Integrating Physical Climate Risks and Adaptation into Sovereign Credit Ratings

Implications for financial stability and fiscal policy at the sovereign-bank nexus

Mark V Bernhofen [1, 2], Matt Burke [1,2,3], Akaraseth Puranasamriddhi [1], Nicola Ranger [1] and Gireesh Shrimali [2]

September 2024

[1] Resilient Planet Finance Lab, Environmental Change Institute, School of Geography and the Environment, University of Oxford
[2] Oxford Sustainable Finance Group, Smith School of Enterprise and the Environment, School of Geography and the Environment, University of Oxford
[3] Sheffield University Management School, University of Sheffield

Citation

Bernhofen, M.V., Burke, M., Puranasamriddhi, A., Ranger, N., Shrimali, G. (2024). Integrating Physical Climate Risks and Adaptation into Sovereign Credit Ratings: Implications for financial stability and fiscal policy at the sovereign-bank nexus. Oxford: Smith School of Enterprise and the Environment and Environmental Change Institute, University of Oxford

Acknowledgements

This research was conducted as part of the UK PACT (Partnering for Accelerated Climate Transitions) project “Greening Thailand’s Financial System: Advancing Climate and Environmental analytics and Knowledge for Resilient Finance”, led by the Smith School of Enterprise and Environment (SSEE), and the Oxford Martin System Resilience Initiative, led by the Environmental Change Institute. Authors express gratitude for the kind funding support of the FCDO and Oxford Martin School. Smith School authors were also supported by funding from the UK Centre for Greening Finance and Investment.

Disclaimer

The analyses presented in this paper are based on open data and represent independent research conducted by researchers at the University of Oxford. The methodologies and findings are preliminary, and as such, the results should be interpreted with caution. They do not constitute financial advice or professional recommendations. The authors bear sole responsibility for the opinions expressed and any errors contained in this paper; they should not be attributed to the funders or affiliated institutions

Executive Summary

Climate change is a risk to financial stability, both directly and indirectly through its impact on sovereign credit risk. As global temperatures rise and extreme weather events become more frequent and severe, the economic costs—including the costs of adaptation—are likely to put considerable strain on government (sovereign) finances. Sovereign credit ratings, which assess a nation's ability to repay its debt, are critical to determining borrowing costs and influencing investor confidence. Given that many financial institutions, including banks, hold substantial amounts of sovereign debt, the impact of climate change on these ratings has direct implications for financial stability. This is the so-called sovereign-bank nexus. This paper applies a new methodology to explore the potential strength of this sovereign-bank nexus for physical climate-related financial risks, and the potential implications for and benefits of adaptation for sovereign credit risk and financial stability.

Today, sovereign credit rating methodologies adopted operationally by agencies do not fully account for physical climate risks or adaptation measures. This omission not only misprices the risk associated with sovereign debt but also has broader implications for global financial stability and economic growth and means that adaptation is undervalued. Recently published academic estimates show that climate-induced sovereign credit downgrades could materialize for nearly 60 countries by 2030 (Klusak et al., 2023) because of the long-run economic impacts of increasing temperatures. These sovereign climate risk estimates are severe, yet likely still an underestimate, as they do not consider the materialization of extreme events (acute climate risk). They also do not explore options to adapt to these risks and how they can be incorporated into sovereign credit ratings.

In this discussion paper, we show how acute climate risk and adaptation can be quantitatively incorporated into sovereign credit ratings. We advance on previous work through linking credit risk modelling to a far more granular assessment of climate-related risks using an insurance catastrophe risk modelling approach. A further advancement of our method is to incorporate adaptation, allowing governments and financial institutions to assess the benefits of investing in adaptation and the potential improvements in costs of capital.

Using the more granular method, potential impacts on sovereign credit ratings are far greater than shown in previous studies. Yet, importantly, we show that these impacts can be largely offset through investment in adaptation demonstrating the importance of adaptation for both fiscal risk and financial stability. In a case study in Thailand, we show that flooding could lead to sovereign downgrades of up to 4 notches, in the most extreme future scenario. National-scale flood adaptation investments reduce the risk significantly: decreasing average annual capital stock losses by up to 64% and reducing downgrades from the most extreme events by up to 2 notches. We show that adaptation benefits can be quantified both in terms of avoided losses and avoided increases in interest payments: providing governments with a stronger economic case for large-scale adaptation investments.

Our analysis provides evidence for why ratings agencies should incorporate acute climate risks and adaptation into their sovereign credit rating methodologies, with important wider implications for debt sustainability analyses and physical climate financial risk assessment by Central Banks and Ministries of Finance. In not doing so, we demonstrate that current methodologies are mispricing the risk of world's largest asset class[2], with potential systemic implications for institutions that hold a lot of sovereign debt. As such, our sovereign rating scenarios that incorporate these climate risks can be used by financial institutions in their climate stress tests. We also argue that "adaptation smart" sovereign credit ratings can be a catalyst for adaptation, particularly in nations that may be perceived as climate risk hotspots. Quantifying what a country is (or isn't) doing to adapt to climate change—and reflecting it in one of the most widely used financial metrics—could incentivize more investment towards adaptation.

[2] According to 2020 estimates from the International Capital Markets Association, the global sovereign bond market is valued at nearly $65 trillion, with Global South countries accounting for around a quarter of this https://www.icmagroup.org/market-practice-and-regulatory-policy/secondary-markets/bond-market-size/

Introduction

Last year (2023) was the warmest year on record (NOAA, 2024). Anthropogenic emissions are causing our climate to warm at an unprecedented rate. Considering emission reduction policies currently in place, the median estimate of global warming by the end of the century is 2.7°C above pre-industrial levels; that is, 1.2°C above the 1.5°C global target set in Paris in 2015 (Climate Action Tracker, 2023). As global temperatures increase, so do the frequency and severity of extreme weather events. In 2023, weather and climate events in Asia impacted more than nine million people and resulted in over 2,000 fatalities (WMO, 2024) while global economic losses from natural catastrophes reached 280 billion USD (Banerjee et al., 2024). The influence of climate change on extreme weather events happening today is increasingly apparent. For example, the 2022 floods in Pakistan, which caused $15 billion in damages and over 1,500 deaths, were made 50% more likely due to climate change (Otto et al., 2022).

Climate change will have enormous impacts on our natural, social, and economic systems. Estimates suggest possible global financial losses in the tens of trillions by the end of the century if we follow a business-as-usual emissions path (Dietz et al., 2016). This emphasises the need to mitigate future warming by reducing our emissions. However, many climate impacts are already *baked in.* Recent estimates suggest—regardless of the emissions path—the global economy is already committed to a loss of income of 19% by 2050 (Kotz et al., 2024). This demonstrates the importance of adapting to climate impacts.

Adaptation needs to happen quickly and at scale. This was enshrined in Article 7 of the Paris Agreement[3], which defined a global goal on adaptation; and further operationalized at COP 27 through the Sharm-El-Sheikh Adaptation Agenda[4], which established 30 global adaptation targets to be met by 2030. However, a significant financing gap remains, especially in Global South countries that will bear the brunt of climate impacts. In its latest adaptation gap report, the United Nations Environment Programme Finance Initiative (UNEP FI) reported that current adaptation financing needs in Global South countries are 10-18 times larger than current finance flows (UNEP FI, 2023). Closing the adaptation financing gap will involve increasing international climate adaptation finance flows[5], mobilizing more private finance for adaptation, and increasing domestic expenditure on adaptation.

[3] https://unfccc.int/sites/default/files/english_paris_agreement.pdf.
[4] https://climatechampions.unfccc.int/wp-content/uploads/2022/11/SeS-Adaptation-Agenda_Complete-Report-COP27_FINAL-1.pdf.
[5] Negotiations are currently ongoing for a new collective quantified goal on climate finance https://unfccc.int/NCQG.

Climate change has enormous implications for financial institutions and for financial stability. Regulators are starting to take note, evidenced by a growing number[6] of climate scenario exercises being conducted in jurisdictions such as the UK (Bank of England, 2022), the US (Federal Reserve Board, 2024), and the EU (European Central Bank, 2022). Climate financial risks are particularly acute in climate vulnerable regions such as Southeast Asia, where growing emissions coupled with more frequent and intense extreme events could lead to losses of gross domestic product (GPD) of up to 11% by the end of the century (Asian Development Bank, 2015). For example, an analysis conducted by the International Monetary Fund (IMF) and the World Bank found that the compound impact of a climate-intensified typhoon and a COVID-like pandemic could significantly strain the capital of banks in the Philippines (Hallegatte et al., 2022). These impacts may be further amplified if nature-related physical risks are taken into account (Ranger et al., 2023a), given the large financial-sector nature dependencies in the region. In Malaysia, over half of banks' lending is to sectors highly dependent on nature (World Bank and Bank Negra Malaysia, 2022). These climate financial risks have systemic implications and can propagate internationally across the financial system (Mandel et al., 2021). However, many of these risks are missing from current climate stress tests of the financial sector (Ranger et al., 2023b).

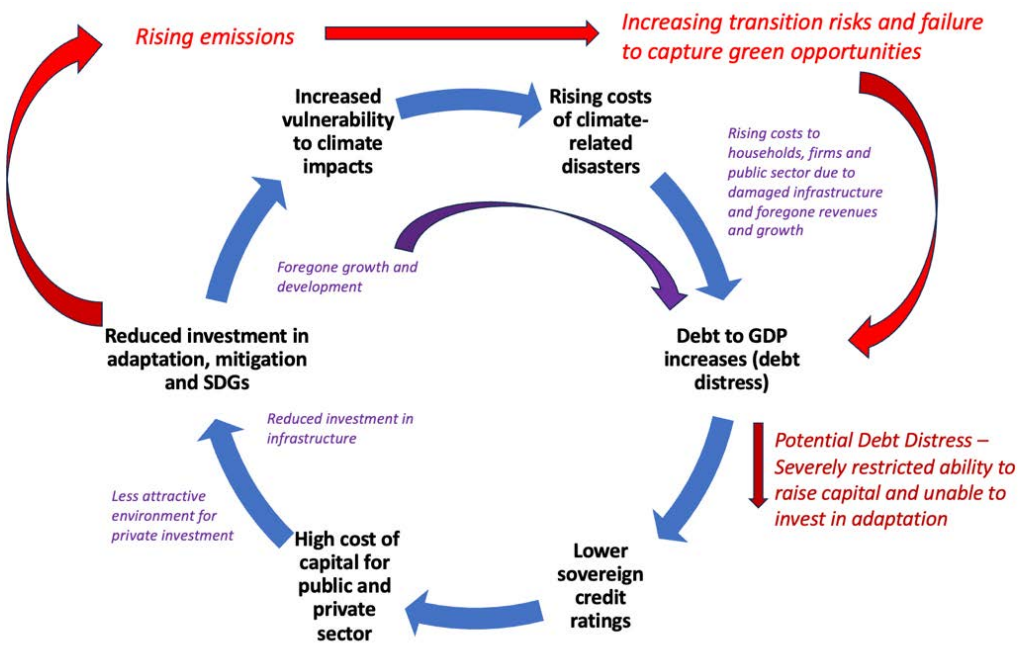
Governments face considerable physical climate financial risk themselves with implications for fiscal resilience, sovereign debt, credit ratings, and the sovereign-bank nexus. Modelled effects of climate change on the macroeconomy show long-term impacts on productivity and growth (Burke et al., 2015, Kahn et al., 2021), which will negatively affect public finances through reduced tax revenues and higher debt. Further, as extreme weather events become more frequent and intense due to climate change, they will impact sovereign finances through the economic disruption they cause and the cost of reconstruction and recovery, especially in countries with low insurance penetration where the government acts as the insurer of last resort (Volz et al., 2020). Climate impacts on the domestic financial sector also have the potential to spillover and amplify sovereign risk, and vice-versa, through the so-called sovereign-banking nexus. This nexus is particularly acute in Global South countries, where banks hold large amounts of government debt (Feyen and Zuccardi, 2019). As a result, any climate-induced stress on either the sovereign or the banking sector can trigger a feedback loop, intensifying financial instability and further constrain a governments' capacity to manage debt and finance adaptation efforts.

Governments carry significant responsibility with regards to adaptation. They develop national adaptation plans, which identify a country's long-term adaptation needs. They are also responsible for the implementation and financing of national adaptation projects. To finance both adaptation and recovery efforts, governments may have to reallocate financing or increase their levels of sovereign debt. However, many of the most climate-vulnerable countries are already in debt distress and face

[6] A 2022 publication by the FSB found that a total of 67 climate scenario analyses had been carried out or were in the process of being carried out across 36 jurisdictions https://www.fsb.org/wp-content/uploads/P151122.pdf

a “climate investment trap” (see Figure 1) that may limit their ability to invest in the large-scale adaptation projects needed to make them resilient to future climate impacts (Ranger et al., Forthcoming).

Figure 1. The climate investment trap for adaptation (from Ranger et al. (Forthcoming))



In this discussion paper, we explore how climate risk and adaptation analytics can be incorporated into sovereign financial risk analysis and serve as evidence for the benefits of investing in adaptation. We advance on previous work through linking credit risk modelling to a more granular assessment of climate-related risks using an insurance catastrophe risk modelling approach. A further advancement of our method is to incorporate adaptation, allowing governments and financial institutions to assess the benefits of investing in adaptation and the potential improvements in costs of capital. We focus on sovereign credit ratings, showing that acute climate events in Thailand can have significant negative impacts on the country’s credit rating. We also demonstrate that when adaptation is incorporated into such analyses, the impacts on sovereign credit ratings are significantly reduced. We argue that climate risks can and should be incorporated into sovereign credit rating methodologies, as not doing so means that sovereign risks are not priced accurately. In addition, the positive actions countries are taking to adapt to climate risks should also be reflected in sovereign ratings. Although adaptation requires significant up-front investments, it reduces future expected losses and improves a sovereign’s ability to meet debt repayment obligations in the future. As such, we need methodologies that can capture these co-benefits of adaptation within sovereign ratings. “Adaptation smart” sovereign credit ratings have the potential to act as both a *carrot* and a *stick* for stimulating adaptation investment—by pricing the failure to adapt while also pricing the return on adaptation.

Climate Change and Sovereign Credit Ratings

Sovereign credit ratings are an indicator of a government's ability to repay its debt. They are necessary for a country to issue bonds and play an important role in attracting foreign direct investment. Sovereign ratings signal to investors the level of risk an investment in that country faces. They also influence a country's borrowing costs. Sovereign credit ratings are determined by ratings agencies[7] and integrate various quantitative and qualitative information around the country's economy, institutions, fiscal health, and exposure to various risks (financial, geopolitical, environmental, etc.)[8] Sovereign ratings are also a good indicator for the ratings of other asset classes. For example, they can have a ceiling effect for other asset class ratings and sovereign downgrades will often result in "spillover" downgrades for other asset classes (Sun et al., 2023).

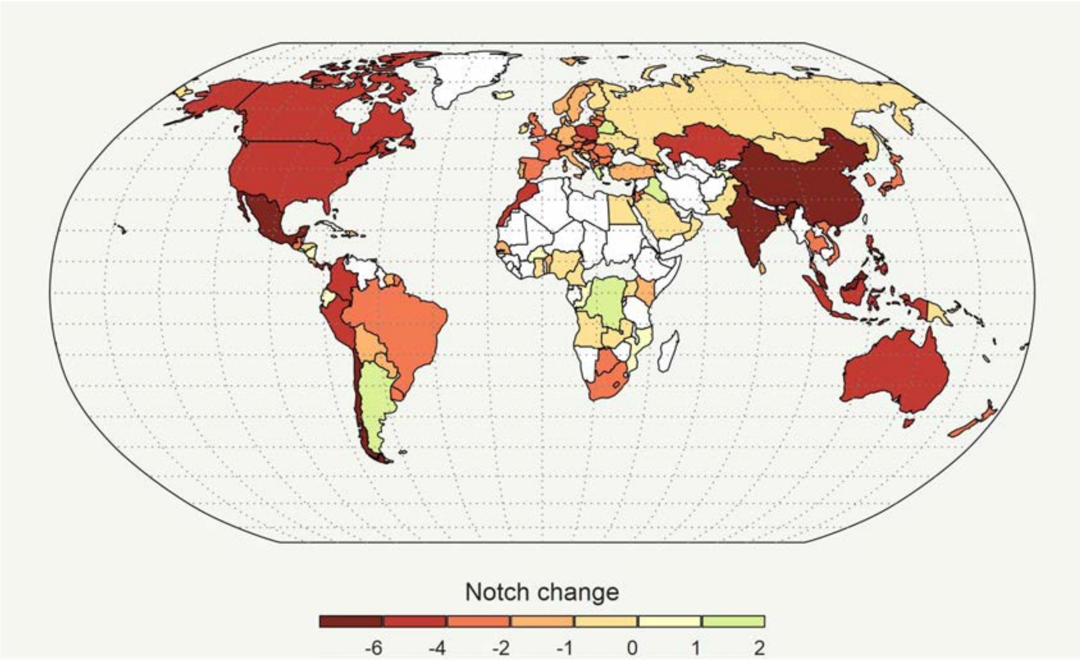
Forward looking climate risk data and analyses are not currently explicitly incorporated into sovereign credit rating methodologies (Agarwala et al., 2024). The extent to which such climate risks are incorporated in sovereign ratings is through qualitative measures (e.g., if a country is located in a hurricane-prone region) or through *ex-post* sovereign ratings adjustments (e.g., Fitch downgraded Pakistan's credit rating following the devastating 2022 floods[9]). This is not to say that ratings agencies aren't cognisant of the risk. Fitch Ratings has published quantitative analysis on sovereign climate risk (Fitch Ratings, 2021b) and S&P have even quantified the potential climate impact on sovereign credit ratings (Standard & Poors, 2015). However, these analyses are accompanied by disclaimers that they are exploratory and are not currently considered in ratings decisions. The rationale behind their exclusion is often that the uncertainty in such assessments is not yet well enough understood (Fitch Ratings, 2021a).

A recent study published the first "climate-smart" sovereign credit ratings, which estimated ratings impacts for 109 countries until 2100 under various climate scenarios (Klusak et al., 2023). The study found that over 50 countries could experience climate-induced downgrades as early as 2030. By 2100, nearly three-quarters of the analysed countries would experience downgrades, with an average downgrade of 2.18 notches in a high-emission (RCP 8.5) scenario (see Figure 2). The climate impacts in the study are based on derived relationships between temperature variability and GDP growth (Kahn et al., 2021). These estimates capture, to an extent, the aggregate, chronic, macroeconomic impacts of climate change; however, they do not capture the effects of extreme events (such as floods or tropical cyclones). This means that these estimates of sovereign climate credit risk may be underestimating the actual risk. GDP impact estimated based on historical empirical analyses also have well known limitations, including missing the potential for tipping points and

[7] The three largest ratings agencies are S&P Global Ratings, Moody's, and Fitch Ratings.
[8] See Moody's sovereign rating methodology here https://www.moodys.com/research/doc--PBC_1346995?WT.mc_id=RateSov and S&P's here https://www.spglobal.com/ratings/_division-assets/pdfs/021519_howweratesovereigns.pdf.
[9] https://www.fitchratings.com/research/sovereigns/pakistan-02-12-2022.

cascading and compounding risks. Further, adaptation is assumed to occur implicitly[10] in the study – and provides little actionable information to demonstrate how countries can become more resilient to climate impacts.

Figure 2. Global climate induced sovereign ratings changes (2100, RCP 8.5) from Klusak et al. (2023)



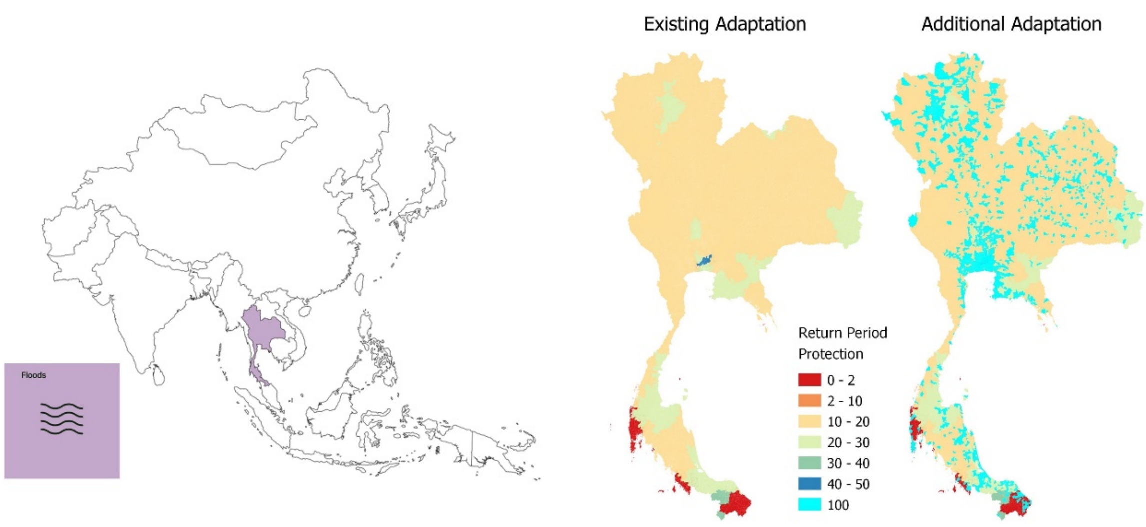
Integrating estimates of acute physical climate risk and adaptation options into sovereign credit ratings would provide a more comprehensive view of sovereign climate risk and how countries could adapt. The increased frequency and intensity of extreme events brought about by climate change has the potential to significantly impact countries in the future. This is particularly true for small island developing states (SIDS), many of which are facing existential threats from the combined impact of sea level rise and tropical storms; as well as countries that are vulnerable to extremes, such as many Southeast Asian economies for flood and tropical cyclone or African economies for drought and flooding. Acute events can have enormous macroeconomic impacts. For example, in 2017 Hurricane Maria caused losses equivalent to 226% of Dominica's GDP (Government of Dominica, 2017). Sovereign ratings should reflect these potential risks in an *ex-ante* manner. More importantly, they should also integrate analyses of how adaptation could reduce risks. This could act as a signal to investors that despite the risks a country faces steps are being taken to reduce these risks. At the same time, "adaptation-responsive" sovereign credit ratings could act as a vehicle to promote further adaptation action, especially if it could lead to improved sovereign credit ratings.

[10] Adaptation is captured implicitly in the study by altering the baseline time-window against which temperature variability is calculated. For example, smaller time-windows assume quicker adaptation while larger time-windows assume slower adaptation.

Thailand Case Study

We demonstrate how quantitative estimates of acute climate risk and adaptation can be incorporated into sovereign credit ratings in Thailand. Uniquely, our approach learns from insurance catastrophe risk modelling and builds upon lessons from analogous studies that use similar approaches to model physical climate financial risks, for example in the Philippines (Hallegatte et al., 2022). We use Thailand as a case study, which has a debt-to-GDP ratio of over 60%, and where over half of government bonds are held by banks, insurers, and contractual funds (Thailand Ministry of Finance, 2024). Thailand is one of the most exposed countries in the world to river flooding. In 2011, it experienced its worst ever flood event, which resulted in over $45 billion in economic damages (World Bank, 2012) and had repercussions for supply chains and manufacturing that affected industry globally. To this day, it remains the costliest flood event ever for the insurance industry (Swiss Re, 2021). Despite the enormous losses, the 2011 flood event was not a rare event from a climatological perspective. Analysis of historical rainfall and river flow records show that the estimated return period of the flood event was between 10-30 years[11] (Gale and Saunders, 2013). Climate change is expected to increase the intensity of flooding in the future for Thailand (Kiguchi et al., 2021), meaning a flood event occurring that is similar to or worse than the 2011 floods is increasingly likely in the future. As such, improving flood management is central to Thailand's national adaptation plan (Government of Thailand, 2023).

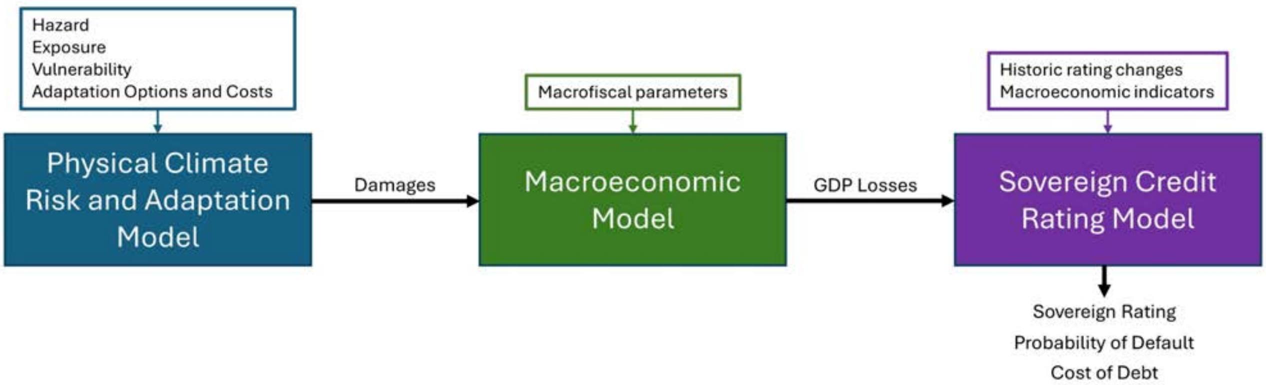
Figure 3. (left) Thailand, the focus of this study, (centre) it's existing levels of river flood adaptation, and (right) the additional adaptation scenario (where river flood protection in all urban areas is increased to protect against a 100-year return period flood)



[11] A return period is the average time you might expect between events occurring. Its inverse is the annual probability of occurrence. For example, a 10-year return period flood has an annual probability of occurrence of 0.1.

We develop a modelling framework for estimating sovereign credit ratings that combines three different types of models (see Figure 4). This framework consists of (1) a flood risk and adaptation model, built using probabilistic catastrophe modelling approaches common in the insurance industry. This model simulates the capital stock damages from thousands of years of simulated flooding. These damages are then fed into (2) a macroeconomic model[12], calibrated for Thailand, which estimates the impacts of disaster years on Thailand's GDP. We finally use the GDP impacts to estimate changes in Thailand's sovereign credit rating, applying (3) the model described in Klusak et al. (2023). Our modelling chain allows us to calculate the capital stock and GDP losses as the result of different loss-probability years as well as what this means for Thailand's sovereign credit rating, probability of default, and cost of debt.

Figure 4. Modelling framework for estimating the impact of acute climate risk and adaptation on sovereign credit ratings.



We consider 5 different combinations of climate and adaptation scenarios (see Table 1). For climate, we consider three scenarios: a baseline scenario that represents the historical distribution of flood risk, and two future (2075) scenarios – one representing a low emission (SSP126) trajectory and one representing a high emission (SSP585) trajectory. We also consider two adaptation scenarios. The first is an *existing adaptation* scenario, where we assume current river flood protection levels (see Figure 3). Existing flood protection levels at the province level are taken from Scussolini et al. (2016). These show an average level of return-period flood protection across the 76 Thai provinces of ~18 years, with the highest level of protection (50 years) in Bangkok Metropolitan Region. The second adaptation scenario is an *additional adaptation* scenario where we assume that all suburban areas or denser in Thailand will increase river protection levels to protect against a 100-year return period flood (see Figure 3). The cost of the *additional adaptation* scenario is calculated following the approach described in Tanoue et al. (2021), which relates the increase in return-period protection and the river length to be protected to a cost of protection. We find that our *additional*

[12] We use the IMF's Debt-Investment-Growth and Natural Disasters (DIGNAD) model which is a general equilibrium model developed to study the effects of natural disasters on the macroeconomy of climate vulnerable countries.

adaptation scenario would cost $55 billion. We only consider the additional adaptation scenario in combination with the future scenarios, assuming it will take several decades for these measures to be implemented.

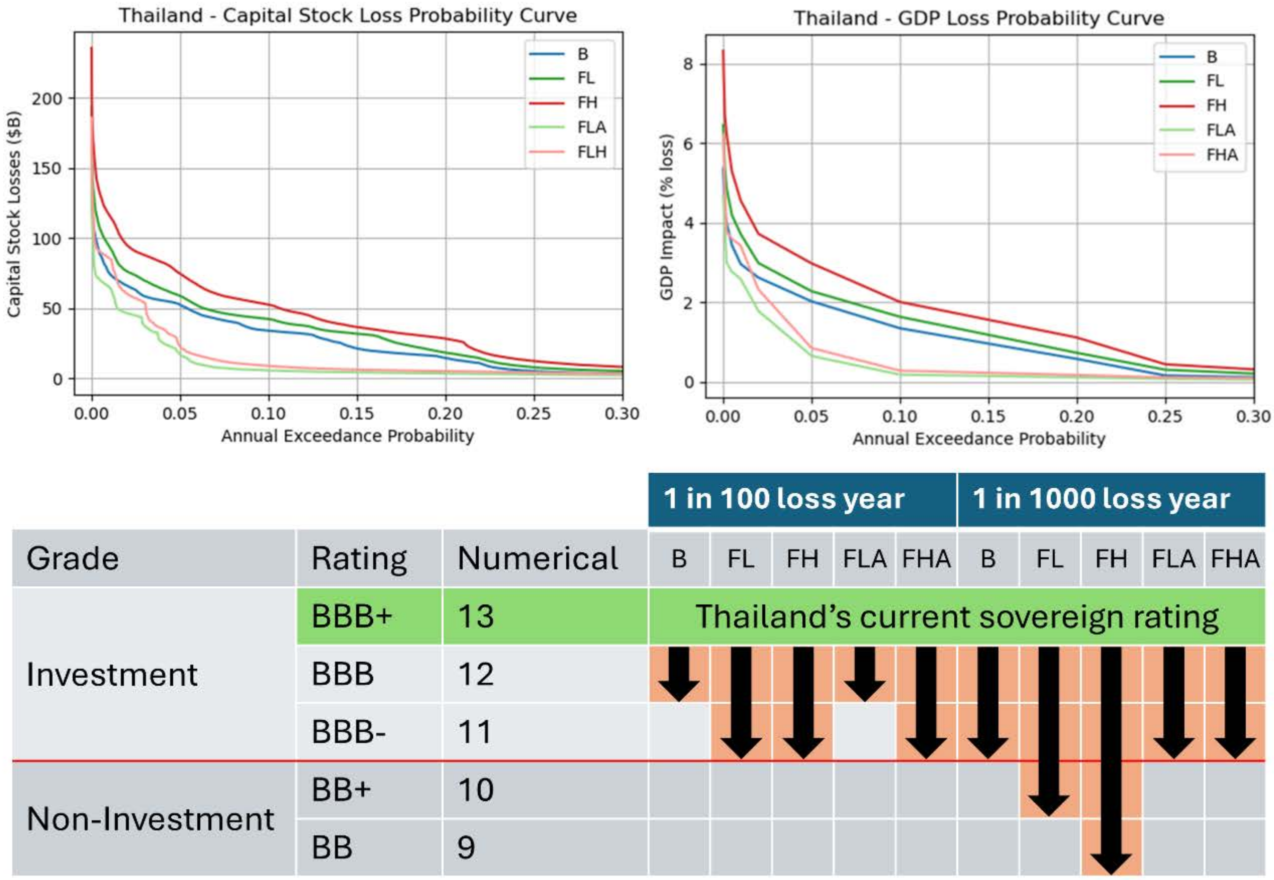
Table 1. Climate and adaptation scenarios

Climate Scenario	Adaptation Scenario	Symbol
Baseline (Historical)	Existing Adaptation	B
Future Low Emission	Existing Adaptation	FL
Future High Emission	Existing Adaptation	FH
Future Low Emission	Additional Adaptation	FLA
Future High Emission	Additional Adaptation	FHA

Our analysis shows that flooding could result in significant capital stock and macroeconomic losses in Thailand with the potential for sovereign credit rating downgrades, both today and in the future. Assuming current protection levels, average annual losses (AAL) to capital stock in Thailand are 0.79% ($9 billion) today and could rise to between 0.98-1.3% ($11.2-14.8 billion) in 2075, depending on the emissions scenario. These average annual loss estimates[13] are in line with previous studies (Alfieri et al., 2017, Ward et al., 2020, World Bank, 2021). We find that a 100-year event today would lead to GDP losses of nearly 3%, which results in a single notch downgrade in Thailand's sovereign credit rating (see Figure 5). In the future, the same probability event would lead to GDP losses between 3.7-4.5%, resulting in a two-notch downgrade. A two-notch downgrade would increase Thailand's probability of default by 4% and lead to increased interest payments of around $1.9 billion a year. In the event of an extremely rare 1000-year return period flood, Thailand's sovereign credit rating risks falling below the investment grade threshold in the future with GDP losses exceeding 6.5% in a high emissions scenario. This signifies a significant increased risk of default, causing borrowing costs to rise and potentially deterring investment. Such an event has the potential to lead to economic instability and could lead to reduced access to international capital markets. These sovereign rating impacts equal and exceed the chronic impacts of climate change estimated by Klusak et al. (2023) who find that Thailand's credit rating drops two notches by the end of the century in a high emission (RCP 8.5) scenario. Our estimates do not yet consider the combined impacts of chronic and acute impacts on Thailand's rating, however, these would likely be additional and result in amplified rating risks.

[13] Our percentage average annual loss figures are in line with previous studies. However, our absolute values are higher as we use capital stock to estimate exposure and previous studies have used GDP-based exposure estimates. In 2022, Thailand's net capital stock to GDP ratio was 2.3.

Figure 5. Results from our climate risk and adaptation modelling. (top left) Capital stock loss-probability curve for the five scenarios (B=baseline, FL=future low emission, FH=future high emission, FLA=future low emission with additional adaptation, FHA=future high emission with additional adaptation). (top right) GDP loss-probability curve for the five scenarios. (bottom) Sovereign credit rating impacts for the 100-year flood and 1000-year flood across the five scenarios (BBB+ is Thailand's current sovereign credit rating)



We show that investing in adaptation can significantly reduce the risks Thailand faces from flooding. Additional adaptation investments can reduce average annual losses from flooding by up to $9.5 billion (64% decrease) in the future. They would also significantly reduce the losses in extreme events. Adaptation would lead to avoided losses of up to $30 billion and $48 billion for a 100-year and 1000-year flood, respectively. These benefits are reflected in the impact on Thailand's sovereign credit rating. The probability of Thailand's rating falling below the investment grade threshold over a 10-year period (the timeframe over which many fiscal decisions are made) is reduced from over 6% in a future high emission scenario to under 1% with additional adaptation. When making the business case for adaptation investments, governments could include the avoided increased cost of debt as an additional benefit of adaptation. For example, our analysis shows that in the event of a 1000-year return period flood event occurring, adaptation investments that reduce a four-notch downgrade to a two-notch downgrade could prevent increases in annual interest payments of over $2.3 billion.

Incorporating these results into a cost-benefit analysis[14] show that adaptation investments are cost-effective across all scenarios. Benefit-cost ratios range from 1.27 to 1.59 for the low emission and high emission scenario, respectively.

Our results have significant implications for financial stability. To illustrate this, we carry out an analysis on the impact of sovereign risk on the banking sector in Thailand. Using recent valuations of Thai sovereign bonds (Thailand Ministry of Finance, 2024) and regional estimates of loss given default (Aslam, 2020) we calculate that in the event of a sovereign default, this could lead to economy-wide losses greater than $150 billion. Assuming Thai banks hold 50% of government debt, this would mean a 10% loss of total portfolio value[15]. However, these estimates do not consider the likelihood of default occurring. Using the default probabilities associated with our scenarios we calculate the Value at Risk (VaR) for the Thai banking sector, assuming different illustrative levels of debt holding (see Table 2). Assuming the Thai financial sector holds 50% of government debt, we find that a 1 in 1000 year flood would result in a VaR for the financial sector of $4.87 billion in today's climate increasing to $12.47 billion in a future high emission scenario. The VaR for the Thai financial sector in this scenario could be reduced by $5.96 billion by investing in additional adaptation. Our estimates of the impacts on the banking sector are likely still an underestimate, as they do not account for the broader economic effects of downgrades nor the feedback impacts of the bank-sovereign nexus.

Table 2. Financial sector Value at Risk (VaR) estimates for different levels of sovereign debt holding

Scenarios			VaR ($ billion) for illustrative levels of debt holding			
Climate	**Adaptation**	**Loss Year**	**10%**	**20%**	**50%**	**100%**
Baseline (Historical)	Existing Adaptation	1 in 100	0.68	1.36	3.4	6.8
Future Low Emission	Existing Adaptation	1 in 100	0.73	1.46	3.65	7.3
Future High Emission	Existing Adaptation	1 in 100	1.11	2.21	5.53	11.06
Future Low Emission	Additional Adaptation	1 in 100	0.66	1.31	3.28	6.55
Future High Emission	Additional Adaptation	1 in 100	0.71	1.42	3.55	7.1
Baseline (Historical)	Existing Adaptation	1 in 1000	0.97	1.95	4.87	9.74
Future Low Emission	Existing Adaptation	1 in 1000	1.64	3.28	8.21	16.42
Future High Emission	Existing Adaptation	1 in 1000	2.49	4.99	12.47	24.93
Future Low Emission	Additional Adaptation	1 in 1000	0.75	1.49	3.73	7.45
Future High Emission	Additional Adaptation	1 in 1000	1.3	2.6	6.51	13.01

[14] In our cost-benefit analysis we assume construction of the adaptation measures begins today, lasts 30 years, and the benefits of adaptation increase linearly until adaptation construction is complete. The benefits of adaptation are a combination of the avoided average annual losses and the avoided expected annual interest payment increases because of sovereign downgrades. We use a discount rate of 5%, assume annual operational costs of the adaptation infrastructure are equivalent to 1% of the total cost of adaptation, and calculate the discounted benefits out to 2100.

[15] Assuming a total Thai bank portfolio value of $730 billion. https://www.statista.com/statistics/1273119/thailand-value-of-assets-among-commercial-banks/

Implications

Our analysis has demonstrated that acute climate risks pose a significant risk to sovereign credit ratings, and we have shown how they can be quantitatively incorporated into sovereign rating analyses in an *ex-ante* manner. It is important that rating agencies begin to incorporate these risks into their own analyses. Risk pricing needs to be accurate. Sovereign debt is the world's largest and most important asset class–representing 28% of global debt (Volz et al., 2020). Pensions funds, central banks, and insurers are all major holders of sovereign debt. If climate risks are not properly priced into sovereign credit ratings it represents a potential systemic financial risk. Improper pricing can lead to misinformed investment decisions, resulting in holders unable to meet their financial obligations if the value of sovereign debt deteriorates due to the impacts of climate change. This could then jeopardize the financial security of those reliant on these institutions, such as pensioners.

Our physical climate risk sovereign rating scenarios could be incorporated into financial-sector climate stress tests. Financial institutions, particularly in the Global South, are large holders of domestic sovereign debt. As such, sovereign ratings often act as credit rating ceilings for domestic financial institutions and sovereign credit rating downgrades could trigger domestic downgrades, leading to increased costs and challenges in market access, profitability, and liquidity (Feyen and Zuccardi, 2019). This risk transmission channel has been explored by the World Bank in their climate risk stress test of the Colombian banking sector (Reinders et al., 2021)

Sovereign credit ratings should also incorporate quantitative estimates of adaptation. In doing so, issuers of sovereign ratings could help stimulate the flow of finance towards adaptation and narrow the $194-366 annual adaptation financing gap in developing countries (UNEP FI, 2023). "Adaptation smart" sovereign ratings could act as both a *carrot* and a *stick* in encouraging adaptation action. A sovereign rating that accurately reflects a country's climate risks works as a stick, especially if not enough is being done nationally to adapt. The carrot would be integrating a country's adaptation progress into sovereign ratings and receiving a favourable sovereign rating in return, which could incentivize countries to invest more. We have demonstrated how this could be done quantitatively in Thailand, using a hypothetical flood adaptation scenario. However, this approach could be linked to the actual adaptation plans of countries, and the analysis could be updated as countries continue to progress on their adaptation targets.

Further Work

This discussion paper has contextualized the importance of sovereign credit ratings that reflect the climate risks a country faces and the steps it can take to reduce those risks through adaptation. We have demonstrated how this can be achieved by combining insurance catastrophe risk modelling approaches with economic and sovereign credit risk models in Thailand. This discussion paper will be followed by an academic paper that explains the modelling framework in greater detail and quantifies the uncertainty of various modelling components and choices. The quantification of uncertainty is an important next step, as uncertainty is often cited as the reason why rating agencies do not incorporate climate change into their existing methodologies (Fitch Ratings, 2021a). We will also be exploring approaches for incorporating additional climate hazards into our risk modelling framework, combining estimates of chronic and acute impacts, and will be scaling our analysis to incorporate further countries.

References

AGARWALA, M., BURKE, M., DOHERTY-BIGARA, J., KLUSAK, P. & MOHADDES, K. 2024. Climate Change and Sovereign Risk: A Regional Analysis for the Carribean. *Janeway Institute Working Papers.* University of Cambridge: Faculty of Economics.

ALFIERI, L., BISSELINK, B., DOTTORI, F., NAUMANN, G., DE ROO, A., SALAMON, P., WYSER, K. & FEYEN, L. 2017. Global projections of river flood risk in a warmer world. *Earths Future,* 5**,** 171-182.

ASIAN DEVELOPMENT BANK 2015. Southeast Asia and the Economics of Global Climate Stabilization. Asian Development Bank.

ASLAM, T. 2020. *When Sovereigns Default: A Global and Regional Look* [Online]. S&P Global. Available: https://www.spglobal.com/marketintelligence/en/news-insights/blog/when-sovereigns-default-a-global-and-regional-look [Accessed September 3 2024].

BANERJEE, C., BEVERE, L., GARBERS, H., GROLLIMUND, B., LECHNER, R. & WEIGEL, A. 2024. Natural catastrophes in 2023: gearing up for today's and tomorrow's weather risks. *In:* RONKE, P. (ed.) *Sigma.* Swiss Re Management Ltd: Swiss Re Institute.

BANK OF ENGLAND 2022. Results of the 2021 Climate Biennial Exploratory Scenario (CBES). Bank of England.

BURKE, M., HSIANG, S. M. & MIGUEL, E. 2015. Global non-linear effect of temperature on economic production. *Nature,* 527**,** 235-239.

CLIMATE ACTION TRACKER. 2023. *2100 Warming Projections. Emissions and expected warming based on pledges and current policies* [Online]. Available: https://climateactiontracker.org/global/temperatures/ [Accessed May 20 2024].

DIETZ, S., BOWEN, A., DIXON, C. & GRADWELL, P. 2016. 'Climate value at risk' of global financial assets. *Nature Climate Change,* 6**,** 676-679.

EUROPEAN CENTRAL BANK 2022. 2022 climate risk stress test. European Central Bank.

FEDERAL RESERVE BOARD 2024. Pilot Climate Scenario Analysis Exercise: Summary of Participants' Risk-Management Practices and Estimates. BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM.

FEYEN, E. & ZUCCARDI, I. 2019. *The Sovereign-Bank Nexus in EMDEs : What Is It, Is It Rising, and What Are the Policy Implications?*, 2019: World Bank, Washington, DC.

FITCH RATINGS 2021a. Climate Change Impact on Sovereign Ratings: A Primer.

FITCH RATINGS 2021b. Climate Change Physical Risks Area a Growing Threat to Sovereigns. *Special Report.* Fitch Ratings.

GALE, E. L. & SAUNDERS, M. A. 2013. The 2011 Thailand flood: climate causes and return periods. *Weather,* 68**,** 233-237.

GOVERNMENT OF DOMINICA 2017. Post-Disaster Needs Assessment Hurricane Maria September 18, 2017.

GOVERNMENT OF THAILAND 2023. Thailand's National Adaptation Plan (NAP). United Nations Framework Convention on Climate Change (UNFCCC).

HALLEGATTE, S., LIPINSKY, M. F., MORALES, P., OURA, M. H., RANGER, N., REGELINK, M. G. J. & REINDERS, H. J. 2022. *Bank Stress Testing of Physical Risks under Climate Change Macro Scenarios: Typhoon Risks to the Philippines*, International Monetary Fund.

KAHN, M. E., MOHADDES, K., NG, R. N. C., PESARAN, M. H., RAISSI, M. & YANG, J.-C. 2021. Long-term macroeconomic effects of climate change: A cross-country analysis. *Energy Economics,* 104**,** 105624.

KIGUCHI, M., TAKATA, K., HANASAKI, N., ARCHEVARAHUPROK, B., CHAMPATHONG, A., IKOMA, E., JAIKAEO, C., KAEWRUENG, S., KANAE, S., KAZAMA, S., KURAJI, K., MATSUMOTO, K., NAKAMURA, S., NGUYEN-LE, D., NODA, K., PIAMSA-NGA, N., RAKSAPATCHARAWONG, M., RANGSIWANICHPONG, P., RITPHRING, S., SHIRAKAWA, H., SOMPHONG, C., SRISUTHAM, M., SUANBURI, D., SUANPAGA, W., TEBAKARI, T.,

TRISURAT, Y., UDO, K., WONGSA, S., YAMADA, T., YOSHIDA, K., KIATIWAT, T. & OKI, T. 2021. A review of climate-change impact and adaptation studies for the water sector in Thailand. *Environmental Research Letters,* 16**,** 023004.
KLUSAK, P., AGARWALA, M., BURKE, M., KRAEMER, M. & MOHADDES, K. 2023. Rising Temperatures, Falling Ratings: The Effect of Climate Change on Sovereign Creditworthiness. *Management Science,* 0**,** null.
KOTZ, M., LEVERMANN, A. & WENZ, L. 2024. The economic commitment of climate change. *Nature,* 628**,** 551-557.
MANDEL, A., TIGGELOVEN, T., LINCKE, D., KOKS, E., WARD, P. & HINKEL, J. 2021. Risks on global financial stability induced by climate change: the case of flood risks. *Climatic Change,* 166**,** 4.
NOAA 2024. Monthly Global Climate Report for Annual 2023. NOAA National Centers for Environmental Information.
OTTO, F., ZACHARIA, M., SAEED, F., SIDDIQI, A., SHAHZAD, K., MUSHTAQ, H., ARULALAN, T., ACHUTARAO, K., CHIATHRA, S. T., BARNES, C., SJOUKJE, P., KEW, S., VAUTARD, R., KOREN, G., PINTO, I., WOLSKI, P., VAHLBERG, M., SINGH, R., ARRAGHI, J., VAN AALST, M. K., THALHEIMER, L., RAJU, E., LI, S., YANG, W., HARRINGTON, L. & CLARKE, B. 2022. Climate change likely increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan. World Weather Attribution
RANGER, N., ALVAREZ, J., FREEMAN, A., HARWOOD, T., OBERSTEINER, M., PAULUS, E. & SABUCO, J. 2023a. The Green Scorpion: The Macro-Criticality of Nature for Finance: Foundations for Scenario-Based Analysis of Complex and Cascading Physical Nature-Related Financial Risks. Oxford: Environmental Change Institute, University of Oxford.
RANGER, N., BLOOMFIELD, H., CALDECOTT, B. & CLACHER, I. 2023b. Recommendations for Central Banks, Supervisors, Financial Institutions and Researchers. *Learning from the 2021/2022 Climate Biennial Exploratory Scenario (CBES) exercise in the UK.* UK Centre for Greening Finance and Investment.
RANGER, N., WEIDINGER, M., BERNHOFEN, M. V., BURKE, M., LAMBIN, R., PURANASAMRIDDHI, A., SABUCO, J. & SPACEY MARTIN, R. Forthcoming. Enabling Adaptation: Sustainable Fiscal Policies for Climate Resilient Development and Infrastructure. Environmental Change Institute, University of Oxford.
REINDERS, H. J., REGELINK, M. J. R., CALICE, P. & URIBE, M. A. 2021. Not-So-Magical Realism: A Climate Stress Test of the Colombian Banking System. Washington D.C.: Equitable Growth, Finance and Institutions Insight.
SCUSSOLINI, P., AERTS, J., JONGMAN, B., BOUWER, L. M., WINSEMIUS, H. C., DE MOEL, H. & WARD, P. J. 2016. FLOPROS: an evolving global database of flood protection standards. *Natural Hazards and Earth System Sciences,* 16**,** 1049-1061.
STANDARD & POORS. 2015. *The Heat Is On: How Climate Change Can Impact Sovereign Ratings* [Online]. S&P Global. Available: https://www.spglobal.com/ratings/en/research/articles/151125-the-heat-is-on-how-climate-change-can-impact-sovereign-ratings-9425836#:~:text=In%20general%2C%20however%2C%20the%20most,%2C%20monetary%2C%20and%20institutional%20assessments [Accessed June 7 2024].
SUN, X., SHEN, Y., GUO, K. & JI, Q. 2023. Sovereign ratings change under climate risks. *Research in International Business and Finance,* 66**,** 102040.
SWISS RE. 2021. *The world's costliest flood: the 2011 Thailand flood, 10 years on* [Online]. Available: https://www.swissre.com/institute/research/sigma-research/Economic-Insights/the-costliest-flood-thailand-flood.html [Accessed August 2 2024].
TANOUE, M., TAGUCHI, R., ALIFU, H. & HIRABAYASHI, Y. 2021. Residual flood damage under intensive adaptation. *Nature Climate Change,* 11**,** 823-826.

THAILAND MINISTRY OF FINANCE 2024. KINGDOM OF THAILAND BOND MARKET FINANCING THAILAND'S FUTURE & CONNECTING ASEAN. Public Debt Management Office, Ministry of Finance.
UNEP FI 2023. Adaptation Gap Report 2023. UN Environment Programme.
VOLZ, U., BEIRNE, J., AMBROSIO PREUDHOMME, N., FENTON, A., MAZZACURATI, E., RENZHI, N. & STAMPE, J. 2020. Climate change and sovereign risk.
WARD, P. J., WINSEMIUS, H. C., KUZMA, S., BIERKENS, M. F. P., BOUWMAN, A., DE MOEL, H., DÍAZ LOAIZA, A., EILANDER, D., ENGLHARDT, J., ERKENS, G., TAFETE GEBTEMEDHIN, E., ICELAND, C., KOOI, H., LIGTVOET, W., MUIS, S., SCUSSOLINI, P., SUTANUDJAJA, E. H., VAN BEEK, R., VAN BEMMEL, B., VAN HUIJSTEE, J., VAN RIJN, F., VAN WESENBEECK, B., VATVANI, D., VERLAAN, M., TIGGELOVEN, T. & LUO, T. 2020. Aqueduct Floods Methodology. Wasington D.C.: World Resources Institute.
WMO 2024. State of the Climate in Asia 2023. World Meteorological Organization.
WORLD BANK 2012. Thai flood 2011: rapid assessment for resilient recovery and reconstruction planning: Overview. Washington, D.C.: World Bank Group.
WORLD BANK 2021. Climate Risk Country Profile: Thailand. Washington D.C.: The World Bank Group and the Asian Development Bank.
WORLD BANK & BANK NEGRA MALAYSIA 2022. An Exploration of Nature-Related Financial Risks in Malaysia. Washington, DC: World Bank.

The Smith School of Enterprise and the Environment

The Smith School of Enterprise and the Environment (SSEE) was established with a benefaction by the Smith family in 2008 to tackle major environmental challenges by bringing public and private enterprise together with the University of Oxford's world-leading teaching and research.

Research at the Smith School shapes business practices, government policy and strategies to achieve net zero emissions and sustainable development. We offer innovative evidence-based solutions to the environmental challenges facing humanity over the coming decades. We apply expertise in economics, finance, business and law to tackle environmental and social challenges in six areas: water, climate, energy, biodiversity, food and the circular economy.

SSEE has several significant external research partnerships and Business Fellows, bringing experts from industry, consulting firms, and related enterprises who seek to address major environmental challenges to the University of Oxford. We offer a variety of open enrolment and custom Executive Education programmes that cater to participants from all over the world. We also provide independent research and advice on environmental strategy, corporate governance, public policy and long-term innovation.

For more information on SSEE please visit: www.smithschool.ox.ac.uk

Oxford Sustainable Finance Group

Oxford Sustainable Finance Group are a world-leading, multi-disciplinary centre for research and teaching in sustainable finance. We are uniquely placed by virtue of our scale, scope, networks, and leadership to understand the key challenges and opportunities in different contexts, and to work with partners to ambitiously shape the future of sustainable finance.

Aligning finance with sustainability to tackle global environmental and social challenges.

Both financial institutions and the broader financial system must manage the risks and capture the opportunities of the transition to global environmental sustainability. The University of Oxford has world leading researchers and research capabilities relevant to understanding these challenges and opportunities.

Established in 2012, the Oxford Sustainable Finance Group is the focal point for these activities.

The Group is multi-disciplinary and works globally across asset classes, finance professions, and with different parts of the financial system. We are the largest such centre globally and are working to be the world's best place for research and teaching on sustainable finance and investment. The Oxford Sustainable Finance Group is part of the Smith School of Enterprise and the Environment at the University of Oxford.

For more information please visit: sustainablefinance.ox.ac.uk/group

Environmental Change Institute

The **Environmental Change Institute (ECI)** is the University of Oxford's interdisciplinary institute for the analysis of the complex processes of global environmental change, the exploration of sustainable responses and the promotion of change for the better through partnership and education. Adaptation to climate change in a very wide range of sectors and locations worldwide has been a central part of the ECI's research agenda since its creation almost 30 years ago. The Institute involves over 100 researchers working across a wide range of themes.

For more information please visit: https://www.eci.ox.ac.uk/

Resilient Planet Finance Lab

The Resilient Planet Finance Lab was established in 2023 as a collaborative research and innovation programme hosted within the Environmental Change Institute, in partnership with the United Nations Office for Disaster Risk Reduction (UNDRR) and the Insurance Development Forum (IDF), to work with financial institutions, governments, civil society organisations and development finance institutions to deliver evidence and common metrics, toolkits, frameworks and guidance to accelerate the mobilisation of finance for resilience and nature.