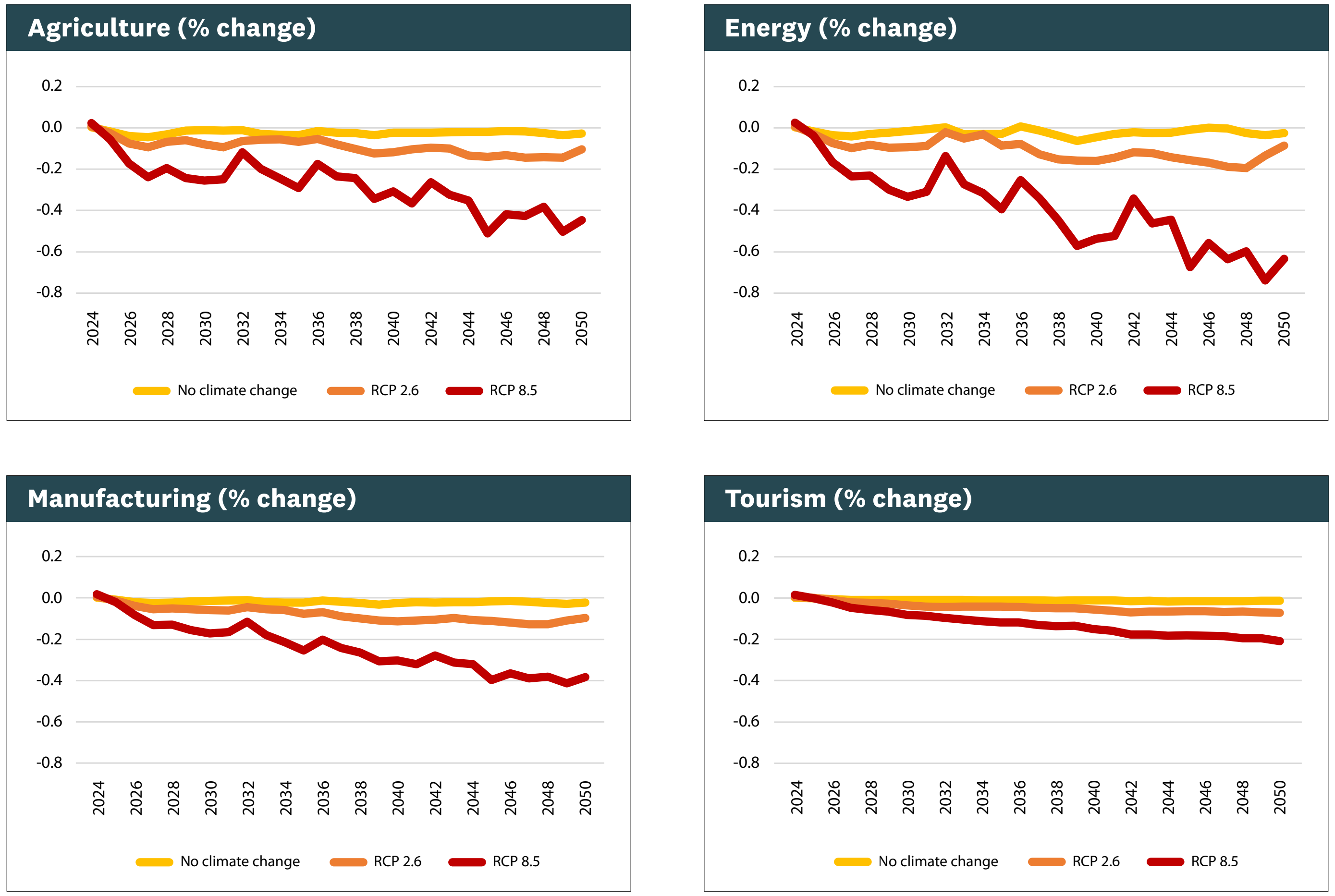


Figure 39: Sectoral GDP under climate change scenarios compared to a baseline without disasters (% change)



model means that historically simulated floods likely underestimate the present-day flash flood risks. Also, since we don't know the likely impacts of very extreme events (rarer than about 100 years), they were excluded from the modelling. That is, we don't 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, and tourism. Figure 39 presents these results.

Each sector has a comparable signal, with the loss of GDP in the RCP8.5 scenario many times worse than the loss of GDP under historical risk. The energy sector is most at risk in this scenario. This result is likely due to risks to hydroelectric infrastructure along rivers. Agriculture and manufacturing see a similar signal, with risk also increasing in the future. Tourism is the sector that is least directly affected since it is easier to restore (most) tourist infrastructure after events. However, many complex processes aren't modelled here, such as the reduction in tourism flows from abroad after major disasters.

Consumption projections

Consumption is a key metric in the DGE-CRED model. It represents the amount of money spent by households and indicates the resources available to individuals. It can, therefore, be considered an indirect measure of the well-being of the population.

Figure 40 shows the mean modelled change in consumption over time in different climate scenarios. The signal here is clearer and stronger than in individual economic sectors: the pressure on the economy from 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.

Adaptation

The DGE-CRED simulations were repeated with the same shocks but where the economy had different levels of adaptation. Adaptation levels were set to give 25 per cent and 50 per cent protection from the direct impacts of disasters from 2035 onwards and were assumed to be divided equally between flood and heat. Figure 41 shows the projected effects of different levels of adaptation on GDP in the RCP8.5 scenario (although the effects are similar in all climate scenarios).

Figure 40: Consumption under different climate scenarios compared to a baseline without disasters (% change)

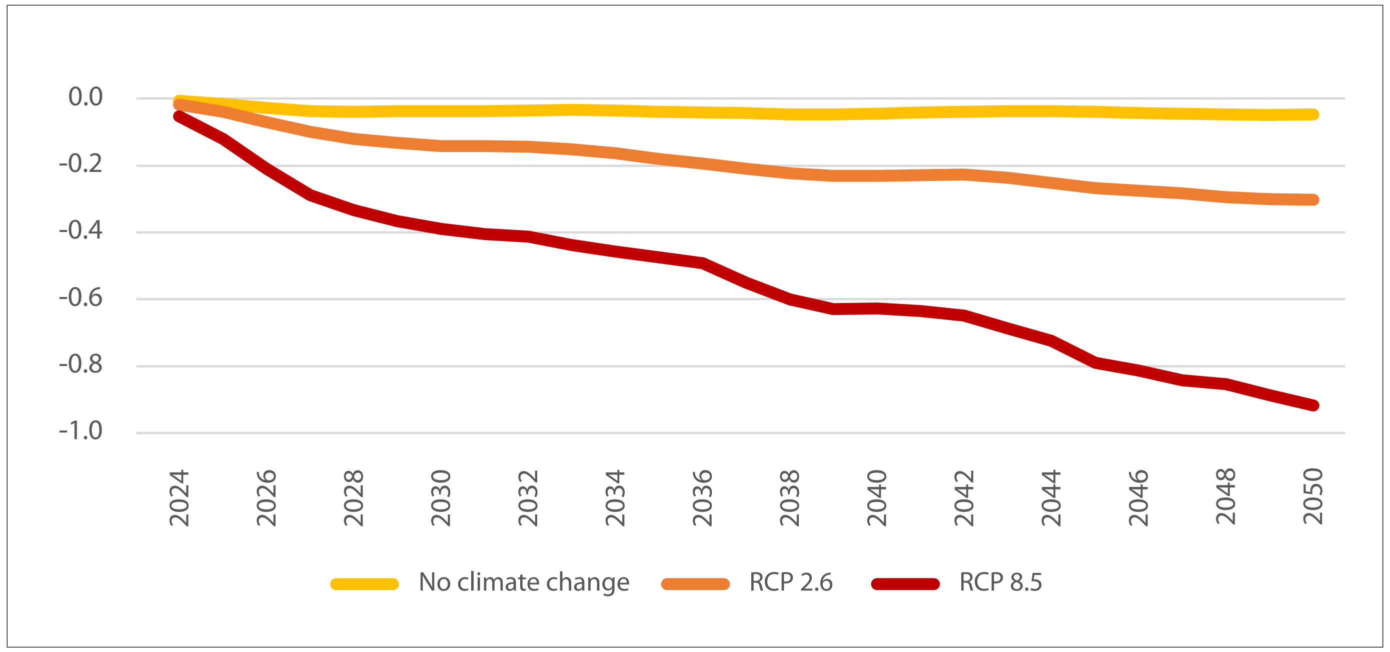
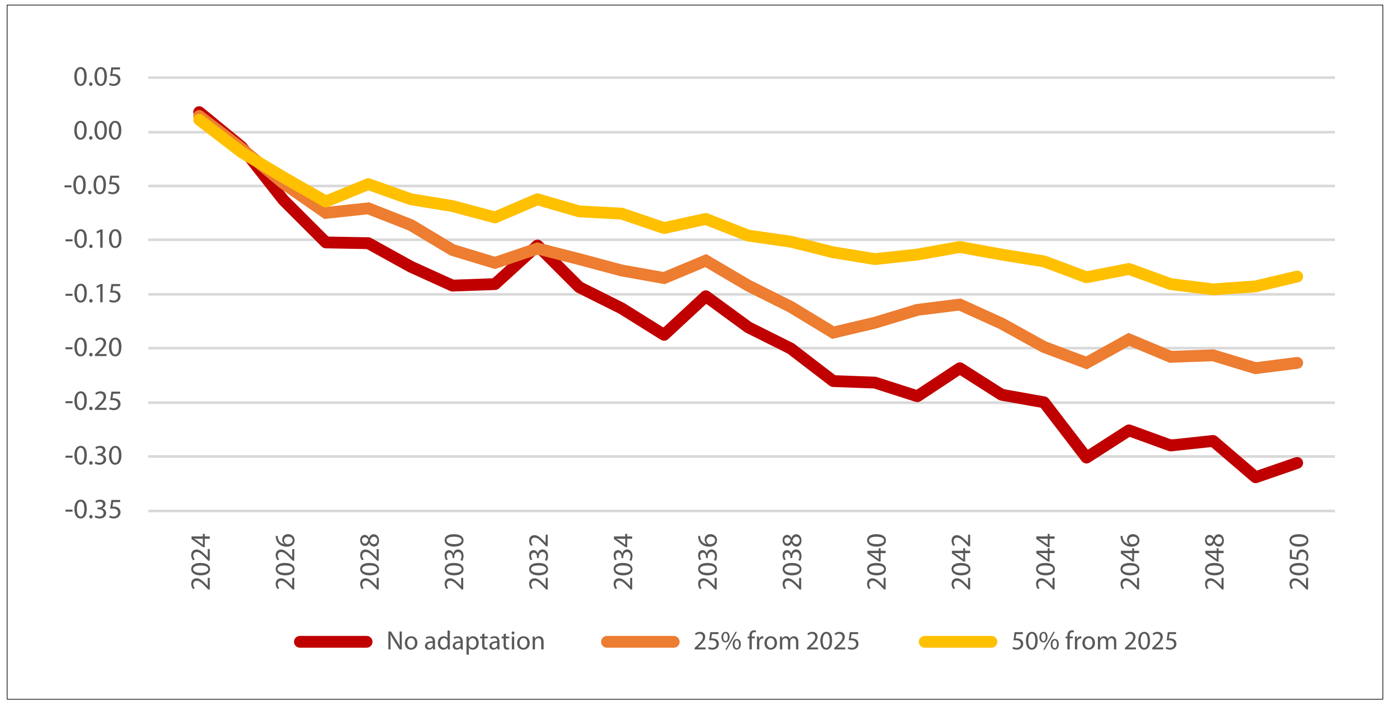


Figure 41: GDP relative to baseline (% change)



In the simulations, adaptations were assumed to come into force in 2035, although in reality, the phase-in will be more gradual. The effects on the economy are almost immediate. Within a couple of years, the mean economic trajectories at different adaptation levels have separated. They are clearly distinguishable from each other, as the economy can resist the impacts of catastrophes.

3.5 Results summary

The economy is a complex system, and it is important to understand how it may be affected by climate-related disasters in the future. From the project's ECA modelling, we have an understanding of the present and future intensities of floods and heatwaves in Egypt and how they affect businesses, economic assets, and humans.

The DGE-CRED model allows us to explore the impacts of heatwaves and floods on the Egyptian 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 Egyptian economy from now to 2050. The impacts are worse in stronger climate change scenarios and are felt in the modelled economic sectors.

Adding climate adaptation measures to the model is an effective way to reduce the modelled impacts. The economic effects are visible in the average modelled economy within a few years of introducing adaptation measures and implementing a 50 per cent adaptation level reduces the impacts of climate-related disasters on the economy by about 50 per cent.

While the effects on the economy from the modelled events are of the order of a percentage, this is huge in a USD 350 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 the impacts of a loss in economic growth affect the economy 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. In particular, DGE-CRED is likely to underestimate the risks to the Egyptian economy from climate change: the assumption of economic equilibrium means that most disruptive disasters do not have the massive, system-wide impacts that are 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.

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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 need to master coding languages to type instructions into the command line and thus tell the system what to do.

4.1 Data input

There were two components in the development of RISK WISE. The first one was the design and functionality of the GUI, which was the first step taken by GIZ, inspired by the user interface built by the European Insurance and Occupational Pensions Authority (EIOPA). EIOPA created the CLIMADA App[2], supported by SWORD Services Greece, the partner working on RISK WISE. 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 component, as shown in Figure 1 in Chapter 1.2, is the data input displayed in the GUI.

The data input to RISK WISE follows the same logic as in CLIMADA. Figure 42 shows a screenshot of the input parameters that should be selected before you run the tool. The options for these parameters are presented in Table 7.

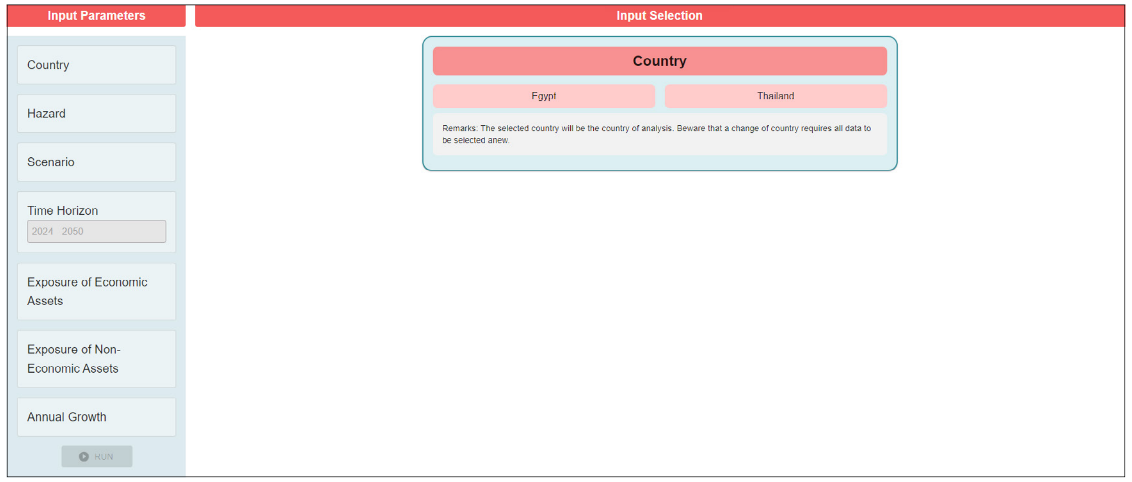
The tool only runs for one type of selected asset at a time. After all the input parameters are specified, the user clicks the 'RUN' button to show the results, which will be explained in the next subchapter.

Table 7: Input parameters RISK WISE

Input parameter	Value
Country	Thailand and Egypt
Hazard	Selected hazard for the study
Scenario	Climate hazard scenarios such as RCP 2.6/RCP 4.5/RCP 8.5
Time horizon	Fixed from 2024-2050
Exposure to 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

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

Figure 42: Input parameter and selection in RISK WISE



4.2 Data output

Users can navigate several results from the top ribbon of RISK WISE (see Figure 43). 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, the user will also find two red buttons, "+ Add to Output" and "+ Save Map/Chart," that are useful for capturing Outputs (Reporting). The Parameters tab selects 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: "Display Map" and "Display Chart". These options 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 chosen 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 (RP10, RP25, RP50, RP75, or RP100). Asset values maps show the total assets grouped by total country (ADMIN0), governorate (ADMIN1), or region (ADMIN2). Impact maps present the total impacted value of assets based on different hazard intensities.

Figure 43: RISK WISE top ribbon

For example, Figure 44, Figure 45, and Figure 46 show the Heatwave Hazard map with a 10-year return period (RP10), the Crops' Economic Asset Values map in billion USD grouped by the second administrative level in Egypt (Governorate), and the Crop's Impact map in thousands USD for 10-years heatwave hazard return period.

When "Display Chart" is selected, an impact chart is 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 selected climate hazard scenario. For example, Figure 47 shows the impact chart for the hotel's electricity consumption due to heatwaves under the RCP 8.5 climate scenario.

Another significant result available in RISK WISE is the adaptation measures benefit/cost analysis. This figure is available under the "Adaptation" tab and under the "Economic and Non-Economic" tab (see Figure 43). 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 damage

Figure 44: Heatwave hazard map with a 10-year return period

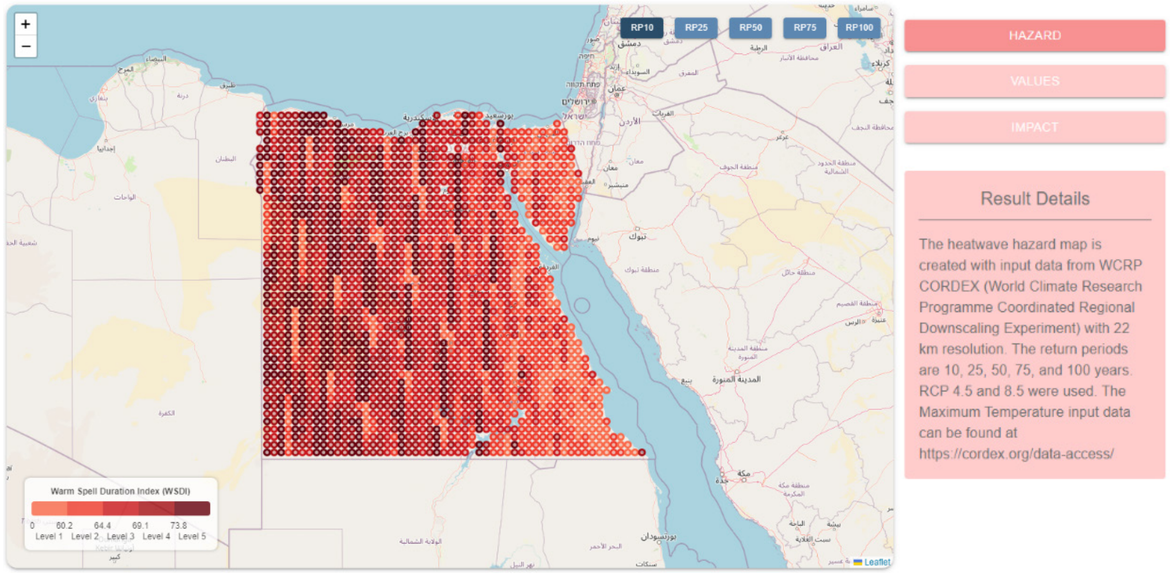


Figure 45: Crops economic asset value in billions of USD grouped by the second administrative level

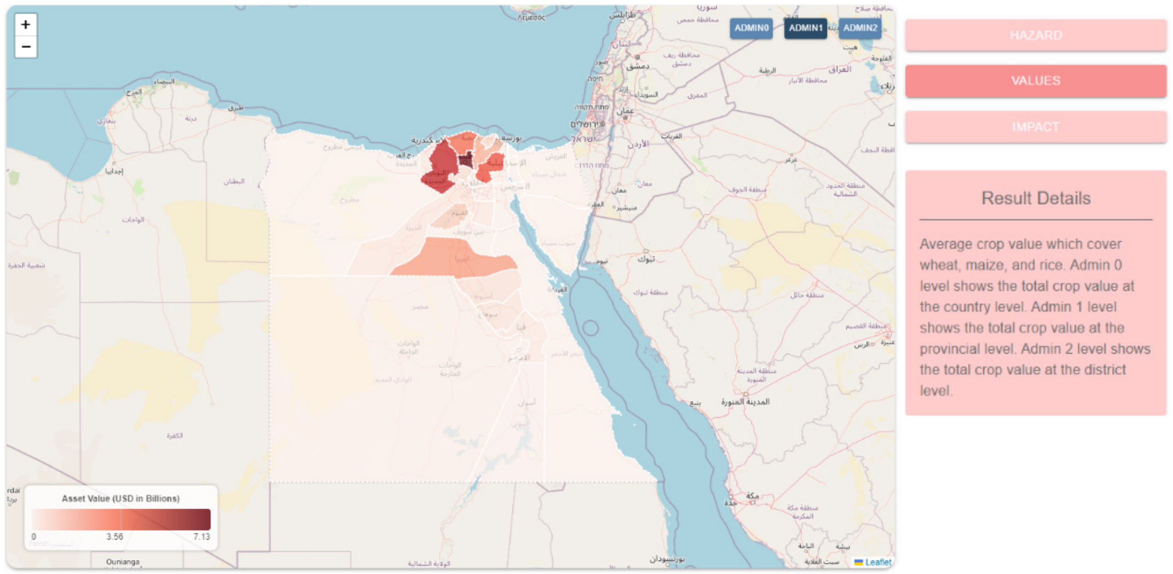


Figure 46: Crops impact map in thousands of USD

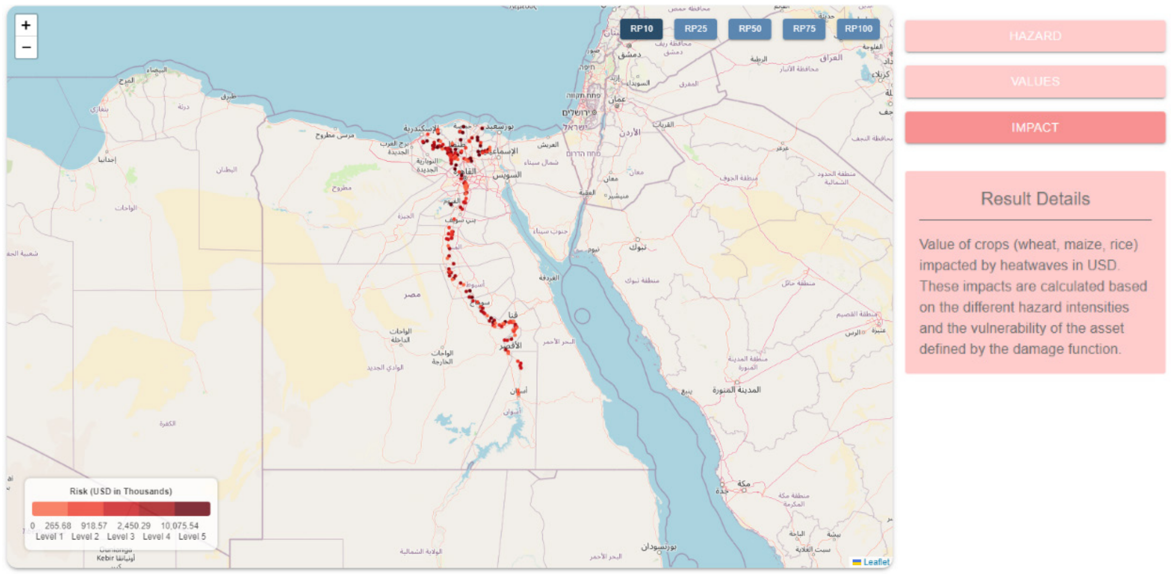


Figure 47: Impact chart for hotel against heatwave at RCP 8.5

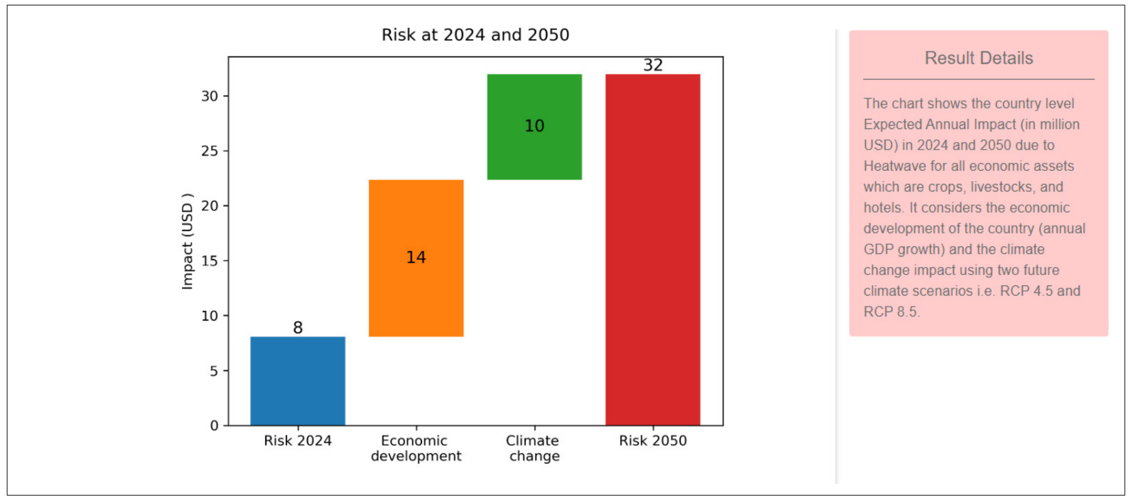
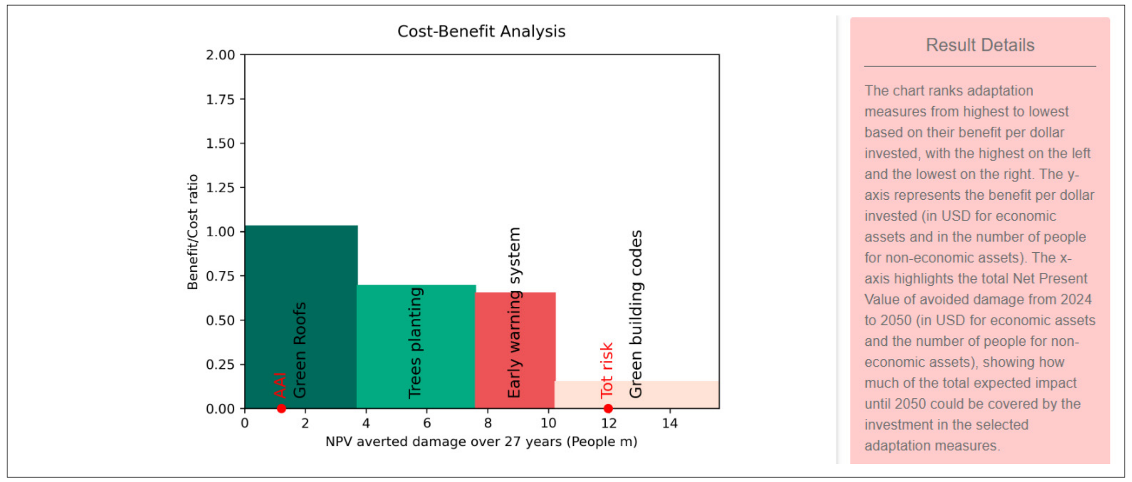


Figure 48: Cost-benefit analysis chart comparing adaptation measures



that could be avoided over the entire time horizon, spanning 27 years from 2024 to 2050 if the measure is implemented in all the locations where it could reduce the impacts of hazards on a given asset. For economic assets, this value is expressed in USD, while for non-economic assets, it is represented by the number of people affected. 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 48 compares measures for students against Heatwave with RCP 8.5. Here, we can see that Green Roof has the highest benefit/cost, with one student per 1 USD invested in green roofs. While implementing Green Building Codes will only benefit 0.12 students per 1 USD invested or 12 students per 100 USD invested.

RISK WISE allows users to download information in various formats and create standard reports, accessible via the “Outputs (Reporting)” tab (see Figure 49). Two key options are “+ 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 can download the data as an Excel file or as Geographic Information System (GIS) files. The “+ Save Map/Chart” button saves the map or chart displayed in the Result window as an image file, 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 49, 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 49: 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 Egypt'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 CLIMADA

CLIMADA focused on the specific impacts of heatwaves and floods on economic assets, including cash crops, livestock, and energy consumption in hotels, as well as non-economic assets, such as access to education, health, and mobility. The main conclusions are:

- High Exposure to Heatwaves and Floods: Egypt's assets are highly exposed to heatwaves, particularly in urban areas, where energy demand and infrastructure strains are expected to grow. While floods are currently less frequent, future projections indicate a significant rise in riverine flood risks, especially along the Nile River, with estimated damages on the studied assets expected to reach an average of $28.7 and $66.2 million annually by 2050 under RCP 2.6 and 8.5, respectively.
- Vulnerable Economic Sectors: Agriculture (particularly wheat in regions like Asyut) and power generation assets are particularly vulnerable to flooding, whereas livestock and tourism (hotels) are more susceptible to heatwaves.
- Non-Economic Impacts: Students and road users are particularly exposed to both heatwaves and floods. The combined effect of increased temperatures and infrastructure vulnerability underscores the need for targeted adaptation in these sectors.
- Adaptation Strategies: A mix of nature-based solutions (NbS), such as afforestation and retention reservoirs, along with early warning systems (EWS), were identified as key to mitigating these risks. Green roofs and tree planting emerged as effective strategies to reduce energy demand and health risks related to heat stress.

Key outcomes from DGE-CRED

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

- Long-term Economic Impacts: The model revealed persistent, growing impacts of climate hazards on the Egyptian economy, particularly under higher emission scenarios. By 2050, the compounded effect of climate change could significantly slow Egypt's economic growth, particularly in agriculture, energy, and tourism.
- Adaptation Effects: Implementing adaptation measures with an even 50 per cent effectiveness could reduce the economic impacts of disasters by approximately 50 per cent. This outcome highlights the potential for economic resilience through early and sustained adaptation investments.
- Economic System Complexity: Although the model simplifies Egypt's economy, it provides critical insights into how the compounding effects of disasters could threaten the country's long-term growth trajectory. It emphasizes the importance of timely adaptation measures to prevent losses that could hinder Egypt's economic expansion.

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. Develop Comprehensive National Adaptation Plans: Given the projected increase in heatwave and flood risks, Egypt should prioritize integrating adaptation strategies into national development and sectoral planning. Key sectors like agriculture, tourism, and infrastructure need tailored solutions that address both current and future climate risks.
2. Prioritize Nature-Based Solutions (NbS): Expanding the use of NbS, such as afforestation, wetland restoration, and retention reservoirs, could help mitigate flood risks while providing co-benefits such as biodiversity enhancement and carbon sequestration.
3. Boost Investments in Early Warning Systems (EWS): Enhancing EWS for heatwaves and floods is critical for safeguarding both economic and non-economic assets. These systems should be integrated with broader resilience-building programs to ensure timely responses and effective disaster management.
4. Economic Resilience through Proactive Adaptation: With macroeconomic impacts expected to grow, Egypt must invest in proactive adaptation strategies. Implementing measures early on can significantly reduce future economic losses, particularly in key sectors like energy, tourism, and agriculture.
5. Strengthen Policy Support for Long-Term Adaptation Funding: Egypt needs to establish funding mechanisms that support sustained investment in adaptation. These mechanisms could include leveraging international climate finance, public-private partnerships, and risk transfer mechanisms such as insurance.

Micro-level recommendations

1. Enhance Protection for Vulnerable Non-Economic Assets: Focus on the protection of education and health infrastructure, especially in urban areas where climate risks intersect with high population densities. Targeted interventions like school infrastructure upgrades and transportation safety measures should be prioritized.
2. Improve Agricultural and Livestock Adaptation Strategies: Adaptation measures such as crop diversification, livestock shelters, and irrigation improvements should be expanded to safeguard agriculture from floods and heat stress. Collaboration with local farmers and agricultural institutions is vital to implement context-specific solutions.
3. Energy Efficiency in the Tourism Sector: To address the increasing energy demand in hotels, particularly during heatwaves, the tourism sector should adopt energy-efficient technologies, including green roofs and improved building insulation.
4. Leverage RISK WISE for Localized Planning: Encourage stakeholders, including local authorities, to use the RISK WISE platform for localized climate risk assessments. While the GUI allows users to upload external datasets, future upgrades should aim to include automatic calibration to enhance the reliability of user-generated inputs.

Final thoughts

To build a resilient future, Egypt must adopt a cross-cutting, multi-sectoral approach to climate risk management. By utilizing both macroeconomic modelling (DGE-CRED) and asset-specific risk assessments (CLIMADA), policymakers and stakeholders can make informed decisions that address the diverse climate risks facing the country. Investing in robust adaptation measures now will protect both economic growth and vulnerable populations, ensuring sustainable development in a changing climate.

Annex 1. Asset Description and Valuation Approaches

Economic assets

1. Crops

Asset location

To determine the location of crops in Egypt, we utilized the Multipurpose Landcover Database for Egypt-AFRICOVER[3], which includes detailed landcover classifications of key crops such as wheat, maize, and rice. The latitude and longitude coordinates were extracted by projecting the shapefile and filtering the attribute table based on the relevant landcover codes. The centroid of each polygon representing crop areas was calculated to pinpoint the exact location for further analysis.

Asset valuation

Tree crops, wheat, maize, and rice were selected for analysis. To estimate the crop values, each crop type's area was calculated within the polygons from the landcover dataset in hectares. The crop yields were determined using the USDA/GAIN Network Report 2023 for Egypt (USDA, 2023). Yield data was calibrated with a five-year average yield using USDA data[4] and crop prices[5]. The final asset value for each location was computed and summed to get the total crop value per location in Egypt valued at USD 10.9 billion.

2. Livestock

Asset location

To assess the impact of flash floods and heatwaves on livestock in Egypt, we utilized geospatial data from the FAO's Global Livestock Systems Distribution dataset[6], which provides detailed raster data on the distribution of cattle and buffaloes. The dataset of 2015 was converted from raster pixels to vector points, with each point representing a specific location of livestock; points with zero livestock concentration were filtered out. The latitude and longitude for each livestock concentration were determined by calculating the centroid of the remaining points, allowing a map of the precise location of cattle and buffaloes across Egypt for further analysis.

Asset valuation

The economic value of livestock at each location was calculated using data from the report (FAO, 2020), which provided numbers and combined values for cattle and buffaloes in Egypt. Cattle represented 53 per cent of the milk production and 86 per cent of the meat production, while buffaloes accounted for 47 per cent of the milk and 14 per cent of the meat. Based on these percentages, we estimated the number of animals and their corresponding values, resulting in 3,544,500 cattle valued at USD 5.56 billion and 1,555,500 buffaloes valued at USD 2.44 billion. The total livestock value is estimated to be USD 9 billion[7], combining cattle and livestock in Egypt.

3. Hotels

The hotel industry is vital to Egypt's economy, playing a significant role in its thriving tourism sector. With a projected revenue of USD 2.78 billion by 2024 (Statista, 2024b), its economic importance is substantial. However, this key industry faces increasing challenges due to extreme weather events, such as flash floods and heatwaves. The rising temperatures in Egypt have increased energy demand for cooling during the summer months (IEA, 2023), potentially driving up hotel energy costs and dissuading some tourists. Additionally, flash floods have caused extensive damage to hotel infrastructure and disrupted operations in certain areas (UNDRR, 2014). Therefore, it is essential to understand the vulnerabilities of climate hazards to ensure the sustainability and resilience of tourism in Egypt.

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3 Available at https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/a7fd1a64-475f-4e34-a3b3-c79e014311ec

4 Available at https://ipad.fas.usda.gov/countrysummary/default.aspx?id=EG

5 The value in Egyptian Pounds (EGP) per metric ton was calculated based on 2023 USDA data and converted this to USD using an exchange rate of 1 USD = 19.16 EGP. Exchange rate based on https://data.worldbank.org/indicator/PA.NUS.FCRF?locations=EG

6 Available at: https://www.fao.org/livestock-systems/global-distributions/cattle/en/

7 Prices adjusted to 2024 values using a GDP deflator of 1.13

Asset location

The location was georeferenced to assess the impact of flash floods and heatwaves in Egypt by utilizing data from the HOTOSM buildings dataset. This dataset includes detailed information on various building types, allowing us to filter the attribute table specifically for hotels. After filtering, we extracted the latitude and longitude coordinates by calculating the centroid of each hotel polygon, providing precise geospatial data for each hotel location.

Asset valuation

In the case of floods, the Global Flood Depth Damage Function from the JRC European Commission (Moel et al., 2016) was used, explicitly referencing the "MaxDamage-Commercial" sheet, which provides the total damage cost for structures and contents at EUR 413 per square meter in 2010 values. The final value for hotels was estimated at USD 138 million, providing a precise estimation of potential flood-related losses for the hotel sector in Egypt[8,9,10].

In the case of heatwave, the asset value was calculated by calculating the total electricity expenditure for the hotel in Egypt. Using the average electricity consumption of 43.99 kWh per guest per night, derived from (Georgei & Bombeck, 2012). A total of 131.05 million overnight stays were recorded in 2022, and total electricity consumption for all hotels was calculated. With electricity costing 0.024 USD/kWh in Egypt, the total annual electricity expenditure was estimated at approximately USD 138.3 million.

4. Power plants

Asset location

Data from the World Resources Institute's Global Power Plants Database 2018[11] was utilized to assess the impacts of flash floods and heatwaves on power plants. This comprehensive database provides detailed information, including latitude and longitude, for each power plant in the country.

Asset valuation

The economic value for power plants at each location was calculated using the Global Flood Depth Damage Functions from the JRC European Commission (Moel et al., 2016). According to the data, the total damage cost for industrial objects in Egypt was estimated at EUR 182,920 per object in 2010. The final asset value for each power plant was estimated at USD 19 million, providing an up-to-date economic valuation for the power plants vulnerable to climate impacts[11,12,13].

Non-economic assets

1. Health (Diarrhoea patients)

Asset location

To accurately assess the impact of floods on diarrhoea cases in Egypt, we required precise geospatial data from health facilities. The location of the health facilities was sourced from the Humanitarian OpenStreetMap Team (HOTOSM), which provided detailed latitude and longitude coordinates for each health facility in Egypt. This data was utilized to create Thiessen Polygons. This method divides the region into distinct zones where each polygon is associated with the nearest health facility, allowing us to partition the entire country systematically and ensuring that each area is mapped based on the proximity of its residents to healthcare services.

Asset valuation

The valuation of diarrhoea patients involved estimating the population at risk in different regions of Egypt. Here, we used population count data from 2020, available as a raster file from the Humanitarian Data Exchange[12], to map the population count across Egypt. We performed Zonal Statistics on each Thiessen Polygon created during the location assessment, summing the population within each zone. This analysis allowed us to assign population values to each area, reflecting the total population of 95,944,315 people in 2020.

2. Health (Heat-related patients)

Heatwaves significantly increase the number of hospitalizations in Egypt by exacerbating heat-related health issues. Prolonged high temperatures can lead to a rise in conditions such as heatstroke, dehydration, and cardiovascular complications. These health problems often necessitate urgent medical attention, resulting in higher hospitalization rates. In Egypt, where heatwaves can be intense and prolonged, healthcare facilities frequently experience surges in patient numbers during extreme heat events. Vulnerable populations, including the elderly and those with preexisting health conditions, are particularly affected. The increased demand for medical services during heatwaves underscores the need for effective public health measures, such as improved hospital cooling systems and enhanced heatwave preparedness strategies, to mitigate the impact on the healthcare system.

Asset location

We required precise geospatial data from health facilities to accurately assess potential heat-related patients in Egypt because of heatwaves. The location of the health facilities was sourced from the Humanitarian OpenStreetMap Team (HOTOSM), which provided detailed latitude and longitude coordinates for each health facility in Egypt. This data was utilized to create Thiessen Polygons. This method divides the region into distinct zones where each polygon is associated with the nearest health facility, allowing us to partition the entire country systematically and ensuring that each area is mapped based on the proximity of its residents to healthcare services.

Asset valuation

Estimating the number of heat-related patients requires quantifying the at-risk population in different regions of Egypt. Here, we used population count data from 2020, available as a raster file from the Humanitarian Data Exchange[13], to map the population count across Egypt. We performed Zonal Statistics on each Thiessen Polygon created during the location assessment, summing the population within each zone. This analysis allowed us to assign population values to each area, reflecting the total population of 95,944,315 people in 2020.

3. Mobility (Road users)

Asset location

Road network datasets were acquired from HOTOSM to assess the impact of floods on road users. 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 Egypt, ensuring comprehensive coverage. The road network was then buffered by 10km to account for the area most likely 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. This allows us to map and analyze precisely the areas where road users are most vulnerable to the effects of flash floods.

Asset valuation

We integrated population data with the road network to estimate the number of road users potentially impacted by flash floods. Using the raster population data for Egypt, 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. By combining the road infrastructure with population data, the value of road users was quantified, reflecting the total of 721,643 road users.

4. Education (Students)

Asset location

To evaluate the impact of floods and heatwaves on students in Egypt, we utilized data from the GAR2015 database, which provides geospatial information on student locations (GAR, 2015). The dataset included the latitude and longitude of educational institutions nationwide, allowing for integrating climate risk with student data to assess potential impacts.

Asset valuation

The total number of students potentially affected by climate hazards was determined using GAR2015 data, which reported a student population of 34,480,271. However, the student population is calibrated in CLIMADA to 17,240,136. This represents the number of students more likely to be affected by floods and heatwaves. This data provides a baseline for assessing the impact of floods and heatwaves on the educational sector in Egypt.

8 Official average yearly exchange rates used to convert from EUR to EGP: https://www.exchangerates.org.uk/EUR-EGP-spot-exchange-rates-history-2010.html#:~:text=Average%20exchange%20rate%20in%202010%3A%207.4735%20EGP

9 Official average yearly exchange rates used to convert from EGP to USD https://data.worldbank.org/indicator/PA.NUS.FCRF?locations=EG

10 Prices adjusted to 2024 values using a GDP deflator of 1.13

11 Data available at: https://global.infrastructureresilience.org/downloads/regions/egy

12 Available at https://data.humdata.org/dataset/worldpop-population-counts-for-egypt

13 Available at https://data.humdata.org/dataset/worldpop-population-counts-for-egypt

Annex 2. Methodology for Adaptation Measures Selection

The methodology for selecting adaptation measures to address flood and heatwave risks in Egypt involves a systematic four-step process. First, a comprehensive list of potential adaptation measures is defined, drawing on existing knowledge and expert input. Next, this list undergoes validation and refinement by weighing selection criteria and prioritizing the most relevant and effective measures. The third step employs a multi-criteria decision analysis (MCDA) to narrow 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 country is estimated, providing a good basis to analyze the cost-benefit of implementing these measures.

A. Defining a long list of adaptation measures

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 Egypt. 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 8 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. Nature-based solutions (NbS) harness natural processes and

Table 8: Long list of identified flood and heatwave adaptation measures for Egypt

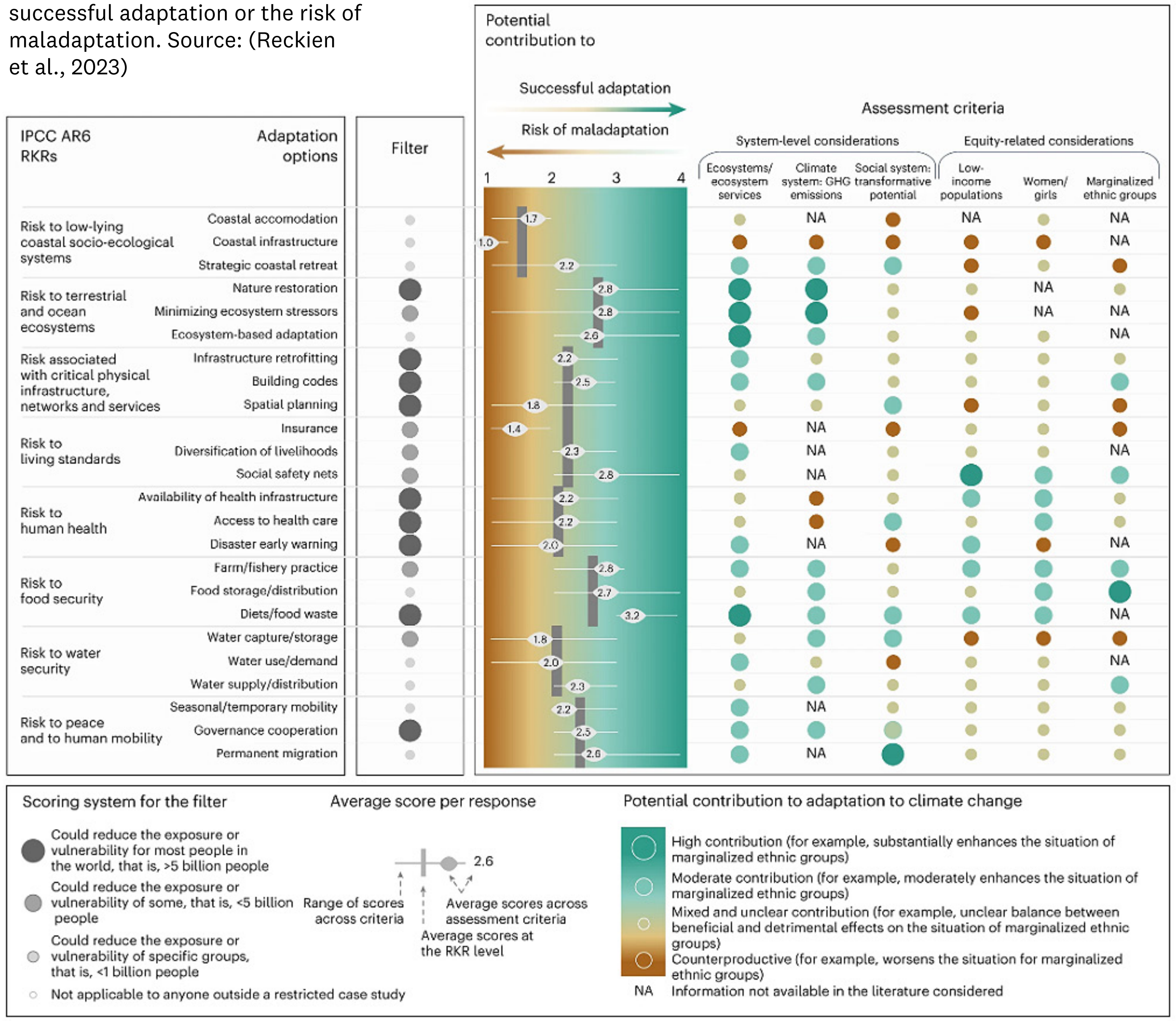
Hazard		Adaptation measures	Types
Flood	1	Embankment walls	Grey
	2	Mobile flood embankments	Grey
	3	Sluice gates	Grey
	4	Ground (building) elevation	Grey
	5	Elevation of electricity substations	Grey
	6	Dry flood proofing	Grey
	7	Flood walls	Grey
	8	Reinforced electricity poles	Grey
	9	Improved drainage system	Grey
	10	Dredging of canals	Grey
	11	Rain collection tanks for existing buildings	Grey
	12	Permeable pavements	Grey
	13	Modular water retention systems	Grey
	14	Wet flood proofing	Grey
	15	Small dams	Grey
	16	Tree planting	NbS
	17	Retention reservoirs	Hybrid
	18	Recharging wells	Hybrid
	19	Infiltration ponds	Hybrid
	20	Road spillways	Hybrid
	21	Detention swales along roads	Hybrid
	22	Constructed wetlands	Hybrid
	23	Flood awareness campaign	Systemic
	24	Smart-city data hub development	Systemic
	25	Hydrological and meteorological monitoring	Systemic
	26	Flood protection storage facilities	Systemic
	27	Improved solid waste management	Systemic
	28	Early warning system	Systemic
	29	Flood index 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	Tree planting	NbS
	8	Urban farming	NbS
	9	Urban forestry	NbS
	10	Green roofs	NbS
	11	Climate-smart agriculture	Hybrid
	12	Cooling by water spray	Hybrid
	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

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 29 measures for flood 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. The following selection criteria, validated by key stakeholders, were used to ensure that the shortlisted measures are both impactful and feasible:

Figure 50: Location of adaptation options along the adaptation–maladaptation continuum, contributing to potentially successful adaptation or the risk of maladaptation. Source: (Reckien et al., 2023)



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 available data.

2. **Up-scaling 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 available 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 available 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 available 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 the potential for high, medium, or low maladaptation. This is assessed and validated by experts and available data where available.

6. **Stakeholder interest (social acceptance):** Another indicator for assessing adaptation strategies is the interest that stakeholders show in a strategy, which 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 available data.

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 available 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 available 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 varying 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 9.

C. Multi-criteria decision analysis – Defining a short list of adaptation measures

Multi-Criteria Decision Analysis (MCDA) is a structured approach 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 9 above. 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 9: Weight of selection criteria. Ranked from 8 (most important) to 1 (least important).

Criterion	Average points	Weight
Cost-effectiveness	7.29	19.75%
Stakeholder interest (social acceptance)	5.86	15.88%
Co-benefits (for SDGs)	5.09	13.79%
Institutional support requirements	4.68	12.68%
Up-scaling potential	4.29	11.61%
No-regret options (risk gradient)	3.61	9.78%
Potential for maladaptation	3.50	9.48%
Nature-based solutions	2.60	7.04%

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 10 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, national action plans such as Egypt's National Strategy for Adaptation, 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 10: Short-listed adaptation measures

Hazard		Adaptation measures	Types	Score
Flood	1	Green spaces	NbS	1.00
	2	Retention reservoirs	Grey	0.82
	3	Dredging of canals	Grey	0.75
	4	Infiltration ponds	NbS	0.75
	5	Recharging wells	NbS	0.75
	6	Early warning system	Systemic	0.72
	7	Small dams	Grey	0.25
Heatwave	1	Green spaces	NbS	1.00
	2	Green/white roofs	Hybrid	1.00
	3	Early warning system	Systemic	0.87
	4	Training on adaptation agricultural practices	Systemic	0.87
	5	Water-saving cultivation and production practices	Systemic	0.82
	6	Research and monitoring	Systemic	0.59
	7	Climate-smart agriculture	Systemic	0.73
	8	Green building codes	Systemic	0.46

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