

Climate Change and Sovereign Risk

October 2020



Centre for
Sustainable Finance
SOAS University of London



Four Twenty Seven



This report was prepared by the SOAS Centre for Sustainable Finance at SOAS University of London; the Asian Development Bank Institute; the World Wide Fund for Nature Singapore; and Four Twenty Seven.

This research has received partial financial support from the International Network for Sustainable Financial Policy Insights, Research and Exchange (INSPIRE). INSPIRE is a global research stakeholder of the Central Banks and Supervisors Network for Greening the Financial System (NGFS), and philanthropic support for INSPIRE is provided by ClimateWorks. The authors thank INSPIRE as well as the NGFS Secretariat for their insightful input and suggestions. The authors take full responsibility for any errors and omissions contained herein.

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Acknowledgments

We gratefully acknowledge the support, assistance, and insights that we received from participants at workshops in Singapore, Tokyo and London, as well as from the following individuals: Sara Ahmed, Rousseau Anai, Swisa Ariyaprunchya, Sylvain Augoyard, Anna Batenkova, Carter Brandon, Léonie Chatain, Wong Dan Chi, Marie Diron, Nigel Foo, Isaam Hanif, David Harris, Irene Heemskerk, Gerhard Kling, Keith Lee, Peter Morgan, Julien Moussavi, Akiho Nagano, Mary Nicola, Thomas Nielsen, Shanty Noviantie, Will Oulton, Samantha Power, Patrick Raleigh, Nick Robins, Andre Roux, Anushka Shah, Viktoria Seifert, Fiona Stewart, KimEng Tan, Romain Svartzman, Joanna Woods, and Naoyuki Yoshino. The views expressed in this report are those of the authors and should not be attributed to any of the aforementioned or the organizations with which they are affiliated. Special thanks are due to Max Schmidt for excellent research assistance and Adam Majoe for leading on the editing and layout. We thank Beyond Ratings/FTSE Russell for providing the data that we have analyzed for this report and Aladdin Rillo for writing the foreword.

Suggested citation: Volz, U., J. Beirne, N. Ambrosio Preudhomme, A. Fenton, E. Mazzacurati, N. Renzhi and J. Stampe. 2020. *Climate Change and Sovereign Risk*. London, Tokyo, Singapore, and Berkeley, CA: SOAS University of London, Asian Development Bank Institute, World Wide Fund for Nature Singapore, and Four Twenty Seven.

To download the report, visit: <https://doi.org/10.25501/SOAS.00033524>

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Foreword

Climate change is an increasingly important issue for policy makers globally, with material impacts on Southeast Asian economies and other regions highly vulnerable to climate risks. This report provides a timely and very comprehensive assessment of the role played by climate change on sovereign risk. In particular, a number of transmission channels through which climate change affects sovereign risk are discussed in the report: the fiscal impacts of climate-related natural disasters, the fiscal consequences of adaptation and mitigation policies, the macroeconomic impacts of climate change, the impacts of climate risk on financial sector stability, the international trade and capital flow dimension, and the impact of climate change on political stability. The report provides a thorough examination of how these transmission channels apply to the economies of Southeast Asia, and shows that there are substantial risks for the majority of Southeast Asia from a macrofinancial stability perspective. As well as this, the report provides new empirical estimates on the impact of climate vulnerability on sovereign risk, with vulnerability to climate change in the economies of the Association of Southeast Asian Nations (ASEAN) being associated with sovereign bond yield premia of around 155 basis points on average. Countries with higher exposure to climate risks are shown to incur even higher premia on their sovereign borrowing costs.

The policy implications outlined in this report should be taken seriously. I would urge policy makers in Southeast Asia and elsewhere to take particular heed of the recommendations provided in this report on how to mitigate and manage climate-related sovereign risks. Without taking appropriate measures to address vulnerability to climate risks, the implications for sovereign risk can have substantial negative ramifications for financial stability, sovereign financing cost, and, indeed, economic growth. With this in mind, I would like to draw attention to three of the policy recommendations in the report. First, I fully concur with the importance for economies to carry out comprehensive climate risk vulnerability assessments and develop national adaption plans that address macrofinancial risks. This report provides valuable insights into the dimensions that should be incorporated into any such assessment. Second, I would like to reinforce further that national governments need to consider the mainstreaming of climate risk adaptation into their budgetary plans. The scale of the negative implications of climate risks for sovereign risk require a full integration of climate risks into the public finance architecture. Third, I would like to highlight the importance of central banks and financial supervisors in addressing climate-related macrofinancial risks. The report provides a number of pertinent policy recommendations related to incorporating climate risks into monetary and prudential frameworks and the importance of financial sector policies to scale-up investment in climate adaptation. It also highlights the role of international financial institutions in providing technical assistance on improving adaptive capacity and macrofinancial resilience.

Overall, this report makes an important contribution to our understanding of the links between climate change and sovereign risk, with concrete recommendations for policy makers on how to deal with the sovereign risk implications of climate change. I hope that these recommendations will be widely adopted. We urgently need to scale up our collective efforts to climate-proof our economies and societies. This report will help us doing so.



Aladdin D. Rillo

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Acronyms

ABS	Association of Banks in Singapore
ADB	Asian Development Bank
AHA Centre	ASEAN Coordinating Centre for Humanitarian Affairs
AMOC	Atlantic meridional overturning circulation
AMRO	ASEAN+3 Macroeconomic Research Office
ASEAN	Association of Southeast Asian Nations
BCBS	Basel Committee on Banking Supervision
BoE	Bank of England
BoT	Bank of Thailand
BNI	Bank Negara Indonesia
BNM	Bank Negara Malaysia
BSI	British Standards Institution
BSP	Bangko Sentral ng Pilipinas
CDS	Credit default swap
CEIC	China Economic Database
CPI	Climate Policy Initiative
CRI	Climate Risk Index
CTI	Carbon Tracker Initiative
DNB	De Nederlandsche Bank
EBRD	European Bank for Reconstruction and Development
EC	European Commission
ECB	European Central Bank
EFI	European Forest Institute
EM-DAT	Emergency Events Database
EME	Emerging Economies
ESG	Environmental, social and governance factors
ESRB	European Systematic Risk Board
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FDI	Foreign direct investment
gCO ₂	Grams of carbon dioxide
GDP	Gross domestic product

GFDRR	World Bank and Global Facility for Disaster Reduction and Recovery
HS	Harmonized Commodity Description and Coding Systems
HydroSHEDS	Hydrological data and maps based on Shuttle Elevation Derivatives and multiple Scales
IAG	Insurance Australis Group
ICE	Internal combustion engine
ICMA	International Capital Market Association
IIF	Institute of International Finance
IFRC	International Federation of Red Cross and Red Crescent Societies
ILO	International Labour Organization
IMF	International Monetary Fund
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
km ²	Square kilometer
kW/h	Kilowatt-hour
Lao PDR	Lao People's Democratic Republic
LGD	Loss given default
MtCO ₂	Million tons of carbon dioxide
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
ND-GAIN	Notre Dame Global Adaptation Initiative
NGFS	Network for Greening the Financial System
NIC	National Intelligence Council
NPL	Non-performing loans
OECD	Organisation for Economic Co-operation and Development
OMFIF	Official Monetary and Financial Institutions Forum
PG&E	Pacific Gas and Electricity
PPP	Public-private partnerships
PPP	Purchasing power parity
PRC	People's Republic of China
PRI	Principles for Responsible Investment
QO	Qualitative Overlay

Acronyms

RCP	Representative Concentration Pathway
RoW	Rest of the world
S&P	Standard & Poor's
SBV	State Bank of Vietnam
SOE	State-owned enterprises
SRM	Sovereign Rating Model
SVAR	Structural panel vector autoregression
TBA	Thai Bankers' Association
TCFD	Task Force on Climate-Related Financial Disclosures
tCO ₂ e	Tons of carbon dioxide equivalent
TEEB	The Economics of Ecosystems and Biodiversity
UK	United Kingdom
UN Comtrade	United Nations Commodity Trade Statistics Database
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNEP FI	United Nations Environment Programme Finance Initiative
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
VAR	Vector autoregression
VIX	Chicago Board Options Exchange's Volatility Index
WAVES	Wealth Accounting and the Valuation of Ecosystem Services
WDI	World Development Indicators
WFE	World Federation of Exchanges
WTO	World Trade Organisation

Executive Summary

Climate change can have a material impact on sovereign risk through direct and indirect effects on public finances. It raises the cost of capital of climate-vulnerable countries and threatens debt sustainability. Governments must climate-proof their economies and public finances or potentially face an ever-worsening spiral of climate vulnerability and unsustainable debt burdens.

This study focuses on the complex nexus between climate change and sovereign risk, identifying and scrutinizing six transmission channels through which climate change can amplify sovereign risk and worsen a sovereign's standing:

1. Fiscal impacts of climate-related natural disasters
2. Fiscal consequences of adaptation and mitigation policies
3. Macroeconomic impacts of climate change
4. Climate-related risks and financial sector stability
5. Impacts on international trade and capital flows
6. Impacts on political stability

The transmission channels are not independent of each other. Climate impacts can magnify the transmission of risk through multiple channels. The socioeconomic and fiscal effects of climate change are multifaceted and depend on the policies taken or not taken to mitigate and adapt to these risks.

This report illustrates the relevance of the six transmission channels for sovereign risk in Southeast Asia, one of the most climate-vulnerable regions of the world. Physical risks are expected to significantly impact economic activity, international commerce, employment, and public finances with national and regional implications. Transition risks will be prominent as exports and economies become affected by international climate policies, technological change, and changing consumption patterns. The implications of climate change for macrofinancial stability and sovereign risk are likely to be material for most if not all countries in Southeast Asia.

The report presents new empirical evidence on the relationship between climate vulnerability, resilience, and the sovereign cost of capital. Using a sample of 40 developed and emerging economies, econometric analysis shows that climate risks and resilience to these risks have significant effects on the cost of sovereign borrowing.

Higher climate risk vulnerability leads to significant rises in the cost of sovereign borrowing. Premia on sovereign bond yields amount to around 275 basis points for economies highly exposed to climate risk, compared to 155 basis points for Southeast Asian countries, and 113 basis points for emerging market economies overall. In contrast, exposure to climate risks is not statistically significant for the group of advanced economies. We also find resilience to climate risk to be statistically significant in reducing bond yields across all country groups, but with smaller magnitudes.

Overall, the analysis confirms that climate vulnerability has significant implications for sovereign borrowing costs, and that the magnitude of the effect is much larger for countries highly vulnerable to climate change. Impulse response analysis suggests that shocks imposed on climate vulnerability and resilience have permanent effects on bond yields, and that economies highly exposed to climate risks experience larger permanent effects on yields than economies with lower exposure.

All branches of government will have to address climate-related risks. Monetary and financial authorities will have to play crucial roles in analyzing and mitigating macrofinancial risks. We recommend five broad policy actions to mitigate and manage climate-related sovereign risk in a coordinated manner.

Executive Summary

First, governments need to conduct comprehensive sectoral and national vulnerability assessments over multiple timespans to identify climate-related sovereign risk and develop national adaptation plans. Systematic, scenario-based assessment of all sources of vulnerability for the macroeconomy, the financial system, and public finances is needed, addressing both physical and transition risks. Such an assessment could be conducted by a dedicated national climate risk board that should include the central bank and supervisor along with the key government departments responsible for finance, economy, planning, and agriculture, among others.

Second, based on vulnerability assessments, financial authorities need to mainstream climate risk analysis into public financial management. This should include appropriate disclosure, analysis, and management of climate risks to public finances. Budgetary processes need to account for climate risk and mainstream climate-relevant policies and laws. Furthermore, finance ministries need to enhance public sector funding and debt management strategies, including through debt instruments with risk-sharing features, and diversification of government revenue streams away from high-risk sectors.

Third, central banks and financial supervisors need to address climate-related risks in their monetary and prudential frameworks and operations. Disclosure of climate and other sustainability risks should become mandatory, and climate stress tests of financial institutions should be conducted regularly. Climate-related financial risks should be mainstreamed into macro and micro prudential supervision. Monetary and prudential measures should be aligned with climate goals. Importantly, supervisors should reconsider the prudential treatment of sovereign exposures in financial regulation.

Fourth, governments and financial authorities should implement financial sector policies to scale-up investment in climate adaptation and develop insurance solutions. Monetary and financial authorities can play an important role in supporting the development of local currency bond markets and fintech solutions for mobilizing domestic savings for financing climate-resilient, sustainable infrastructure and other adaptation measures. Developing insurance markets and broadening insurance coverage can help to enhance the financial resilience of households and businesses and take the burden off public finances.

Fifth, international financial institutions—including the International Monetary Fund, multilateral development banks, and regional financing arrangements—have a special role in supporting vulnerable countries to better address climate-related sovereign risks and strengthen adaptive capacity and macrofinancial resilience. Building on their respective strengths, they can provide technical assistance and training, support surveillance and risk monitoring, provide finance for adaptation and resilience investment, help develop insurance solutions, and provide emergency lending and crisis support.

1. Introduction

For large countries with solid tax bases and relatively favorable climates, the socialization of climate risk may be manageable. For smaller, highly exposed island nations, it will be overwhelming. Before they are physically inundated, their sovereignty will be drowned under an economic and financial deluge.

(Adam Tooze 2019)

Climate change has emerged as one of the mega-challenges of our time. It poses a potentially catastrophic threat to humanity. Climate change is threatening livelihoods and will require our economies to adapt in profound ways. As Weitzman (2011, 275) pointed out, “[d]eep structural uncertainty about the unknown unknowns of what might go very wrong is coupled with essentially unlimited downside liability on possible planetary damages.” Even in the most optimistic climate mitigation scenarios, the effects of global warming are likely to have a substantial impact on our economies. For many countries, climate change poses a significant risk to their macroeconomic and financial stability and, as a consequence, threatens to undermine their fiscal and debt sustainability. For some countries, there is a real danger that climate change will lead to a “fiscal tsunami” (Farmer 2019).

Over the last years, credit rating agencies have started to flag climate change as a potential risk to sovereign credit ratings,¹ and international organizations, including the International Monetary Fund (IMF) and the World Bank, have acknowledged the macroeconomic and financial risks emanating from climate change. Moreover, investors are increasingly “recognising the need for a broader understanding of emerging risks in the bond markets” and the “mounting threat of systemic risks outside of the financial system, notably environmental risk, which can impact multiple financial markets” (UNEP FI and Global Footprint Network 2012, 3).

A growing body of research has studied the macroeconomic impacts of climate change (e.g. Hochrainer 2009; Batten 2018). However, despite the potentially profound implications, little systematic analysis has been conducted to date on the nexus between climate change and sovereign risk. Furthermore, no meaningful research has focused thus far on how central banks and supervisors may integrate the climate–sovereign risk nexus into their operational frameworks to help them achieve their mandated goals of maintaining price and financial stability, thus contributing to broader macroeconomic stability. Against this backdrop, this report puts forward an analytical framework for analyzing the potential impact of climate change on sovereign risk and debt sustainability and illustrates the relevance of these risk channels for the countries of Southeast Asia, which is one of the regions that is most vulnerable to climate change. The report also assesses the implications from the perspective of monetary and financial authorities. While this report focuses on climate risks, we should emphasize that climate change is not the only environmental risk that can exert an impact on sovereign risk. In particular, research has increasingly acknowledged that the depletion of natural capital and biodiversity loss also pose a sovereign risk threat (Pinzón et al. 2020). As the report will discuss later, climate change and the depletion of natural capital are closely intertwined.

¹ Standard & Poor’s Ratings Services describes climate change as “a Global Mega-trend for Sovereign Risk” (S&P 2014a, 1).

Sovereign risk is the risk that a government will become unable or unwilling to meet its debt obligations.² It has a direct link to fiscal risks, which the International Monetary Fund (IMF) (2018, 95) defines as “factors that may cause fiscal outcomes to deviate from expectations or forecasts,” comprising “potential shocks to government revenues, expenditures, assets, or liabilities, which are not reflected in the government’s fiscal forecasts or reports.” The analysis of fiscal risk has tended to focus on risks that “have a reasonable chance of materializing during a horizon of a few years” to “keep the analysis manageable” (Cebotari et al. 2009, 2). Even when adopting a time horizon of a few years, climate change is a material risk for many countries. The risks, however, are significantly higher when taking a longer-term perspective. Estimates have put the cost of unmitigated climate change at 23% or more of the global gross domestic product (GDP) by the year 2100 (Burke, Hsiang, and Miguel 2015a). This will inevitably have impacts on public finances and debt sustainability. In the absence of meaningful mitigation efforts, the world may indeed be at risk of “climate ruin” (Heine and Black 2019, 3).

While climate change is affecting the entire globe, global warming and the associated physical processes will differ in their manifestation and severity across countries and regions. Poorer countries with temperate and hot climates will suffer greater output losses. Indeed, the economic effects of climate change are likely to be disproportionately larger in developing countries, which “are most vulnerable to extreme events, [and] are projected to experience the strongest increase in [temperature] variability” (Bathiany et al. 2018, 1) and sea-level rise (Lincke and Hinkel 2018). Some small developing island states may even vanish entirely (IPCC 2019a). Poorer countries tend to be economically less diversified and more reliant on sectors that are particularly vulnerable to physical risk (including agriculture, fishing, and tourism) and transition risk (such as fossil fuel extraction), while limited financial and institutional resources tend to constrain their capacities to adapt to climate change. A lack of insurance compounds the risks. A recent study by Moody’s Analytics stated that “[e]merging economies, oil producers, and those in warmer climates are most vulnerable” and that the “most draconian effects [of climate change will] occur during the second half of this century” (Lafakis et al. 2019, 12). As this report will analyze in detail, both physical and transition effects of climate change can have profound consequences for fiscal sustainability and affect sovereign credit risk in countries with a less diversified economy and climate impacts on key sectors that generate high corporate tax revenue and provide large-scale employment.

Sovereign risk matters. Sovereign debt is the single most important asset class. At the end of 2019, the total amount of outstanding government debt stood at US\$70 trillion or 28% of total global debt (IIF 2020). Government bonds account for 47% of the US\$115 trillion global bond market. Sovereign debt, which is often treated as a risk-free asset, serves as a benchmark for the pricing of corporate debt. A worsening of sovereign risk means that the refinancing of public debt becomes more expensive and fiscal space is constrained, limiting the scope for public investment in important areas such as infrastructure, health, and education. A worsening sovereign risk profile also has implications for corporate risk (Augustin et al. 2018). Recent evidence has shown a link between the climate vulnerability of countries and the cost of corporate capital for the firms in these countries (Kling et al. 2020).

² As Fitch, the credit rating agency, pointed out, “[c]ountry risk and sovereign credit risk are related but distinct concepts” (Fitch 2019, 3). Country risk is related to risks to doing business in a given country, including an unpredictable operating environment, feeble property rights, and a weak legal framework, whereas sovereign credit risk is specifically related to a government’s payments on its debt obligations.

The structure of this report is as follows. Chapter 2 reviews how the major credit rating agencies have started to analyze climate change as a potential risk for sovereign credit ratings. Chapter 3 dissects the ways in which climate change can amplify sovereign risk. Subsequently, and building on this conceptual work, Chapter 4 examines the potential impact of climate change on sovereign risk for the ten member countries of the Association of Southeast Asian Nations (ASEAN).³ Chapter 5 presents an empirical analysis of the effects of climate vulnerability on the price of sovereign debt, using a global sample of 40 advanced and emerging economies. Chapter 6 discusses the implications of the preceding analysis for macro-financial governance. Finally, Chapter 7 concludes with a summary of the main findings and insights of this report and puts forward a set of recommendations for monetary and financial authorities to mitigate climate-related sovereign risk.

³ The members of ASEAN are Brunei, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam.

2. Rating Agencies and Climate Risk

Although rating actions mainly caused by environmental factors are not deemed to increase considerably in the short- to medium-term, they may need to be recognized as a big risk factor in the long term.

(Hosoda, Ishiwata, and Nagao 2018, 4)

Ratings agencies are increasingly paying attention to the exposure of sovereigns and local governments to climate risk.⁴ To date, no major credit rating agency has downgraded a sovereign based on an explicit attribution to climate risks (Buhr et al. 2018; Tigue 2019). However, when Moody's Investors Service (Moody's) downgraded Sint Maarten in June 2019, the explanation included "[t]he increase in Sint Maarten's main debt metrics, resulting from the still-ongoing economic and fiscal shock following Hurricane Irma's landing in 2017" (Moody's 2019a). Further, ratings agencies are considering climate risks more strongly, though indirectly, in their sovereign rating methodologies. The agencies' methodologies of credit analysis themselves still remain vastly unchanged, but a trend toward using additional tools for climate risk assessment is becoming clear. A stronger consideration of climate change impacts would most likely lead to further downgrading of those sovereigns affected the most by climate change, particularly in the global south.

Standard & Poor's described climate change as a "global mega-trend for sovereign risk" in 2014 and highlighted that "[t]he impact on creditworthiness will probably be felt through various channels, including economic growth, external performance, and public finances" (S&P 2014a, 1). It also emphasized that "lower-rated sovereigns tend on average to be more vulnerable than higher-rated sovereigns" (S&P 2014a, 10) and that "[s]overeigns will probably be unevenly affected by climate change, with poorer and lower rated sovereigns typically hit hardest, which could contribute to rising global rating inequality" (S&P 2014a, 1). Moody's (2020a) also recently highlighted sea-level rise as a long-term credit threat to several Asian, Middle Eastern, North African, and small island countries.⁵

2.1 Climate risks in the current methodologies of the “big three” rating agencies

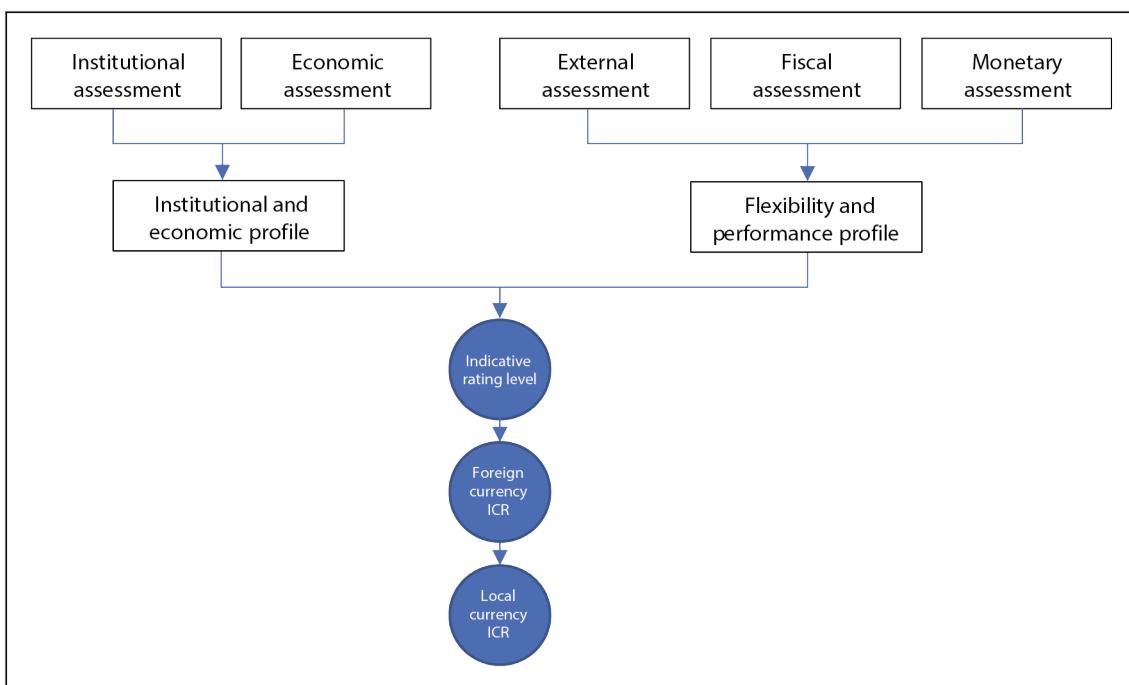
S&P's sovereign issuer criteria framework rests on the five pillars of institutional, economic, external, fiscal, and monetary assessment (S&P 2017). An ESG Risk Atlas, which comprises a country risk component for governance risks and natural disasters and a sector risk component in 34 sectors, informs it (S&P 2019). According to S&P, the energy sector and the consumer products sector are the most at risk from climate change, for example due to disruptions of supply chains or market dislocations (S&P 2014b). S&P's current sovereign rating methodology considers climate risks only as intermediary variables influencing its key measures of economic, fiscal, and external performance (S&P 2015b, 2017). It considers natural disasters such as tropical cyclones or floods—as a crucial part of climate risks—to be responsible for the biggest single rating impacts. While most disaster events are "relatively benign, and do not cause economic damage of a magnitude that would have any meaningful repercussions on the credit standing of the sovereigns where they occur," S&P highlighted

⁴ More generally, credit rating agencies have started to account for climate change risks across assets. See, for instance, Mathiesen (2018).

⁵ In 2017, Moody's was the first rating agency to place a sub-sovereign entity—the city of Cape Town in South Africa—under review for downgrading on the grounds of climate-related credit repayment risks.

that, “in the rare cases when severe natural catastrophes hit densely populated and economically developed areas, they bear large economic costs and are more likely to hurt a sovereign’s credit standing” (S&P 2015a, 2). Figure 1 summarizes S&P’s sovereign issuer criteria framework.

Figure 1: S&P’s sovereign issuer criteria framework

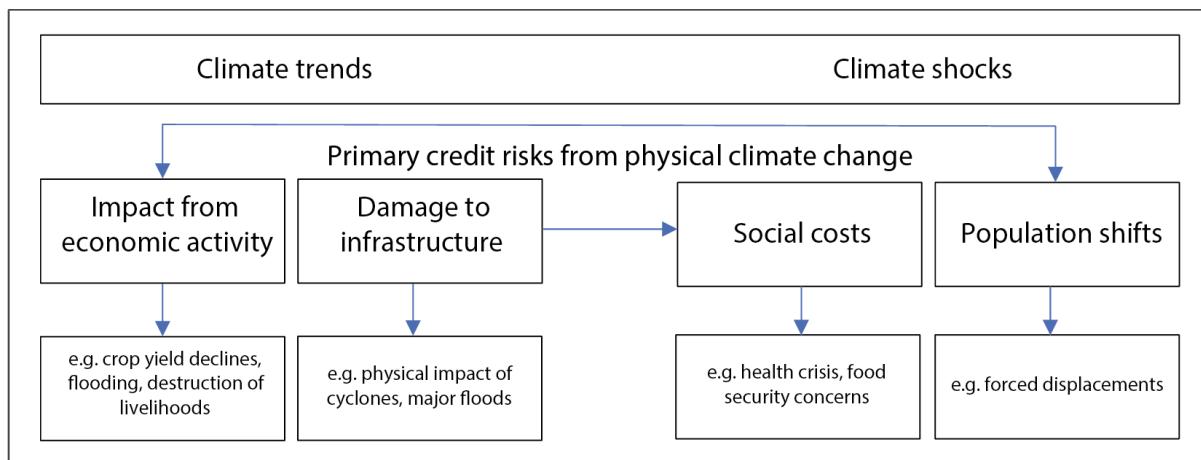


Note: ICR stands for issuer credit rating.

Source: Compiled by authors based on S&P (2017, 2).

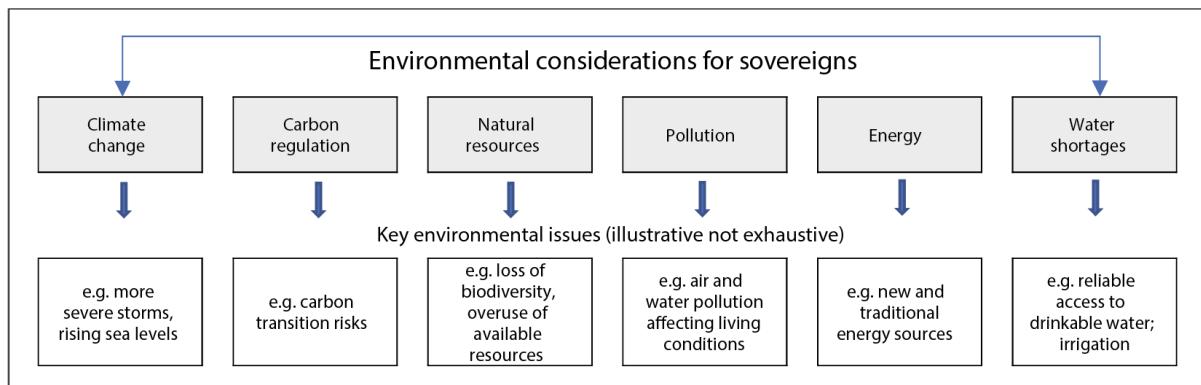
Moody’s bases its assessment of sovereign credit risk on the interplay of four factors: “economic strength,” “institutions and governance strength,” “fiscal strength,” and “susceptibility to event risk” (Moody’s 2019b). This methodology does mention climate risks briefly. Moody’s (2016b) has identified four primary transmission channels through which physical climate change may affect sovereign risk: (1) impacts on economic activity, (2) damage to infrastructure, (3) social costs, and (4) population shifts (Figure 2). It views the susceptibility to climate risks as a function of exposure and resilience. The former includes two dimensions: economic diversification (e.g. the size of the economy, the concentration of agriculture as a share of the total output, and employment) and geographic location (e.g. the magnitude and frequency of economic disruptive climate events and the population density in low-lying areas). Resilience comprises three dimensions: the development level (income per capita and adaptive capacity), fiscal flexibility (debt burden and debt affordability), and government policies (e.g. insurance or savings funds to mitigate against natural disasters).

Figure 2: Moody's primary transmission channels from physical climate change



Source: Compiled by authors based on Moody's (2016b, 4).

Figure 3: Moody's environmental considerations for sovereigns



Source: Compiled by authors based on Moody's (2018b, 3).

Moody's has also laid out how environmental, social, and governance (ESG) risks may influence sovereign ratings (Moody's 2018b). Environmental credit risks relate to the current and future "physical conditions in which societies operate" (Moody's 2018b, 3), including the impact of climate change and the global transition to less carbon-intensive economic development (Figure 3). Moody's has developed a set of tools to improve the transparency of its climate risk-related rating changes, including ESG taxonomies, a global heat map, and sector scorecards (Moody's 2018a, 2018c). Moody's (2018a) has also published an assessment of the susceptibility of sovereigns' credit quality to climate change. It has identified 36 small, agriculture-reliant countries—17 in Africa and 12 in the Asia and the Pacific region—as being the most susceptible to climate change.

Fitch Ratings bases its assessment of sovereign risk on a "synthesis of quantitative and qualitative judgements that capture the willingness as well as the capacity of the sovereign to meet its debt obligations" (Fitch 2019b, 1). The analysis comprises four analytical pillars: structural features; macroeconomic performance, policies, and prospects; public finances; and external finances (Table 1). The rating criteria and the rating model make no explicit reference to climate risks or climate-related shocks. However, Fitch has affirmed that climate factors (and other ESG factors) can influence each of the four analytical pillars and that increasing climate vulnerabilities could undermine sovereign ratings (Fitch 2019a).

Table 1: Fitch Ratings' sovereign rating criteria

		Macroeconomic performance, policies, and prospects				
Analytical pillar		Structural features		Public finances		External finances
Input	Key criteria factors	Governance quality Wealth and flexibility of the economy Political stability and capacity Financial sector risks	Policy framework GDP growth Inflation Real effective exchange rate	Government debt Fiscal balance Debt dynamics Fiscal policy	Balance of payments External balance sheet External liquidity	
Sovereign Rating Model (SRM)	Regression-based, point-in-time rating model based on 18 key variables	Governance indicators GDP per capita Share in world GDP Years since default or restructuring event Broad money supply	Real GDP growth volatility Consumer price inflation Real GDP growth	Gross government debt/GDP General government interest (% of revenues) General government fiscal balance/GDP Foreign currency government debt/general government debt	Reserve currency flexibility Sovereign net foreign assets (% of GDP) Commodity dependence Foreign exchange reserves (months of cover of import payments) External interest service (% of current external receipts) Current account balance + FDI (% of GDP)	
Qualitative Overlay (QO)	Forward-looking adjustment framework to provide a subjective assessment of key criteria factors that are not explicitly included in the SRM	Political stability and capacity Financial sector risks Business environment and economic flexibility	Macroeconomic policy credibility and flexibility GDP growth outlook (5 years) Macroeconomic stability	Fiscal financing flexibility Public debt sustainability Fiscal structure	External financing flexibility External debt sustainability Vulnerability to shocks	

Source: Compiled by authors based on Fitch (2019b, 2).

Fitch, in an approach similar to that of S&P, relies on the ESG Relevance Scores in its consideration of climate risks for its sovereign rating (Fitch 2019a, Table 2). Interestingly, it considers environmental factors to be less impactful on the current ratings than social or governance factors. Only two sovereigns have an environmental ESG element scored at “4” (“relevant to rating, a rating driver”), while all the other sovereigns have a score of “3” (“relevant, but only impacts sovereign rating in combination with other factors”) for at least three out of five environmental risk factors.

S&P acknowledged that lower-rated sovereigns have greater vulnerability to climate change (S&P 2015a). The same holds true for Moody’s (Moody’s 2018b), which, as early as 2016, highlighted that those countries that are more reliant on agriculture and possess weaker infrastructural and institutional quality are more susceptible to climate risks (Moody’s 2016b).

Table 2: Fitch Ratings' environmental relevance score

General issues	Key sovereign issue	Sovereign rating criteria references
Greenhouse gas emissions and air quality	Emissions and air pollution as a constraint on GDP growth	SRM—macroeconomic performance, policies, and prospects (macro); macro: real GDP growth; QO—macro: GDP growth outlook
Energy management	Management of energy resource endowments affecting exports, government revenue, and GDP	SRM—external finances; commodity dependence; SRM and QO—indirectly affects other SRM variables and QO judgments
Water resources and management	Water resource availability and management as a constraint on GDP growth	SRM—macro: real GDP growth; QO—macro: GDP growth outlook
Biodiversity and natural resource management	Management of natural resource endowments affecting exports, government revenues, and GDP	SRM—external finances: commodity dependence; SRM and QO—indirectly affects other SRM variables and QO judgments
Natural disasters and climate change	Likelihood of and resilience to shocks	SRM—structural features: share in the world GDP; macro: GDP volatility; QO—external finances: vulnerability to shocks; SRM and QO—potential impact on other variables

Note: SRM stands for sovereign rating model; QO stands for qualitative overlay.

Source: Compiled by authors based on Fitch (2019a, 5).

Some of the challenges in anticipating the impact of climate risks on sovereigns' credit profiles relate to the complexity of the relationship between climate change and rating factors, which involves widely varying time horizons between increased severity of climate change and impact, the multiple dimensions of resilience for sovereigns that ultimately determine the impact of exposure to a given risk, and the many other factors that drive a sovereign rating. Whilst all rating agencies have pointed out that the impact of climate change on sovereign credit profiles is most likely to grow further over time and that can be expected the first changes soon, their projections do not extend beyond 2050. S&P, with its focus on natural disasters as one dimension of physical climate change, highlighted that they might lead to sudden downgrades by 1.5 notches at once and exacerbate the current negative sovereign rating impacts due to climate change by as much as 20% (S&P 2015b).

In the case of Moody's, it is necessary to highlight that the outlined transmission channels result from the dimensions of climate trends and climate shocks. Hence, phenomena such as sea-level rising can affect these transmission channels via one or even both of the dimensions simultaneously (Moody's 2016b). Consequently, low-lying and densely populated states, such as Bangladesh, may become equally more exposed and less resilient to sea-level rising in general and monsoon-related flooding in particular due to worsened credit ratings themselves.

2.2 Greater awareness of climate risks for sovereigns

In the meantime, a number of initiatives have taken off. In 2016, the Principles for Responsible Investment (PRI) launched the "ESG in Credit Risk and Ratings Initiative," which put forward a "Statement on ESG in Credit Risk and Ratings" (Box 1), which 20 credit rating agencies, the Big Three, and 158 investors signed (as of March 2020). The statement highlighted risks at the sovereign and sub-sovereign level related to "natural resource management, public health standards and corruption [that] can all affect tax revenues, trade balance and foreign investment" (PRI 2019). In October 2019, the World Bank launched an online sovereign ESG data portal to facilitate the analysis of sovereign risk (World Bank 2020).

Box 1: The PRI Credit Risk and Ratings Initiative's statement on ESG in credit risk and ratings

We, the undersigned, recognise that environmental, social and governance (ESG) factors can affect borrowers' cash flows and the likelihood that they will default on their debt obligations. ESG factors are therefore important elements in assessing the creditworthiness of borrowers. For corporates, concerns such as stranded assets linked to climate change, labour relations challenges or lack of transparency around accounting practices can cause unexpected losses, expenditure, inefficiencies, litigation, regulatory pressure and reputational impacts.

At a sovereign level, risks related to, inter alia, natural resource management, public health standards and corruption can all affect tax revenues, trade balance and foreign investment. The same is true for local governments and special purpose vehicles issuing project bonds. Such events can result in bond price volatility, and increase the risk of defaults.

In order to more fully address major market and idiosyncratic risk in debt capital markets, underwriters, credit rating agencies and investors should consider the potential financial materiality of ESG factors in a strategic and systematic way. Transparency on which ESG factors are considered, how these are integrated, and the extent to which they are deemed material in credit assessments will enable better alignment of key stakeholders.

In doing this the stakeholders should recognise that credit ratings reflect exclusively an assessment of an issuer's creditworthiness. Credit rating agencies must be allowed to maintain full independence in determining which criteria may be material to their ratings. While issuer ESG analysis may be considered an important part of a credit rating, the two assessments should not be confused or seen as interchangeable.

With this in mind, we share a common vision to enhance systematic and transparent consideration of ESG factors in the assessment of creditworthiness.

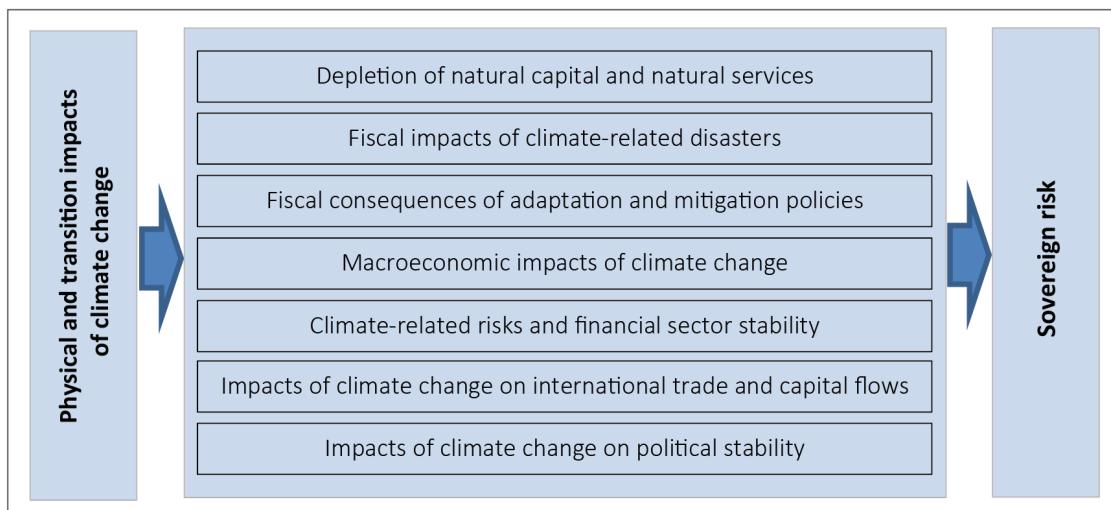
Source: PRI (2019).

3. Transmission Channels of Risk

Recent research on the relationship between climate vulnerability, sovereign credit profiles, and the cost of capital in climate-vulnerable developing countries has shown that these countries incur a risk premium on their sovereign debt, reducing their fiscal capacity for investments in climate adaptation and resilience (Buhr et al. 2018; Kling et al. 2018). This raises serious questions regarding the possible impacts of climate risk on the sustainability of public finances for climate-vulnerable countries, the fiscal health of which is also under threat from potential output losses related to climate hazards and disaster recovery costs as well as transition risks that may hit specific sectors or the economy at large.

To assess and mitigate climate-related sovereign risk properly, it is important to understand the ways in which climate change can amplify sovereign risk. In the following, we identify and analyze different transmission channels, which Figure 4 displays. We first discuss the importance of natural capital and natural services as the very foundation of economic well-being (3.1) before turning to the different risk channels that could worsen a sovereign's standing: the fiscal impacts of climate-related disasters (3.2); the fiscal consequences of adaptation and mitigation policies (3.3); the macroeconomic impacts of climate change (3.4); climate-related risks and financial sector stability (3.5); the impacts of climate change on international trade and capital flows (3.6); and the impacts of climate change on political stability (3.7).

Figure 4: Transmission channels of risk



Source: Compiled by authors.

3.1 Natural capital as the basis of economic prosperity

Debrun et al. (2019) emphasized the difficulty of assembling and assessing a government's balance sheet. Like a corporate balance sheet, a government's balance sheet lists assets and liabilities. However, it is not easy to determine the present value of many assets and liabilities. Many items on the asset side, such as the present value of future tax income, the revenue from future natural resource extraction, or the value of public infrastructure and cultural treasures, are hard to quantify as they have no market value and therefore no known price. Likewise, many items on the liability side, such as pension obligations and contingent liabilities, are very hard to establish. It is therefore also

very difficult to assess a country's sovereign net worth, which is the difference between its assets and its liabilities. The exercise becomes even more complicated when trying to account for a country's natural capital or its depletion.

All economic activity, and hence a country's economic and fiscal sustainability, is ultimately dependent on natural assets and eco-services.⁶ Continued depletion of natural capital is clearly not sustainable. As Pinzón et al. (2020, 4) pointed out, "[a]griculture and the soft commodity trade are heavily linked to natural capital, as drivers of depletion and as processes reliant on a secure stream of ecosystem services. The value of sovereign bonds relies in part on the management of natural capital by the countries concerned. However, this dependency is still largely ignored or mispriced in sovereign bond markets." While it is difficult, if not impossible, to account for a country's natural capital, any analysis of sovereign risk ought at least to consider how trends in the ecosystem may affect a country's economic prospects and well-being in the future and the government's ability to remain fiscally sustainable.⁷

How natural capital underpins economies

The natural environment provides the foundation for all societies and economies. It does this through the provision of natural capital assets and ecosystem services, henceforth "natural capital."⁸ Natural capital assets are natural resources such as forests and rivers. Ecosystem services derive from these assets. The Millennium Ecosystem Assessment (2003) identified four ecosystem services that contribute to human well-being:

- Provisioning services: products that people obtain directly from nature (e.g. wild foods, crops, fresh water, and plant-derived medicines).
- Regulating services: benefits that people obtain from ecosystem processes (e.g. pollutant filtration by wetlands, climate regulation through carbon storage, pollination, and disaster risk reduction).
- Cultural services: non-material benefits that people obtain through recreation, spiritual experience, and educational development.
- Supporting services: ecosystem services that are necessary for the production of all other ecosystem services (e.g. soil formation, photosynthesis, water cycling, and nutrient cycling).

Natural capital directly or indirectly underpins all economic productivity, social well-being, and ecological sustainability (TEEB 2011). One of the most published depictions of the Sustainable Development Goals (SDGs) is the layer cake, developed by the Stockholm Resilience Centre, with biosphere-related SDGs 6 (Clean Water and Sanitation), 13 (Climate Action), 14 (Life Under Water), and 15 (Life on Land) underpinning those related to society and economy (Figure 5).

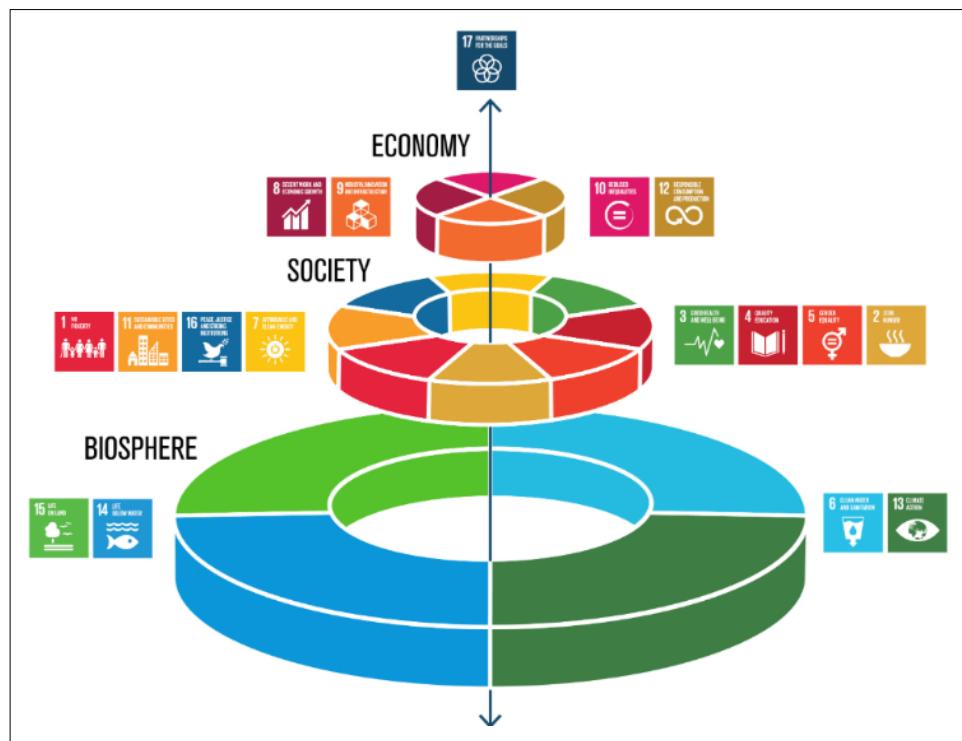
Natural capital can produce benefits in perpetuity if managed sustainably. However, their valuation is rarely appropriate and there are major inconsistencies in the way in which stakeholders in decision-making processes value ecosystem services. This has been a major reason for these resources' and services' rapid and severe deterioration (TEEB 2011).

⁶ This notion is in line with Arrow et al.'s (2004) conceptualization of sustainability as non-decreasing net wealth of a country.

⁷ The Wealth Accounting and the Valuation of Ecosystem Services (WAVES) partnership promoted by the World Bank is an example of an attempt to integrate the accounting of natural resources into development planning to promote sustainability.

⁸ For the purposes of this report, we consider biodiversity as a natural capital asset.

Figure 5: Sustainable Development Goals wedding cake



Source: Azote Images for Stockholm Resilience Centre, Stockholm University.

Recently, the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services⁹ estimated that the annual economic value of the world’s terrestrial ecosystem services approximately equals the global annual GDP (IPBES 2019). A recent report estimated the total asset base of the ocean to be at least US\$24 trillion,¹⁰ meaning that, if it were a country, it would be the seventh largest in the world in terms of asset value (Hoegh-Guldberg 2015). Academic studies have arrived at similar conclusions, with one seminal study estimating that globally nature provides annual assets and services worth approximately US\$125 trillion, therefore contributing more than twice as much to human well-being as the global GDP (Costanza et al. 2014).

For many countries, some of their most important economic sectors depend directly on ecosystem services as inputs into their production or value generation process. These include “nature-dependent soft commodity” exports resulting from agriculture, aquaculture, and forestry as well as others, such as tourism. These activities and others are not only of immediate importance to employment but also have deeper macroeconomic importance, with impacts on the balance of payments. However, it is important to note that all economic sectors depend on natural capital in one way or another; even the power generation sector with coal-fired power plants depends heavily on fresh water to function.

⁹ The Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services is an intergovernmental organization, the establishment of which aimed to improve the interface between science and policy on issues of biodiversity and ecosystem services.

¹⁰ This conservative value derives from direct outputs (fishing, aquaculture), services enabled (tourism, education), trade and transportation (coastal and oceanic shipping), and adjacent benefits (carbon sequestration, biotechnology). This conservative estimate did not include intangible values, such as the ocean’s role in climate regulation, the production of oxygen, or the spiritual and cultural services provided. Therefore, the actual value is much higher than the reported figure.

Fresh water is of paramount importance to economic prosperity and stability as it is a key input into many industries, such as agriculture, textiles, mining, energy, transport, and the beverage industry. The consequences of climate change will be most apparent through fresh water scarcity. The demand for fresh water is increasing annually by 1%, with frequent forecasts of supply shortfalls (Boretti and Rosa 2019). Currently, agriculture and meeting the demands of growing populations consume 70% of fresh water. Conflict over water usage will increasingly become an issue as the expectation is that, by 2050, the water demand will increase by 55% and the food demand by 60% and approximately half of the global population will live in water stressed areas (Schlosser et al. 2014; Opperman et al. 2018; Granzo and Morgan 2019). The management of fresh water is a complicated issue to address as it is often a transboundary problem requiring international cooperation (cf. Bernauer and Böhmelt 2020).

Low-income and otherwise disadvantaged groups, often those in rural areas, depend disproportionately on natural capital for their livelihoods and are especially vulnerable to natural hazards. Natural capital is of particular importance to wealth generation in low-income and lower-middle-income countries (Lange, Wodon, and Carey 2018).

In addition to being a source of wealth generation, natural capital supports economic stability by providing protection against natural hazards. Notable examples are wetlands and floodplains, which, if managed sustainably, will reduce the damage from flooding. Natural capital underpins stable economies by:

- Improving the ecosystem's resilience to disturbances—and thus the likelihood that they will persist and support economic activities.
- Enhancing the protective functions of ecosystems—and thus the degree to which they can absorb natural hazards and protect economic activities.
- Contributing to social resilience—and thus the likelihood that societies can recover and continue to function in the face of natural hazards (Monty, Murti, and Furuta 2016).

Economic systems are causing severe decline in natural capital

Across the world, economic activity is undermining the natural environment, and the damage is accelerating (c.f. TEEB 2011; IPBES 2019). This in turn is causing a severe loss of natural capital assets and biodiversity and devastating ecosystems and the services that they provide. Many of the ecosystem services that nature provides are not fully replaceable, and some are not replaceable at all. Countries need to value, account for, and protect natural capital.

Declining natural capital is a contributing factor behind many natural disasters that threaten economic resilience, creating negative feedback loops that jeopardize economic growth and stability. For instance, biodiversity loss and unsustainable land management practices cause soil degradation, which can increase landslide and flood risk. This can further damage the productive layer of topsoil on which agriculture depends, which in turn can exacerbate biodiversity loss. This example is especially pertinent because, between 2012 and 2017, flooding accounted for 71% of natural disasters within Southeast Asia (AHA Centre 2018).

Instead of sustainably managing natural capital, economies are utilizing ever more of the earth's resources. Approximately 33% of the world's land surface and 75% of freshwater resources are devoted to agriculture (IPBES 2019). Humans have combined technology with natural capital to achieve impressive increases in production. Agricultural production has increased threefold since 1970. Forestry production has increased by almost 50%. However, these gains are not sustainable; of the 18 categories of nature's contributions that the latest IPBES study assessed, 14 have declined (IPBES 2019).

In the last century alone, socioeconomic activity has resulted in the loss of 35% of mangrove forests, 40% of terrestrial forests, and 50% of wetlands (TEEB 2011). Overfishing has resulted in the full or overexploitation of 80% of the world's fisheries. Estimations have indicated that 60% of ecosystem services that the natural environment provides have degraded in the last fifty years (TEEB 2011).

Biodiversity loss is rampant, increasing, and undoubtedly a result of human activity. Of the estimated 8 million animal and plant species, around 1 million are facing the threat of extinction (IPBES 2019). In the current period, the loss of species is 100 to 1,000 times greater than in previous geological times (TEEB 2011; WWF 2018). In 2018, the WWF (2018) reported that humanity had wiped out 60% of mammals, birds, fish, and reptiles since 1970.

While it always has impacts, the loss and associated cost of natural capital can pass unnoticed. This is because the value of natural capital is often missing from decisions, indicators, accounting systems, and market prices (TEEB 2011). The stress to ecosystems can remain unnoticed because many are resilient up to certain thresholds before experiencing a decline. This decline can be abrupt, severe, unpredictable, and irreversible. In other words, the risk profile associated with deteriorating natural capital is nonlinear. For example, coral reef systems are vital biodiversity hotspots and provide numerous ecosystem services, such as being important nurseries for many fish species. If ocean waters are too hot over a prolonged period of time, coral reefs bleach rapidly and will die quickly unless the waters quickly cool to safe levels.

Research is increasingly indicating that we are approaching multiple planetary boundaries. One much-noted study presented nine planetary processes that regulate the stability and resilience of the earth as far as it pertains to accommodating human life, concluding that only three natural systems (fresh water use, stratospheric ozone depletion, and ocean acidification) are currently operating within the limits, although ocean acidification is close to its safe boundary (Steffen, Kirschenmann, and Korte 2015). Importantly, the study found that we have crossed the safe planetary boundary for climate change, which will further stress other planetary boundaries, such as fresh water use and ocean acidification. Further deterioration will trigger multiple “tipping points,” points at which climate change pushes a part of the earth’s system into abrupt or irreversible change with global implications (Table 3).

Table 3: Nine “tipping points” that could be triggered by climate change

Tipping point	Description	Type	Implication
Greenland ice sheet disintegration	Irreversible retreat of the ice sheet as a result of rising temperatures	Melting	Sea-level rise of up to 7 meters
Permafrost loss	Abrupt increase in emissions of CO ₂ and methane through the thawing of frozen carbon-rich soils	Melting	Greenhouse gas release
Atlantic meridional overturning circulation (AMOC) breakdown	Shutdown of the AMOC caused by an increased influx of fresh water into the North Atlantic	Circulation change	Disruption to the ocean ecosystem Regional cooling
Boreal forest shift	A shift in boreal forests, seeing expansion into the tundra to the north and dieback to the south	Biome shift	Regional warming Ecological shift
Amazon rainforest dieback	Deforestation and hotter, drier conditions causing dieback of the rainforest and a shift toward savannah	Biome shift	Biodiversity loss Decreased rainfall
West Antarctic ice sheet disintegration	Collapse of the ice sheet triggered by persistent grounding-line retreat in one sector, cascading to other sectors	Melting	Sea-level rise of up to 3 meters
West African monsoon shift	An abrupt change in Sahel rainfall resulting from a shift northward (wetter) or southward (drier) in the West African monsoon	Circulation change	Disruption to agriculture Ecosystem change
Indian monsoon shift	Strengthening of the monsoon caused by rising CO ₂ emissions or weakening as a result of high aerosol emissions	Circulation change	Disruption to agriculture Greater rainfall extreme
Coral reef die-off	Rising temperatures pushing warm water corals beyond tolerable levels of thermal stress into an alternative state dominated by macroalgae	Biome shift	Ecosystem change Losses to fisheries and tourism

Source: Compiled by authors based on Carbon Brief (2020), which used various academic sources of information.

Climate change will exacerbate the existing decline of natural capital

The impact of climate change as a direct driver of changes in natural environments is likely to increase over the coming decades. Climate change is expected to have dramatic and adverse effects on natural capital, even with the achievement of the mitigation goals of the Paris Agreement (IPBES 2019). Furthermore, climate change will exacerbate the existing degradation of the natural environment and further diminish natural capital.

The most notable example is coral reefs, which are already in decline and are highly sensitive to climate change. Climate change is causing oceans to rise, warm, and become more acidic; this is contributing to the death of coral reefs, with significant implications for food security and livelihoods. Over 25% of all marine species live in coral reefs, and about 850 million people directly benefit from their economic, social, and cultural services (WWF 2015), so the loss of these reefs will be catastrophic. Another example is agricultural practices that have led to the degradation of soils and made the surrounding landscape much more sensitive to heavy precipitation events and therefore vulnerable to flooding, which in turn causes more soil degradation.

The natural environment will increasingly be unable to sustain healthy national economies

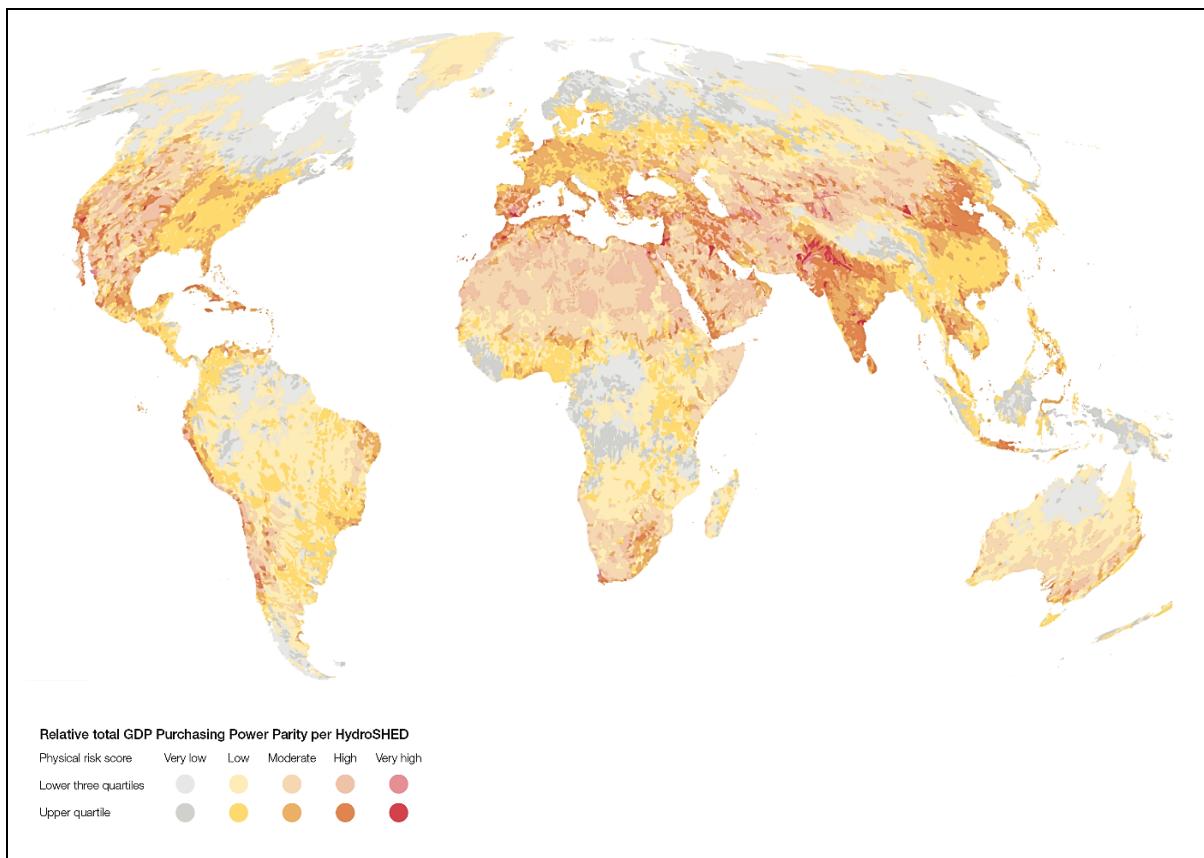
As the UNEP FI and Global Footprint Network (2012, 3) pointed out, “As resource constraints tighten globally, countries that depend, in net terms, on levels of renewable natural resources and services beyond what their own ecosystems can provide may experience profound economic impacts as resources become more unreliable or costly.” Estimations of the loss in value of ecosystem services vary, but they all indicate a significant decline, which climate change will exacerbate. Costanza et al. (2014) calculated the global loss of ecosystem services during the period 1997 to 2011 due to land use change at US\$4.3 to US\$20.2 trillion per year.¹¹ A recent analysis by the Global Futures initiative warned that continued erosion of natural capital at the current levels will lead to deterioration of the annual global GDP of 0.67% by 2050, equivalent to US\$479 billion, and total losses of US\$9.87 trillion between 2011 and 2050 (Roxburgh et al. 2020).¹²

Deteriorating natural capital means that the natural environment will be less able to support economic prosperity and stability without major efforts at every level. There are already examples of deteriorating natural capital and climate change affecting the economy.

An increasingly important area for concern is fresh water scarcity, which already exists in many places and will increase due to climate change. A recent report found that 19% of the global GDP derives from areas with high to very high water risk (Figure 6) (WWF and Investec Asset Management 2019). The effects of freshwater scarcity are already apparent. In 2018, the CDP (2018) reported corporate losses of US\$38.5 billion due to water risks. Examples of material financial risks relating to fresh water scarcity are higher price volatility of agricultural ingredients, reduced agricultural production, higher transport costs, greater inconsistency in supply chains, and stranded assets due to shifting production zones (Ceres 2018). It is an issue that affects every country. In 2018, a drought in Europe, with a link to climate change, caused the river Rhine in Germany to fall so low that freighters could not transport goods and materials, denting the GDP. Fresh water scarcity is an issue that reaches all aspects of the economy. Electricity generation can depend significantly on fresh water and is vulnerable to droughts, particularly electricity from hydropower and coal power. In 2018, disclosures demonstrated that water risks caused US\$9.6 billion in financial impacts on the power generation industry, often as a result of increased operating costs, compliance costs, and impacts on assets (CDP 2018).

¹¹ The differences in valuations are dependent on the unit values used.

¹² The authors of this study consider these estimates to be highly conservative and not suitable as an assessment of the total costs of nature’s loss. This is because the model only considers six ecosystem services (those for which there is enough evidence to quantify). It also does not account for tipping points—thresholds beyond which habitats change rapidly and irreversibly. The expectation is that future versions of the model will address these problems and further strengthen the economic case for halting and reversing the deterioration in natural capital. The model also does not capture climate change and water scarcity and other related environmental changes that are taking place.

Figure 6: Relative total GDP purchasing power parity per HydroSHEDS

Source: WWF and Investec Asset Management (2019).

Deteriorating natural capital also increases disaster risk, which undermines economic prosperity and stability (Monty, Murti, and Furuta 2016). The flooding event that occurred in Thailand in 2011 was so significant that it had repercussions for the entire global economy. The United Nations Office for Disaster Risk Reduction (UNDRR) estimated that the flood reduced the world's industrial production by 2.5% (Haraguchi and Lall 2015). The increased costs associated with disaster recovery and rehabilitation mean that fewer resources can be devoted to other activities. According to the UNDRR (2015), disasters worldwide caused more than US\$1.3 trillion in damage from 2005 to 2015, a significant proportion of which was uninsured.

Deterioration of natural capital will increasingly impact on sovereign risk

Deteriorating natural capital will inevitably become an increasingly core concern for financial regulators as deterioration continues and climate change impacts increasingly worsen in line with rising greenhouse gas emissions. Understanding the deterioration of natural capital and the environmental and climate risks that it poses to economies is the key to profiling economic prospects and the ability to repay debt at the national level. This has not been lost on sovereign debt investors and ratings agencies, which are increasingly gauging how a country is using its natural capital (WWF and Investec Asset Management 2019).

Unfortunately, there has been limited analysis of the impact of deteriorating natural capital on sovereign debt and risk. There are several reasons for this, most notably the inability of traditional measures of economic activity, such as GDP, to capture the goods and services that the natural environment provides (WWF and Investec Asset Management 2019). Additionally, until recently, it has been difficult to map economic activity as well as the intensity of that activity spatially and to contrast it with the existing or projected deterioration in natural capital. New advancements in

geospatial data and tools are helping to resolve this issue, particularly in relation to the way in which sub-national vulnerability can influence national-level vulnerability (WWF and Investec Asset Management 2019). However, analysis will continue to face the challenge of assessing the possibility that depletion of natural capital in one geographic area may have a significant economic and credit impact in other areas, including geographically distant ones.

One of the few studies that has specifically assessed the link between natural capital and sovereign risk highlighted a stark choice for sovereign bond issuers: actively protecting and enhancing natural capital and reinforcing the environmental fundamentals of sovereign bonds or instead continuing with business as usual, which undermines flows of ecosystem services, increases vulnerability to natural hazards, and intensifies market risk (Pinzón et al. 2020).

Disclosure of nature-related financial risks is required as part of efforts to stabilize economies and protect long-term growth

Currently, the need for climate-related financial disclosures is receiving a considerable amount of attention. This is due to the belief that a strong disclosure regime will increase market efficiency, improve transparency and the accurate pricing of risk, support economic resilience, help to attract capital, and maintain confidence in capital markets. There is also a belief that disclosures will enable investors to assess climate change impacts and support them in understanding how climate-related issues might affect future financial performance.

Deteriorating natural capital poses similar risks and has the potential to create systemic challenges to global and economic financial systems as well as societies around the world. Consequently, calls for “nature-related financial disclosures,” similar to climate-related financial disclosures, have recently gained much traction (see WWF and AXA 2019), leading to the establishment of a Task Force on Nature-Related Financial Disclosures in July 2020. Nature-related financial disclosures would improve the understanding and monitoring of the impact of economic activities on nature, ascertain the amount of impact before the resilience of ecological systems deteriorates, and ensure the integrity of the ecological systems that provide the foundation of global economic activity (WWF and AXA 2019).

3.2 Fiscal impacts of climate-related disasters

Government finances and countries’ debt sustainability face exposure to different fiscal risks related to climate disasters. There has been a clear upward trend in the number and severity of climate-related hazards. Climate scientists have predicted an increase in extreme weather events. Although the quantification of climate-related fiscal risks is challenging, it is safe to say that the fiscal risks related to climate change are bound to increase.

The IMF classified fiscal risk into two categories: macroeconomic risks and specific fiscal risks, which may “arise from the realization of contingent liabilities or other uncertain events, such as a natural disaster, the bailout of a troubled public corporation or subnational government by the central government, or the collapse of a bank” (IMF 2018, 95). The IMF’s (2011, 47) *Public Sector Debt Statistics* guide defined contingent liabilities as “obligations that do not arise unless a particular, discrete event(s) occurs in the future.” Whether such an event will happen, whether an obligation will arise, and its potential size, are uncertain. Explicit contingent liabilities include public guarantees and other legal or contractual liabilities. Law and contracts do not establish implicit contingent liabilities, but they may arise because of public expectations or a necessity for the government to intervene. Implicit contingent liabilities may result from fiscal problems at the sub-national level, the bailout of public or private corporations or financial institutions, or spending on natural disaster relief (IMF 2011, 2018).

Table 4 provides an overview of the different fiscal risks stemming from climate-related disasters, following the IMF’s classification of macroeconomic risks and contingent liabilities, respectively. Macroeconomic risks related to natural disasters and extreme weather include risks of a disruption of

economic activity, which may adversely affect tax income and other public revenues and increase social transfer payments (e.g. Schuler et al. 2019); changes to commodity prices that could affect revenue or increase spending via fossil fuel or food subsidies; effects on inflation and interest rates through supply or demand shocks; and exchange rate effects (e.g. Farhi and Gabaix 2016).

Table 4: Climate-related fiscal risk factors and illustrative climate change channels

Risk factor	Climate change channels
<i>Macroeconomic risks</i>	
Economic growth (GDP or industry-level growth)	Drought, excessive rainfall, storms, etc. cause shocks to economic growth by disrupting agriculture, fishing, mining, tourism, transport, hydro-power, insurance, etc., and affect revenue and spending Reduced income tax revenue if climate hazards affect workers' health and productivity, employment, and output Payouts for unemployment insurance and other social protection schemes differ from the planned level Extreme weather events in other countries can potentially boost the demand for exports or affect commodity prices
Trade	Changes and disruptions to trade affect customs duty collection
Commodity prices	The increased severity and likelihood of extreme weather events in large producers increase the volatility of world commodity prices For extractives exporters: the government revenue differs from the expected level Changes in agricultural prices may affect domestic farm and food subsidy spending
Interest rates	Shortages in food or energy supply, among others, may cause inflation spikes
Exchange rates	A disaster may cause devaluation of the currency and increase external debt service costs Government procurement spending on imports differs from expectations
<i>Contingent liabilities</i>	
Physical damage of public assets	Destruction of government buildings or damage to public infrastructure through climate-related disasters Unexpected spending on the repair and reconstruction of government buildings and other public assets Unexpected relief and recovery spending; possible spending to cover private sector losses (including, for example, government-run fire, flooding, and crop insurance)
State-owned enterprises (SOEs)	SOEs suffer losses due to damage or lost revenue resulting from operation disruptions from extreme weather events; increased costs for carbon-intensive operations Sovereign loan guarantees are called Expectation that the government will cover SOE losses
Public–private partnerships (PPPs)	Infrastructure PPPs suffer damage or losses from extreme weather events Contractual obligations (for example, service-level guarantees) Expectation that the government will cover losses if the project fails
Humanitarian crisis and public health emergency	Changing climate and increased severity and likelihood of extreme weather events may affect the spread of vector-borne diseases, deaths from heat events, etc. Increased health spending Emergency relief and aid social safety net
Judicial awards	Courts may determine that governments are liable for climate adaptation measures

Source: Compiled by authors, in part drawing from Schuler et al. (2019, Table 4.1).

There are several explicit and implicit contingent liabilities that expose governments to fiscal risks (Mitchell, Mechler, and Peters 2014; Hochrainer-Stigler 2018; Schuler et al. 2019). Natural disasters may damage or destroy physical government assets and public infrastructure. Governments may hence have to spend on damage repair or reconstruction. Natural disasters may also affect the assets or operations of state-owned enterprises (SOEs). This could diminish the asset value of SOEs or affect dividend payments to the government. Governments may also have to realize contingent liabilities and step in to bail out SOEs that a disaster has hit hard. Disasters may damage or destroy private

property and require government support for households and corporations to rebuild homes and businesses. To the extent that disasters cause instability to the financial sector, they may force governments to bail out ailing financial institutions (cf. Section 3.5). Last but not least, disasters can cause a severe humanitarian crisis, which may require public emergency measures, including rescue missions, temporary relocation of people, provision of food and shelter, or medical treatment. Such crisis response measures can be very expensive and have a significant impact on public spending. Bova et al.'s (2019) analysis of contingent liability realizations in a sample of 80 advanced and emerging economies for the period 1990–2014 showed that natural disasters (including geophysical events) are one of the most important sources of contingent liabilities, the realization of which can be a substantial source of fiscal distress.

Table 5 provides an overview of the 20 most damaging natural disasters, relative to the afflicted countries' GDP, in the period 1998–2019. By far the most damaging disaster was Hurricane Maria, in 2017, which caused estimated damage equaling 260% of Dominica's GDP. In 2004, Hurricane Ivan destroyed around 150% of Grenada's GDP. Historically, climate-related disasters have inflicted the most damage on small, disaster-prone countries (Cantelmo, Melina, and Papageorgiou 2019). Small disaster-prone states also display higher volatility of tax revenue (Cabezon et al. 2015). It is therefore not surprising that disaster-prone economies face significantly higher public debt than economies that are less susceptible to disasters (Cabezon et al. 2015; Munevar 2018) and that natural disasters have in the past been contributing factors to sovereign debt defaults (Moody's 2016a, 2020b).¹³

Table 5: The 20 most damaging natural disasters, 1998–2019

Country	Year	Type	Name	Damage (% of GDP)	Disaster-prone country	Small economy
Dominica	2017	Storm	Hurricane Maria	260.0	Yes	Yes*
Grenada	2004	Storm	Hurricane Ivan	148.0	Yes	Yes*
Dominica	2015	Storm	Tropical Storm Erika	90.2	Yes	Yes*
Honduras	1998	Storm	Hurricane Mitch	72.9	No	No
The Bahamas	2019	Storm	Hurricane Dorian	66.0	Yes	Yes*
Guyana	2005	Flood	N.A.	35.5	No	Yes*
Belize	2000	Storm	Hurricane Keith	33.4	Yes	Yes*
Tonga	2001	Storm	Tropical Cyclone Waka	29.0	Yes	Yes*
Belize	2001	Storm	Hurricane Iris	28.7	Yes	Yes*
Haiti	2016	Storm	Hurricane Matthew	25.1	Yes	Yes**
Nicaragua	1998	Storm	Hurricane Mitch	21.3	No	No
Samoa	2012	Storm	Cyclone Evan	16.6	Yes	Yes*
Tajikistan	2008	Ex. temp.	N.A.	16.3	Yes	Yes**
Mozambique	2019	Storm	Tropical Cyclone Idai	16.0	Yes	Yes**
Fiji	2016	Storm	Tropical Storm Winston	12.9	Yes	Yes*
Myanmar	2008	Storm	Cyclone Nargis	12.6	No	No
Guyana	2006	Flood	N.A.	11.6	No	Yes*
Thailand	2011	Flood	N.A.	10.9	No	No

Notes: The computation for damage (% of GDP) uses data for each single event. Small economies comprise small states and low-income countries. * denotes small states, which are countries with a population below 1.5 million that are not advanced economies or high-income oil-exporting countries (IMF). ** denotes low-income countries, which are countries with a GNI per capita below \$995 in 2018.

Source: Compiled by authors using data from the Emergency Events Database (EM-DAT) and the World Bank's World Development Indicators (WDI) database and from Cantelmo, Melina, and Papageorgiou (2019).

¹³ Hurricane Ivan, which caused damage of more than 200% of its GDP, prompted Grenada's sovereign debt restructuring during the period 2004–2006 (Moody's 2016a; Asonuma et al. 2018). The Dominican Republic's sovereign debt restructuring in 2005 was also partly due to damage caused by hurricanes in the two preceding years (Moody's 2016).

The economic and fiscal losses resulting from a disaster depend on the intensity of the disaster, the vulnerability of the population and key industries, the physical resilience of the infrastructure and buildings, the quality of the crisis response, and the speed of recovery. The amount of the costs borne by governments themselves after natural disasters will vary based on how much infrastructure they choose to or are able to rebuild or repair and based on how international financial institutions support rebuilding efforts. The fallout also depends on the extent to which insurance covers assets and economic activities. The empirical evidence suggests that the uninsured part of catastrophe-related losses drives the macroeconomic costs (Von Peter, von Dahlen, and Saxena 2012; Cebotari and Yousseff 2020), while insurance boosts financial resilience and supports the speed of recovery (Tesselaar, Wouter Botzen, and Aerts 2020). A major problem, however, is that many risks are not insurable or are insurable only at premiums that are unaffordable (IFRC 2018).

Melecky and Raddatz (2011) examined the effects of geological, climatic, and other natural disasters on public expenditures and revenues in 81 middle-income and high-income countries over the period 1975–2008 and found that government expenditure increased on average by 15% while government revenue fell by 10% over the five years following a natural disaster. They also found that countries with low insurance penetration experience greater expansion of fiscal deficits (by 15%) whereas government deficit remains unchanged in those with high insurance penetration. Using synthetic control analysis, Koetsier's (2017) investigation of the impact of natural disasters in 163 countries for the period 1971 to 2014 revealed a significant surge in government debt following the most damaging and deadliest disasters. On average, public debt rises by 11.3% of the GDP in comparison with a synthetic control group, with a median effect of 6.8% of GDP. Some natural disasters cause an increase in the debt-to-GDP ratio of over 20%.

Overall, it is clear that climate-related natural disasters pose a significant risk to sovereign debt sustainability through both macroeconomic and contingent liability risks. Despite the complexities involved in modeling these risks, it is crucial for fiscal sustainability analysis to incorporate climate disaster scenario analysis. Risk projections of disaster losses and their fiscal implications need to include changes to exposure and vulnerability under different climate pathways (Bouwer 2011). Schuler et al. (2019) provided an example of fiscal sustainability analysis that aimed to quantify the range and likelihood of potential fiscal consequences of alternative natural disaster scenarios. This analysis included the simulation of stochastic shocks to important macroeconomic variables and projections of public finance variables and the way in which shocks may affect them.

Of course, it will also be important to mitigate fiscal risk through adaptation policies. Bouwer et al. (2007) emphasized that disaster risk reduction ought to be at the center of climate adaptation policies and put forward three recommendations: (i) improve data collection for a better evaluation of disaster policies, the identification of the factors driving loss trends, and the development of early warning systems; (ii) expand the role of disaster risk reduction in adaptation; and (iii) develop and apply innovative finance mechanisms including insurance and risk transfer instruments.

3.3 Fiscal consequences of adaptation and mitigation policies

Adaptation and mitigation policies are indispensable for responding to the challenges that climate change poses. To achieve the Paris climate goals and limit global warming to manageable levels, large investments are needed in a low-carbon transformation of infrastructure and energy systems. Moreover, economies need to invest in resilience to address vulnerabilities from extreme weather events and the effects of gradual global warming. The Global Commission on the Economy and Climate (2016) estimated that globally, until 2030, it will be necessary to spend around USD90 trillion on infrastructure, including energy, all of which needs to be sustainable and climate resilient. While the private sector has to finance parts of these investments, governments will have to play an important role in setting the right incentives through climate policies such as carbon prices/taxes,

border adjustments, and prudential frameworks for financial institutions. Moreover, the public sector will have to finance a considerable share of adaptation and mitigation measures directly.¹⁴

3.3.1 Fiscal implications of adaptation policies

Public adaptation to climate change affects public budgets directly on the expenditure side (e.g. Bachner, Bednar-Friedl, and Knittel 2019). Adaptation costs comprise all the expenses associated with policies and measures aimed at easing the environmental, social, and economic impacts of climate change, both preventive and remedial (Forni, Catalano, and Pezzolla 2019). The Global Commission on Adaptation (2019) emphasized the need to invest strategically to reduce exposure and vulnerability, prepare for climate impacts, and develop schemes that help recovery (Table 6).

Table 6: Basic elements of climate change adaptation

Reduce (and prevent)	Prepare (and respond)	Restore (and recover)
<ul style="list-style-type: none"> • Agriculture research and development • Climate-proofing buildings and infrastructure • Land use planning • Nature-based solutions to protect people and assets • Permanent relocation (migration) 	<ul style="list-style-type: none"> • Early warning systems • Forecast-based action (contingency planning) • Strengthen first responders • Temporary evacuation 	<ul style="list-style-type: none"> • Insurance and risk finance instruments • Social safety nets • Recovery services, including health and education • Build back better

Source: Replicated by authors from Global Commission on Adaptation (2019).

The 2016 Adaptation Finance Gap Report estimated the costs of adaptation at between US\$140 billion and US\$300 billion per year by 2030 and between US\$280 billion and US\$500 billion per year by 2050, with potentially higher costs for worse emission pathways (Puig et al. 2016). However, Neufeldt et al. (2018) pointed to the existence of major information gaps and emphasized that particularly the omission of adaptation cost estimates for biodiversity and ecosystem services is likely to increase the overall cost of adaptation further. Adaptation finance in 2016 amounted to only USD22 billion (Oliver et al. 2018). There is general agreement that the current amounts financing adaptation, both public and private, are insufficient (e.g. Micale, Tonkonogy, and Mazza 2018). This is despite the dividends that adaptation investment generates (Tanner et al. 2015).

To scale up adaptation finance (as well as mitigation finance), multilateral development banks (MDBs) have advanced the “billions to trillions” agenda to “unlock, leverage, and catalyze private flows and domestic resources” (African Development Bank et al. 2015, 2). The idea is to use official development assistance, or “blended finance,” to mobilize private capital for investment in sustainable development. Critics of this approach have raised concerns about the financial stability risks associated with “the escorting of international capital by multilateral development agencies into frontier and emerging market settings” (Carroll and Jarvis 2014, 540). A fundamental problem of initiatives aimed at leveraging private investment by “de-risking” is that the risk itself does not disappear but merely shifts to public balance sheets (Mazzucato et al. 2018). This may create new contingent liabilities (cf. Section 3.2).

¹⁴ Some have argued that the private sector should conduct adaptation measures and that the role of the government is limited to setting the right incentives (e.g. Tol 2005; Jones, Keen, and Strand 2013).

In particular, concerns have been raised that issues around the “complexity, accountability and transparency” of blended finance (Mawdsley 2018, 194) and the growing risks of related financial innovation and over-financialization in developing economies (Akyuz 2017) may contribute to debt crises. Financial stability risks may also arise from the fact that both development finance institutions and private financers usually provide finance only in international currency, which leaves borrowers with foreign exchange risk.¹⁵ UNCTAD (2019a, viii) stated critically that “the focus of the development finance agenda on complex – and mostly non-transparent – new financial instruments and on securitized finance, does not bode well for its ability to deliver reliable financing at the required scale to where it is most needed.” UNCTAD’s (2019) estimations for a group of 31 developing countries suggest that public debt-to-GDP ratios would have to rise from 47% to 185% to finance basic investments to meet the SDGs in poverty, nutrition, health, and education if financed through debt (alternatively, countries would have to grow at an average of 11.9% p.a.). Many of these investments have a link to adaptation.

Especially lesser developed economies tend to have a relatively low debt servicing capacity and are vulnerable to the build-up of external debt. Since these are the countries with the greatest needs for adaptation finance, it will be important to develop robust debt management frameworks and limit risk exposure to international debt financing.

3.3.2 Fiscal implications of mitigation policies

Mitigation costs comprise all the expenses associated with policies and efforts aimed at reducing or preventing greenhouse gas emissions to limit global warming (Forni, Catalano, and Pezzolla 2019). Climate change mitigation will require substantial investment in low-carbon sources of energy, which will strain public finances. The IPCC (2018) estimated that USD1.6–3.8 trillion annually will be necessary for investment in energy systems alone to limit global warming to 1.5°C. As discussed in the context of adaptation finance, there is a risk that the necessary investments will overstretch public finances and that opaque and complex financing practices will lead to higher debt burdens than expected.

There are, however, further impacts that mitigation policies, both at home and abroad, may have on public finances. Various “transition drivers” could trigger a (forced) decline of high-carbon industries and cause macroeconomic disruptions (Semieniuk et al. 2020). These may require greater public spending to offset the reduction in private investment and consumption, public support programs for regions particularly affected by the transition, higher budget deficits because automatic stabilizers will lead to higher social spending, or a bailout of dwindling financial institutions that failed to mitigate the transition risk (cf. Section 3.5).

A low-carbon or even zero-carbon transition would inevitably have to involve the phasing out of fossil fuels. This could cause trouble for governments that currently rely to a high degree on revenues from fossil fuels. As can be seen in Table 7, some governments rely heavily on revenues from the extraction of oil, natural gas, and coal resources. These make up 5.6% for G20 countries on average, with France, Germany, Japan, the Republic of Korea, and Turkey earning (almost) no revenue from fossil fuel extraction on the one side and the Russian Federation, where a third of government revenues, and Saudi Arabia, where the government’s entire revenues stem from fossil fuel extraction, on the other side. Clearly, governments that rely on fossil fuel revenue face high transition risks and need to diversify their revenue streams away from fossil fuels (OECD, World Bank, and UN Environment 2018).¹⁶

¹⁵ For a discussion of the shortcomings of blended finance in leveraging private capital, see Attridge and Engen (2019).

¹⁶ Morris, Kaufman, and Doshi (2019) analyzed the risk of fiscal collapse in coal-reliant communities in the US. They emphasized that the coal industry is “an important contributor to local government finances through a complex system of property, severance, sales, and income taxes; royalties and lease bonuses for production on state and federal lands; and intergovernmental transfers” in 26 “coal-mining dependent” US counties.

Table 7: Estimated rents from the extraction of oil, natural gas and coal resources in G20 countries

	Estimated rent (US\$ billion)			Share of GDP (%)			Share of total government revenue (%)		
	2001– 2005	2006– 2010	2011– 2016	2001– 2005	2006– 2010	2011– 2016	2001– 2005	2006– 2010	2011– 2016
G20 (excl. European Union)	483	1,015	1,032	1.6	2.3	1.8	4.8	7.1	5.6
Argentina	6	12	11	3.6	3.6	2.0	16.4	13.3	6.1
Australia	8	25	24	1.6	2.7	1.7	4.6	7.9	4.9
Brazil	11	29	37	1.8	1.8	1.6	5.1	5.0	4.9
Canada	35	46	24	3.8	3.2	1.4	9.4	8.1	3.6
People's Republic of China	51	180	184	2.9	4.1	1.9	18.2	18.3	6.8
France	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
Germany	2	5	3	0.1	0.1	0.1	0.2	0.3	0.2
India	13	37	41	2.2	2.9	2.1	11.9	14.8	10.3
Indonesia	11	27	30	5.0	5.3	3.3	27.1	31.8	22.6
Italy	1.0	2.0	3.0	0.1	0.1	0.1	0.2	0.2	0.3
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mexico	27	50	47	3.5	4.9	3.9	17.6	21.1	16.7
Republic of Korea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russian Federation	82	195	230	16.9	14.5	12.2	44.8	38.6	33.8
Saudi Arabia	91	205	276	38.7	45.2	39.3	101.4	104.6	102.9
South Africa	5	12	9	2.8	4.0	2.5	11.5	14.5	8.8
Turkey	1	2	1	0.2	0.2	0.1	0.5	0.8	0.4
United Kingdom	17	26	19	0.8	1.0	0.7	2.3	2.6	1.9
United States	119	162	94	1.0	1.1	0.5	3.3	3.8	1.8
Rest of World	304	751	857	3.8	5.4	4.9	3.2	15.8	15.8
OPEC (excl. Saudi Arabia)	178	457	531	26.4	26.9	25.1	30.4	78	84.5
World	787	1,766	1,889	2.0	3.0	2.5	4.0	9.0	7.7

G20 = Group of Twenty, OPEC = Organization of the Petroleum Exporting Countries.

Source: Compiled with data from OECD, World Bank, and UN Environment (2018).

The decline of fossil fuel and other carbon-intensive industries may increase public social expenditure to cushion the effects on unemployment. It may also require public investments to support structural change in regions that the low-carbon transition affects badly to create new opportunities for “stranded workers.” For instance, the European Union—where the coal sector and directly linked activities employ 238,000 people—has announced funding plans to ease the socio-economic consequences for coal regions, including a “Just Transition Fund” (Widuto 2019). Importantly, the loss of jobs in carbon-intensive industries may be offset by good structural and industrial policies. Based on empirical evidence from India, Ethiopia, and Mexico, Norton et al. (2020) highlighted the potential of employment-based social assistance to address the “triple challenges of global inequality, climate change and biodiversity loss.”

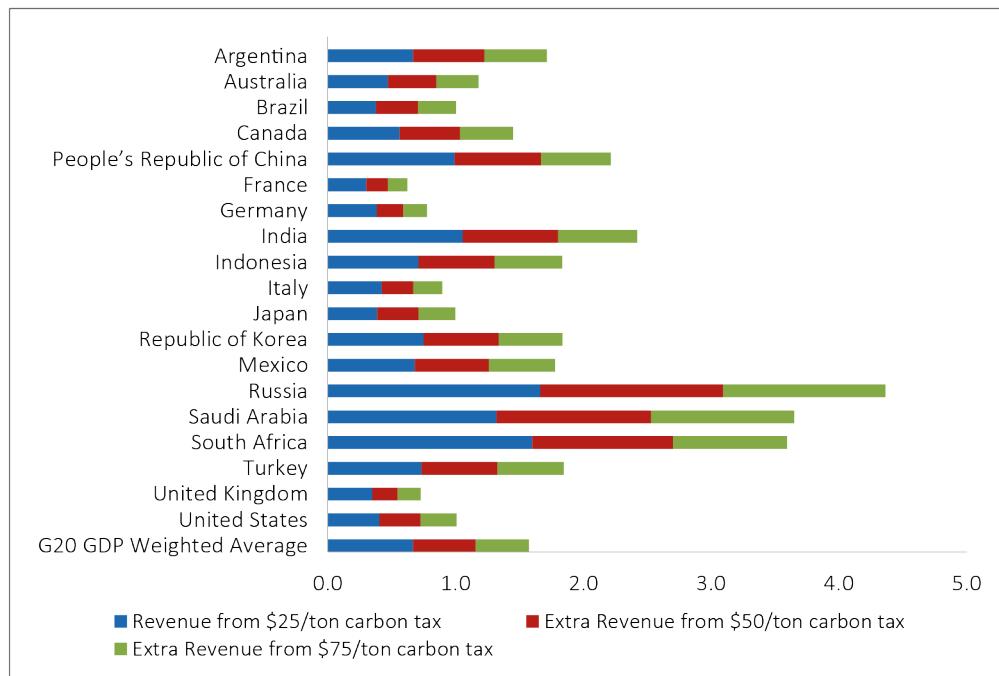
At the same time, a low-carbon transition could generate significant public savings, for instance from phasing out fossil fuel subsidies. The IMF’s estimates put global subsidies for fossil fuel energy at US\$5.2 trillion in 2017, equal to 6.5% of the world GDP (Coady et al. 2019).¹⁷ By promoting greater

¹⁷ Coady et al. (2019, 2) defined fossil fuel subsidies “as fuel consumption times the gap between existing and efficient prices (i.e. prices warranted by supply costs, environmental costs, and revenue considerations).”

fossil fuel consumption, which disproportionately benefits the wealthiest parts of the population (Coady, Flamini, and Sears 2015), fossil fuel subsidies exacerbate air pollution, which has dire consequences for human health (Watts et al. 2019) and public health expenditure.

Moreover, governments could generate substantial revenue from carbon taxes, which they could use for adaptation and mitigation investment or for financing a “just transition.” The IMF (2019a) estimated that a tax of US\$75 per ton of carbon would generate revenue amounting to 1.6% of the GDP for G20 countries on average (weighted by the GDP). As Figure 7 shows, the revenue from carbon taxes would vary considerably across the G20 countries, ranging from 0.6% of GDP in France to 4.4% in the Russian Federation.

Figure 7: Revenue from comprehensive carbon taxation in 2030, selected countries (% of GDP)



Source: Compiled by authors with data from IMF (2019a).

It is impossible to give a wholesale assessment of the fiscal implications of mitigation policies as these will depend very much on the structure of an economy and the specific policies that countries adopt both domestically and internationally. The overall fiscal impact of introducing carbon taxes, phasing out fossil fuel subsidies, and foregoing rents from the extraction of oil, natural gas, and coal resources will differ across countries, as will the costs of structural change. It is apparent, however, that the implications for public finances will be greater in economies centered on carbon-intensive activities and those in which the government relies heavily on revenues from fossil fuel extraction. In addition, as Huxham, Anwar, and Nelson (2019, 11) pointed out, “[w]ell managed and less concentrated risk can facilitate the transition and lower its cost in countries across the world.”

3.4 Macroeconomic impacts of climate change

The physical and transition impacts of climate change can cause aggregate supply and demand shocks. Table 8, which is loosely based on a taxonomy that Batten, Sowerbutts, and Tanaka (2018)

proposed, shows different types of supply- and demand-side shocks that may result from either physical or transition climate impacts. We will discuss them briefly in turn.

3.4.1 Supply shocks

Supply shocks affect an economy's production or productive capacity and, accordingly, their actual or potential output. Climate change may exert an impact on the aggregate supply in various ways (e.g. Cœuré 2018; Batten, Sowerbutts, and Tanaka 2020).

As Section 3.2 discussed, extreme weather events can interrupt production, damage the capital stock and infrastructure, or diminish the output in the agriculture, forestry, and fishing industries. They can also disrupt transport routes and value chains and cause input shortages (see Section 3.6 for a more detailed discussion). Climate disasters may divert resources from innovation to reconstruction and replacement. Importantly, they can cause shocks to local labor markets (e.g. Belasen and Polachek 2009; Kirchberger 2017). With extreme weather events becoming more frequent, some have argued that climate-related supply shocks may be “no longer temporary but close to permanent” (Debelle 2019, 4).

Gradual global warming can also cause supply shocks. Predictions indicate that climate change will have a significant impact on land use through sea-level rise, desertification, and land degradation, among others (IPCC 2019b; Kulp and Strauss 2019), as well as on marine ecosystems (IPCC 2019a). All these can affect the productive capacity in agriculture, forestry, fishing, and other industries that directly rely on ecosystems (cf. Section 3.1). Although macroeconomics has generally viewed land as a production factor of relatively little importance (Hubacek and van den Bergh 2006), climate change may impose new constraints on land use (e.g. Hertel 2018; Froese and Schilling 2019). Climate change could also have substantial effects on the number of hours worked due to extreme heat and on labor productivity (Burke, Hsiang, and Miguel 2015a; Day et al. 2019). Burke, Hsiang, and Miguel’s (2015a) analysis of data on economic production for 166 countries over the period 1960–2010 revealed nonlinear effects of temperature on economic production. They found that economic productivity peaks at around 13°C, with higher temperatures causing productivity to decline. Colder countries hence benefit from global warming up to a certain point, while temperate and hot countries suffer. Building on Burke, Hsiang, and Miguel’s (2015a) analysis with expanded data coverage, the IMF’s (2017) estimates indicate that a 1°C temperature rise from 25°C would reduce growth by 1.2 percentage points for the same year for a median low-income developing economy. Furthermore, alterations in the physical environment could make living conditions in some regions unbearable and cause large-scale migration, which would affect the labor supply. Impacts on productive assets (e.g. loss of production sites through a sea-level rise) could affect capital stock. The need for investment in adaptation may divert resources away from productive investment or spending on new technologies, although adaptation investment could also spur innovation.

Supply-side shocks can also be a result of transition impacts (McKibbin et al. 2017). In particular, climate policies can lead to stranded assets and stranded technology (Bos and Gupta 2019; Semieniuk et al. 2020). There is a risk that structural change of an economy away from high-carbon and toward low-carbon sectors will render parts of the workforce unemployed if the sectors that previously employed them cease. If work skills are not transferable to other industries, this could lead to a problem of “stranded workers” or migration. Climate policies may constrain the use of land or ecosystem services, with impacts on an economy’s output potential. Climate policies could also lead to substantive changes in the energy supply. It is not clear, however, whether decarbonization policies and the development of new renewable energy sources would amount to a negative or a positive supply shock.

Table 8: Macroeconomic impacts of climate change

		Physical impacts		
		From extreme weather events	From gradual global warming	Transition impacts
Demand	Investment	Damage to household and corporate balance sheets causes reduction of investment	Changes to household and corporate balance sheets affect investment	Effects on household and corporate balance sheets Growing demand for responsible investment Public investment push (“green new deal”) “Crowding out” from climate policies
	Consumption	Loss of income and damage to household balance sheets reduce consumption	Effects on household income Wealth effects due to changes in property prices Effects on corporate balance sheets Effects on public finances	“Crowding out” from climate policies Changes of consumption patterns because of a shift in preferences or taxation (e.g. carbon taxes) Shifts in demand from migration or political instability Wealth effects due to share and bond prices Effects on public finances
	Trade	Disruption to import/export flows due to climate disasters	Changes to patterns and volumes of trade	Distortions from asymmetric climate policies Changes to patterns and volumes of trade
	Labor supply	Loss of hours worked due to climate hazards	Loss of hours worked due to extreme heat Labor productivity effects of climate change Migration effects	“Stranded labor” Migration effects
	Natural capital		Loss of arable land, biodiversity loss, water stress	Climate policies may constrain/restrict the use of land or ecosystem services
	Energy, food, and other inputs	Food and other input shortages (e.g. through supply chain disruptions)		Changes to the energy supply through decarbonization policies and new renewable energy sources
Supply	Capital stock	Damage due to extreme weather	Loss of productive assets Diversion of resources from productive investment to adaptation capital	Stranded assets Diversion of resources from productive investment to mitigation capital
	Technology	Diversion of resources from innovation to reconstruction and replacement	Diversion of resources from innovation to adaptation capital	Technology may become stranded Uncertainty about the rate of innovation and adoption of low-carbon technologies

Source: Compiled by authors based on the taxonomy of Batten, Sowerbutts, and Tanaka (2018).

3.4.2 Demand shocks

As Batten, Sowerbutts, and Tanaka (2020) pointed out, climate change impacts can also cause demand-side shocks. Extreme weather events can reduce household income and wealth and therefore private consumption. Furthermore, damage to corporate balance sheets can lead to a reduction of investment. However, after the initial stage of loss, a period of recovery, during which the rebuilding of infrastructure and production sites and the replacement of stocks give a temporary boost to investment and consumption, typically follows natural disasters (IMF 2016). A negative demand shock is more likely to occur when a large share of losses is uninsured (Batten, Sowerbutts, and Tanaka. 2016). Extreme weather events can also affect the international demand for goods and services (cf. Section 3.6).

Furthermore, slow-onset changes to global warming can lead to structural economic changes, which may affect the aggregate demand through effects on household income (e.g. income from farming or fishery), wealth effects (e.g. through changes in property prices), effects on corporate balance sheets, or effects on public finances. Global warming may also exert an impact on investment through effects on household and corporate balance sheets. Last but not least, global warming can influence the patterns and volume of trade, which we will discuss in greater detail in Section 3.6.

Climate policies aimed at advancing the transition to a low-carbon economy, changes in consumer preferences, and technological change can have a significant impact on the domestic and foreign demand as well as investment. A global transition to a low-carbon world economy would imply falling demand for carbon-intensive goods and services, which could contribute to the stranding of assets. Private investment could be affected through effects on household and corporate balance sheets from structural changes to the economy (e.g. the growth or demise of different industries) or a growing demand for sustainable investment. In particular, a stricter climate policy could cause a reduction of investment in high-carbon sectors (Batten, Sowerbutts, and Tanaka 2020). Furthermore, a boost in public investment to finance climate change mitigation ("green new deal") could have impacts on both public and private investment, including the potential crowding out of private investments from climate policies.

3.4.3 Implications for long-run growth and sovereign risk

As Section 3.2 discussed, the economic impacts of extreme weather events can constitute a significant risk for fiscal sustainability, especially for smaller developing economies. Supply and demand shocks from extreme weather events, although short term in nature, can also have lasting impacts on growth (Acevedo 2014; Klomp and Valckx 2014; Botzen, Deschenes, and Sanders 2019) and public finances.

Moreover, the supply- and demand-side effects of gradual global warming and transition impacts, which we discussed above, can cause fundamental and enduring structural changes to the economy. For many countries, climate change will have profound impacts on their long-run productive capacity and potential output. A country's long-term growth potential will inevitably have ramifications for its public finances and debt sustainability.

Models estimating climate change's impacts on economic growth inexorably make a host of assumptions about climatic trends, tipping points, technological innovation, adaptive capacity, and the effects of all these on human well-being and economic activity. Long-term growth projections hence require caution. In particular, quantifications of the long-term economic impact of climate change, and as a corollary the impact on government debt, may underestimate the cumulated impact by not taking into account the non-linear implications of increasingly frequent natural disasters on investment and incomes, given the difficulties to model such implications. Still, they provide a useful indication of growth trends in different climate scenarios. Most projections have suggested that the economic cost of inaction is immense.

Table 9 displays Khan et al.'s (2019) recent projections on losses in GDP per capita by the years 2030, 2050, and 2100 in two different representative concentration pathway (RCP) scenarios, RCP2.6 and RCP8.5. RCPs are the greenhouse gas concentration trajectories that the Intergovernmental Panel on Climate Change (IPCC) uses. The RCP2.6 pathway is a relatively optimistic scenario in which the increase in global warming is limited to 0.01°C per annum, in line with the Paris Agreement. RCP8.5 is commonly referred to as the high-emission or “business-as-usual” scenario. The RCP2.6 scenario projects that sea levels will rise between 29 and 59 centimeters, while the likely range in the RCP8.5 scenario would be between 61 and 110 centimeters, relative to 1986–2005 (Oppenheimer et al. 2019). Khan et al.'s (2019, 7) estimations suggested that “a persistent change in climate conditions has a long-term negative effect on per capita GDP growth.” In particular, the world's real GDP per capita would be 7.22% lower in 2100 under RCP8.5 compared with an output loss of 1.7% under RCP2.6. According to these estimates, GDP per capita would decline in all countries, both rich and poor, cold and hot, in the business-as-usual scenario, although the estimated effects would differ by country.

Table 9: Percentage loss in GDP per capita by 2030, 2050, and 2100 in the RCP 2.6 and RCP 8.5 scenario

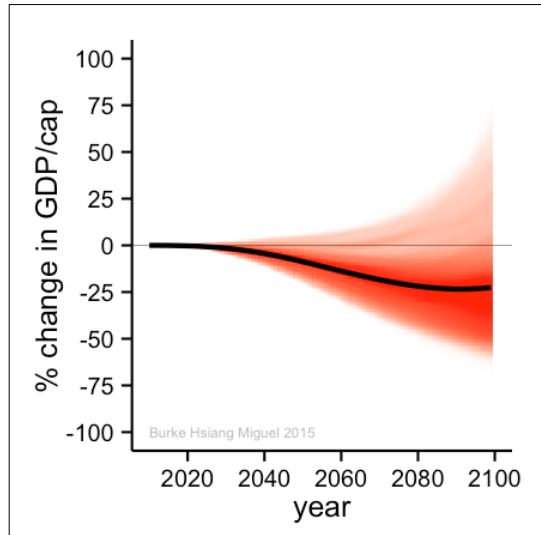
	2030			2050			2100		
	m=20	m=30	m=40	m=20	m=30	m=40	m=20	m=30	m=40
World									
RCP2.6	-0.01	-0.01	-0.02	0.06	0.11	0.16	0.58	1.07	1.57
RCP8.5	0.40	0.80	1.25	1.39	2.51	3.67	4.44	7.22	9.96
People's Republic of China									
RCP2.6	-0.22	-0.45	-0.71	-0.38	-0.80	-1.31	0.24	0.45	0.67
RCP8.5	0.31	0.58	0.87	0.90	1.62	2.30	2.67	4.35	5.93
European Union									
RCP2.6	-0.04	-0.08	-0.13	-0.06	-0.13	-0.22	0.05	0.09	0.13
RCP8.5	0.24	0.50	0.80	0.79	1.53	2.35	2.67	4.66	6.69
India									
RCP2.6	0.12	0.26	0.42	0.41	0.81	1.27	1.44	2.57	3.69
RCP8.5	0.60	1.16	1.78	2.13	3.62	5.08	6.37	9.90	13.39
Russian Federation									
RCP2.6	-0.07	-0.14	-0.23	-0.16	-0.34	-0.56	-0.33	-0.71	-1.19
RCP8.5	0.51	1.03	1.63	1.62	3.08	4.61	5.28	8.93	12.46
United States									
RCP2.6	0.10	0.20	0.33	0.29	0.60	0.96	0.98	1.88	2.84
RCP8.5	0.60	1.20	1.86	2.13	3.77	5.39	6.66	10.52	14.32
Rich countries									
RCP2.6	0.02	0.05	0.09	0.12	0.33	0.37	0.58	1.09	1.62
RCP8.5	0.42	0.84	1.33	1.46	2.67	3.93	4.74	7.76	10.75
Poor countries									
RCP2.6	-0.08	-0.16	-0.25	-0.08	-0.18	-0.32	0.55	0.99	1.43
RCP8.5	0.37	0.72	1.09	1.24	2.18	3.11	3.78	6.05	8.25
Hot countries									
RCP2.6	0.00	0.00	0.01	0.08	0.15	0.23	0.62	1.11	1.60
RCP8.5	0.39	0.76	1.17	1.35	2.37	3.39	4.17	6.65	9.10
Cold countries									
RCP2.6	-0.01	-0.02	-0.03	0.05	0.09	0.14	0.56	1.05	1.57
RCP8.5	0.41	0.81	1.28	1.40	2.56	3.76	4.53	7.40	10.24

Note: The computation of the estimations uses moving averages of temperature and precipitation for the respective countries based on the past m years, with m=30 as the baseline and m=20 and m=40 as robustness checks.

Source: Compiled with data from Khan et al. (2019, Table 7).

Burke, Hsiang, and Miguel's (2015a) projections suggest that, because of global warming, global average incomes will be 23% lower in 2100 in a "business-as-usual" (RCP8.5) emissions scenario compared with a non-climate change scenario (Figure 8). Their estimates also implied that a small number of cooler, rich countries will benefit from global warming while poorer countries with a tropical climate will suffer particularly bad effects.

Figure 8: Economic impact of climate change on the world

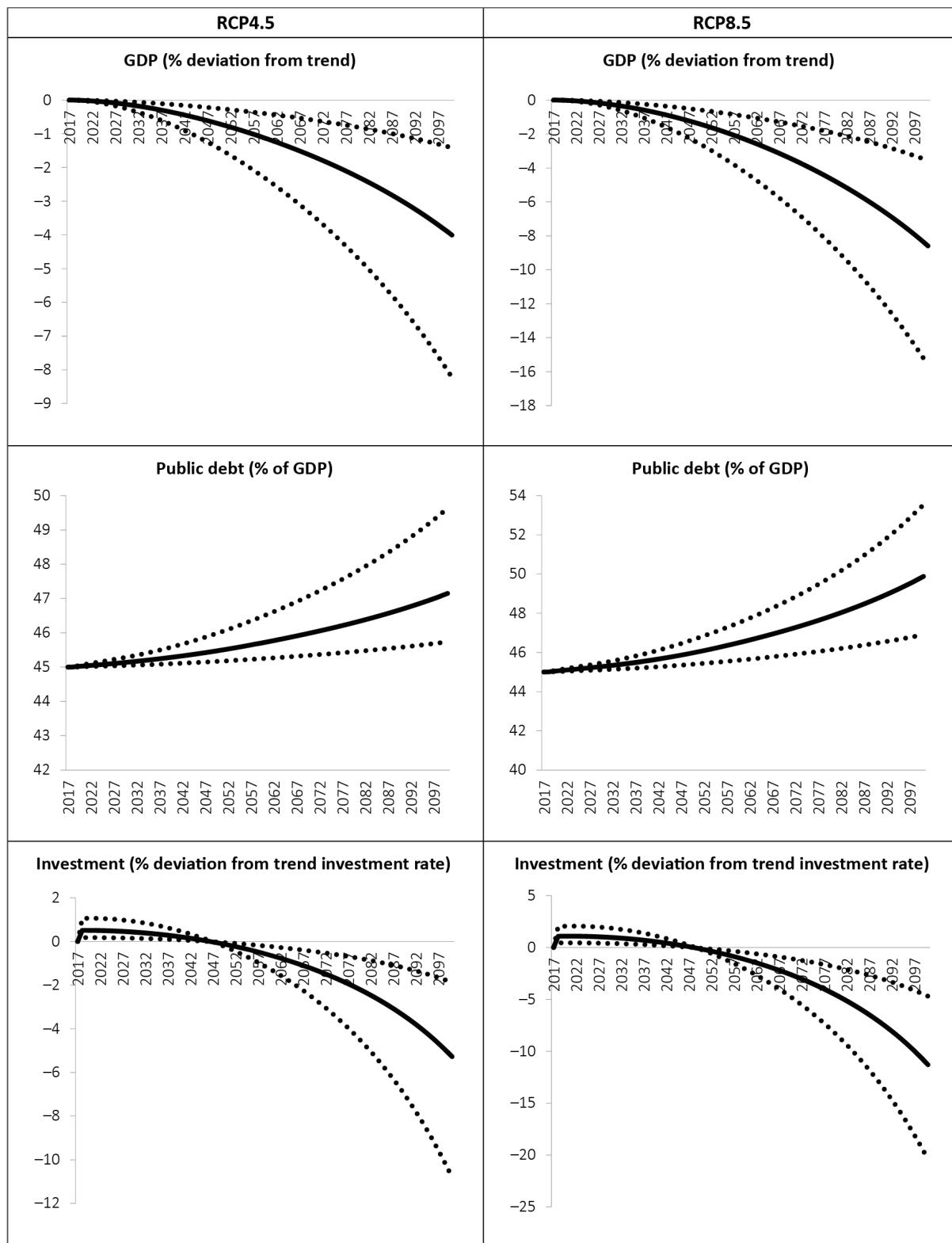


Source: Burke, Hsiang, and Miguel (2015a), <https://web.stanford.edu/~mburke/climate/map.php>.

Using a dynamic general equilibrium model, the IMF (2017) estimated the long-run effects of global warming on GDP and public debt for a representative low-income country. Figure 9 shows the estimates for an RCP4.5 scenario, leading to a temperature of about 2.4°C (left panel), and, for the unmitigated RCP8.5 climate change scenario, leading to a 4.3°C temperature increase by 2100 (right panel). Assuming a static economic structure, in the RCP8.5 scenario, the estimates indicate that the output would decline by about 9% and private investment by 11% by 2100, while the public-debt-to-GDP ratio would increase by 5 percentage points. In the RCP4.5 scenario, the output would only fall by 4% and private investment by 5% by 2100, while the public-debt-to-GDP ratio would increase by 2 percentage points. In terms of net present value, these estimates would correspond to cumulative losses amounting to 100% and 48%, respectively, of the current GDP. However, the IMF emphasized that wide confidence intervals surround their central projections and that there are "sizable downside risks": the output could decline by more than 8% in the RCP4.5 scenario and more than 16% in the RCP8.5 scenario, while public debt could increase by 10% and 20% of GDP, respectively.

Whilst projections have differed, most have suggested that climate change is likely to have significant impacts on growth trajectories, with implications for debt sustainability. It is therefore imperative that national authorities as well as international organizations such as the IMF integrate climate scenario analysis into debt sustainability analysis.

Figure 9: Long-term impact of a temperature increase for a representative low-income developing country



Source: Compiled by authors with data from the IMF (2017).

3.5 Climate-related risks and financial sector stability

3.5.1 Impact of climate risks on the financial sector

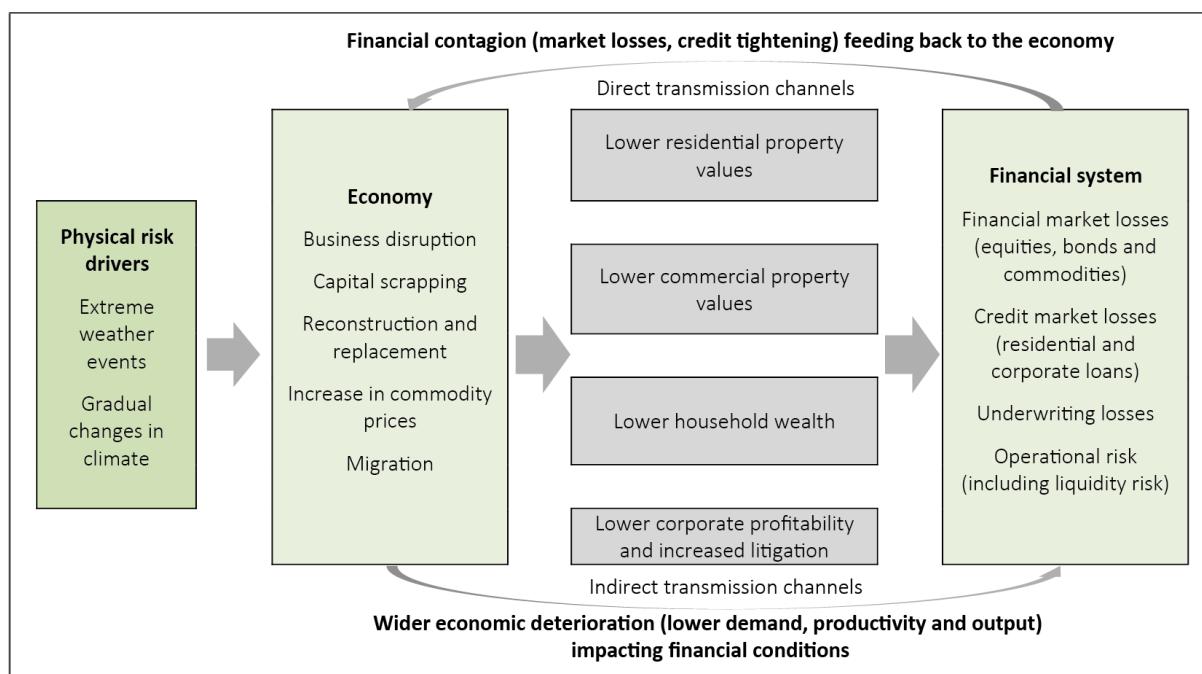
The Central Banks and Supervisors Network for Greening the Financial System (NGFS) highlighted climate change as a key risk affecting the financial system. The NGFS (2019) noted four distinctive characteristics of climate change: (i) a far-reaching impact in breadth and magnitude, (ii) a foreseeable nature, (iii) irreversibility, and (iv) dependency on short-term actions. It is for these reasons that it recommended that central banks and supervisors integrate climate risks into financial stability monitoring and supervision.

Physical climate risks manifesting as credit risks for banks

Acute physical risks, that is, extreme weather events, and chronic physical risks, such as worsening water stress or a sea-level rise, can result in direct damage to operating assets and reduce the production output of borrowers. Raw material shortages in supply chains and disruptions to transport, storage, distribution, or retail capabilities can lead to reductions in output and revenues. Companies may not have adequate insurance coverage for both property and business interruption risk or may find that their premiums rise significantly. Reduced household and corporate expenditure due to the diversion of expenditure toward disaster recovery can also affect the demand for goods and services. Other physical risks, such as heat stress, can reduce labor productivity and increase energy consumption costs due to the need to cool buildings and manufacturing plants.

These pressures can combine to reduce borrowers' operating margins and cash flows and the value of collateral assets, leading to credit downgrades, a higher probability of default, and a reduction in the secondary market value of loans held on bank balance sheets. In more severe situations, borrowers will not be able to meet their debt service obligations, resulting in a higher incidence of non-performing loans (NPL) and a higher loss given default (LGD) due to the reduced value of collateral assets. Figure 10 illustrates the transmission mechanisms from physical risks to financial stability risks for banks, investors, and insurers.

Figure 10: From physical risk to financial stability risks



Source: Replicated by authors from NGFS (2019, Figure 1).

The 2018 UNEP FI banking pilot project on the implementation of the recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD), involving 16 banks assessing physical risks, showed a downgrade in credit rating and a higher probability of default in some cases (UNEP FI and Acclimatize 2018). For example, one bank's agriculture loan portfolio showed an increase of 1.1x–1.5x in the probability of default in a 4°C scenario, with the average portfolio rating deteriorating by one notch. The Toronto Dominion Bank tested 20 borrowers in its North American power and utilities portfolio and found that the majority experienced a one-notch credit downgrade in all three climate scenarios that it employed.

The bankruptcy of Pacific Gas and Electricity (PG&E) company is a dramatic example of how physical climate-related risks can affect banks, investors, and insurers. Its rating downgrade and 2019 bankruptcy filing triggered a default on all its debt (Kirong 2018). The company recently agreed a US\$24.5 billion settlement payable to victims and insurance companies that faced significant claims from businesses and individuals under their insurance coverage for wildfire damage (Gonzales 2019). The company's equipment had ignited catastrophic wildfires, the size and extent of which were significantly magnified by the worsening drought and heat due to climate change, causing severe damage (Union of Concerned Scientists 2018; Borunda 2019). However, this bankruptcy does not seem to have increased the perception of climate risk in the US utilities sector for a variety of reasons, leading to weak market signals to encourage climate risk mitigation (Macwilliams, Lamonaca, and Kobus 2019). In the long run, this may worsen the financial stress that utilities, banks, investors, insurers, state and local governments, rate payers, and tax payers face.

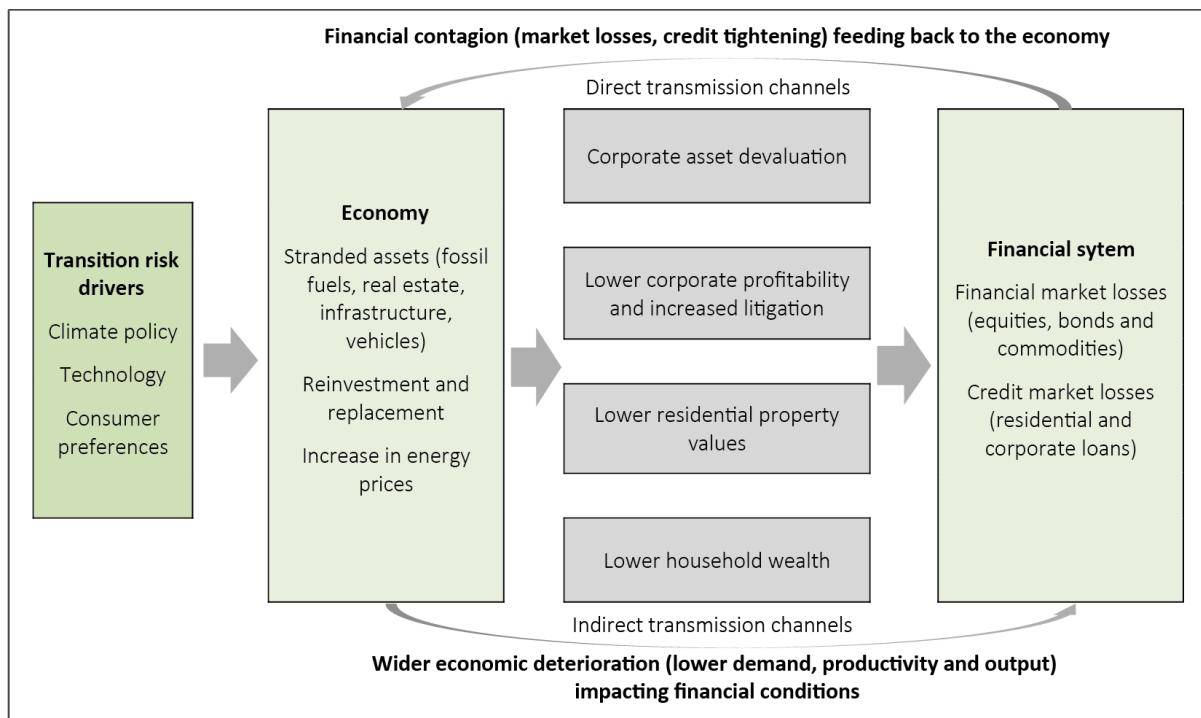
Regarding other chronic physical risks, the International Labour Organization (ILO) has estimated that an increase in heat stress resulting from global warming will cause productivity losses worth US\$2.4 trillion, with the impact being most pronounced in lower-middle- and low-income countries (ILO 2019). The expectation is that the agriculture and construction sectors will be the worst hit, accounting for 60% and 19%, respectively, of working hours lost in 2030, with potential negative consequences for food prices.

Transition climate risks manifesting as credit risks for banks

Climate risks related to policy, technology, and market changes may also have a negative impact on borrowers' credit profile by stranding production assets and/or reducing the demand for their products and services. Manufacturing assets, natural resources, and infrastructure assets, which typically have longer useful lives, are at risk of obsolescence and early closure. For example, the decision of a growing number of governments to phase out internal combustion engines (ICEs) will result in reduced market demand for such cars and lower utilization rates or even early closure of ICE auto manufacturing plants (Climate Centre 2018). The increasing cost competitiveness of renewable energy versus coal-fired power generation is another case in point.

These risks can materialize to reduce the profitability and cash flows of businesses as well as the value of assets that banks hold as collateral. These could result in credit downgrades, higher incidence of NPLs, and more loss given defaults. Figure 11 illustrates the transmission mechanisms from transition risks to financial stability risks for banks, investors, and insurers.

The above-mentioned 2018 UNEP FI-led TCFD pilot project showed more severe impacts from transition risks than from physical risks (UNEP FI and Acclimatize 2018). Barclays Bank tested 35 electric utilities in the EU and US under the 2040 2°C scenario, which showed that the average probability of default of the portfolio was 2.2 times higher in the US and 2.3 times higher in the EU than the baseline. Another bank tested its metals and mining portfolio and found that the probability of default increased by between 1.4 and 2.0 times by 2040.

Figure 11: From transition risk to financial stability risks

Source: Replicated by authors from NGFS (2019, Figure 2).

De Nederlandsche Bank (DNB), the Dutch central bank, performed an energy transition risk stress test for the Dutch financial sector using four scenarios: a policy shock scenario, a technological shock scenario, a confidence shock scenario, and a double shock scenario (policy and technology shocks combined) (DNB 2018). The DNB found that banks had the lowest losses at 1–3% of the total stressed assets, pension funds' losses ranged from 7 to 10%, and insurers' losses ranged from 2 to 11%.

The Bank of England intends to use its 2021 biennial exploratory scenario to assess the risks to the United Kingdom (UK) banking and insurance sectors from climate change (BoE 2019). The intention is to use three scenarios that include both physical and transition risk transmission mechanisms: (i) an early policy action scenario in which countries implement policy changes early and global warming stays below 2°C, (ii) a late policy action scenario in which the delayed policy response is more severe and physical risks manifest more quickly, although the global average temperature rise is still below 2C, and (iii) a no policy action scenario in which the policy risk is low but the global average temperature increases substantially by 2080.

The UK banking sector has considerable exposure to sectors with high climate risk. The loan exposures to fossil fuel producers, energy utilities, and emission-intensive sectors are equivalent to 70% of the largest banks' common equity Tier 1 capital. Around 12% of equity and 8% of corporate bond portfolios of UK insurers face exposure to high-carbon technologies. As such, the potential impact could be significant and the learnings from performing such a stress test will be invaluable for other supervisors with similarly exposed finance sectors.

Banks: Climate risks as liquidity risks due to impact on balance sheet from credit risks and fire sales of assets in financial markets

Unforeseen increases in NPLs and significant write-downs of assets due to abrupt policy changes or physical climate events can lead to sharp downward revisions of profit forecasts for banks. A climate Minsky moment, as the governors of the central banks in England and France (BoE 2019) warned

about, would see fire sales of climate-affected assets that people perceive to be declining in value. The credit and market risks can combine to create a lack of confidence in the financial soundness of counterparties and uncertainty regarding banks' own funding needs. These can lead to the freezing of the interbank lending market or a spike in lending rates. A lack of insight into the level of climate-related risks in loan portfolios is likely to worsen the situation.

A lack of data on banks' and their corporate borrowers' ESG policies and exposure to climate risk may exacerbate any turmoil as counterparties cannot assess and price the true level of risk. This was apparent during the sub-prime crisis due to the complexity of the financial instruments and the lack of transparency (Dodd and Mills 2008). As such, any repricing due to climate risk may be more abrupt and of a greater magnitude due to the fear factor, the complexity of measuring nonlinear climate impacts, and the lack of data.

Investors: Effects on portfolio valuations due to stranding and repricing of assets

In the same way as physical and transition climate risks manifest as credit risks for banks via higher NPLs and LGD arising from deteriorating operating margins, cash flows, and value of assets, climate risks can affect the value of investors' portfolios. The pressure on earnings, asset values, and lower growth forecasts for businesses with less climate-resilient business models that cannot easily rebound from short-term shocks will result in a drop in securities' prices or valuations for non-listed assets. Even if investors do not crystallize the losses through an immediate sale of the affected assets, the mark to market value of their portfolios will receive a negative impact with no certainty of future recovery.

In 2019, 20 institutional investors participated in a pilot study on climate risk scenario analysis to quantify the physical and transition risks in investment portfolios (UNEP FI 2019). The study used a portfolio of 30,000 companies to represent the investable market universe and found that an average level of physical climate risk had a -2.14% impact on value. Transition risk in a 1.5°C scenario had a far stronger negative impact of up to -13.16%. Adding both types of risk but netting off the +10.74% upside from technological opportunities resulted in downside exposure of -4.56% to investment portfolios. The agriculture and utility sectors faced the greatest exposure to policy changes with -82.5% and -50.6% value at risk, respectively.

Insurers/reinsurers: Negative effects on margins due to higher insurance claims

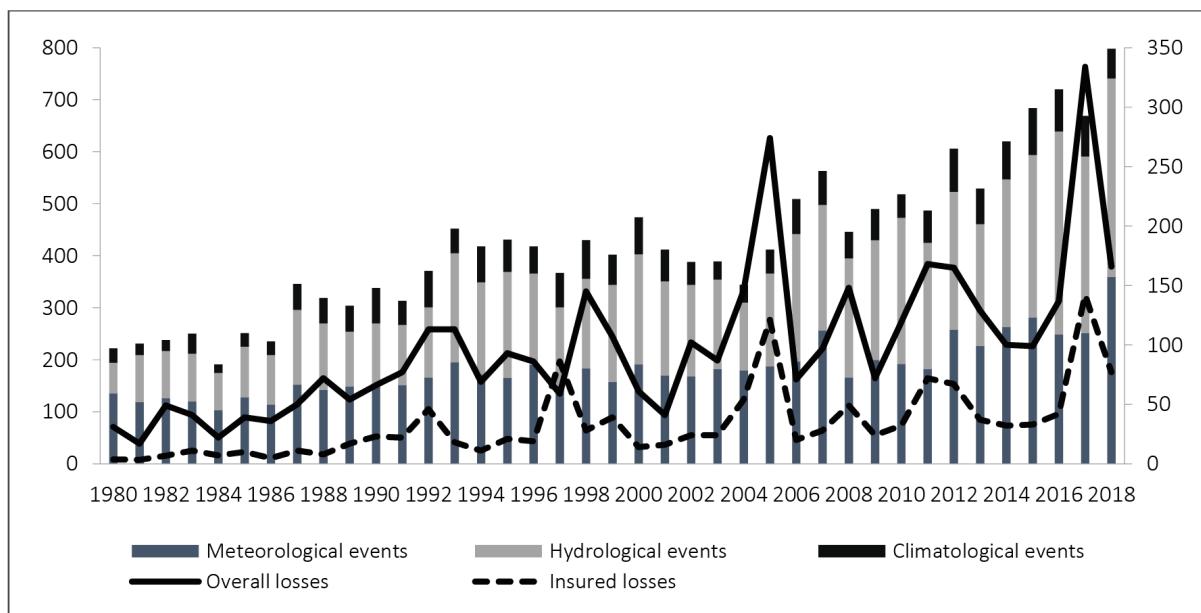
Besides the impact on insurance firms' investment portfolios, there will be an effect on the underwriting business of insurers/reinsurers. Extreme weather events may cause unexpectedly high insurance claims on property, casualty, medical, travel, and business interruption policies, which predictions show will increase in frequency and intensity with climate change and chronic climate-related changes. Transition climate risk can manifest as lower insurance premiums sold if corporate assets become stranded or as higher claims on directors' and officers' liability policies as company boards and management face lawsuits for inadequate management of climate risks (Willis Towers Watson 2019). The higher claim incidence can reduce the profitability of insurance firms and potentially influence their credit ratings. Insurers may respond by either reducing their insurance coverage or increasing their premiums, both of which will have negative impacts on the credit profile of businesses.

The DNB (2017) used climate scenarios of 1.5°C and 3.5°C warming by 2085 to assess the potential impact of flooding damage on the non-life insurance sector. The DNB estimates suggested that climate-related claims' burden from homeowners' insurance policies would increase by 25%–131% in the 3.5°C scenario compared with 10%–52% in the 1.5°C scenario.

Even now, the insurance industry is already experiencing a higher incidence of loss events as well as higher insured losses (Figure 12). The average number of weather-related loss events for the last 10 years up to 2018 was 612 registered events per year, compared with 425 for the period 1980–2018, as recorded by Munich Re's NatCatSERVICE (Munich Re 2020). In 2018, there were

798 registered loss events with US\$166 billion overall losses, of which US\$77 billion were insured losses—the fourth costliest year since 1980 (Löw 2019). The insured loss for 2017 was US\$142 billion, the highest annual figure in the period 1980–2018 and considerably higher than the average of US\$49 billion for the ten years prior to 2017. The 2019–2020 Australian wild fires have already affected the largest domestic insurance companies' performance (Fernyhough 2020; Insurance Australis Group (IAG) 2020), which may have consequences for their future cost of reinsurance and capital and hence their appetite to insure Australian companies.

Figure 12: Number of relevant weather-related loss events worldwide and overall and insured losses in US\$ billion (in 2018 values), 1980–2018



Note: The numbers of events are on the left axis, and losses are on the right axis.

Source: Compiled by authors with data from NatCatSERVICE (Munich Re 2020).

3.5.2 The negative feedback loop between financial sector instability and sovereign risk

Climate risks in banking, credit conditions and growth in the real economy

The banking sector is the primary market for corporate finance. Climate risks that result in liquidity issues for banks will reduce their ability to lend to corporates to fund their operations and growth. A growing level of NPLs and the inability to project climate-related risks accurately will lead banks to tighten their lending criteria. As insurers and reinsurers face higher insured losses due to climate events, the ability of corporates to secure adequate insurance coverage decreases. This will mean lower protection of the value of bank collateral and will further reduce banks' appetite to lend to high-risk companies and sectors. These are precisely the system-level impacts that a growing number of central banks and supervisors, such as the Bank of England, are testing through climate stress tests (BoE 2019).

In addition, if central banks raise the discount rate to counter inflation resulting from supply chain shocks due to climate events, the higher borrowing costs that banks face will pass to borrowers, making credit more expensive for the real economy. A resultant credit crunch would have additional negative consequences for the GDP, employment, exports, and tax revenues from corporates, all of which combine potentially to worsen the sovereign risk profile.

Multiple studies have investigated the impact on the interbank market and the consequent effect on the real economy as firms and households face credit constraints. Altavilla et al. (2019) estimated that interbank rate uncertainty increased the lending rates of euro area banks for loans to non-financial firms by up to a maximum of 100 basis points during the 2007–2009 global financial crisis and the 2010–2012 European sovereign crisis. Ivashina and Scharfstein (2010) estimated that, during the 2008 financial crisis, the US banking sector experienced new loans to large borrowers dropping by 47% during the peak period relative to the prior quarter and by 79% relative to the peak of the credit boom. The reduction in lending was due to the combined effect of a run by short-term bank creditors and a run by borrowers that drew down credit lines in anticipation of liquidity issues.

The credit squeeze also affects households. Antoniades (2014) used micro-level data on mortgage loan applications to separate out any contraction in the loan demand and found that there would have been a 14% increase in the number of mortgage applications originating during 2007 and 2008 if banks had entered the crisis with levels of exposure to liquidity risk reduced to the lowest quartile.

Estimates have indicated that the economic costs of banking crises occurring across 13 countries between 2007 and 2009 amounted to a median output loss of 25% of GDP (Laeven and Valencia 2010). This demonstrates that the combined direct costs—including impacts on the banking sector's contribution to GDP, tax revenues, and employment—and indirect costs of shocks to the banking sector can have a significant impact on the economic and fiscal health of the country. Research has also shown that banking recessions are deeper and last longer than other recessions, with the recovery of pre-recession output levels requiring one more year in banking recessions (IMF 2015a). This is due to banks' need for rapid deleveraging via restrictions on credit expansion, exacerbating the debt overhang and uncertain macroeconomic outlook arising from credit booms that typically precede banking recessions.

Impact of financial upheavals on governments and state linked pension funds and investment companies

Banks can form a significant component of local stock market capitalization and may have state pension funds or sovereign wealth funds as anchor shareholders. State-owned banks are a case in point, with the asset share of government-owned banks accounting for 18% of banking system assets across 65 developing countries in 2010 (Cull, Soledad Martinez Peria, and Verrier 2017). Significant reductions in their valuations due to climate shocks would result in lower investment income for state pensions as well as lower sovereign fund returns and asset values. The potential pension deficits and lower state investment returns could worsen the budget deficit, resulting in a strain on government debt levels or reserves, which are considerations for sovereign credit ratings.

Impacts of government-funded bank bailouts or the expectation of such, and realization of finance sector-related contingent liabilities on the debt burden and/or sovereign credit ratings

In a more severe crisis resulting from climate shocks, sovereign contingent liabilities, as defined by the Public Sector Debt Statistics Guide (IMF 2011), may crystallize. Liabilities related to the finance sector would include guarantees for non-sovereign borrowing by subnational governments and public and private sector entities (including guarantees for mortgages and student and small business loans), state insurance schemes for commercial bank deposits, minimum returns from private pension funds, bank failures, and investment failures of pension funds (Bova et al. 2016). For example, there may be a need for bank bailouts via asset purchase programs, equity injections, debt guarantees, and/or renationalization, as occurred in the global financial crisis, the European sovereign debt crisis, and the Asian financial crisis.

Both types of liabilities can result in a spike in government debt to GDP ratios, which affects sovereign credit risk. There is also the risk of contagion across borders, which may be stronger in countries with a monetary or fiscal union. Bova et al. (2016) found that, across 80 countries between 1990 and 2014, realizations of contingent liabilities related to the financial sector cost an average of 9.7% of the GDP,

significantly more than other types of liabilities, such as those related to subnational governments (3.7%) or the private non-financial sector (1.7%).

The risk of central banks having to act as “climate rescuers of last resort” in a systemic financial crisis and purchase significant amounts of financial sector assets with impaired value due to physical or transition climate shocks arises as a serious consideration for central banks (Bolton et al. 2020). Using their 13-country sample for recent crises from 2007 to 2009, Laeven and Valencia (2010) found a median increase in public debt of 24% of the GDP over the 3-year period following the start of the crisis. The European Central Bank’s analysis (ECB 2015) showed a similar impact, with the finance sector bailout contributing to an increase of 27 percentage points in general government debt in the euro area between 2008 and 2014.

Acharya, Drechsler, and Schnabl (2014) assessed the change in debt to GDP ratios in 2008–10 for the eurozone countries, Denmark, Great Britain, Norway, Sweden, and Switzerland and found that a 10% increase in financial sector distress prior to the bailouts predicted a 2.4 percentage point increase in the public debt to GDP ratio. Their analysis suggested a significant transfer of financial sector credit risk to sovereign balance sheets as the average pre-bailout period bank and sovereign credit default swap (CDS) spreads of 63 bps and 14 bps increased to 184 bps and 112 bps, respectively, in the post-bailout period. They also found that, during the bailout period, a 10% increase in the sovereign CDS spread led to a 4.5% decrease in the bank CDS spread, further supporting this direction of risk transfer.

Breckenfelder and Schwab’s (2018) analysis of cross-border contagion effects of such bank to sovereign risk transfers concluded that, during the ECB’s comprehensive assessment of the 130 largest banks in the euro area, a 1% decline in bank equity in stressed countries was associated with a 0.33% increase in sovereign CDS in non-stressed countries. Kallestrup, Lando, and Murgoci (2016) modeled the potential for banks’ foreign exposures (public sector, banks, and non-bank private sector) to affect their domestic sovereign risk, finding that a change of 1 basis point in risk-weighted foreign exposure corresponded to an average change of 0.4 basis points in domestic sovereign CDS spreads.

Outside of the EU, the US faced its first ever credit rating downgrade from AAA to AA+ due to concerns about the government’s ability to manage and reduce its medium-term debt (Reuters 2011) arising from bipartisan disagreements over fiscal policy. The debt burden increased due to the bailouts necessary to stabilize the financial system during the sub-prime mortgage crisis.

Sovereign risk ratings as a ceiling on private credit ratings of banks, affecting their costs of lending to the real economy

Credit rating agencies refer to sovereign ratings or country ceilings as a significant determinant of private credit ratings (Moody’s 2019c). As such, any downgrades of sovereign ratings will put pressure on banks’ own ratings. Banks’ own funding costs may increase as a reflection of higher domestic sovereign risk, leading investors to require higher yields as compensation. This effect will be stronger if a bank’s loan assets are largely domestic, have the national government as the borrowing counterparty, or include loans with domestic sovereign guarantees, such as infrastructure-related financing. The implicit sovereign guarantee of a bailout also figures in the equation.

Certain investors, such as pension funds and insurance companies, are also subject to stricter investment restrictions regarding the credit rating profile of issuers, and, in a more severe downgrade, the bank will have reduced access to wholesale funding and public bond markets. This may result in banks’ on-lending to the real economy decreasing or becoming more expensive.

Acharya, Drechsler, and Schnabl (2014) demonstrated the negative feedback loop between the government and the financial sector, whereby a fall in the value of public guarantees that an overburdened sovereign provides exposes the banking sector to its own sovereign risk. For example, they noted that the S&P downgrade of US Treasuries led to downgrades of Fannie Mae and Freddie

Mac and a rise in the CDS rates of US financial institutions. In assessing European sovereigns and banks, they found that, after the bailouts, a 10% increase in the level of sovereign CDS was associated with a 0.9% increase in the level of bank CDS.

Breckenfelder (2018) found that the credit risk of the companies that are most reliant on bank financing was most sensitive to increased sovereign risk. The analysis of 226 firms from 15 European countries showed that a 10% increase in the level of sovereign credit risk resulted in a 1.1% increase in the level of corporate credit risk. This was partly due to tighter lending conditions from an affected domestic financial sector. The sovereign credit risk manifested via two channels, the financial channel and the fiscal channel, through which governments increase taxes and reduce subsidies or guarantees. The fiscal pressures, if significant, will deteriorate the borrower credit profile, creating a secondary negative feedback loop to affect the credit ratings of banks.

Effects of economic or currency crises banks' NPLs and credit ratings

Severe economic downturns can create significant pressure on the financial sector through a widespread impact on borrowers' cash flows. The European Systematic Risk Board (ESRB) (2019) highlighted business cycles and asset price shocks as two of the main drivers behind system-wide increases in NPLs, especially if shocks affect the sectors to which banks are most exposed, such as retail and commercial real estate. The data suggested that most of the eurozone countries that had experienced a system-wide NPL increase had faced a severe recession after the global financial and European sovereign debt crises. Studying a panel of 27 banks from the Baltic region over the period 2005–2014, Kjosevski and Petkovski (2017) estimated that a 1 percentage point increase in unemployment and inflation led to an increase of 1.4 and 0.7 percentage points in NPLs.

Currency crises can have a more devastating effect if the loans are foreign currency denominated whilst borrowers' revenues are local currency denominated or if the borrowers' raw materials and revenues have different currency denominations. Laeven and Valencia (2012) estimated that, of the 147 banking crises that occurred between 1970 and 2011, 16% were preceded by a currency crisis in the same country within 3 years prior to the start of the banking crisis. All of these led to increases in NPLs, which, if severe enough, will require the state to step in to bail out or even close banks. Banks with more geographically diversified businesses may have a lower direct impact from their own sovereign, but this also allows for the contagion effect from other countries that may face higher climate risk-related shocks.

Sovereign risk in bank and non-bank financial institutions' balance sheets

Banks hold government bonds, which are liquid and low risk, as part of their own liquidity management strategy. The IMF (2015a) noted that the home bias in sovereign debt is due to factors such as the preferential treatment of sovereign debt in regulator frameworks, the use of sovereign debt as collateral, the liquidity of sovereign bond markets, and government policies. To the extent that banks hold bonds issued by sovereigns that are impacted by climate risk, the worsening sovereign credit will have a direct impact on the capital base of banks and hence their credit profile and/or their lending appetite. The credit crunch feeds back to the sovereign profile through a dampening of economic growth. Insurance firms and investors may also have large exposures to their domestic sovereign, as Angelini, Grande, and Panetta (2014) noted. They found evidence to suggest that sovereign insolvency risk transmits to all of a country's private institutions and not just to its banks. This would increase the potency of the negative feedback loop as it will affect the wider finance sector.

Farhi and Tirole (2018) described the other feedback loop, the doom loop, as a deadly embrace, which weakens the sovereign balance sheet due to public debt-funded bailouts of banks. This further weakens the credit profile of banks due to their sovereign debt holdings. Governments may also rely on domestic banks as a source of funding during periods of financial crisis, putting additional pressure on them to hold more government bonds. The eventual sovereign default triggers a banking crisis.

Acharya, Drechsler, and Schnabl (2014) found that the average European bank held about one sixth of its risk-weighted assets in sovereign bonds, typically on their banking book rather than their trading book. 69.4% of these bonds were issued by the country in which the bank was headquartered. Hence, banks are directly exposed to home-country sovereign risk via their bond holdings.

Looking beyond Europe, Gennaioli, Martin, and Rossi (2018) conducted a wider study of 20,000 banks in 191 countries and assessed the role of their public bond holdings in 20 sovereign defaults during the period 1998–2012. They found that banks hold on average 9% of their assets (12% for non-OECD) in government bonds and that the worsening sovereign credit directly affects the value of banks' assets. Dell'Ariccia et al. (2018) found even more extensive holdings in their study of 858 banks from 46 countries over the period 1999–2014. They determined that the government debt-holding figure for emerging and developing economies ranged from 15.6% to 20.9% of their total assets, potentially reflecting the less developed private banking and bond markets and the greater role of state-owned banks, among other possible reasons. The IMF (2015a) found that a higher ratio of bank loans to GDP and a larger share of sovereign debt instruments on banks' balance sheets had a significant positive relationship with the probability of sovereign distress conditional on bank stress (bank to sovereign contagion).

There is also evidence of cross-border contagion when banks face exposure to foreign sovereign risk. Alogoskoufis and Langfield (2019) and Steffen, Kirschenmann, and Korte (2017) highlighted the need for regulatory reform to consider cross-border contagion from banks' concentrated exposure to foreign sovereign credit risk.

The pressure or inclination for state-related banks to purchase more domestic sovereign debt was apparent in the eurozone banking crisis. Ongena, Popov, and Van Horen's (2019) analysis of 60 banks in Greece, Ireland, Italy, Portugal, and Spain during the sovereign debt crisis of 2010–2012 found that domestic banks, especially state-owned banks, purchased significantly more domestic sovereign debt in the months when their governments needed to issue new or refinance debt. Altavilla, Pagano, and Simonelli (2017), who investigated 226 banks in the euro area between 2007 and 2015 and found that public, bailed out, and poorly capitalized banks purchased domestic public debt more than other banks, supported this finding. Public banks in the stressed country increased their sovereign debt holdings by 17% more than private banks, in line with the "moral suasion" hypothesis. These purchases coincided with the largest ECB liquidity injections. Becker and Ivashina (2018) reported findings consistent with this hypothesis of financial repression. Dell'Ariccia et al. (2018) affirmed a more general pattern with their finding that exposure to domestic sovereign debt increased disproportionately more in distressed eurozone countries (from 2.5% to 7% of assets) than in non-distressed countries (2.7% to 4%).

Acharya et al.'s (2018) analysis of the impact of sovereign bond holdings on banks' lending behavior found that, during the European sovereign debt crisis, the impairment in banks' value due to exposure to sovereign debt and the risk-shifting behavior of weakly capitalized banks resulted in a 53% reduction in the probability of firms securing new syndicated loans. Lending contraction explained between 44% and 66% of the overall negative real effects on European firms. Gennaioli, Martin, and Rossi (2018) found a similar effect in their study covering 191 countries, estimating that a 1-dollar increase in government bonds was associated with a 0.60-dollar decrease in bank loans during defaults and that the average quantum of bonds held before the default occurred accounted for 90% of the decline.

Central banks' exposure to climate risk and cross-border contagion risk for the financial sector

Central banks are lenders of last resort and hold on average 67% of their assets in government bonds (OMFIF 2019). Hentov et al.'s (2019) assessment of 30 large reserve holders concluded that high-grade sovereign and quasi-sovereign bonds made up 59.9% of the total portfolio of central banks (or 68% of reserves excluding gold and IMF allocations). Central banks will need to understand their

exposures to other countries' sovereign risks arising from climate change if they hold those countries' government bonds.

The ECB initiated its Corporate Sector Purchase Programme as part of a quantitative easing policy to boost growth. As of 21 February 2020, the ECB held EUR194 billion of corporate bonds (ECB 2020). This portfolio also faces exposure to climate transition risk. Nguyen and Merle (2019) found that, for the portfolio to align with a 50% carbon footprint reduction to meet one of the requirements of the Paris-aligned benchmark, the ECB would have to exclude 25 out of the 113 issues in the portfolio.

Some central banks have recently started to incorporate climate and sustainability matters into their portfolio management practices. The Banque de France recently published its first responsible investment report (BdF 2019), which reflected the requirements of Article 173 and the TCFD on climate risk exposure and management. The Banque de France has also committed to aligning its investments to a 2°C trajectory. The Swedish central bank divested bonds issued by the Canadian province of Alberta and the Australian states of Queensland and Western Australia due to these issuers' large negative climate impact (Sveriges Riksbank 2019).

Sovereigns which are under financial stress may tighten fiscal policies, putting pressure on cash flows of banks' borrowers

Sovereigns that are stressed may increase taxes or reduce subsidies, which will have a negative impact on banks via cash flow reductions for themselves as well as their borrowers. Reductions in government guarantees will also weaken the credit risk profile of borrowers, increasing the LGD for banks.

Cuadra, Sanchez, and Sapriza (2010) discussed the tendency of emerging market governments to pursue procyclical fiscal policies whereby public expenditures fall and tax rates rise during recessions and vice versa. Reinhart, Kaminsky, and Vegh (2004) (which Vegh 2015 updated) analyzed 104 countries over the period 1960–2003 and found that over 90% of low-income and middle-low-income countries exhibited a positive amplitude of the fiscal spending cycle compared with 50% for OECD countries. They also found that the inflation tax rate was procyclical for all groups, with low-income countries showing the largest amplitude (3 percentage points) and OECD countries the smallest (0.9 percentage points). They posited that these governments face difficulties in borrowing during times of sovereign stress and that international creditors' requirements for fiscal consolidation (or austerity) in providing rescue packages result in the need to cut spending and raise taxes even during severe recessions. Greece is a recent case study of this.

Breckenfelder (2018) attributed the finding that a 10% increase in the level of sovereign credit risk is associated with a 1.1% increase in the level of corporate credit risk to the financial channel and fiscal channel. Governments under fiscal stress may increase taxes and reduce subsidies or guarantees, causing deterioration of their borrower credit profile and creating a secondary feedback loop to the finance sector.

Clearly, multiple interacting channels create the sovereign–bank nexus. Dell’Ariccia et al. (2018) provided policy reform recommendations that account for the nexus acting as a multiplier and accelerator of vulnerabilities in both sectors. These do not factor in climate risk transmission mechanisms, which add additional layers of complexity due to both the nonlinear dynamics of climate risk and the difficulties of modeling socio-political responses to what is inherently a problem of global common resources.

Banks, as well as investors and insurers, will need to apply climate stress testing to both their sovereign bond assets and their loans, investments, and potential claims to understand how sovereign-related climate risks can affect both their assets and their liabilities. Due to their cross-border loan/claim and sovereign debt exposures, banks and insurers will have to work closely with their supervisors to assess the risk of cross-border contagion. Regional contagion risk creates a

greater need for central banks to work with each other to understand exposures and resilience to climate risks.

3.6 Impacts of climate change on international trade and capital flows

Climate change can have substantial impacts on an economy's trade in goods and services and capital flows with the rest of the world. Both the physical impacts of climate change and the disruptions resulting from the climate policies that trading partners adopt, technological change, or changes to consumption patterns can affect international trade and financial flows. Historically, balance of payments problems have often been at the root of country risk and led to external debt crises (Bouchet, Fishkin, and Goguel 2018). Protracted current account imbalances tend to cause liquidity problems and, if not resolved, solvency problems. We can hence consider the current account balance to be an important indicator of sovereign risk, as discussed in Chapter 2.

A current account deficit is not a problem as such. For instance, a country may be a net borrower internationally and use its external credit to finance productive investment that will enhance its long-term productivity and development so that it can repay international debt without difficulty at a later stage. A current account deficit will be problematic, however, if the underlying cause is a lack of international competitiveness or if the economy in question simply lacks goods and services that it could export to the rest of the world. A country with a large current account deficit is dependent on foreign finance and, to paraphrase Mark Carney, relying on the "kindness of strangers."

3.6.1 Impacts of climate change on international trade

There are several ways in which climate change could affect the patterns and the volume of international trade flows (Wilbanks et al. 2007; WTO and UNEP 2009; Dellink et al. 2017; UNCTAD 2019b). These can have potentially significant effects on countries' balance of payments positions and, ultimately, sovereign risk. Impacts can be grouped in three categories: (i) disruptions to trade from climate-related extreme events and disasters; (ii) long-term effects of global warming on endowments and production; and (iii) transition impacts on international trade.

(i) Disruptions to trade from climate-related extreme events and disasters

Climate-related extreme weather events could cause physical damage and disruptions to critical transport infrastructure and activities and make the industrial supply, transport, and distribution chains more vulnerable. For example, ports or transport routes, including train lines, roads, and waterways, may have to close temporarily due to impacts from extreme weather events.¹⁸ This could cause delays in the shipping and distribution of goods and impede international commerce. An increase in the frequency and intensity of weather events that results in disruptions of supply, transport, and distribution chains may raise transportation costs. This would have a negative impact on trade in general but could cause particular problems for the operation of international production chains, which often rely on in-time delivery of parts and components. The impacts could particularly affect developing economies, the export models and integration into the global economy of which have often relied on participation in international trade-production networks (WTO and UNEP 2009). Indeed, climate change could lead to permanent changes to trade-production networks and transport routes and change a country's access to and opportunities in international trade.

¹⁸ Curtin (2019), for instance, warned of major disruptions to container shipping because of rising sea levels and an increase in the frequency and intensity of storms.

Moreover, climate-related disasters could damage the productive capital stock and physical infrastructure that the export sector relies on, such as utilities' infrastructure. Disasters could also destroy facilities that were producing goods and services for the domestic market that now need to be replaced by imports. Floods, droughts, storms, and other severe weather could also destroy harvests, livestock, or fish production and diminish food exports or increase the demand for food imports. The damage that extreme weather events causes could reduce profitability and make new projects less attractive. Given the growing importance of global value chains and trade-production networks, extreme weather events could also cause significant disruptions to production in countries that are not directly affected by disasters. Empirically, the evidence suggests that natural disasters diminish exports while exerting ambiguous effects on imports.¹⁹

(ii) Long-term effects of global warming on endowments and production

The physical effects of gradual global warming could affect domestic output in various ways through changes in endowments and production, with potential impacts on an economy's export capacity and import needs. For instance, long-term climatic trends may have a significant impact on agricultural output, for example crop yields, with positive or negative impacts on export capacity. Climate change consequences, such as increasing average temperatures, water scarcity, or sea-level rise, may also affect other sectors, including manufacturing. Additionally, climate change could have a significant impact on international tourism, which often relies on natural assets and pleasant and safe climatic environments (Scott, Jones, and McBoyle 2006; Wilbanks et al. 2007; WTO and UNEP 2009). For many developing countries, tourism constitutes an important service export in the balance of payments.

Overall, rising temperatures and other effects of climate change could reshape comparative advantages and thereby change international trade patterns and specialization. The impact is likely to be greater for economies with a comparative advantage that is due to their climatic or geophysical characteristics (WTO and UNEP 2009). It is necessary to note that regions within an economy may experience very different effects, with some gaining and others losing.

The empirical evidence on the historical impact of physical climate change on trade flows is still sketchy. Osberghaus's (2019) recent survey of the empirical literature, covering 21 studies, found that average temperature rises appear to affect export values negatively, particularly those of manufactured and agricultural exports, while imports experience lower impacts. Using a dynamic computable general equilibrium model, Dellink et al. (2017) projected that the economies that climate change affects the most will experience a greater decline in exports than in imports and GDP, while producers in the least-affected economies are likely to experience improvements in their competitive position on both domestic and export markets. Their model predicted that trade in agricultural commodities would experience particularly strong effects. Moreover, Dellink et al. (2017) found that the impacts will be most pronounced in Africa and Asia.

(iii) Transition impacts on international trade

The climate policies that trading partners adopt, technological change, and changes to consumption patterns, either at home or abroad, could have a significant impact on imports or exports. If major economies adopted forceful measures to curb carbon emissions, including decarbonization of their energy and transport systems, this would have significant repercussions for the global demand for fossil fuels and their prices (Holz et al. 2018; Huxham, Anwar, and Nelson 2019). Oil price shocks have led in the past to significant changes in the balance of payments of both oil exporters and oil importers (e.g. Özlake and Pekkurnaz 2010; Cheung, Furceri, and Rusticelli 2013; Allegret 2014). Moreover, oil price shocks can cause significant fiscal disruption (IMF 2015b).

¹⁹ Cf. Gassebner, Keck, and The (2010), Oh and Reuveny (2010), Felbermayr and Gröschl (2013), El Hadri, Mirza, and Rabaud (2019), and Osberghaus (2019).

The pace of technological change will shape the global demand for fossil fuels, especially in the field of renewable energy, climate policy, and other policy trends that affect their demand, including policies to reduce local pollution (Holz et al. 2018). Stringent climate and environmental policies could lead to rapid changes in a country's energy mix, as could a continued fall in the cost of renewable energy generation. Countries that are currently dependent on fossil fuel imports may be able to substitute these with domestic renewable energy. Indeed, fossil fuel importers may benefit from a double dividend from a reduced energy import bill and the ability to spend leftover income in the domestic economy (Mercure et al. 2018). Current fossil fuel importers would also benefit from greater energy security. Fossil fuel exporters, in contrast, would stand to lose a source of revenue. For instance, the European Bank for Reconstruction and Development estimated that Kazakhstan, the exports of which comprise more than 50% fossil fuels, could see its fiscal revenues declining by 40% by 2040 compared with business as usual if the global economy were to transition to a green scenario (EBRD 2018). At the same time, growing investment in renewable energy would create opportunities for countries with endowments of materials (such as nickel, cobalt, lithium, or rare earth elements) that certain renewable energy technologies or electrical vehicles require as well as countries that have an edge in the development and production of these new technologies.

Climate change policies can have implications for competitiveness across sectors but also across countries (Mani 2007). To address concerns about potentially adverse effects on the domestic economy, proposals for border tax adjustment measures initially emerged in the late 1990s (Hoerner 1998), and researchers have discussed them more widely since the mid-2000s (e.g. Hontelez 2007; Mattoo et al. 2009, Werksman, Bradbury, and Weischer 2009). Border tax adjustments are essentially duties that countries with high carbon prices levy on imported manufactured goods from countries without or with lower carbon prices. There are three main motives for introducing border adjustments (Brandi 2010). First, countries that implement carbon prices may seek to protect their domestic industry from the adverse effects that carbon prices may have on their international competitiveness. The idea is to create a level playing field and make sure that domestic producers do not have a competitive disadvantage compared with producers in places without similar climate policies. Second, related to the first motive, countries may seek to avoid carbon leakage, that is, the relocation of carbon-intensive operations to countries with laxer emission constraints. Third, countries may introduce carbon border adjustments to put pressure on other countries to implement more ambitious climate policies and prevent other countries from free riding on international climate policy.

The discussions around carbon border adjustments have intensified recently, not least in the European Union (EU) with the European Commission's plans for a European Green New Deal (Brandi 2019). As Tooze (2020, 7) stated recently, "[i]f labor costs and migrant workers were the trade policy issues of the 20th century, carbon border taxes are the frontier of trade policy in the 21st." Indeed, carbon border adjustments have become a real possibility in the EU, with a potentially significant impact on the EU's trading partners.²⁰ Major trading partners' climate policies and carbon border adjustments could have substantial impacts on economies with carbon-intensive export sectors.

²⁰ Imported carbon emissions account for a growing share of the EU's consumption-based emissions, with most imported carbon emissions originating from emerging economies, especially the PRC (Simola 2020). In 2018, the French Government put forward a national strategy that seeks to end deforestation resulting from imports of beef, palm oil, soy, cocoa, and wood. The EU–Mercosur Trade Agreement, which the parties reached in July 2019, has not received ratification due to concerns that it contradicts the EU's climate goals.

Overall, there are various ways in which the physical and transition impacts of climate change could affect international trade volumes and patterns. Gains and losses will spread unevenly across countries. Economies with high dependency on carbon-intensive exports and relatively undiversified export sectors are particularly at risk, as are climate-vulnerable economies in geographies with a relatively high average temperature. Commodity-dependent developing countries may be particularly at risk. UNCTAD Secretary-General Mukhisa Kituyi described climate change as an “existential threat to commodity-dependent developing countries” (UN News 2019).²¹

Climate-related supply and demand shocks could have short- or long-term impacts on international prices and the terms of trade as well as on the exchange rate. There is little understanding of these yet. Furthermore, climate-related supply and demand shocks and changes to international trade patterns may have significant impacts on capital flows into and out of the economy.

3.6.2 Impacts of climate change on international capital flows

One of the three main goals of the Paris Agreement is “making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development” (Article 2.1c). Dasgupta et al. (2016, 6) thus argued that the Paris Agreement “provides the seeds for deeper reforms of the global financial system.” Nevertheless, only a few studies have so far investigated how climate change may affect international financial flows.²² Of those that have, almost all have focused on the impact of natural disasters on remittances or foreign aid inflows (Osberghaus 2019). Osberghaus’s (2019) review of 12 studies revealed that most studies have found small increases in remittances and aid inflows after disasters, as we may expect. David (2010) reported that bank lending and equity funding have not helped to offset disaster effects and may even have amplified negative economic outcomes. David therefore cautioned that countries with high vulnerability to natural disasters should consider this in their management of their capital account. Escaleras and Register (2011) found that natural disasters have a negative association with foreign direct investment inflows.

One dimension that has been explored very sparsely thus far is the potential longer-term impact of climate change on the international financial system and the patterns of international financial flows.²³ If climate change has an impact on trade and current accounts, by implication it will also have impacts on financial flows and capital accounts. Countries in which the current account deteriorates because of climate-related impacts on their economies may turn from current account surplus countries into deficit countries; alternatively, those that previously had a current account deficit may see this worsen, which could in turn enlarge the sovereign risk.

A corollary of major changes to countries’ current account positions is that the private and/or public financial in- and outflows would change. While many small climate-vulnerable countries have never had access to international capital markets, even countries with previous access to international private capital may face permanent exclusion from foreign direct investment, portfolio investment, and debt flows because of climate risk. These countries would then have to rely exclusively on export income, remittances, and international aid transfers.

²¹ According to UNCTAD (2019b), all of the ten most climate-vulnerable countries in 2017 were commodity-dependent developing countries, while only three of the 40 most climate-vulnerable countries were not reliant on commodity exports.

²² A large and growing literature has examined climate finance, that is, international investment flows aimed at climate change mitigation and adaptation in developing countries. For a framing, see, for instance, UNFCCC (2007).

²³ Carnevali et al. (2019) developed an ecological open-economy stock flow-consistent model aimed at exploring the international transmission channels of climate risk.

Importantly, major changes to a country's current account position could have profound impacts on its foreign exchange reserves, which in turn could have direct consequences for its sovereign risk. Moreover, large-scale changes to the foreign exchange reserve holdings of several sizable economies could have substantial implications for the global reserve system. For instance, a drying up of revenue from oil exports would not only have an adverse impact on oil exporters' current account positions. The waning of petrodollar income, much of which has hitherto been invested in financial assets in major international financial centers (Higgins, Klitgaard, and Lerman 2006), could reduce the international demand for financial assets denominated in US dollars or other reserve currencies and affect international interest rates.

Last but not least, the financial market instability that climate risk induces could affect international capital flows, as we discussed in section 3.5. If a major financial center were to experience a financial crisis, say because of the burst of a carbon bubble in its financial system, this may have regional or global repercussions. Likewise, a crisis in a country's domestic financial system, for example triggered through climate-related losses in the banking system, could lead to capital flight, which could then trigger an exchange rate and balance of payments crisis. These may be extreme scenarios, but it will be important to explore them further.

To sum up, the physical and transitional impacts of climate change could affect the volumes and patterns of international trade and finance in several ways. For some countries, this may have a material impact on their balance of payments and hence their sovereign risk. How important these impacts may be for individual countries depends, on the one hand, on the speed at which change impacts are unfolding and, on the other hand, on the capacity of countries to adapt and safeguard or enhance the resilience of their export and financial sectors.

3.7 Impacts of climate change on political stability

Political instability can undermine the ability or willingness of a government to repay its debt. For instance, Clark (1997) emphasized the potential impact of political events on the probability of sovereign default, while Cuadra and Sapirza (2008) maintained that countries that are politically unstable and more polarized have higher default rates and as a result have to pay a higher default risk premium in international credit markets.^{24,25} The economic and social effects of climate change may accentuate the social tensions within a society and fuel political instability. Moreover, climate change leads to large-scale migration movements, which could also lead to political tensions or even inter- and intrastate conflicts. The following sections will briefly discuss in turn the links between climate change and inequality, migration, and conflict.

Inequality

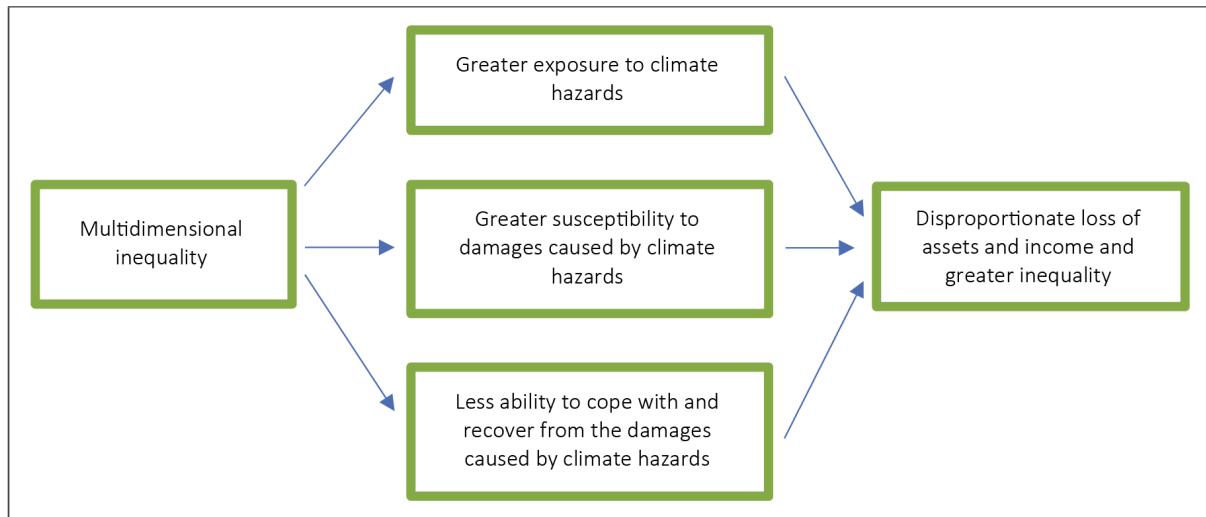
As we discussed earlier, climate change is disproportionately affecting developing countries in warmer climates. Using counterfactual historical temperature trajectories, Diffenbaugh and Burke (2019, 9808) found a "very high likelihood that anthropogenic climate forcing has increased economic inequality between countries." Their results indicated that the ratio of per capita income in the top and bottom deciles is 25% larger because of global warming. Even though between-country inequality has fallen over the last five decades, their findings give a likelihood of about 90% that the reduction was slower because of climate change.

²⁴ See also Balkan (1992).

²⁵ The literature on political risk has mostly focused on election outcomes (e.g. Block and Vaaler 2004; Kirikkaleli and Ozun 2019).

However, global environmental change can also affect inequality within countries and stir social tensions. Islam and Winkel (2017) described the impact of climate change on within-country inequality as a vicious circle, in which the adverse impacts of global warming disproportionately affect disadvantaged groups, which causes inequality to worsen (Figure 13). They pointed to three main channels: (i) greater exposure of disadvantaged groups to climate hazards; (ii) greater susceptibility to climate-related losses and damage; and (iii) a lower ability to cope with and recover from losses and damage, due to a lack of resources.

Figure 13: Effects of inequality of disadvantaged groups



Source: Compiled by authors based on Islam and Winkel (2017, Figure 1).

Migration

Climate-related disasters can lead to migration within and between countries, which may induce political instability. Black et al. (2011, 447) predicted that climate change will “almost certainly alter patterns of human migration” and that environmental factors will become a greater driver of migration. Froese and Schilling (2019) described climate change as a multiplier of risk, which exacerbates existing societal problems and aggravates human security risks, including food and water insecurity. Extreme weather events, such as storms and droughts, can lead to a loss of livelihoods and spur migration. Likewise, rising temperatures and sea-level rises can make entire regions uninhabitable, lead to displacements, and create “climate refugees.”

According to Hauer et al. (2020), a median sea-level rise of 0.79 meter by the year 2100 could permanently inundate about 88 million people—0.79% of the world’s population. Burzyńska et al.’s (2019) projections indicated that climate change will lead to voluntary and forced displacement in the magnitude of 100 to 160 million workers in the 21st century, a figure that would result in 200 to 300 million climate migrants when including dependents.

Migration tends to flow from rural to urban areas and from poorer to more affluent locations (Penning-Rowsell, Sultana, and Thompson 2013). In response to hazard events, people relocate to locations where they are safe and can recover their income. With the socio-economic effects of climate change being greater in countries with higher temperatures, predictions have shown that inter-state migration will occur from low- to high-latitude countries. However, given the legal limits to cross-border migration, around 80% of forcibly displaced people will relocate within their country (Burzyńska et al. 2019). The World Bank has estimated that, by 2050, 143 million people (or 2.8% of the population) in Sub-Saharan Africa, South Asia, and Latin America could have to relocate within their countries away from “less viable areas with lower water availability and crop productivity and from areas affected by rising sea level and storm surges” to “escape the slow-onset impacts of climate change” (Kumari Rigaud 2018, xix).

Climate and conflict

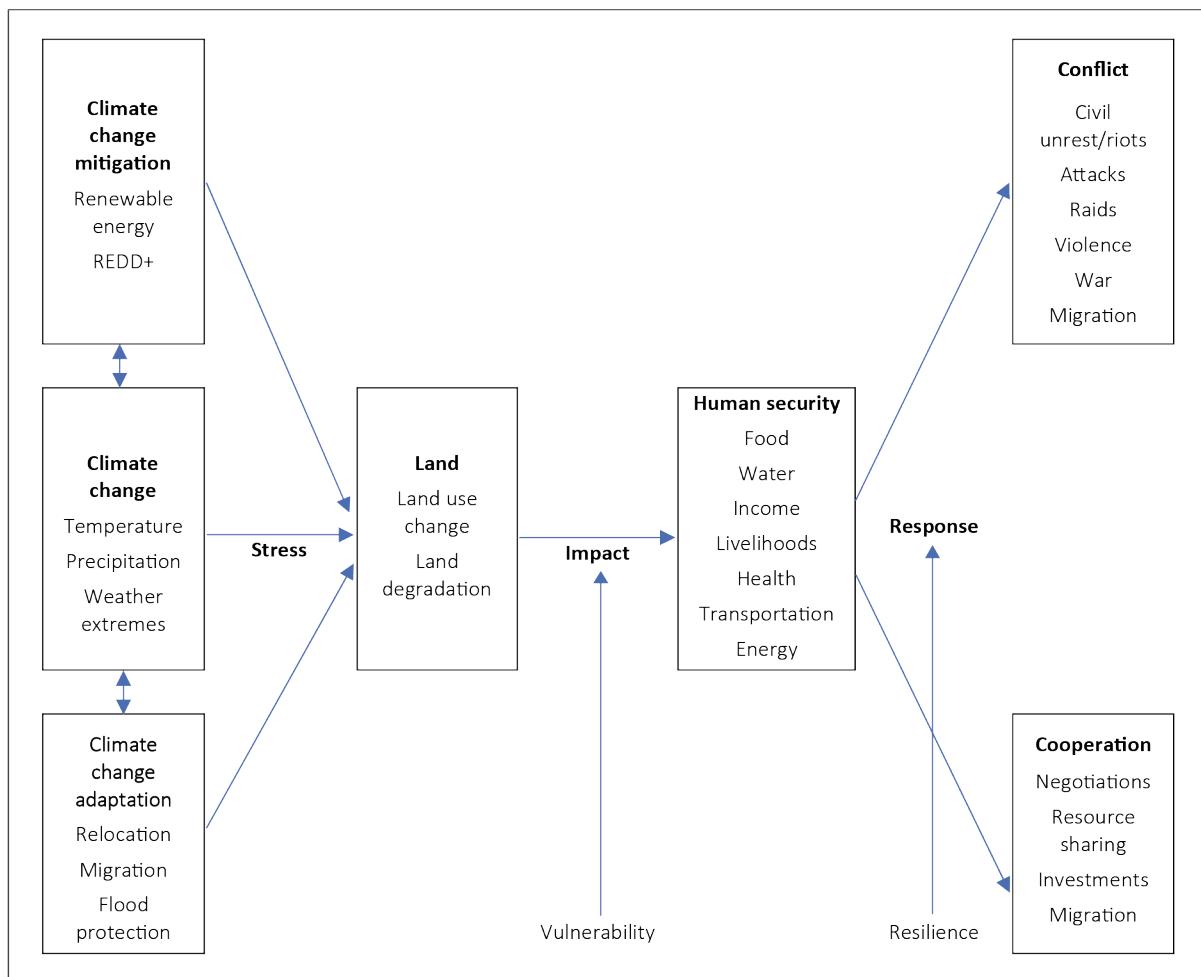
Conflicts are hardly ever monocausal, but research has emphasized climate change as an additional driver that can trigger new or intensify existing conflicts (Gleick 2018). Buhaug (2016) stressed that climate change has an indirect and conditional effect on crises, rather than a general causal effect.²⁶ Burke, Hsiang, and Miguel’s (2015b, 577) meta-analysis of 55 studies found that “deviations from moderate temperatures and precipitation patterns systematically increase conflict risk.” Abel et al.’s (2019) empirical analysis with data on asylum-seeking applications for 157 countries over the period 2006–2015 suggested that climatic conditions had significant effects on the number of asylum seekers in the years 2011–2015. They concluded that the impact of climate on conflict and asylum seeking is limited to specific time periods and contexts. Nevitt (2020) argued that climate change accelerates existing national security threats and acts as a “catalyst for conflict,” creating a “new climate-security nexus.” As such, it is widely accepted that climate change can be a “threat multiplier” (CNA Corporation 2007, 6) and influence the dynamics of interaction between societal actors (Buhaug 2016).²⁷

Importantly, climate change-induced migration could cause conflict in receiving areas (Reuveny 2007). Others have highlighted energy insecurity, resource scarcity, water insecurity, and poverty as sources of vulnerability and conflict (Blondel 2012; ADB 2017). Figure 14 displays the direct and indirect effects of climate change on resource availability, which can contribute to unleashing potential conflict and cooperation dynamics. Land degradation and a change in land use related to climate change mitigation and adaptation can lead to stress on food, water, income, livelihoods, health, and transportation and energy systems (Froese and Schilling 2019). The increased stress could trigger conflict, but it could also lead to efforts to find cooperative solutions.

²⁶ See also Bernauer, Böhmelt, and Kouki (2012), Adger et al. (2014), Buhaug et al. (2014), and Salehyan (2014).

²⁷ See also Wallace (2018), Mach et al. (2019), Van Weezel (2019), Vestby (2019), Work (2019), Roche et al. (2020), and Scheffran (2020).

Figure 14: Conceptual framework of the direct and indirect effects of climate change on resource availability and potential conflict and cooperation dynamics



Source: Compiled by authors based on Froese and Schilling (2019).

3.8 Summary

The discussion in this chapter has shown that the impacts of climate change and the efforts to achieve climate change adaptation and mitigation can constitute material risks to sovereign credit. Table 10 summarizes the main points and lists the relevant indicators that could be useful for analyzing climate risks.

Table 10: Risk channels, potential effects and relevant indicators

Risk channel	Potential effects	Relevant indicators
Depletion of natural capital and natural services	<ul style="list-style-type: none"> • Loss of natural capital increases vulnerability to climate shocks • Erosion of ecosystem services undermines an economy's output potential 	<ul style="list-style-type: none"> • Ecological footprint • Dependency of an economy on ecosystem services
Fiscal impacts of climate-related disasters	<ul style="list-style-type: none"> • Direct disaster losses/costs of reconstruction or repair • Contingent liabilities • Loss of tax revenue 	<ul style="list-style-type: none"> • Projected frequency of climate-related disasters • Historical insured and uninsured losses from climate-related disasters • Historical and projected contingent liabilities • Availability of contingency arrangements/disaster funds
Fiscal consequences of adaptation and mitigation policies	<ul style="list-style-type: none"> • Direct public spending on adaptation and mitigation investment • Public cost of facilitating structural change ("just transition") • Loss of revenue from carbon-intensive sectors 	<ul style="list-style-type: none"> • Projected change to land uses due to climate change • Expected fiscal cost of required adaptation and mitigation investment (adaptation finance gap/mitigation finance gap) • Share of government revenues from high-risk sectors
Macroeconomic impacts of climate change	<ul style="list-style-type: none"> • Greater intensity and magnitude of supply and demand shocks 	<ul style="list-style-type: none"> • Projected impact of climate change on economic sectors • Economic diversification
Climate-related risks and financial sector stability	<ul style="list-style-type: none"> • Financial stability risks to the financial sector 	<ul style="list-style-type: none"> • Exposure of financial institutions to climate risks based on the location/exposure of their investments
Impacts of climate change on international trade and capital flows	<ul style="list-style-type: none"> • Disruption of international supply chains and trade flows • Lasting changes to comparative advantages and international trade patterns and specialization • Impacts on balance of payments 	<ul style="list-style-type: none"> • Openness of the economy and export diversification • Carbon intensity of exports • Share of high-risk commodities (e.g. fossil fuels and agriculture) in total exports
Impacts of climate change on political stability	<ul style="list-style-type: none"> • Accentuation of social tensions and resource conflicts • Greater intra- and inter-state migration movements, which may foster inter- and intrastate conflicts 	<ul style="list-style-type: none"> • Existing resource conflicts • Dependency on food imports

Source: Compiled by authors.

4. Climate Change and Sovereign Risk in Southeast Asia and Implications for Macrofinancial and Fiscal Stability

Southeast Asian countries are among those most heavily affected by climate change, with devastating impacts on the economy that are increasing at a faster pace than in other regions (Yusuf and Francisco 2009, ADB 2017). Financial investors in the region are increasingly recognizing the investment risks associated with climate change (Munich Re 2013, CWR et al. 2019), and a growing number of financial authorities across the Association of Southeast Asian Nations (ASEAN) have started to address climate-related financial risks in their work (Volz 2019, Durrani, Masyitah, and Volz 2020). The central banks and monetary authorities of six ASEAN countries have already become members of the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) and started to consider impacts of climate change on their economies and how to address these.²⁸

This chapter assesses the macrofinancial risk for ASEAN countries and the implications for macrofinancial stability. We first review climate risks in Southeast Asia as a whole, before examining which of the potential transmission channels discussed in Chapter 3 are particularly relevant for ASEAN countries.

4.1 Climate risks in Southeast Asia

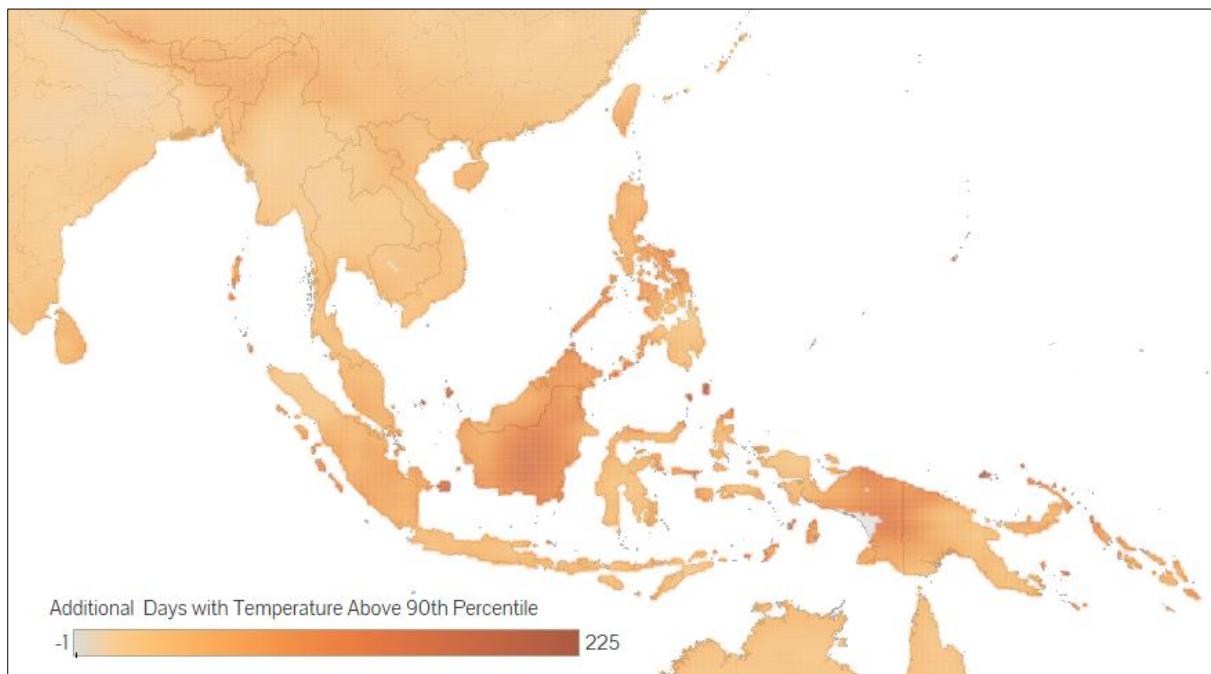
According to the IPCC (2014)'s Fifth Assessment Report (AR5), average temperatures in Southeast Asia have increased by approximately 0.14°C–0.2°C every decade since 1960. If global increases in greenhouse gas emissions follow the business-as-usual scenario, parts of Southeast Asia could enter into new climate regimes due to the frequent occurrence of unprecedented heat extremes (IPCC 2014). Even if the 2°C goal of the Paris Agreement is achieved, Southeast Asia is projected to be affected by summer heat extreme events every 2–5 years. Under a business-as-usual scenario they are expected to occur every year (ADB 2017). Figure 15 displays the change in the number of days in a year where the daily temperature is projected to exceed the local 90th percentile in 2030–2040, compared to the baseline period of 1975–2005. The darkest orange represents the most days, while grey represents a decrease in days.

The AR5 IPCC report indicates that precipitation patterns will undergo significant changes at the regional level, although inter-regional differences do exist and projections remain problematic (IPCC 2014). Annual total wet-day rainfall, rainfall from extreme rain days, and the ratio of rainfall between the wet to the dry seasons has increased. However, while there has been an increasing frequency of extreme events in northern Southeast Asia there are decreasing trends in Myanmar. Additionally, Peninsular Malaysia has experienced a decrease in the frequency of wet days and total rainfall during the monsoon season, but the Southeast Asian region has experienced an increase in rainfall intensity (IPCC 2014). An increase in the frequency and intensity of extreme rainfall events is projected for the Southeast Asia region (ADB 2017). In the Lao People's Democratic Republic (Lao PDR), two-thirds of the country's population face an average of 1.5 serious floods or drought every year (World Bank and GFDRR 2012). Figure 16 shows the change in the number of days in a year when the daily rainfall volume is projected to exceed the historical local 95th percentile in 2030–2040, compared to the

²⁸ The six central banks and monetary authorities are the National Bank of Cambodia, Bank Indonesia, Bangko Sentral ng Pilipinas, the Bank of Thailand, Bank Negara Malaysia, and the Monetary Authority of Singapore.

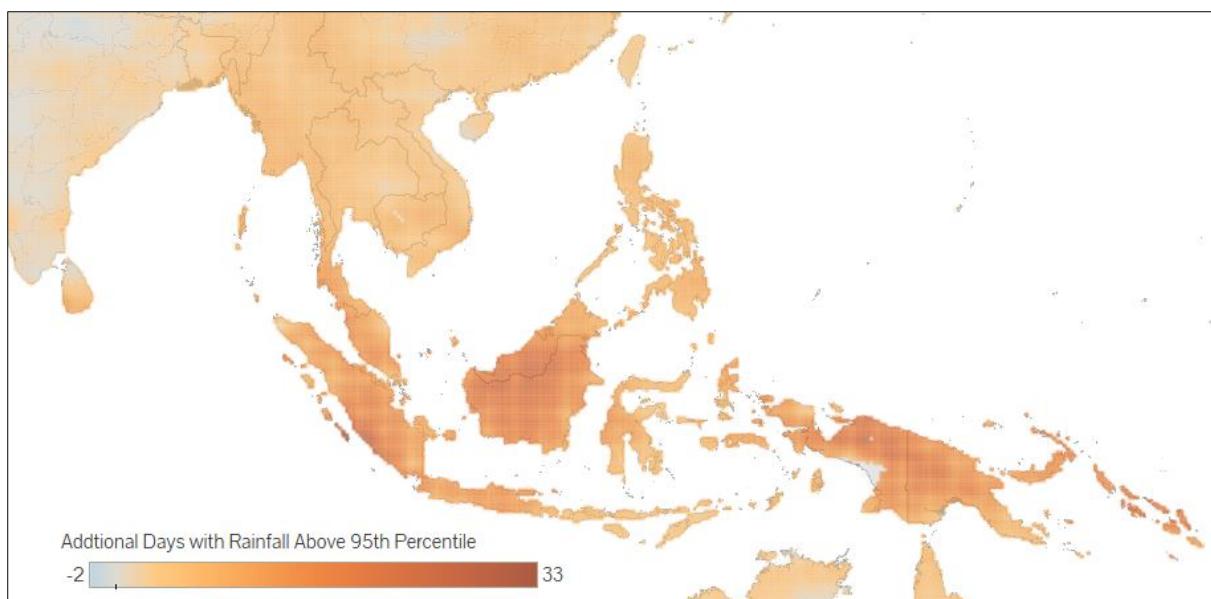
baseline period of 1975–2005. The darkest orange represents the most days, while light blue represents a decrease in days.

Figure 15: Change in the number of days in a year where the daily temperature is projected to exceed the local 90th percentile in 2030–2040



Source: Four Twenty Seven.

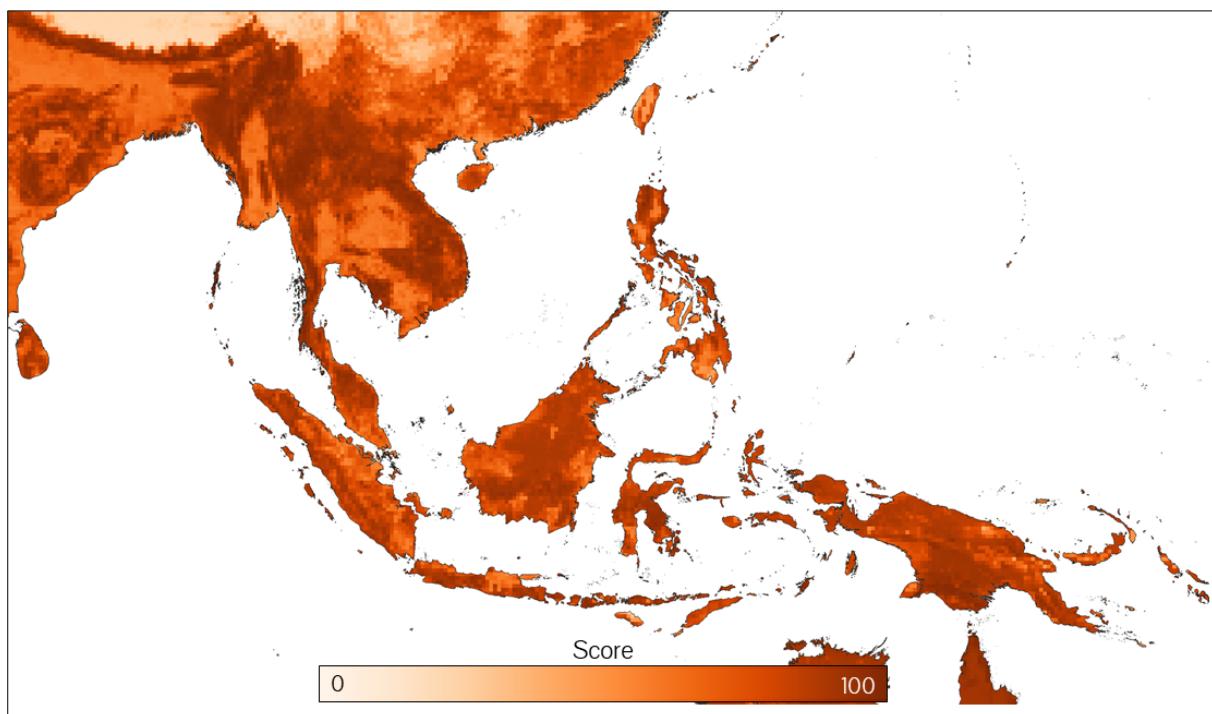
Figure 16: Change in the number of days in a year when the daily rainfall volume is projected to exceed the historical local 95th percentile in 2030–2040



Source: Four Twenty Seven.

Rising temperatures and droughts also increase wildfire risk. Figure 17 depicts projected change in wildfire potential for the period 2030–2040, based on the availability of burnable vegetation and on projected soil moisture deficit. The darkest areas have the most exposure to increased wildfire potential, while the lightest areas have the least exposure.

Figure 17: Projected change in wildfire potential in 2030–2040



Note: Soil moisture deficit is modelled using the Keetch-Byram Drought Index. Wildfire fuel is derived from high resolution land cover data from the European Space Agency.

Source: Four Twenty Seven.

Several ASEAN countries are at high risk of experiencing water stress, i.e. the competition among water users relative to available surface water resources (Table 11, Figure 18). Singapore is facing extremely high water stress, and is ranked number 1 globally in terms of water stress. Indonesia and the Philippines are also projected to face high water stress, while Malaysia and Thailand face low to medium water stress. Global warming of 1.5°C is projected to increase the number of people exposed to water scarcity by 79 million across Southeast Asia (UNESCAP 2020).

Sea level rise rates in the Western Pacific Ocean were about three times greater than the global mean during 1993–2012. This is a particular concern for Southeast Asia and especially for the Philippines and Indonesia which are archipelagic states (IPCC 2014). Projections indicate an increase in sea levels of 3–6 meters by 2030 (Marzin et al. 2015). This will result in land loss and contribute to coastal erosion, flooding, and salt-water intrusion. Global warming of 1.5°C is also projected to increase the incidence of river flooding. The population affected by river flooding is projected to increase by 71% in Cambodia, 135% in the Lao PDR, 47% in Myanmar, 129% in Thailand, and 139% in Viet Nam (UNESCAP 2020). Resulting economic damage is projected to increase by 70% in Cambodia, 143% in the Lao PDR, 49% in Myanmar, 119% in Thailand, and 148% in Viet Nam (UNESCAP 2020).

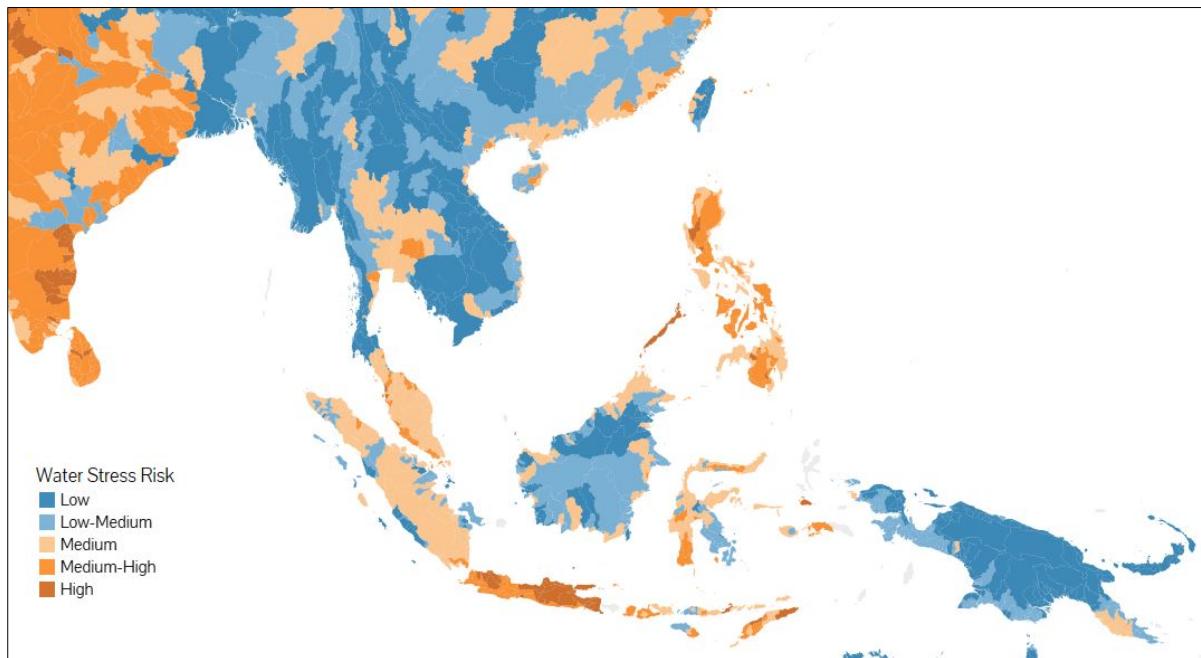
Table 11: Projected water stress ranking for ASEAN countries for 2040 under a business-as-usual scenario

	Rank	All sectors	Industrial	Domestic	Agricultural
Brunei Darussalam	157	0.01	0.01	0.01	0.01
Cambodia	135	0.38	0.52	0.41	0.37
Indonesia	51	3.26	3.42	3.28	2.99
Lao PDR	149	0.08	0.10	0.11	0.07
Malaysia	83	1.78	1.78	1.70	2.00
Myanmar	146	0.17	0.20	0.20	0.15
Philippines	57	3.01	2.96	2.92	3.26
Singapore	1	5.00	5.00	5.00	NA
Thailand	80	1.82	1.71	1.59	1.85
Viet Nam	107	0.96	1.02	0.98	0.95

Note: Higher scores on the scale from 0 to 5 correspond to greater competition among water users relative to available surface water resources. A score of 0–1 corresponds with low water stress, with a ratio of withdrawals to available water of <10%; a score of 1–2 corresponds with low to medium water stress, with a ratio of withdrawals to available water of 10–20%; a score of 2–3 corresponds with medium to high water stress, with a ratio of withdrawals to available water of 20–40%; a score of 3–4 corresponds with high water stress, with a ratio of withdrawals to available water of 40–80%; and a score of 4–5 corresponds with extremely high water stress, with a ratio of withdrawals to available water of >80%.

Source: Compiled with data from Luo, Young, and Reig (2015).

Figure 18: Projected water stress risk in ASEAN countries in 2040



Note: Distribution of water-stress levels, comprised of six indicators that measure current water stress, water availability, and projected changes in water availability in volume and in relative terms in 2040. Data derived from Aqueduct Global Maps 2.1 and Aqueduct Water Stress Projections.

Source: Four Twenty Seven.

Even though the vulnerability to climate risks varies significantly across Southeast Asian countries, the region constitutes one of the most climate vulnerable regions in the world where economic impacts of global warming are predicted to be among the largest (Yusuf and Francisco 2009; ASEAN 2017; Kompas, Pham, and Che 2018; UNESCAP 2020). More than 152 million people (24% of the population) across Southeast Asia reside in areas that experience flood events, and more than 389 million people (62% of the population) reside in areas that experience drought events (UNESCAP 2020). There are numerous multi-hazard hotspots across Southeast Asia, including the Mekong Delta in Cambodia and Viet Nam, the eastern coastline of Viet Nam up to the Red River Delta, the Ayeyarwady (Irrawaddy) Delta in Myanmar, the Chao Phraya Delta in Thailand, Manila and other vulnerable areas across the Philippines, and various populated islands in Indonesia (Thomalla, Boyland, and Calgaro 2017). In Viet Nam and the Philippines, 76% of the population lives in high multi-hazard risk areas, in Cambodia the percentage is 56%, in Indonesia 53%, and in Myanmar 51% (UNESCAP 2019).

In the widely-used Climate Risk Index by Germanwatch, which ranks countries according to fatalities and economic losses due to weather-related loss events, four ASEAN countries—Myanmar, the Philippines, Viet Nam, and Thailand—are listed among the 10 countries most affected by climate-related disasters over the period 1999 to 2018, with Cambodia coming close behind on rank 12 (Table 12). At the same time, Brunei Darussalam and Singapore rank among those countries with the least fatalities and damage. Figure 19 shows a significant increase in the absolute number of extreme weather events in ASEAN since the start of the last century. The increase has been driven by a rapid growth in the number of floods, storms, and landslides.

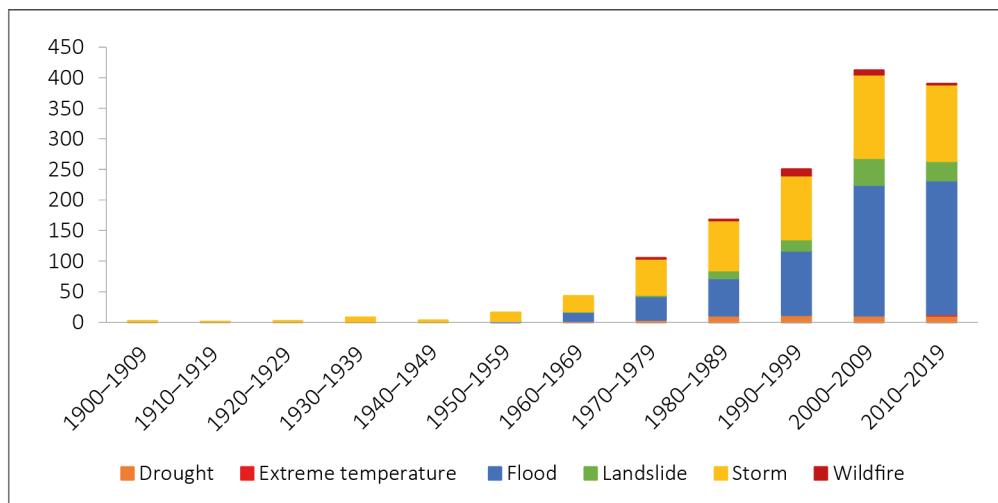
Table 12: Climate Risk Index for 1999–2018

CRI Rank	Country	CRI score	Fatalities per 100,000 inhabitants 1999–2018		Losses in million US\$ (PPP) 1999–2018 (Rank)	Losses per unit GDP in % 1999–2018 (Rank)
			Fatalities 1999–2018 (Rank)	2018 (Rank)		
175	Brunei Darussalam	169.17	168	154	179	180
12	Cambodia	35.33	40	34	52	26
77	Indonesia	76.83	16	92	21	120
76	Lao PDR	76.33	86	77	92	63
114	Malaysia	103.33	64	102	66	143
2	Myanmar	10.33	1	1	19	20
4	Philippines	17.67	7	16	9	29
180	Singapore	172.17	172	172	163	177
8	Thailand	31.00	22	62	4	18
6	Viet Nam	29.83	14	42	13	34

CRI = Climate Risk Index, GDP = gross domestic product, PPP = purchasing power parity.

Note: The CRI score is calculated as a weighted average of the individual scores. For instance, with Viet Nam ranking 14th in fatalities among all countries, 42nd in fatalities per 100,000 inhabitants, 13th in losses, and 34th in losses per unit GDP, Viet Nam's CRI score is calculated as follows: $14 \times 1/6 + 42 \times 1/3 + 13 \times 1/6 + 34 \times 1/3 = 29.83$.

Source: Compiled by authors with data from Eckstein et al. (2019).

Figure 19: Historical occurrences of extreme weather events in ASEAN, 1900–2019

Source: Compiled by authors with data from EM-DAT (2020).

Table 13 provides a breakdown of the average number of annual fatalities, people affected, absolute losses, losses as share of GDP for the period 2000–2019, as well as the total number of events over this period. Average total annual losses amounted to 0.44% of GDP in Cambodia, 0.27% in the Lao PDR and Myanmar, and 0.19% in Thailand. These averages, however, conceal the damage that can be caused by single events. In 2008, Cyclone Nargis caused economic damage totaling an estimated 12.6% of GDP in Myanmar. The damage caused by the 2011 flood in Thailand is estimated at 10.9% of GDP. Over the period 1993–2018, the 10 ASEAN countries and their combined population of 622 million experienced direct economic losses from weather-related events worth US\$124 billion, which equates to an annual loss of US\$5.2 billion (Table 14). Of these, only 14% were insured. However, this figure is due to a relative high insurance coverage in Thailand, where 27% of losses were insured. In the Lao PDR, Myanmar, Viet Nam, and Cambodia, hardly any losses were insured, while insurance covered only 5% of losses in the Philippines, 8% in Indonesia, 11% in Singapore, and 14% in Malaysia.

Table 13: Impacts of climate-related disasters in ASEAN countries, 2000–2019

Country	Total deaths (average 2000–2019)	Total people affected (average 2000–2019)	Total losses in US\$ million (average 2000–2019)	Total losses as share of GDP in % (average 2000–2019)*	Number of events (total 2000–2019)
Cambodia	42	646,601	54.46	0.44	24
Indonesia	30	37,010	44.78	0.01	189
Lao PDR	14	177,989	22.85	0.27	20
Malaysia	4	65,377	30.19	0.01	47
Myanmar	3,489	158,644	104.62	0.27	40
Philippines	83	522,994	76.23	0.04	273
Thailand	31	941,647	574.33	0.19	82
Viet Nam	34	268,182	135.4	0.11	142

Notes: No events were reported for Brunei Darussalam and Singapore between 2000 and 2019. Numbers for total deaths and people affected are rounded. * These numbers are not weighted by GDP/year but by the average of total losses in US\$ million by the GDP average between 2000 and 2019.

Sources: Compiled by authors with data from EM-DAT (2020), World Development Indicators, and International Monetary Fund.

Table 14: Losses from weather-related events, 1993–2018

	Overall losses (2018 values in US\$ million)	Insured losses (2018 values in US\$)	Fatalities
Brunei Darussalam	3	NA	2
Cambodia	2,200	2.3	1,221
Indonesia	15,000	1,200	5,960
Lao PDR	460	NA	188
Malaysia	2,300	330	974
Myanmar	5,500	NA	143,070
Philippines	24,000	1,200	20,617
Singapore	42	4.4	2
Thailand	55,000	15,000	3,681
Viet Nam	19,600	43	9,247

Source: Compiled by authors with data from NatCatSERVICE. <https://natcatservice.munichre.com>.

4.2 How can climate change affect sovereign risk in Southeast Asia?

The preceding overview clearly shows that climate risk is very high for the region as a whole, although there are marked differences across countries. The following analysis will first review the depletion of natural capital in Southeast Asia and then examine the relevance of the six risk channels discussed in Chapter 3 for sovereign risk in Southeast Asia.

4.2.1 Natural capital as the basis of economic prosperity

The consumption of natural capital in all Southeast Asian countries has increased dramatically over the last thirty years as consumption and population sizes have increased. According to Global Footprint Network data, every country in Southeast Asia has a higher ecological footprint per capita in comparison to bio-capacity per capita (Table 15). “Ecological footprint per capita” represents the domestic and foreign biologically productive land and water individuals require to produce all resources they consume and absorb all associated waste generated, using prevailing technology and resource management practices (Global Footprint Network 2020). “Bio-capacity per capita” represents the capacity of ecosystems to produce the biological materials used by an individual and to absorb waste material generated, under current management schemes and extraction technologies (Global Footprint Network 2020). The result is a bio-capacity deficit meaning that the region is importing bio-capacity through international trade, liquidating domestic ecological assets, or emitting wastes into global common resources such as the atmosphere in the case of greenhouse gas emissions. Myanmar and the Lao PDR are the only countries which do not operate at a bio-capacity deficit; however, they are close to operating at net-zero.

The depletion of natural capital is reflected in the deteriorating of ecosystems across the region. Southeast Asia is home to some of the world’s most diverse terrestrial and marine ecosystems. As of 2007, 792 key biodiversity areas—sites of global biodiversity significance—were identified. Globally, approximately one-third of all coral reefs (Box 2), mangroves, and seagrass areas are in Southeast Asia. Unfortunately, Southeast Asia is experiencing massive habitat and species loss, largely due to economic activities (production and pollution). Reducing the rate of biodiversity loss is a major challenge. Deforestation of tropic forests has and continues to be a problem, historically due to logging, but recently largely due to oil palm cultivation. Mangrove losses are among the highest in the world with 630 square kilometers being stripped away annually over the last two decades. Losses of coral reefs are also reported to be the highest in the world, in 2008 the rate of loss was estimated at 40% (Brander and Eppink 2012).

Table 15: Depletion of natural capital across Southeast Asia

	Bio-capacity per capita	Ecological footprint per capita	Bio-capacity reserve/deficit
Brunei Darussalam	2.8	4.3	-1.5
Cambodia	1.1	1.4	-0.3
Indonesia	1.3	1.7	-0.4
Laos PDR	2	1.9	0.1
Malaysia	2.3	3.9	-1.6
Myanmar	1.9	1.7	0.2
Philippines	0.6	1.3	-0.7
Singapore	0.1	5.9	-5.8
Thailand	1.2	2.5	-1.3
Viet Nam	1.0	2.1	-1.1

Source: Compiled by authors with data from Global Footprint Network (2020).

Box 2: The Coral Triangle

The Coral Triangle is a 6 million square kilometer (km^2) region spanning six countries, where 76% of the world's coral species and six of the world's seven marine turtle species can be found (WWF 2019). There is over 100,000 km^2 of coral reefs within the Coral Triangle, comprising 30% of the global total (Hoegh-Guldberg et al. 2009). The Coral Triangle directly provides livelihoods to 120 million people and supports a nature-based tourism industry worth US\$12 billion a year (Brander and Eppink 2012). Commercial fisheries within the Coral Triangle amount to over US\$3 billion, with annual tuna exports alone amounting to US\$1 billion. The natural capital within the Coral Triangle provide significant ecosystem services such as contributing to water quality maintenance along coastlines, stabilizing sediments, and acting as filtration systems as water runs from land to sea. Coral reefs act as vital green infrastructure by reducing wave power. These functions cannot be economically replaced if these ecosystems are lost (Hoegh-Guldberg et al. 2009). The annual economic net benefits per km^2 of healthy coral reefs in Southeast Asia ranges from US\$23,100 to US\$270,000 in relation to the benefits they provide in relation to coastal protection, fisheries, tourism, recreation, and aesthetic values (Burke, Selig, and Spalding 2002).

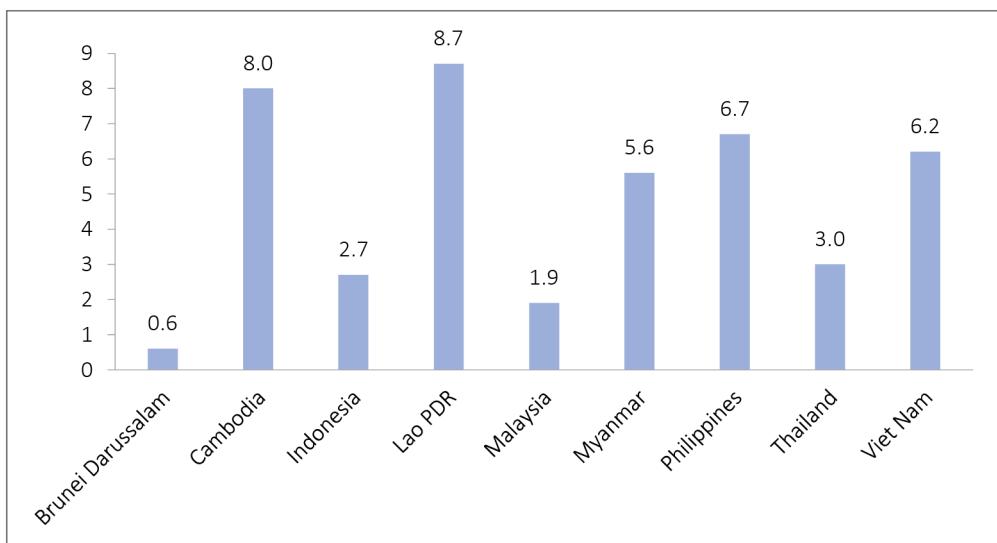
If unsustainable practices continue, these ecosystems will be under considerable threat and are at risk of collapse. It has been estimated that 96% of coral reef areas will be in highly, very highly, and critical condition by 2050. This will significantly damage and alter coastal economies and livelihoods, particularly for the fisheries and tourism sectors. The foregone value of reef-related fisheries is estimated at US\$5.64 billion per year (Brander and Eppink 2012). Mangrove areas are expected to decline by 2.08 million hectares from 6.04 million hectares by 2050 if current trends continue, with associated losses of US\$2.16 billion (Brander and Eppink 2012).

Climate change will exacerbate existing and introduce new risks posed by declining natural capital in the ASEAN region. Projected sea level rise in the Western Pacific Ocean will result in land loss and contribute to coastal erosion, flooding, and salt-water intrusion, deteriorating the natural capital of coastal environments with subsequent impacts on coastal economies such as agriculture and aquaculture. This will subsequently impact local food security through straining livelihoods and food supply.

4.2.2 Fiscal impacts of climate-related disasters

As discussed before, the Southeast Asian region has seen an increase in the number and intensity of climate-related disasters. Figure 20 shows the average annual loss as percentage of GDP for ASEAN countries. The Lao PDR (8.7%), Cambodia (8.0%), the Philippines (6.7%), and Viet Nam (6.2%) face the largest average annual losses, relative to GDP. In contrast, Brunei Darussalam and Singapore face almost no losses.

Figure 20: Average annual loss as percentage of GDP, by country



Note: Figures are based on probabilistic risk assessment. Singapore is not displayed as its value is below 0.5%.

Source: Compiled by authors with data from UNESCAP (2020).

The immediate impact of disasters on public finances, which comprises the cost of damage and repair of public property, spending on crisis responses and recovery, as well as foregone tax income due to output losses, is not easy to measure, given indirect effects. The account of contingent liabilities related to climate-related disasters in Southeast Asia is patchy. Table 16 provides an overview of historic contingent liabilities of five ASEAN countries—Indonesia, the Lao PDR, Malaysia, the Philippines, and Thailand—over the last three decades. Besides financial crises (and associated problems with public–private partnerships), natural disasters were the main trigger of contingent liabilities. In this list the largest contingent liability related to a climate-related disaster was realized in Thailand after the flooding of 2011, amounting to 3% of GDP.

Table 16: Historic contingent liabilities of ASEAN countries, 1990–2019

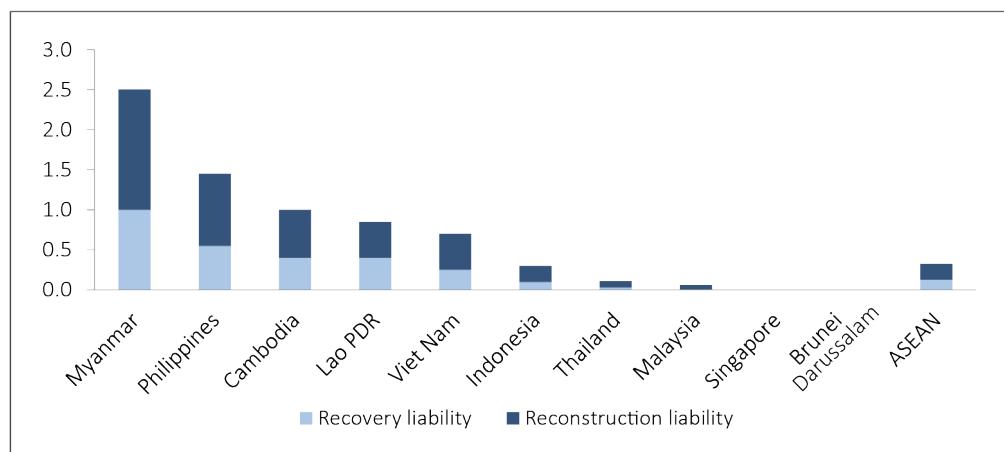
Country	Year(s)	Subtype of contingent liability	Impact amount (% of GDP)	Additional information
Indonesia	1994	Financial sector	2.0	Nonperforming assets equaled to more than 14% of banking system assets, with more than 70% in state banks. Recapitalization costs for five state banks amounted to nearly 2% of GDP.
	1997–2001	Financial sector	56.8	Widespread systemic banking crisis associated with the Asian crisis affected both state-owned banks and private commercial banks. The government declared a temporary blanket guarantee and a bank restructuring package that ultimately implied the closure of more than 60 banks and gross outlays of over 50% of GDP.
	1997–1998	Natural disaster(s)	NA	Total damage from huge fires estimated at 3.1% of GDP in 1997 and 1.3% of GDP in 1998.
	1998	SOEs	4.0	During the 1998 crisis the central government paid for the electricity company's fuel costs, amounting to 4% of GDP.
	1998	PPPs	NA	Substantial obligations on PPP contracts in power plants and roads became due during the Asian crisis.
	2004	Natural disaster(s)	1.8	Public expenses for recovery and reconstruction efforts following the Aceh and West Sumatra tsunami amounted to US\$4.6 billion.
	2005–2007	Natural disaster(s)	0.7	Total damage estimated at 1.6% of GDP. Total cost of reconstruction estimated at US\$4.5 billion but a large part donor financed (around \$4 billion pledged for 2005–2009 on and off budget). Total impact on overall balance (considering budget disaster related expenditures minus on budget grants and concessional loans) for 2005–2009 was 0.7% of GDP.
Lao PDR	2009		0.4	Public expenses for recovery and reconstruction efforts following Typhoon Ketsana.
Malaysia	1997–1999	Financial sector	16.4	Large systemic banking crisis (associated with the Asian crisis) with nonperforming loans peaking at 25–35% led to substantial government support.
	2001	Private nonfinancial sector	3.5	An assumption of debt by the government (equivalent to about 3.5% of GDP) associated with the debt restructuring of the Malaysian Airline System and two other large infrastructure projects (Putra and Star Light Rail), which until then were managed and operated by the private sector.
Philippines	1991	Natural disaster(s)	0.4	EM-DAT estimates the total damage at 1.7% of GDP. A powerful earthquake in July 1990 and a strong typhoon in November interrupted export production and inflicted heavy damage on infrastructure. A sharp rise in capital outlays for earthquake reconstruction (by P\$5 billion, or 0.4% of GNP) was included in the 1991 budget.
	1995	Natural disaster(s)	NA	Total damage from storm estimated at 1.2% of GDP.
	1997–2001	Financial sector	13.2	The crisis raised the magnitude of NPLs in bank portfolios. This in turn necessitated recapitalization to restore asset qualities.
	2009	Natural disaster(s)	1.4	Typhoon Ketsana and a second typhoon directly after resulted in recovery and reconstruction requirements totaling US\$4.4 billion, including US\$2.4 billion public spending needs.
	2014	Natural disaster(s)	1.0	Typhoon Yolanda, the strongest storm ever to make landfall, struck the central Philippines in November 2013, causing an estimated total damage of 4.6% of GDP. The government earmarked about ₱120 billion (1% of GDP) for reconstruction spending in 2014.
Thailand	1993	Natural disaster(s)	NA	Total damage due to flood estimated at 1.7% of GDP.
	1997–2000	Financial sector	43.8	Finance companies had large exposure to the property sector and were severely affected by the economic downturn. Widespread nationalization and bank closures took place amid large systemic crisis and very high nonperforming loans.
	1998	PPPs	NA	Substantial obligations on PPP contracts in power plants and roads became due during the Asian crisis.
	2011	Natural disaster(s)	3.0	The total damage of the Thai flooding is estimated at 11.7% of GDP. A reconstruction investment program equivalent to 3% of GDP was initiated as a response.

PPP = public–private partnership, SOE = state-owned enterprise.

Source: Compiled with by authors with data from Bova et al. (2019), Cevik and Huang (2018), and World Bank and GFDRR (2012).

The expected annual fiscal burden arising as a consequence of natural disasters (including recovery and reconstruction liabilities) as a percentage of government expenditure was estimated by the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) at 2.5% for Myanmar, 1.5% for the Philippines, 1.0% for Cambodia, 0.9% for the Lao PDR, 0.7% for Viet Nam, 0.3% for Indonesia, and 0.1% for Thailand and Malaysia, respectively (World Bank and GFDRR 2012, Figure 21). However, the estimated probable fiscal burden arising as a consequence of a 1-in-200-year probable maximum economic loss event as a percentage of annual government expenditure are significantly higher. The World Bank and GFDRR (2012) estimate these at 23% for the Lao PDR, 19.5% for the Philippines, 18% for Cambodia, 5% for Viet Nam, 4% for Indonesia, and 1.5% for Malaysia and Thailand, respectively (Figure 22). With global warming accelerating, chances are that disaster losses will rise further, unless investment in adaptation and resilience is scaled up substantially, which would also increase direct fiscal burdens.

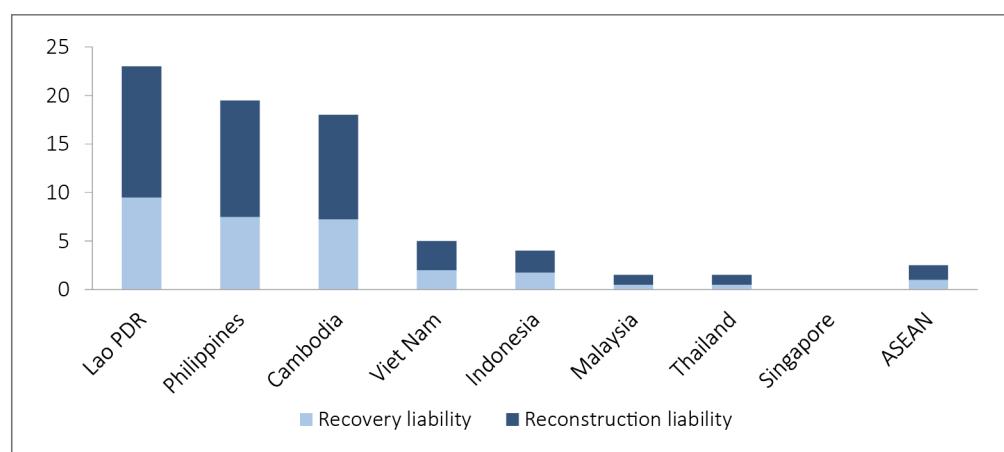
Figure 21: Annual expected fiscal burden arising as a consequence of natural disasters as a percentage of annual government expenditure



Note: Limited data were available for Myanmar and therefore the data may not accurately reflect long-term average annual losses.

Source: Compiled by authors with data from World Bank and GFDRR (2012).

Figure 22: Estimated probable fiscal burden arising as a consequence of a 1-in-200-year probable maximum economic loss event as a percentage of annual government expenditure



Note: Myanmar and Brunei Darussalam did not represent sufficient number of loss years, either historically or simulated, to compute reliable probable maximum economic losses.

Source: Compiled by authors with data from World Bank and GFDRR (2012).

A major problem is that disaster losses, both private and public, are largely uninsured across Southeast Asia. According to the ASEAN Insurance Pulse 2019 report, in 2018 nonlife insurance premiums in ASEAN accounted for only 1.0% of GDP, less than one-third of the global average of 2.8% (Schanz, Alms & Company 2019). Because of this insurance protection gap, governments will have to step in to cover losses more often, requiring them to fund disaster response and recovery and reconstruction activities.

Most ASEAN countries have contingency lines in public budgets or reserves for unforeseen expenditures, often explicitly related to natural disasters. However, these tend to be modest and insufficient in the face of larger events. A prominent example is the Philippines, which has established Calamity Funds and Quick Response Funds to provide contingency financing in case of disasters. Every local government unit is required to allocate 5% of its annual budget to a Calamity Fund, 30% of which goes into a Quick Response Fund, while the rest is dedicated to mitigation, prevention, and preparedness programs (Cevik and Huang 2018).

4.2.3 Fiscal consequences of adaptation and mitigation policies

Fiscal implications of adaptation policies

To protect people and the economy from the physical effects of climate change, ASEAN countries will need to substantially scale-up adaptation finance, including investment in physical and social infrastructure that will help to reduce exposure and vulnerability, and prepare for climate impacts. ASEAN governments will also need to invest in faster and more efficient recoveries. Although various studies look into the cost of adaptation (e.g. UNEP 2016, 2018), the literature is sketchy and comprehensive assessments or syntheses of the cost of adaptation for Southeast Asian countries are lacking to date.

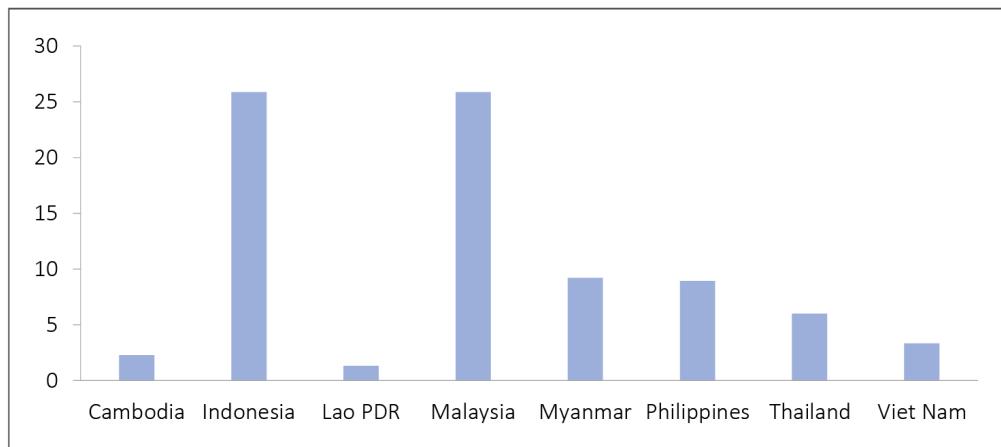
In many ways, public infrastructure forms the backbone of a nation and is essential for health, safety, and economic continuity. Transportation infrastructure provides an important example when discussing the fiscal consequences of climate adaptation. Economies and communities depend on continuous transportation infrastructure and a system that is not prepared for climate change is likely to affect fiscal resources by necessitating increased expenditures due to repair costs and potentially reducing revenue when assets such as toll roads, ports, and airports are disrupted. Climate-resilient infrastructure is critical to economic continuity. Persistent disruptions to infrastructure can lead to declines in economic productivity and reduced revenue. By investing in adaptation and proactive planning, governments can avoid some of these costs. However, upfront infrastructure investment is also costly and presents significant fiscal challenges. How and when sovereigns invest in infrastructure adaptation can have impacts on their fiscal resources as well as other credit indicators.

ADB (2017) estimates infrastructure investment needs in Southeast Asia at US\$2,759 billion (in 2015 prices) for the period 2016–2030. This amounts to annual investment needs of US\$184 billion on average, or 5.0% of projected GDP. Taking into account additional cost for climate mitigation and adaptation,²⁹ climate-adjusted estimates of total investment needs are US\$3,147 billion or US\$210 billion annual average, or 5.7% as share of GDP. Compared with the baseline estimates, the estimated costs are US\$388 billion or 14% higher when investments are climate proofed, i.e. made resilient to climate change impacts such as sea level rise and intensified extreme weather events that can damage infrastructure and reduce its lifespan. In terms of annual expenditure, costs would rise from US\$184 billion to US\$210 billion. ADB (2017) estimates total infrastructure investment needs in Indonesia at US\$1,108 billion, or US\$74 billion annual average (5.5% of GDP) for the period 2016–2030. The climate-adjusted estimates for Indonesia are US\$1,229 billion or US\$82 billion or 6% of GDP annually.

²⁹ In terms of climate mitigation, these figures include incremental costs for low-carbon energy investment. It should be noted that low-carbon energy is in most cases cheaper now than fossil-fuel based energy (IRENA 2020).

Figure 23 shows estimates by UNESCAP (2020) for annual average additional investment of ASEAN countries to meet global average investments in the social sectors and 2% of GDP in infrastructure required to reduce disaster losses over the period 2016–2030. UNESCAP (2020) points out that the additional investment needs are lower than the average annual expected losses from disasters. Indeed, their estimates suggest that in Cambodia, the Lao PDR, the Philippines, Thailand, and Viet Nam the additional investments required per year are more than 50% lower than the average annual expected losses. Considering the potential loss and damage related to major disasters, returns of these investments are even more favorable. For instance, the US\$47 billion in additional investment estimated for Thailand over the period 2016–2030 is only 13% of the losses incurred as a consequence of the 2011 flood (UNESCAP 2020).

Figure 23: Average additional investment required per year, 2016–2030 (US\$ billion)



Note: Additional investment figures refer to the difference between projected average annual investment if public expenditure in each sector, from 2016–2030, continues at the same percentage of GDP as in 2016, and average annual investment required over 2016–2030, if investments in each sector meet global averages.

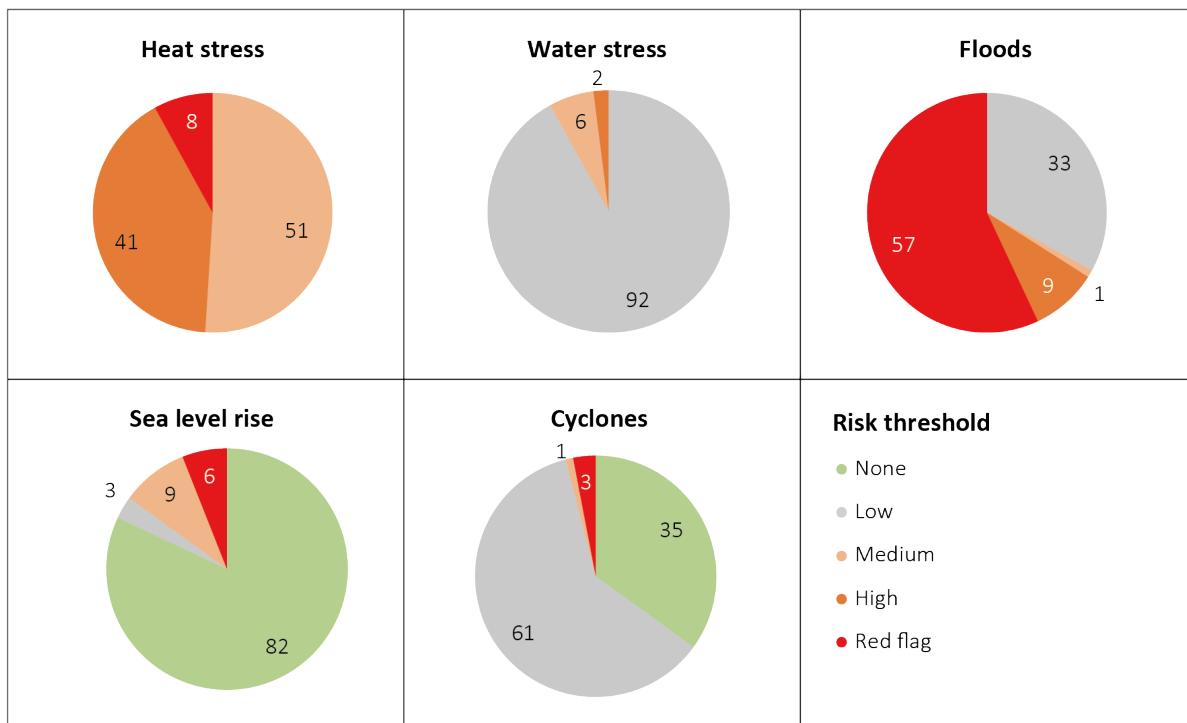
Source: Compiled by authors with data from UNESCAP (2020).

When reviewing 4,135 transportation infrastructure sites across ASEAN, we find that floods present the most significant risks to a large proportion of these assets (Figure 24). Transportation infrastructure is most at risk in Myanmar, where 62% of the roads are exposed to floods. Transportation infrastructure is essential for commuters and supply chains, underpinning national economies. While infrastructure can be funded in several different ways, public assets require government financing for maintenance and repairs. In many cases, infrastructure is built to withstand the historical occurrences of extreme events but is not prepared for the repeated severe inundation or record high temperatures that it will increasingly endure in a changing climate.

Public infrastructure funding typically comes from national or local budgets or from spending supported by financing instruments such as debt, insurance or grants from development finance institutions (Ambrosio et al. 2019). Climate change can have impacts on each of these funding options. For example, shifting temperature patterns or rainfall regimes can affect travel demand at airports and ports, as commodity production and tourism may shift. This can lead to reduced revenue and in turn make it more challenging to pay back loans, which can eventually lead to reduced credit ratings and more expensive debt in the future. This creates a negative feedback loop in which those cities and countries that are most vulnerable to climate hazards often find it the most challenging to obtain financing. The increasing frequency of floods and storms can complicate insurance options and

increase premiums. However, there is a potential for increased grant opportunities as development finance institutions increasingly identify climate adaptation as an investment opportunity. When approached proactively, infrastructure adaptation will change fiscal planning but not deteriorate fiscal resources.

Figure 24: Proportion of ASEAN transport infrastructure exposed to climate hazards



Source: Compiled with data from Four Twenty Seven.

Infrastructure projects have long-life times and it is thus essential to factor changing climate conditions and resilience into their development. If climate resilience is not integrated into decision making, there will be fiscal impacts as governments incur sudden costs, reduce their debt reserves, and ultimately have trouble repaying their loans. However, if governments integrate climate considerations up front into both infrastructure development and fiscal planning, they will likely incur lower unexpected costs and can work climate change resilience into the infrastructure investment upfront.

In the Philippines, 80% of assessed infrastructure, primarily ports and airports, has at least high risk for heat stress (Figure 25), 75% has at least high risk to hurricanes and typhoons, 52% has at least high risk to floods, and 32% has at least high risk to sea level rise. Each of these hazards has potential to cause disruption and increase costs, with rippling impacts on public finances. For example, when flood events that used to be rare increasingly occur every several years, ports, airports, and highways experience inundation that they were not built for.

Figure 25: Exposure of the Philippines transportation infrastructure to floods

Source: Four Twenty Seven (2020).

In the Philippines, infrastructure has traditionally been funded and operated publicly, although public-private partnerships have started to increase (MacLean 2017). The Duterte administration, which began in 2016, has identified infrastructure development as a high priority, with a commitment to spending up to 7% of the country's annual GDP on these investments (UNESCAP 2017). Integrating climate resilience and adaptation into these considerations in the initial investment phase can help to make the best use of these fiscal resources and reduce unexpected costs in the future. The federal government is responsible for most of the country's infrastructure funding, along with official development assistance and the private sector. The government's funding is dependent on comprehensive tax reform, which can be particularly vulnerable to climate change. Population displacement after storms can reduce the tax base, while business disruptions and reduced labor productivity affect economic activity and consumer behavior with implications for tax reform, political sentiment, and associated revenues.

In its National Communications to the United Nations Framework on Climate Change, the Philippines identified climate proofing infrastructure as an adaptation priority (Philippines 2014), which has implications for its budgeting and fiscal planning. It is exploring the possibility of implementing levies on road and port users, as well as airline and shipping services, to help finance adaptation.

Fiscal implications of mitigation policies

According to ADB (2015), if the goals of the Paris Agreement are to be met, then greenhouse gas emissions reductions in Southeast Asia will be driven mostly by improving energy efficiency, halting deforestation (critical to reducing decarbonization costs), and increasing low-carbon energy investment. ADB estimates put the annual cost for the region at US\$2 billion—roughly 0.6% of the combined GDP of ASEAN countries.

Table 17 shows a summary of the emissions and the carbon intensity of generation in the year 2030, as well as the total investment required under the Nationally Determined Contributions (NDCs) and an enhanced low-carbon action scenario for Indonesia and Viet Nam. The latter foresees a significant rise of renewable energy in the overall energy generation mix as well as enhanced energy efficiency. The total investment needs to achieve the NDCs in the energy sector are estimated at US\$298 billion for Indonesia and US\$209 billion for Viet Nam. To achieve the more ambitious enhanced low-carbon action scenarios, which would reduce power sector emissions compared to the NDCs by 13% in Indonesia and 12% in Viet Nam, US\$330 billion and US\$194 billion are needed, respectively. It should be noted that the estimated additional cost of achieving the enhanced scenario, compared to the NDCs, are negative, partly because of energy efficiency savings.

Table 17: Emissions and total investment to achieve Nationally Determined Contributions—scenario and enhanced low-carbon goals in Indonesia and Viet Nam

Power sector emissions in 2014 (MtCO ₂)	Power sector emissions in 2030 (MtCO ₂)			Carbon intensity of generation in 2030 (gCO ₂ /kwh)			Total investment (US\$ billion)			
	NDC Scenario	Enhanced low carbon scenario		NDC Scenario	Enhanced low- carbon scenario		NDC Scenario	Enhanced low- carbon scenario		
		% change	NDC Scenario		% change	NDC Scenario		% change		
Indonesia	168	496	431	-13	606	526	-13	298	330	11
Viet Nam	50	299	264	-12	537	503	-6	209	194	-7

gCO₂ = grams of carbon dioxide, kWh = kilowatt-hour, MtCO₂ = million tons of carbon dioxide, NDC = nationally determined contribution.

Source: Compiled by authors with data from Zhai, Mo, and Rawlins (2018).

The ADB pointed out that mitigation costs for ASEAN are lower than the amount spent on subsidizing fossil-fuels, which in 2010 equated to 3% of GDP; gradually and predictably reducing fossil-fuel subsidies would free financial resources to finance mitigation efforts and set the right price signals for the low-carbon transformation to occur (Raitzer et al. 2015). However, a low-carbon or even zero-carbon transition would have to involve a phasing out of fossil fuels. This could cause trouble for governments that currently rely to a high degree on revenues from the extraction of oil, natural gas, and coal resources. In Indonesia, revenues from fossil fuel accounted for 22.6% of total government revenues in the period 2011–2016 (OECD, World Bank, and UN Environment 2018). A back-of-the-envelope calculation for Indonesia suggests that the introduction of a US\$75 per ton carbon tax (+1.8%/GDP), the loss of fossil fuel revenues (−3.3%/GDP for 2011–2016), and the saving of fossil fuel subsidies (0.7%/GDP in 2017) would worsen the fiscal balance by 0.8% of GDP.³⁰ Foregone revenues from fossil fuel extraction would be a particular problem for Brunei Darussalam, where the oil and gas industry contributes around 60% of the country's GDP.

4.2.4 Macroeconomic impacts of climate change

ASEAN members will likely experience larger economic losses from climate change than most other areas of the world due to climate change impacts on agriculture, tourism, energy demand, labor productivity, health, and ecosystems integrity (Raitzer et al. 2015). Estimations of climate change impacts on economic growth are inexorably based on a host of assumptions on climatic trends, tipping points, technological innovation, adaptive capacity and the effects of all these on human well-being and economic activity. Long-term growth projections hence need to be taken cautiously.

³⁰ Estimates for carbon tax revenues and data on fossil fuel revenues are from OECD, World Bank, and UN Environment (2018), while data on fossil fuel subsidies are from International Energy Agency's Energy Subsidies database (2019).

Still, they do provide a useful indication of growth trends under different climate scenarios. Most projections suggest that the economic cost of inaction is immense. The ADB estimates that under a business-as-usual scenario, Southeast Asian GDP will decline by 11% by 2100 (Raitzer et al. 2015).³¹

Table 18 displays recent country-by-country projections by Kahn et al. (2019) on losses in GDP per capita by the years 2030, 2050, and 2100 under RCP2.6 and RCP8.5 scenarios. As discussed earlier, Kahn et al. (2019)'s estimations suggest that the world's real GDP per capita would be 7.22% lower in 2100 under RCP8.5, compared to an output loss of 1.7% under RCP2.6. According to Khan et al. (2019)'s estimates, under RCP8.5 real GDP per capita would be 8.46% lower in 2100 in the Philippines, 7.51% in Indonesia, 5.15% in Viet Nam, 4.12% in Malaysia, and 3.89% in Thailand.

Table 18: Percent loss in GDP per capita in Southeast Asian countries by 2030, 2050, and 2100 under the RCP2.6 and RCP8.5 scenarios

	RCP2.6 Scenario			RCP8.5 Scenario		
	2030	2050	2100	2030	2050	2100
Brunei Darussalam	-0.15	-0.07	1.41	0.16	0.50	1.65
Cambodia	-0.36	-0.38	1.84	0.10	0.26	0.74
Indonesia	0.19	0.61	1.92	0.91	2.79	7.51
Lao PDR	-0.09	-0.07	0.78	0.19	0.65	2.34
Malaysia	-0.15	-0.31	-0.34	0.53	1.51	4.12
Myanmar	-0.34	-0.61	0.25	0.29	0.80	2.24
Philippines	0.29	0.98	3.05	0.98	3.09	8.46
Thailand	-0.03	-0.05	0.06	0.29	1.12	3.98
Viet Nam	0.00	0.01	0.02	0.38	1.51	5.15

RCP = Representative Concentration Pathway.

Note: No data available for Singapore.

Source: Compiled by authors with data from Kahn et al. (2019, Table A.2).

Projections by Burke et al. (2015a) are even bleaker (Table 19). Their estimates suggest that because of global warming, global average incomes will be 23% lower in 2100 under a RCP8.5 emissions scenario compared to a scenario without climate change. According to their estimates, climate change will not only hold back economic growth of Southeast Asian countries but even reverse their economic development in the second half of the century. By 2050, the estimated impact of global warming on per capita GDP ranges from -30.6% in the Philippines to -38.9% in Cambodia. By the end of the century, GDP per capita is projected to be lower by around 80% across the region. Projections by Kompas, Pham, and Che (2018), presented in Table 20 show a similarly bleak picture.

³¹ Earlier estimates by the ADB put these losses at 6.7% of GDP (ADB 2009).

Table 19: Impacts of global warming (3°C) on the GDP of Southeast Asian countries

Country	Projected average temperature increase by 2100 (in °C)	Peak of positive growth rate over time with climate change (approximately)	Peak of GDP per capita over time with climate change (in US\$)	GDP per capita without climate change in 2099 (in US\$)	Change in GDP per capita, 2040–2059	Change in GDP per capita, 2080–2099
Brunei Darussalam	3.25	2,044	41,737.88	126,684.7	-34.16	-81.47
Cambodia	3.60	2,075	3,740.398	24,706.32	-38.94	-81.57
Indonesia	3.32	2,067	8,841.082	38,561.36	-31.44	-77.93
Lao PDR	3.84	2,069	3,567.634	17,327.95	-32.31	-79.17
Malaysia	3.41	2,058	11,768.98	48,048.28	-33.53	-80.70
Myanmar	3.85	NA	NA	NA	NA	NA
Philippines	3.05	2,074	6,785.432	32,200.74	-30.61	-76.38
Singapore	3.23	NA	NA	NA	NA	NA
Thailand	3.69	2,058	8,341.051	40,265.12	-37.81	-84.70
Viet Nam	3.74	2,066	3,593.551	17,668.67	-33.60	-80.82

Source: Compiled by authors with data from Burke et al. (2015a).

Table 20: Projections on the GDP of ASEAN countries under different climate change scenarios

Country	Impacts of Global Warming (3°C) on GDP (% Change/Year)					Long-Run Impacts of Climate Change Scenarios on GDP (% Change/Year)			
	2027	2037	2047	2067	Long run	1°C	2°C	3°C	4°C
Brunei Darussalam	-0.373	-0.815	-1.308	-2.385	-5.563	-1.202	-3.314	-5.563	-8.173
Cambodia	-1.175	-2.439	-3.758	-6.482	-12.101	-3.509	-7.572	-12.101	-17.183
Indonesia	-1.242	-2.594	-4.020	-6.973	-13.267	-3.347	-7.980	-13.267	-19.040
Lao PDR	-1.039	-2.164	-3.342	-5.765	-10.621	-3.369	-6.795	-10.620	-15.759
Malaysia	-1.091	-2.293	-3.568	-6.229	-12.118	-3.084	-7.145	-12.118	-17.339
Philippines	-1.206	-2.592	-4.093	-7.275	-14.798	-4.113	-9.185	-14.798	-20.986
Singapore	-0.905	-1.958	-3.106	-5.562	-11.652	-2.729	-6.923	-11.652	-16.566
Thailand	-0.766	-1.605	-2.500	-4.401	-9.243	-2.541	-5.749	-9.243	-13.269
Viet Nam	-0.802	-1.636	-2.500	-4.276	-7.959	-2.223	-4.862	-7.959	-11.641
Rest of Southeast Asia	-1.342	-2.767	-4.237	-7.234	-12.924	-3.811	-8.110	-12.924	-18.573

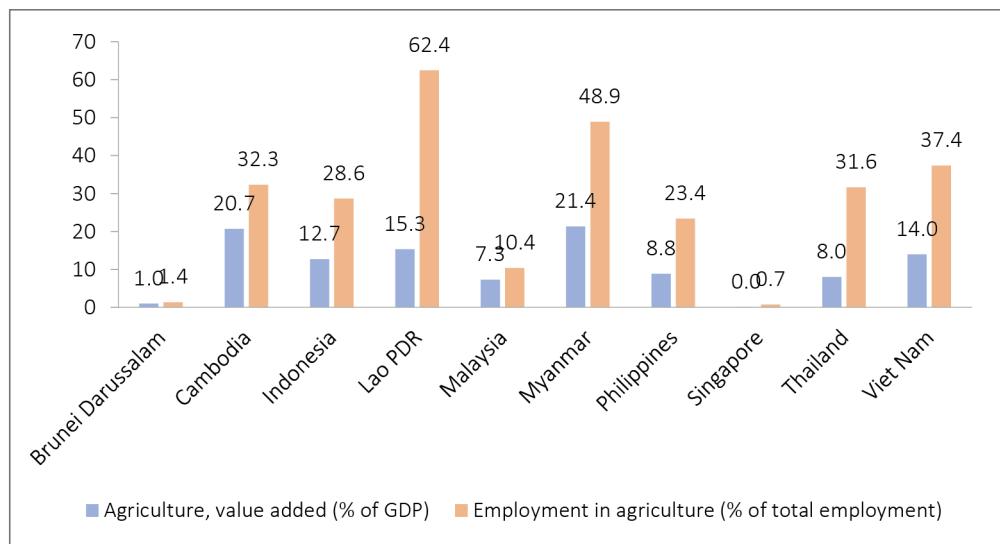
Note: separate data for Myanmar are not available.

Source: Compiled by authors with data from Kompas, Pham, and Che (2018).

The agricultural and fisheries sectors are among the sectors most exposed to the physical impacts of climate change. Despite a growing importance of manufacturing, agriculture (including forestry, hunting, and fishing, as well as cultivation of crops and livestock production) still plays a major role in most economies of Southeast Asia, with the exception of Brunei Darussalam and Singapore (Figure 26). Except for these two countries, employment in agriculture constitutes between 10% and 62% of total employment, and value added to GDP ranges between 7% and 21%. Climate change is projected to lower employment in agriculture due to lower crop yields (Rutten et al. 2014). Rising temperatures and changing precipitation patterns, along with rising sea levels, a higher probability of floods and droughts, and more intense tropical storms will impact the availability of arable land and agricultural production, (Parker et al. 2019) and could have material impact on the economy at large. Already now, average annual losses in agriculture are estimated at 2.4% of GDP for ASEAN countries

on average, with losses highest in Cambodia and the Lao PDR, with 5.5% and 5.4% of GDP, respectively (Figure 27).

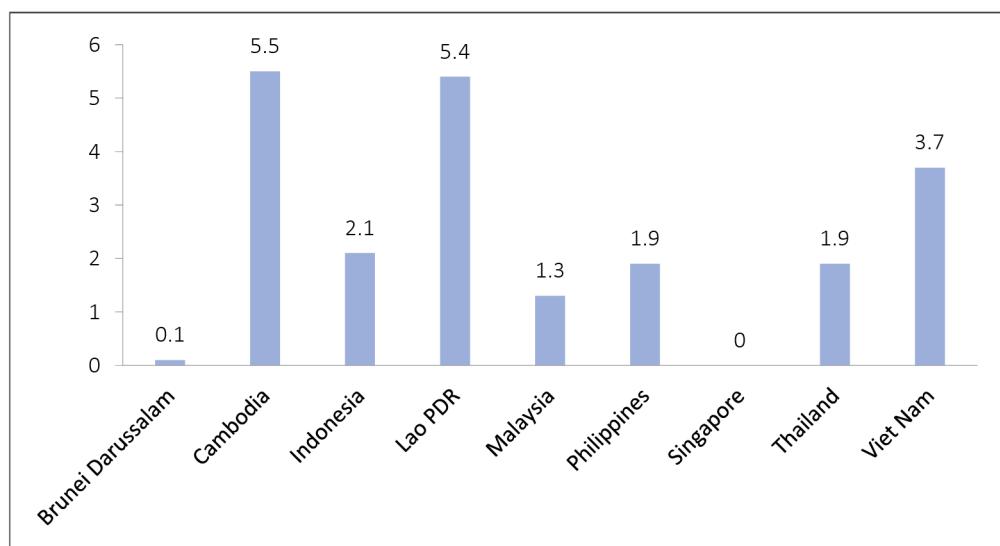
Figure 26: Role of agriculture in GDP and employment, 2019



Note: Agriculture includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production.

Source: Compiled by authors with data from World Development Indicators.

Figure 27: Average annual agricultural loss as percentage of GDP



Note: Data for Myanmar are not available.

Source: Compiled by authors with data from UNESCAP (2020).

In Viet Nam, climate-related flood risks threaten the population, economic assets, and food security in the Red River Delta and the Mekong River delta (Rutten et al. 2014). In the Red River Delta and the Mekong River Delta, both of which are vital agricultural and industrial regions in Viet Nam, floods are imperiling around 67% of the total population and over US\$400 billion in assets, and up to 32% of

built-up land, 47% of paddy rice areas, and 32% of other agricultural land are at risk of flooding (Rutten et al. 2014). Overall, as much as 7% of agricultural land may be lost in Viet Nam in the case of a 1-meter sea level rise (Dasgupta et. al 2009). In case of sea level rise of 5 meters, Viet Nam is estimated to lose 23% of its agricultural land, while 11% of agricultural land would be inundated in Myanmar, 6% in Indonesia, 4% in Thailand, and 2% in the Philippines (Chen, McCarl, and Chang 2012).

The coastal Mekong Delta is also facing growing problems of soil and water salinization linked to climate change (Tuong et al. 2003). Moreover, agricultural production in the Mekong Delta will be affected by a “high exposure to flooding, sea level rise and drought” and “a decline in the climatic suitability of rice and maize” (Parker et al. 2019: 1). In Viet Nam’s highlands, coffee production will be affected by “a loss of climatic suitability for coffee” and “the presence of flooding and drought (Parker et al. 2019: 1). Overall, large parts of Viet Nam’s agricultural sector are at risk of being severely affected by climate change, with potentially devastating effects on the livelihood of tens of millions of people. This underlines the crucial importance of enhancing adaptive and protective measures to limit adverse socioeconomic effects of climate change. Going forward, ASEAN countries need to conduct comprehensive climate-risk vulnerability assessments to systematically mitigate risks.

4.2.5 Climate-related risks and financial sector stability

The financial sector, and especially banking, forms an important part of ASEAN economies. In Singapore, Southeast Asia’s leading financial hub, the finance and insurance sector accounted for 13.9% of GDP in 2019 (SingStat 2020), while in Malaysia it accounted for 11.4% of GDP in 2019 (MOF Malaysia 2020). Across ASEAN, the financial, insurance, and pension sectors combined are a net exporter of services, accounting for 9.3% of 2018 exports and 6.2% of imports (ASEANstats 2019). Section 3.5 discussed the physical and transition risks that financial institutions are exposed to, and how these risks can translate into sovereign risk. Given the substantial climate-related risks facing Southeast Asian economies, it is evident that financial institutions across the region are exposed to material financial risks. For the time being, however, only a few ASEAN-based financial institutions have started to systematically analyze and quantify their exposure to climate-related risks, and financial supervisors across the region are also in early stages in understanding and monitoring these risks.

Physical climate risks manifesting as credit risks for banks

ASEAN is already witnessing the negative impact of climate risks on the banking sector. The severe floods in Thailand in 2011 impacted borrowers’ credit profiles and ability to repay debt. The Bank of Thailand had to step in to support flood-affected borrowers by allowing banks to maintain pre-flood credit ratings, reduce interest rates, delay repayment amounts, and extend repayment periods for these borrowers (BOT 2012). Insurance was also inadequate to cover losses, with insured losses accounting for approximately US\$10.8 billion of the US\$45.7 billion economic costs of the floods (Aon Benfield 2012).

Bangkok Bank, one of the largest commercial banks in Thailand, announced at the start of 2020 that it expected the level of NPLs in the Thai banking industry to increase that year due to Thailand’s worst drought in 40 years, which was compounding a global economic slowdown (Banchongduang 2020). Bangkok Bank already had to reschedule and suspend repayments for some of its own clients, while Bank of Thailand data showed that NPLs in small and medium-sized enterprises increased from 4.25% in Q2 to 4.75% in Q3 2019 (Banchongduang 2020). The state-backed Bank for Agriculture and Agricultural Cooperatives had to step in to offer emergency and restoration loans to support affected farmers (Chantanusornsiri 2020).

Other ASEAN countries have seen similar increases in NPLs due to extreme weather-related events, which will increase in severity and frequency with climate change. In Cambodia, NPLs in the agriculture sector increased in 2018 due to natural disasters, rising to 8.2%, which was considerably higher than other sectors such as manufacturing (4.1%) and construction (4.2%) and the overall rate

of 2.8% (NBC 2019). The recent drought led the Ministry of Agriculture, Forestry and Fisheries to ask farmers to plant only one crop during the 2019–2020 dry season to prevent water shortages (Vireak 2019). This may also lead to higher NPLs for 2020 for the agriculture sector (Hutt 2020).

In the Philippines, which has one of the highest rates of extreme-weather related events in ASEAN, has also seen its agriculture sector impacted. In 2018, the agriculture, hunting, forestry, and fishing sector grew by only 0.8%, compared to a 4% expansion in 2017 (BSP 2019a), due to the 19 typhoons that hit the Philippines, especially typhoon Ompong which hit the major rice-producing area of northern Luzon. The central bank, the Bangko Sentral ng Pilipinas (BSP), provided temporary rediscounting relief measures to banks in calamity-affected areas in 2018. This is not the first time the BSP had to step in. In 2013, the BSP granted regulatory relief (e.g. reduced loan loss provisions) to banks so they could assist customers affected by extreme weather events (BSP 2013a). In December 2012, cooperative banks saw their NPLs rise to 19.84% compared to 9.49% six months earlier, largely due to typhoons (BSP 2013b).

The International Labour Organization (2019) estimated that 3.1% of working hours in ASEAN were lost in 2015 due to rising temperatures and this is projected to rise to 3.7% (equivalent to 13 million full time jobs) in 2030. Viet Nam, Thailand, and Cambodia are projected to bear the brunt of the heat with over 5% of working hours lost. If these effects are not factored into bank credit projections, there will be unforeseen and unpriced credit risks. For Cambodia, the agriculture, forestry, and fisheries sector accounted for 9.4% and the construction sector accounted for 9.1% of overall bank credit in 2018, so the two sectors most impacted by heat stress together account for almost 20% of banks' exposure (NBC 2019).

Transition climate risks manifesting as credit risks for banks

The European Union recently decided to transition away from palm oil as a biofuel by 2030 and also published a new framework to address deforestation through measures including shifting demand toward deforestation-free products (Dusser 2019, EC 2019a, EC 2019b). Such policy and market changes may result in stranded landbanks for Indonesian and Malaysian palm oil growers if no alternative sources of demand materialize (Morel et al. 2016). The Indonesian and Malaysian governments have stepped up the domestic use of palm oil-based biofuel to absorb the oversupply. The French government's decision to remove tax breaks for the use of palm oil in biofuel has already resulted in stranded capital expenditures and losses for the Total biorefinery in France (De Clerq and Trompiz 2019).

Similarly, the necessary transition toward renewable energy for the People's Republic of China (PRC), India, Japan, and the Republic of Korea in a sustainable development scenario compatible with the Paris Agreement (IEA 2019) has potential implications for the medium and long-term profitability of coal mines in Indonesia. Reduced demand in these key export markets will reduce the ability of coal companies to service and refinance debt obligations.

In the power sector, over three-quarters of onshore wind and four-fifths of solar photovoltaic projects due to be commissioned in 2020 across the globe will produce energy at lower cost than the cheapest fossil fuel options, even without subsidies (IRENA 2019). For example, there is increasing evidence of the cost competitiveness of solar energy versus coal-fired energy in India due to technological advances, which is enhanced by the lower water requirements of solar energy in water scarce India (Buckley 2019). The technological risk compounds the policy risk.

If Viet Nam, Indonesia, and Philippines are to meet the necessary commitments under the Paris Agreement, estimates show that up to US\$60 billion of coal-fired power plants are at risk of stranding through earlier retirement at 15 years rather than 40 years (CTI 2018). The Carbon Tracker Initiative estimates that a phasing out of coal power in Indonesia in accordance with the Paris climate goals would lead to asset stranding in the order of US\$34.7 billion (CTI 2018). Under the same scenario, owners of assets of coal power utilities in Viet Nam stand at risk of losing US\$11.7 billion of mostly

operating capacity. In the Philippines, US\$21 billion of assets associated with the current expansion of coal capacity are at risk of stranding (CTI 2018). Caldecott, McCarten, and Triantafyllidis (2018) estimate that 87.7% of Southeast Asia's current fossil fuel generation assets are incompatible with a 1.5°C budget, and 17.8% are incompatible with a 2°C budget. Around half of planned generation assets are incompatible with both the 2°C and 3°C carbon budgets. These pose significant risks for both the banks financing the projects as well as for the sovereign where state guarantees are provided.

Banks: Climate risks as liquidity risks due to impact on balance sheet from credit risks and fire sales of assets in financial markets

In ASEAN, the lack of disclosure and relatively slow progress on portfolio level climate scenario analysis by banks may increase liquidity risk. None of the 35 largest ASEAN headquartered and listed banks disclose the breakdown of their energy financing portfolio (coal/fossil fuels vs. renewables), nor their exposure to other high climate risk sectors such as mining and agriculture. 14 of the 35 banks disclosed sensitive sector policies but some have only one or two policies, suggesting potential unmitigated climate risk in other sectors. Only three Singapore banks stopped financing new coal-fired power plants, while other banks continue to increase balance sheet exposure to coal. Only two banks have disclosed a climate risk strategy and only two banks have undertaken a portfolio climate analysis.

To address the uneven progress by ASEAN banks, there has recently been positive momentum on the harmonization of ASEAN sustainable banking regulations. Banking regulators and associations in Indonesia (Otoritas Jasa Keuangan 2017, 2018), Malaysia (BNM 2019), Singapore (ABS 2018), Thailand (TBA 2019), and Viet Nam (SBV 2015, 2018) have recently issued sustainable banking guidelines that require banks to strengthen their governance of environmental, social and governance issues and highlight climate change as a key issue. The BSP is currently conducting an industry consultation on its proposed sustainable finance framework (BSP 2019b). Thus far, only the Monetary Authority of Singapore has highlighted the need for forward looking stress tests and increased supervisory focus on climate risk (Kung 2019).

Investors: Effects on portfolio valuations due to stranding and repricing of assets

ASEAN capital markets had an aggregated market capitalization size of US\$2.5 trillion as of December 2018 (WFE 2019). The ASEAN bond market has been growing, with Indonesia, Malaysia, Philippines, Singapore, and Thailand seeing robust growth in their local currency bond markets which grew from US\$1.117 trillion in March 2017 to US\$1.518 trillion in December 2019 (ADB 2020). The equity and debt capital markets are an increasingly important source of funding for companies. Potential reductions in portfolio value faced by investors could be greater due to the higher physical climate risks faced by Southeast Asian countries compared to Europe or North America and also the relatively slower progress to transition business models to improve climate alignment. Of the 800 companies that have committed to set science-based targets to decarbonize their business models in line with the Paris Agreement, only nine are based in ASEAN.

Indonesian coal mining companies saw their bond prices fall to 70–85 cents in the dollar in the six months to October 2019 (Wee and Dahrul 2019). This has been attributed by some investors partly as a result of the shift to renewable power in Europe, and partly due to the highest production volumes in the last decade. The Government of Indonesia has responded to the 28% drop in Indonesian coal prices by ordering production cuts (Listiyorini 2020).

Insurers/reinsurers: Negative effects on margins due to higher insurance claims

The fact that Southeast Asia is one of the most vulnerable regions to physical climate risk will have a negative impact on insurers providing coverage in this region if they are unable to either increase premiums or purchase adequate reinsurance. Thai insurers suffered at least US\$10.8 billion in losses from the 2011 Thai floods, and rating agencies highlighted the negative impact on the insurance sector. Due to the significant losses incurred by reinsurers, some reinsurers decided to limit future

exposure to flood risk through various measures including total exclusion of natural catastrophe cover, significant increases in the price of reinsurance cover, and for some, a total exit of the Thai market (AON Benfield 2012). The high cost of reinsurance will reduce the coverage and/or affordability of insurance for companies and could have implications for the value of banks' collateral assets in the event of any default by their clients and also for the value of investors' portfolios when catastrophe recovery costs are not adequately covered.

Overall, depending on the extent of physical risks and the abruptness of transition risks, climate risks can have a significant negative impact on banks, investors, insurers, and other financial institutions. ASEAN financial authorities in each country need a deep understanding of climate risk resilience of their financial sector and must work with other national policy makers to create a smoother transition to reduce shocks. Given the complexities involved in modelling the nonlinear effects of climate change and the lack of robust data, there could be significant turmoil and instability in ASEAN's banking systems and financial markets. As such, there is an urgent need to understand the data and types of analysis required for robust risk management.

There is a high risk of contagion due to the interconnectedness of ASEAN markets and supply chains, as well as to the exposure of ASEAN banks, in particular banks in Malaysia, Singapore, and Thailand, to regional assets. ASEAN central banks, financial supervisors, and policy makers will need to work together to assess and manage intra-ASEAN risk exposures and harmonize policies and regulations to address the potential contagion effect and maximize regional climate resilience.

Financial sector risk can become sovereign risk

Although ASEAN does not have a monetary or fiscal union and may not face the same contagion risk as was seen in the eurozone's sovereign debt crisis, the Asian financial crisis of 1997–1998 showed how contagion effects could cause a crisis to spread from one country—Thailand—to the entire region, even affecting countries with relatively strong macroeconomic fundamentals like Malaysia (Hassan 1999). The large intraregional trade and supply chain linkages and intraregional exposure of banks may increase the risk of contagion. Moreover, the Asian crisis showed how weaknesses of initially a few financial institutions could fuel speculation and capital flight and develop into a systemic financial crisis that would then turn into a sovereign crisis. As discussed earlier, contingent liabilities of ASEAN countries were historically often related to financial crisis, often with serious fiscal implications (Table 16). After the global financial crisis, the Philippines government highlighted financial sector risks as one of the five main sources of risk that could threaten fiscal stability (Republic of the Philippines 2012).

Even though ASEAN economies have reduced the currency and maturity mismatch problems that contributed to the Asian crisis, and most have turned into current account surplus countries, the speed and scale of capital outflows during the COVID-19 crisis have revealed the vulnerability to changes in market sentiments (Beirne et al. 2020). Government-funded bank bailouts or the expectation of such, or a weakened banking sector may worsen the debt burden and/or sovereign credit risk by exacerbating economic or financial crises.

Governments and state linked pension funds and investment companies are significant shareholders of banks and will be directly exposed to decreased stock market valuations of bank stocks

Sovereign risk may also be affected because of the close links that exist between ASEAN governments, their state linked pension funds and investment companies, and the banking sector. Banks feature prominently in the largest companies by market capitalization on ASEAN stock exchanges. For example, seven out of the largest 30 companies listed on Bursa Malaysia's main board are financial institutions (Bursa Malaysia 2019), and three Singapore banks make up over 39% of the weighting of the STI Index of the largest 30 companies on the Singapore Exchange (FTSE Russell 2020). In Malaysia, government-linked pension funds and investment companies such as the

Employees Provident Fund, Permodalan Nasional Berhad, Kumpulan Wang Persaraan, and the sovereign wealth fund Khazanah Nasional Berhad are key stakeholders in several banks. Together they hold directly or via trustees 54.5% of CIMB Bank (CIMB 2020) and 23.7% of Maybank (Maybank 2019), the two largest banks in Malaysia. Singapore's sovereign wealth fund Temasek owns 11.1% of DBS Bank (DBS 2019), Southeast Asia's largest bank. The government of Indonesia owns 56.75% of Bank Rakyat Indonesia (BRI 2019), 60% of Bank Negara Indonesia (BNI 2020), and 60% of Bank Mandiri (Bank Mandiri 2020)—three of the four largest banks in the country. In Myanmar, the four state-owned banks account for 31% of the banking system's assets as of September 2018 (AMRO 2019). In the Philippines, two of the top 10 banks are state owned, including Land Bank of the Philippines, the country's fourth largest bank. The predominance of state-linked shareholdings in ASEAN banks creates a very direct transmission channel from the financial sector to sovereign risk via the value of state-owned assets, even in a more benign scenario.

Due to the dual role of the financial sector as a direct contributor to GDP, tax revenues, employment, exports, and sovereign assets and as the main source of funding for businesses and to some extent for governments, climate shocks to the financial sector will reverberate across the wider economy. This could result in a larger negative impact, which may be exacerbated by a worsening of government debt burden to fund any required bailouts, leading to increased sovereign risk.

The potential for cross-border contagion is not trivial due to the high levels of intra-ASEAN business, trade, and financing activity and also dependence on key trading partners. ASEAN central banks and supervisors will have to work together to understand the vulnerabilities and resilience of the financial sector in each of their home markets and any potential cross-border contagion effects.

4.2.6 Impacts of climate change on international trade and capital flows

Most Southeast Asian economies are highly integrated into the world economy. In 2018, the ratio of exports of goods and services over GDP was larger than the OECD average of 29.2% in all ASEAN countries but Indonesia (21.0%). Given the importance of the export sector for growth and employment, ASEAN countries are exposed to a number of material climate-related risks. There are several ways through which climate change could affect the patterns and the volume of international trade flows of ASEAN countries, with potentially significant effects on countries' balance of payments positions and, ultimately, sovereign risk.

Supply chains across Southeast Asia face disruptions from climate-related hazards

As discussed, physical impacts of climate change can interrupt production and transportation, which can disrupt trade. Such disruption may be particularly problematic in Southeast Asia given the region's trade is closely related to regional and global value chains, where parts and components are shipped between different production sites across countries to benefit from countries' respective comparative advantages. These value chains depend on timely delivery and are sensitive to disruptions. Starting with Singapore and Malaysia, Southeast Asian countries have become major participants and regional and global trade-production networks since the early 1970s, especially in the electronics and automotive sectors. Indeed, engagement in global production sharing has been a major factor behind the export-led development success of Southeast Asian countries. The share of network trade in total manufacturing exports is much larger in Southeast Asia than in any other region of the world, with products related such networks accounting for 71.5% of merchandise exports of Southeast Asia over the period 2011–2012 (Athukorala 2016). Malaysia, the Philippines, Singapore, Thailand, and Viet Nam are particularly integrated in network trade, and to a somewhat lesser degree Indonesia (Athukorala 2016, 2019). More recently, Cambodia and the Lao PDR have also started to participate in regional production networks, especially in the garment sector (DiCaprio and Suvannaphakdy 2017).

The most prominent example of a large-scale disruption of supply chains are the Thai floods of 2011. Among other impacts, the floods inundated numerous industrial parks where components for the

supply chains of automotive and electronic products were produced, causing standstill of operations across the region and the world, prominently in Japan (Haraguchi and Lall 2015). Although often unnoted, the region regularly experiences impactful weather events that degrade infrastructure and disrupt commerce and supply chains. In 2019 alone, landslides and rainstorms damaged roadways along major transportation routes in Thailand, Cambodia, Myanmar, and Viet Nam (BSI 2020).

Manufacturing is exposed to multiple climate hazards

Manufacturing accounts for the majority of merchandise exports in all ASEAN countries except Brunei Darussalam and the Lao PDR.³² As manufacturing centers, most ASEAN countries provide key inputs into global supply chains and economies. The impacts of climate hazards on manufacturing facilities pose significant economic risks where the damage occurs, but can also significantly affect international trade and capital flows, particularly in industries with complex global supply chains. Manufacturing is an industry that is particularly vulnerable to climate hazards due to its reliance on energy intensive equipment, onsite operations, employee labor, in addition to complex supply chains. Manufacturing facilities are disrupted during floods and storms, sometimes due to onsite damage but often due to employees' inability to get to work due to damaged regional infrastructure, or lack of critical components due to disrupted supply chains. Likewise, during extreme heat events, employee health can be threatened and productivity can decline. Energy intensive facilities are also vulnerable to blackouts due to high demands on the grid during heat waves. As average temperatures increase this can lead to a persistent decline in productivity and increase in energy costs.

Manufacturing facilities from large listed companies in the ASEAN countries are highly exposed to climate hazards, with 99% of assessed facilities in the region at least highly exposed to heat stress and 43%, 38% and 21% at least highly exposed to water stress, floods, and hurricanes and typhoons, respectively (Table 21). Newman and Hewston (2018, 1) identify Southeast Asia as one of four regional hotspots (besides West Africa, Central Africa, and the Middle East and North Africa), "where, without adaptation, rising heat stress will drive labor capacity losses in key sectors, with the potential to substantially undermine their export economies." Based on the current sectoral composition of exports and projected daily temperatures for the period 1980–2045, they estimate that 5.2% of Southeast Asia's export value—including agriculture, forestry and fishing, as well as extractive activities—is projected to be at risk by 2045 because of heat stress-induced labor capacity losses.

Table 21: Percent of manufacturing facilities with at least high risk to climate hazards

	Heat stress	Water stress	Floods	Sea level rise	Hurricanes and typhoons	Total number of facilities assessed
ASEAN	99	43	38	4	21	2,931
Indonesia	98	66	57	2	0	576
Malaysia	100	36	36	3	0	280
Philippines	96	79	39	7	88	380
Singapore	100	99	33	7	0	335
Thailand	100	8	27	2	0	612
Viet Nam	100	1	34	4	48	522

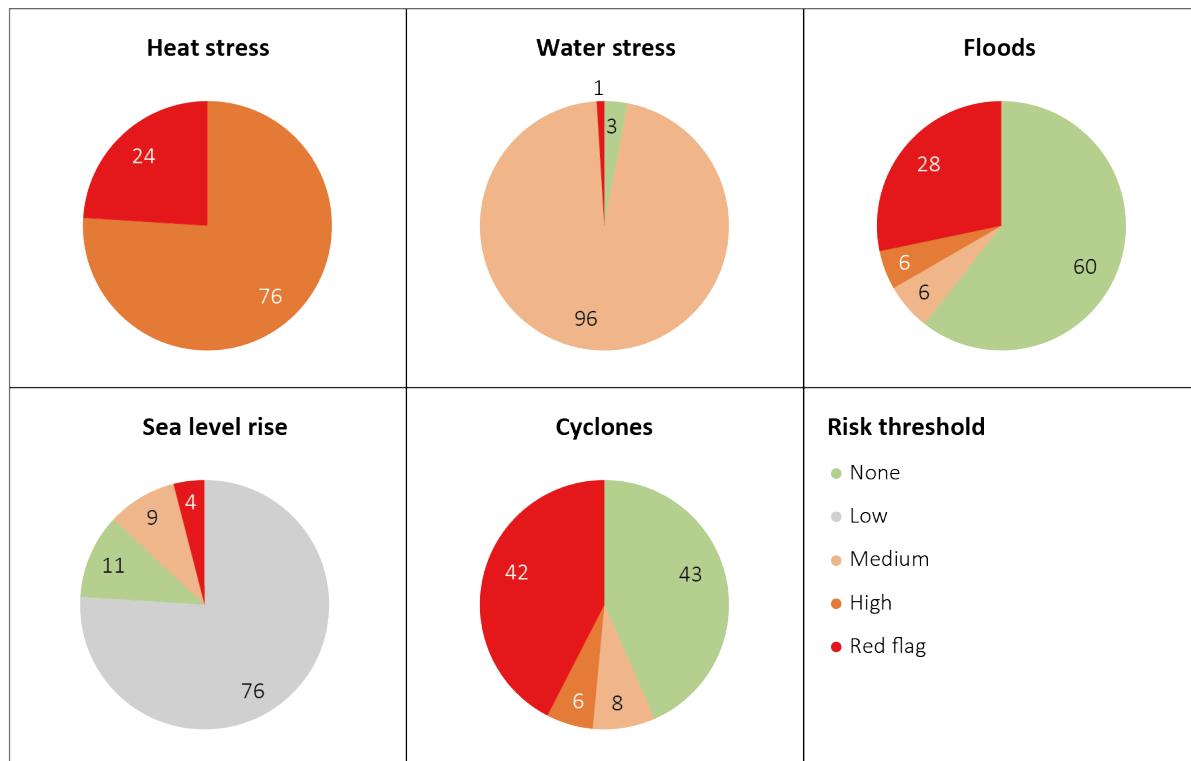
Note: Percent of manufacturing facilities owned or operated by large listed companies in ASEAN Countries with high exposure to key climate hazards.

Source: Compiled with data from Four Twenty Seven.

³² In 2018, the share of manufacturing in total merchandise export was 8.6% in Brunei Darussalam, 94.4% in Cambodia, 54.4% in Indonesia, 41.1% in the Lao PDR, 75.0% in Malaysia, 50.2% in Myanmar, 87.5% in the Philippines, 77.1% in Singapore, 81.3% in Thailand, and 85.2% in Viet Nam (ASEANstats database).

Viet Nam in particular stands out with all of its assessed manufacturing facilities exposed to at least high heat stress and almost half with at least high exposure to hurricanes and typhoons (Figure 28). Viet Nam's key exports include broadcasting equipment, telephones, integrated circuits, textile footwear, and leather footwear. These are industries with many manufacturing operations, as well as global supply chains, making Viet Nam's exports largely dependent on resilience to climate hazards both domestically and in nations that produce the other components upon which Viet Nam manufacturing relies.

Figure 28: Proportion of Viet Nam's manufacturing facilities exposed to each climate hazard



Source: Compiled with data from Four Twenty Seven.

Viet Nam's exports have increased consistently over the past several years, but disruption to manufacturing of its key export products could adversely affect its trade balance. Circuits and other electrical equipment are typically components in long supply chains with both downstream and upstream manufacturing operations across Southeast Asia. Meanwhile these products' end destinations are consumer markets across the globe. Viet Nam's top export destination is the United States, followed by the PRC, Japan, the Republic of Korea, and Germany. These trade partners may begin to seek products elsewhere if Viet Nam's manufacturing is consistently disrupted due frequent storms. Likewise, if companies need to increase their products' prices to respond to an increase in operating cost due to consistently warmer temperatures, countries that do not have this exposure will likely have a competitive advantage. For example, one of the PRC's top exports is also telephones. As a larger nation with more financial resources and more diverse climate risk exposure, the PRC may continue to produce telephones with similar prices even when Viet Nam manufacturers may have to consider increasing prices. The exposure of other key industries such as agriculture, may also reduce the nation's exports or increase its import demands. With a relatively small trade balance, Viet Nam could see its trade balance become negative if its key industries are constantly affected by climate hazards and its export partners have to look elsewhere for a stable supply of products.

Risks to agricultural exports and tourism

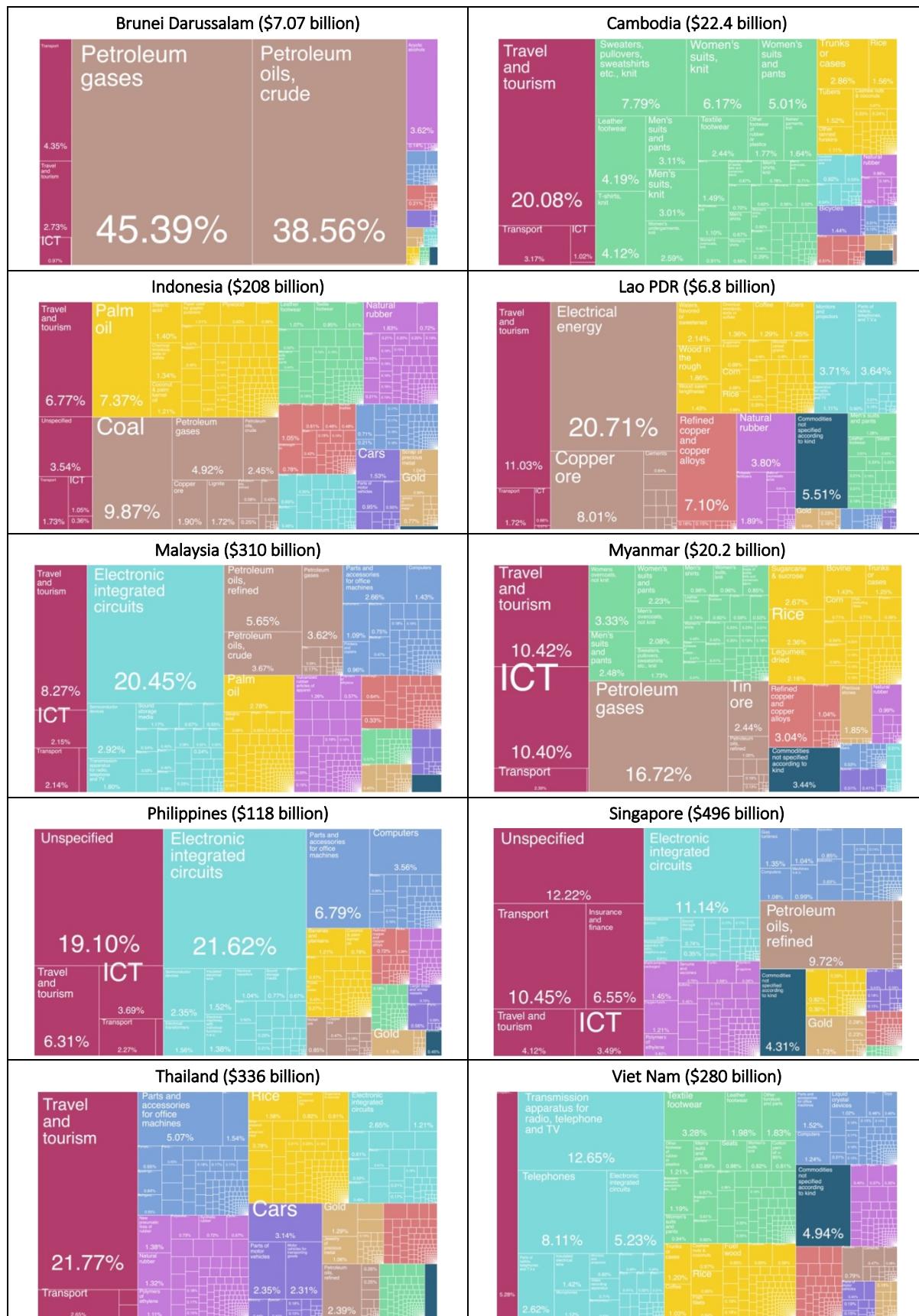
Manufacturing is not the only export sector across Southeast Asia that is being affected by the physical impacts of climate change. Figure 29 displays the composition of ASEAN countries' total exports for 2018. The agricultural and fisheries sectors of Southeast Asian countries have become increasingly involved in international agro-food trade (OECD and FAO 2017). For most ASEAN countries, agricultural exports—displayed in yellow—are of great importance, accounting for 23.6% of exports in Indonesia, 17.2% in Myanmar, 16.8% in the Lao PDR, 12.3% in Thailand, 10.9% in Viet Nam, 10.2% in Cambodia, 8.9% in Malaysia, and 6.2% in the Philippines. Thailand and Viet Nam are among the largest exporters of rice globally, and Myanmar and Cambodia have also ranked among the top 10 exporters. The only two ASEAN countries for which agricultural exports are not substantial are Singapore and Brunei Darussalam, with shares of 3.0% and 0.3%, respectively. As was discussed earlier, the agricultural and fisheries sectors are among the sectors most exposed to the physical impacts of climate change. Agricultural production and hence export capacity will be severely affected in several parts of Southeast Asia. Simulations by Le (2016) suggest that under a low-emissions scenario and without interventions, Viet Nam's rice production would drop by as much as 18% by 2030 relative to the 1980–1999 average. Although (export) prices would rise by about 7%, export quantity would fall by 55%, with an overall loss of export sales of 48%. Modeling by Chen, McCarl, and Chang (2012) indicate that along with Myanmar and Egypt, Viet Nam would be one of the three rice exporters globally that would turn from a rice exporter to an importer in the case of extreme sea level rise. Besides the socioeconomic implications, this would also impact on food supply and security across the region.

In services exports (colored red in Figure 29), the tourism sector plays an important or very important role for most ASEAN countries. Travel and tourism account for 21.8% of total exports in Thailand, 20.1% in Cambodia, 11.0% in the Lao PDR, 10.4% in Myanmar, 8.3% in Malaysia, 6.8% in Indonesia, 6.3% in the Philippines, 4.1% in Singapore, and 2.7% in Brunei Darussalam (no data for Viet Nam). International tourism across ASEAN relies to a large degree on pleasant nature and safe climatic environments. While sea level rise will hurt coastal tourism (Marks 2011), heat stress and other natural hazards may diminish the attractiveness of Southeast Asia as a tourist destination. The ADB (2009) raised concerns that an increase in coastal erosion and deterioration of natural resources may cause losses for the tourism industry in Thailand. With more than 10% of Thailand's workforce employed in the tourism sector before the outbreak of the COVID-19 crisis, adverse effects of climate change could have a significant impact on the Thai economy, and the same may be true for Cambodia, and, to a lesser extent, for the Lao PDR.

Transition impacts on international trade

A decarbonization of the global economy would have profound impact on most Southeast Asian economies and their international trade. ASEAN comprises both importers and exporters of fossil fuels, and some ASEAN countries are both. While importers of fossil fuel energy would benefit from reduced energy import bills (Dowling and Russ 2012), the impending decline in global demand for fossil fuels will hurt major exporters if they fail to anticipate it (Holz et al. 2018).

Figure 29: Composition of ASEAN countries' exports, 2018



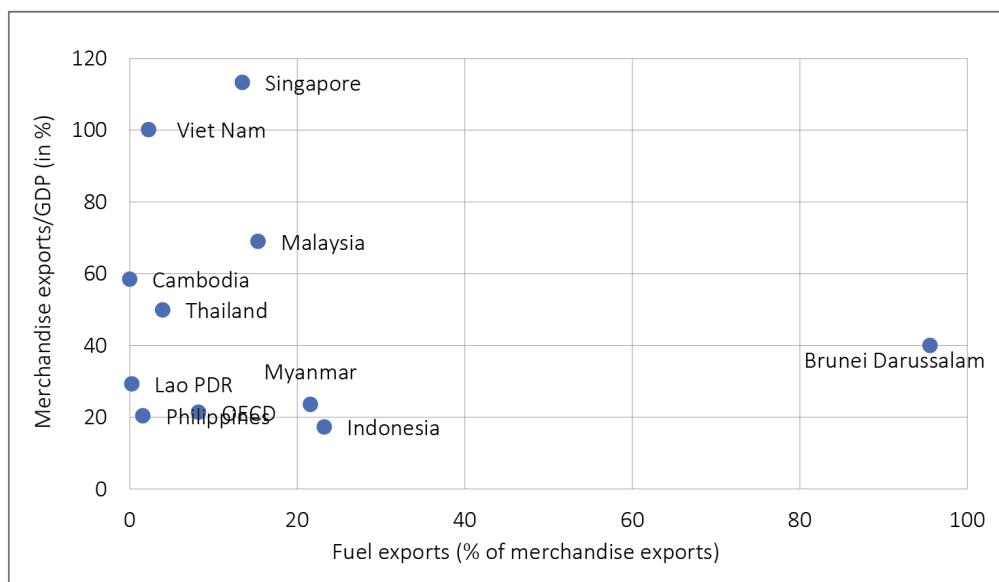
Note: Standard International Trade Classification categories disaggregate to 4-digit detail level.

Source: Compiled by authors with Harvard Growth Lab's Atlas of Economic Complexity, based on UN Comtrade data.

Among the fossil fuel exporters, Brunei Darussalam stands out: 45.4% of its total exports are in petroleum gases and another 38.6% in petroleum oils and crude (colored copper in Figure 29). It is no exaggeration to say that a drying up of fossil fuel exports would cause severe trouble to the economy and public finances. The effects would be less severe in other ASEAN countries but could still be problematic for some. With petroleum gases constituting 16.7% of Myanmar's total exports, and coal constituting 9.9% and petroleum gases 4.9% of Indonesia's total exports, a rapid transition of Myanmar's and Indonesia's trading partners to a low-carbon economy would have significant impact of these countries' trade balances. As pointed out by Holz et al. (2018, 5), along with other major coal exporters to the PRC (such as Australia), Indonesia could find itself "in a very vulnerable position quite quickly" if the PRC was to reduce its coal consumption soon. The effects of dwindling fossil fuel trade would be less severe for Singapore, where refined petroleum oils account for 9.7% of total exports, and Malaysia, where refined and crude petroleum oils constitute 5.7% and 3.7% of total exports, respectively.

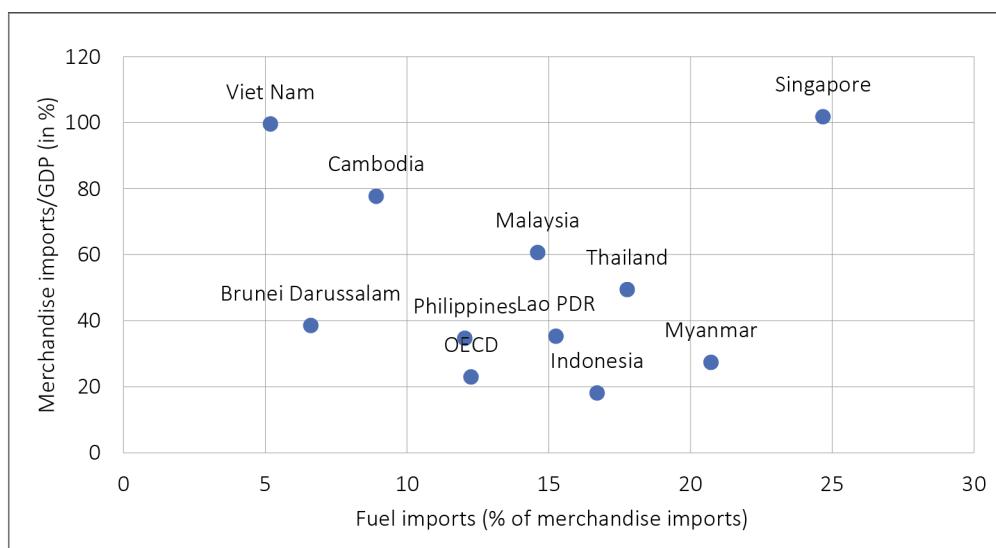
Figure 30 plots fuel exports as share of merchandise exports of ASEAN countries as well as the OECD average against merchandise exports as share of GDP. Figure 31 shows the same for imports. Brunei Darussalam's merchandise exports, which amount to 40% of GDP, constitute almost entirely (96%) of fossil fuels. With 23.2%, Indonesia has also a significant share of fossil fuels in its total merchandise exports, as has Myanmar with 21.6%, Malaysia with 15.3%, and Singapore with 13.5%. For these countries, a sudden drop in fossil fuel exports would likely pose problems. For Thailand, the share is a mere 3.9%, and for all others it is lower. The countries with the largest share of fossil fuel imports in total merchandise imports are Singapore with 24.7%, Thailand with 17.8%, Indonesia with 16.7%, the Lao PDR with 15.3%, Malaysia with 14.6%, and Philippines with 12.0%. Among the fossil fuel importers, Singapore, Myanmar, Thailand, Indonesia and the Lao PDR have the highest share of fossil fuel imports as share of merchandise imports. A switch to non-fossil fuels would reduce the import bill. Indeed, the Lao PDR is not only seeking to reduce energy imports; it envisages to boost exports of hydroelectricity generated at the Mekong river, becoming the "battery" of Southeast Asia.

Figure 30: Fuel exports (% of merchandise exports) vs merchandise exports as share of GDP



Note: Fuel exports for Cambodia and the Lao PDR from 2016, for Viet Nam from 2017.

Source: Compiled by authors with data from WDI.

Figure 31: Fuel imports (% of merchandise imports) vs merchandise imports as share of GDP

Note: Fuel imports for Cambodia and the Lao PDR from 2016, for Viet Nam from 2017.

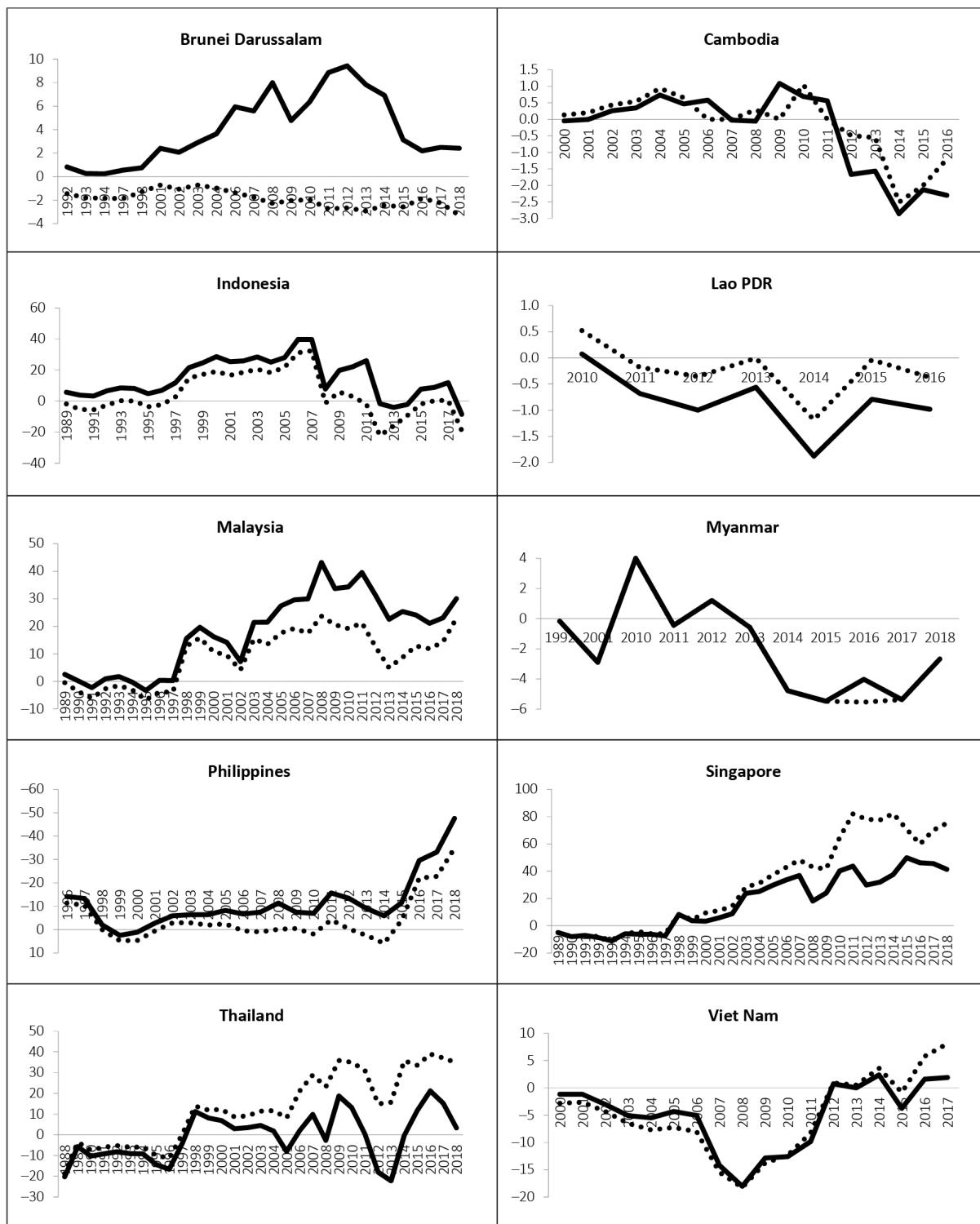
Source: Compiled by authors with data from WDI.

Figure 32 shows the balance of trade in goods for all ASEAN countries. The straight lines show the actual values, while the dotted lines show values excluding mineral fuel imports and exports. Unsurprisingly, countries with large net imports or exports of mineral fuels see significant changes to their balance of trade when mineral fuels are excluded. In such a scenario, Brunei Darussalam would have seen its trade balance for goods turn into a deficit. For instance, in 2018, Brunei Darussalam would have recorded a deficit of US\$3.3 billion—the equivalent of 24.3% of its US\$13.6 billion GDP—in its goods trade, instead of a US\$2.4 billion (or 17.8% of GDP) surplus. In 2012, the difference in the balance of trade in goods would have been a whopping US\$12.1 billion (or 49.5% of GDP). Between 1989 and 2018, Indonesia would have recorded a deficit in its balance of trade in goods in 13 years, instead of the 4 years it actually did. The US\$ 8.5 billion deficit in its goods trade—0.8% of GDP—that Indonesia recorded in 2018, would have been US\$10.4 billion larger in the absence of mineral fuel trade, so that the goods trade balance would have stood at −1.8% of GDP. Malaysia’s accumulated trade surplus in goods over the same period of US\$530 billion would have been reduced to almost half in the absence of mineral fuel trade, to US\$277 billion. In contrast, the Lao PDR’s accumulated goods trade deficit over the period 2010–2016 would have been only US\$1.6 billion, instead of the actual US\$5.8 billion—a significant amount for an economy of US\$15.1 billion in 2016. Thailand would have accumulated a goods trade surplus of US\$399 billion over the period 1988 to 2018, instead of a deficit of US\$24 billion.

One should be careful not to take the results of such simplistic simulations literally, but they illustrate an important point: a rapid replacement of fossil fuel-based energy and transport systems would have a significant impact—positive or negative—on the trade balance of most ASEAN countries. A significant worsening of the balance of payments could have material impact on macroeconomic stability and sovereign credit risk.

It should be noted, however, that also new export opportunities may open up. For instance, Indonesia may benefit from growing demand for industrial metal such as nickel, the demand for which is projected to rise significantly due to its role in electrical vehicle batteries. The government of Indonesia is seeking to develop nickel processing and battery production in Indonesia to capitalize on expected strong global demand (Sanderson 2020).

Figure 32: ASEAN countries' trade balance for goods (in US\$ billion), including (straight line) and excluding (dotted line) mineral fuels

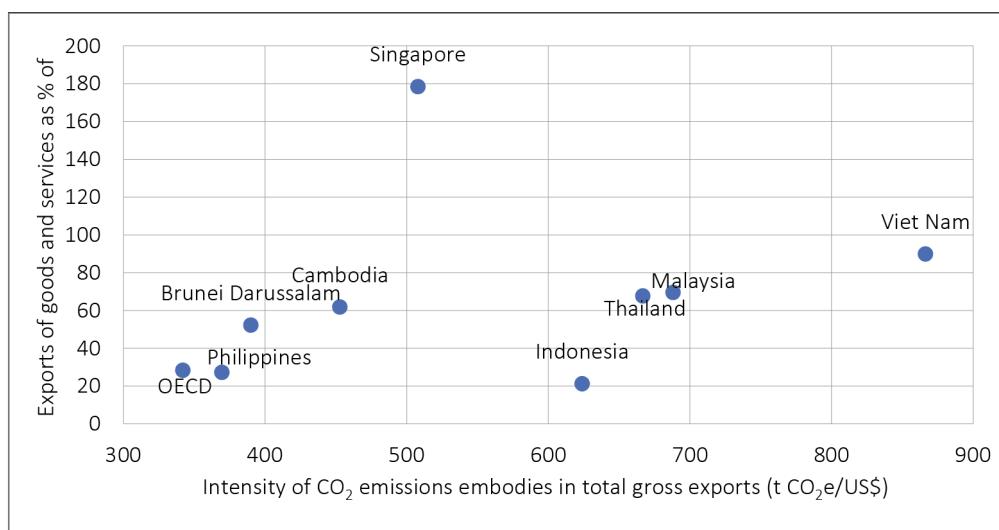


Note: The definition of mineral fuels follows the Harmonized Commodity Description and Coding Systems (HS), where HS27 comprises mineral fuels, mineral oils, and products of their distillation; bituminous substances; and mineral waxes.

Source: Compiled by authors based on calculations with UN Comtrade data.

A decarbonization of the world economy would inexorably also affect Southeast Asian countries' external trade beyond imports and exports of fossil fuels. Figure 33 shows the carbon footprint of exports ($t\text{ CO}_2/\text{US\$}$) plotted against the exports of goods and services as share of GDP for ASEAN countries as well as the OECD average for the year 2015. It clearly shows that the carbon intensity of exports of ASEAN countries is much larger for all ASEAN countries, compared to the OECD average. The exports of Viet Nam, Malaysia, Thailand, and Indonesia have a particularly large carbon footprint. Moreover, Figure 33 also shows that most ASEAN economies are export-dependent, as discussed before. This implies that they are facing large transition risks. For instance, carbon border taxes, as they are currently being discussed in the European Union, could have a significant impact on external revenue and domestic employment, and by implication also on public finances.

Figure 33: Carbon footprint of exports ($t\text{CO}_2\text{e}/\text{US\$}$) vs exports of goods and services as share of GDP (%) for ASEAN countries and OECD in 2015



Note: Data on carbon footprint of exports were not available for Myanmar and the Lao PDR. $t\text{CO}_2\text{e}$ = tons of carbon dioxide equivalent.

Sources: Compiled by authors with data from World Development Indicators and OECD Statistics.

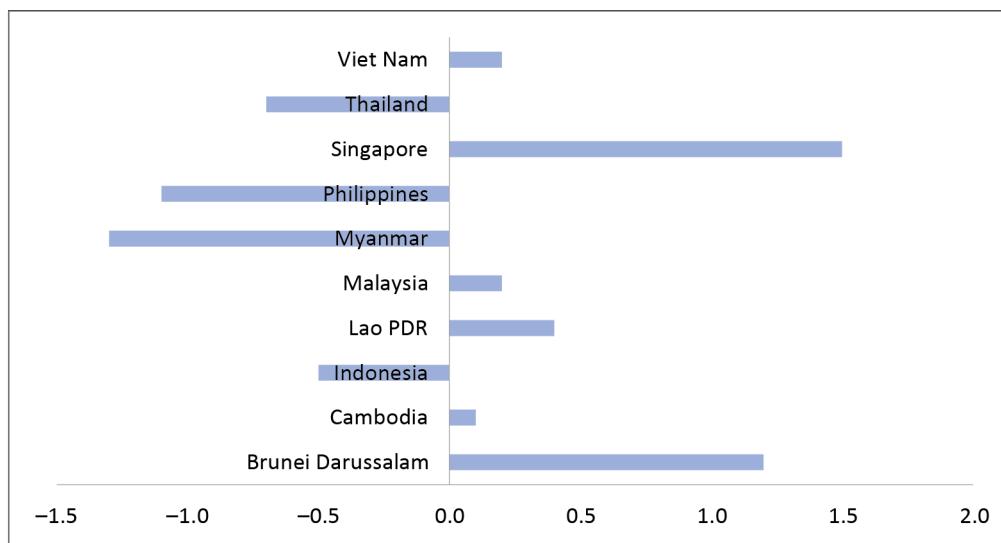
While more granular analysis is certainly needed, several ASEAN countries show vulnerabilities in their external balance to climate-related physical and transition risk. ASEAN economies with a high dependency on carbon-intensive exports and little diversified export sectors—most notably Brunei Darussalam—are particularly at risk. All of them face an increase in heat and water stress, along with an increase in other climate hazards, which may have severely adverse effects on manufacturing exports and participation in regional and global value chains.

4.2.7 Impacts of climate change on political stability

According to S&P (2016, 2), “political developments have the most potential to shape sovereign rating trends in parts of Southeast Asia”. Figure 34 displays the scores of ASEAN countries for an indicator of political stability and absence of violence and/or terrorism from the World Bank’s Worldwide Governance Indicators. This indicator is based on perceptions and should be interpreted with caution, but it does reflect that several ASEAN countries—Myanmar, the Philippines, Thailand, and Indonesia in particular—have been dealing with issues of political instability and/or intrastate violence or terrorism. One should be cautious with making any predictions about future trends regarding political stability as a consequence of climate change, but the literature reviewed in Section 3.7 indicates that

environmental change can accentuate existing social tensions and resource conflicts and cause greater intra- and inter-state migration movements which may contribute to political instability or, in the worst case, even intra- and inter-state conflicts. As highlighted before, climate change is worsening heat and water stress in large parts of Southeast Asia. Not only will a more frequent occurrence of drought cause water shortages, sea level rise will cause an intrusion of saltwater into coastal and groundwater resources, threatening supplies of fresh water for drinking and irrigation.

Figure 34: Political stability and absence of violence and/or terrorism, 2018



Note: The indicator measures perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism. Estimate gives the country's score on the aggregate indicator, in units of a standard normal distribution, i.e. ranging from approximately -2.5 (weak) to 2.5 (strong).

Source: Compiled by authors with data from the World Bank's Worldwide Governance Indicators (World Bank 2019).

There are already numerous examples of prolonged droughts that had devastating effects on livelihoods in Southeast Asia. A severe drought in 2010 saw the water level of the Mekong River falling to its lowest level in 50 years and affected at least 7.6 million people in 59 of Thailand's 76 provinces (Marks 2011). A prolonged drought from early 2015 to mid-2016 caused "an increased level of food insecurity" that affected around 2.5 million people in 18 out of 25 provinces in Cambodia (FAO 2016). Over the last decades, Indonesia also experienced several severe droughts that reduced harvests and threatened food security, including extreme droughts in 1998 (which worsened the socioeconomic situation at a time when Indonesia was facing the economic fallout from the Asian financial crisis) and in 2015 (which caused food shortages in 16 of Indonesia's 34 provinces) (FAO 1998, Dagur 2015). In 2019, Indonesia's Meteorology, Climatology and Geophysics Agency warned that a longer and more intensive dry season that year could threaten food security (Jakarta Post 2019). Rising food prices and food shortages can fuel social tensions and unrest.

Environmental change has already exacerbated social tensions in some areas. For instance, water shortages in Viet Nam gave rise to local conflicts between farmers and other stakeholders (Van Huynh et al. 2019). Examining the case of northern Myanmar, Borras, Franco, and Nam (2020) highlight that climate change and land are linked politically, and show how land rush can incite old and new conflicts both between states and within societies. In an analysis of climate impacts on Thailand, Marks (2011) asserts that climate change will exacerbate the socioeconomic gap between the capital and underdeveloped rural regions, particularly the northeast, and heighten class-related tensions. Social tensions in Thailand may be compounded by internal migration to urban centers and the influx

of climate refugees from poorer neighboring countries (ADB 2012).³³ In Viet Nam, between 2008 and 2015 more than 2 million people were internally displaced by natural hazards (Anh, Leonardelli, and Dipierri 2016).

Climate change is worsening competition over shared water resources, both within countries and across borders. Singapore, for one, is dependent on and vulnerable to Malaysia for its water supplies. Malaysia has several times threatened to cut off Singapore's water supplies. There is also a complex situation around shared water resources involving many nations in the Mekong Delta region (European Parliament 2018), with some even worrying of a rising risk of a "water war" on the Mekong (Hutt 2019). The Mekong River flows from the PRC through Myanmar, the Lao PDR, Thailand, Cambodia, and Viet Nam and provides water, food, and livelihood to more than 60 million people along its banks (Shkara 2018). It has also become a source of tension between neighboring countries. For example, Thailand's plans to divert water from the Mekong to irrigate agriculture in northeast Thailand has caused concerns in Viet Nam about resulting water shortages in the Mekong Delta.

To reduce dependency on fossil energy, countries have been turning to generating hydropower, which can give rise to water conflicts (Klöpper 2008). The PRC has already built several hydroelectric dams along the Mekong, and more are being planned. The Lao PDR has also constructed numerous dams in its quest to export hydroelectricity. The construction of dams often requires large-scale displacement of people, which can cause friction and new land and resource conflicts elsewhere. Moreover, dams have downstream effects as they disrupt the natural cycle and reduce variations between wet and dry seasons, with adverse effects on agricultural production along the riverbanks (European Parliament 2018). Dams also disrupt migration of fish along the river, with potentially adverse effects for fishery. A report by US intelligence agencies has raised concerns that water conflicts along the Mekong would be aggravated by climate change, reducing regional food security, and negatively impacting livelihoods, thereby fueling instability and regional tensions (NIC 2012). The same report also highlighted the potential to use water as a leverage over neighboring countries or even as a weapon, "with more powerful upstream nations impeding or cutting off downstream flow" or governments using water "to pressure populations and suppress separatist elements" (NIC 2012, 4).

Marginalized people are more vulnerable to climate disasters. Regions that face high levels of disaster risk and high economic losses due to disaster tend to cope also with high inequalities of income and opportunity, which can incite social and political tensions. According to UNESCAP (2020), on average the richest quintile of populations in Southeast Asia are 49% less likely to live in high multi-hazard risk areas than the poorest quintile. UNESCAP (2020) highlights that disaster risk can perpetuate inequality and poverty and estimates that 13 million people across ASEAN will remain in extreme poverty by 2030 because of vulnerability to disasters.

Jasparro and Taylor (2008, 232) highlight that climate change could enlarge potential vulnerability to transnational security threats across Southeast Asia as "livelihood and social systems will be pressured, while state and civil society capacity will be strained." (see also Moran 2011). This could strengthen substate networks and enhance violence, crime, smuggling, trafficking, and terrorism, among others. Climate change can also alter the causes and dynamics of violent conflict in Southeast Asia (Nordqvist and Krampe 2018). Increased poverty and reduced state capacity as outcomes of climate-related impacts may provide functional space for terrorist groups to flourish (Smith 2007). A loss of livelihood in coastal areas could also give rise to piracy and threaten maritime security (Germond and Mazaris 2019).

³³ In Indonesia, flood risk in Jakarta led to the government's decision (now postponed) to relocate the capital city to Borneo. This has been described as "one of the first examples of systematic, mass migration expected to occur linked to the climate change crisis" (Van de Vuurst and Escobar 2020, 1).

Overall, this review suggests that potential impacts of unmitigated climate change could indeed destabilize societies by diminishing economic progress in parts of Southeast Asia. The likelihood that this could affect sovereign risk are higher for countries which are already facing issues of political instability and/or intrastate violence or cross-border tensions of resources.

Governments across ASEAN need to work toward climate-proofing their economies and public finances. In addition, scalable social safety nets should be promoted further in Southeast Asia to enable a rapid transmission of financial support to targeted populations following climate-related disasters. At the level of the corporate sector, more efforts need to be made in ASEAN to incorporate science-based targets into business models. ASEAN may consider launching its own regional initiative, similar to the global ‘Climate Action 100+’ initiative, targeting regional corporate greenhouse gas emitters. Related to this, given the interconnectedness of supply chains in Southeast Asia, the corporate sector in the region should be encouraged to clean up their supply chains through the adoption of regional, industry carbon emission standards, as well as financial instruments such as transition bonds. In addition, pension funds in ASEAN should be encouraged to champion the promotion of climate change adjusted investment into their portfolios for the region, such as currently takes places with major pension funds in the US and Europe.

5. Climate Risk and Sovereign Bond Yields: An Econometric Analysis

While there is a rich body of literature analyzing the drivers of the price of sovereign risk, studies have focused on macroeconomic fundamentals as well as international financial contagion. Only recently, a new strand of the literature has emerged that tries to empirically assess the link between climate change and sovereign risk. The first study to systematically analyze the impact of climate change on the cost of sovereign capital is Kling et al. (2018) who show that countries particularly vulnerable to climate change incur a risk premium on their sovereign debt, reducing their fiscal capacity for investments in climate adaptation and resilience.³⁴ In this chapter, we present new research that investigates the relationship between climate vulnerability, resilience and the sovereign cost of capital further, using improved data.

5.1 Overview and main findings

Using a sample of 40 developed and emerging economies—many of which are particularly vulnerable to climate risks due to their geographical location and exposure to climate hazards—econometric evidence is provided to show that climate risks and resilience to these risks have significant effects on the cost of sovereign borrowing. In particular, higher climate risk vulnerability leads to significant rises in the cost of sovereign borrowing. Premia on sovereign bond yields amount to around 275 basis points for economies highly exposed to climate risk, compared to 155 basis points for ASEAN, and 113 basis points for EMEs overall. In contrast, exposure to climate risk is not statistically significant for advanced economies overall. As regards resilience to climate risk, this is statistically significant in reducing bond yields across all country groups, although with magnitudes of less than 10 basis points. Our analysis confirms that climate vulnerability has significant implications for sovereign borrowing costs, and that the direct effects of climate change matter substantially more than climate risk resilience. Furthermore, our results confirm and quantify the magnitude of the much larger effect on bond yields for countries deemed highly vulnerable to climate change. Finally, impulse response analysis suggests that the reaction of bond yields to shocks imposed on climate vulnerability and resilience become permanent after around 12 quarters, and that high-risk economies experience larger permanent effects on yields than other country groups.

5.2 Climate risk vulnerability, resilience to climate risk, and the cost of sovereign borrowing

Across the sample of 40 developed and emerging economies used in our econometric work,³⁵ Figure 35 and Figure 36 demonstrate the relationship between sovereign bond yields and two measures of climate risk: climate risk vulnerability and climate risk resilience. To measure climate vulnerability, we use a refined measure of the Notre Dame Global Adaptation Initiative (ND-GAIN) vulnerability index developed by Kling et al. (2020). The refined vulnerability measure comprises all of the components from the ND-GAIN vulnerability index that are not highly related to economic variables in order to mitigate against endogeneity concerns.³⁶ Data for climate resilience were kindly

³⁴ See also Buhr et al. (2018). In a related study, Kling et al. (2020) use firm-level data and find that climate vulnerability also affects the cost of corporate financing and access to finance, controlling for various firm-specific and macroeconomic factors.

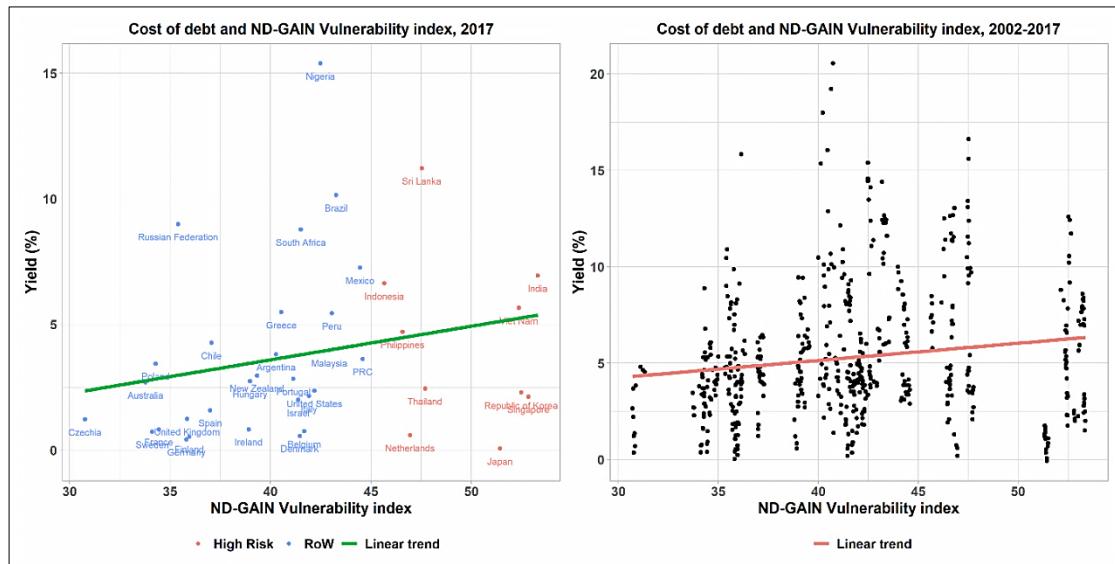
³⁵ Please refer to Table A.1 in the Appendix for the list of countries.

³⁶ The original ND-GAIN vulnerability index (Chen et al. 2015) comprises three core measures: (i) the extent to which an economy is exposed to significant climate change from a biophysical perspective; (ii) the degree to which an economy is

Climate Change and Sovereign Risk

provided by FTSE Russell. This indicator refers to the extent to which an economy has measures in place to address exposure to climate risks.

Figure 35: Cost of sovereign debt and climate risk vulnerability, 2002–2017

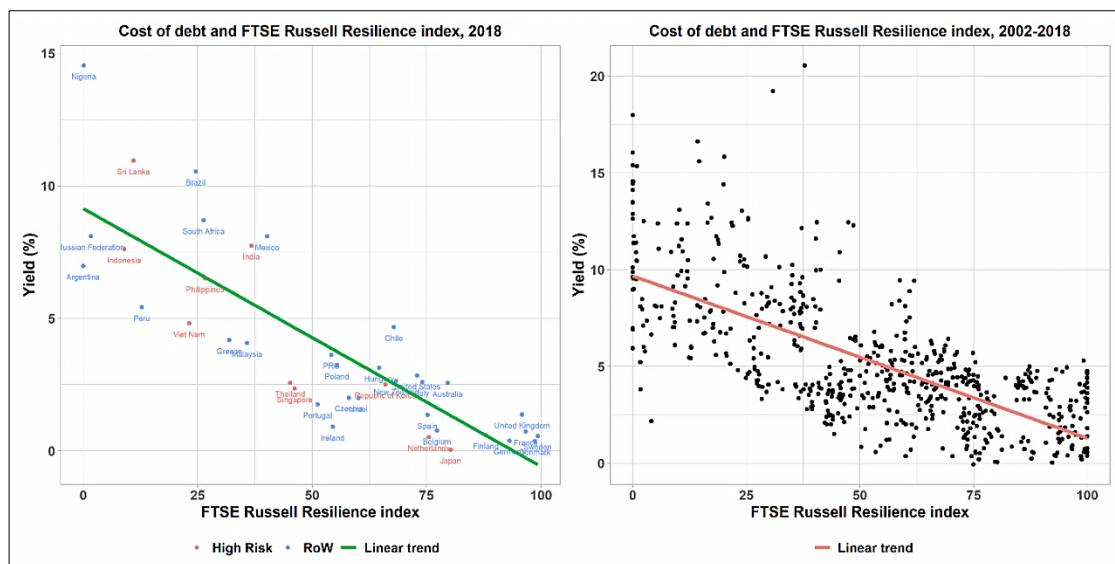


RoW = rest of the world.

Note: High risk countries denote those countries that are in the highest quartile for exposure to climate risk.

Source: Compiled by authors with data from Bloomberg, FTSE Russell, ND-GAIN (2020), and Kling et al. (2020).

Figure 36: Cost of sovereign debt and climate risk resilience, 2002–2018



RoW = rest of the world.

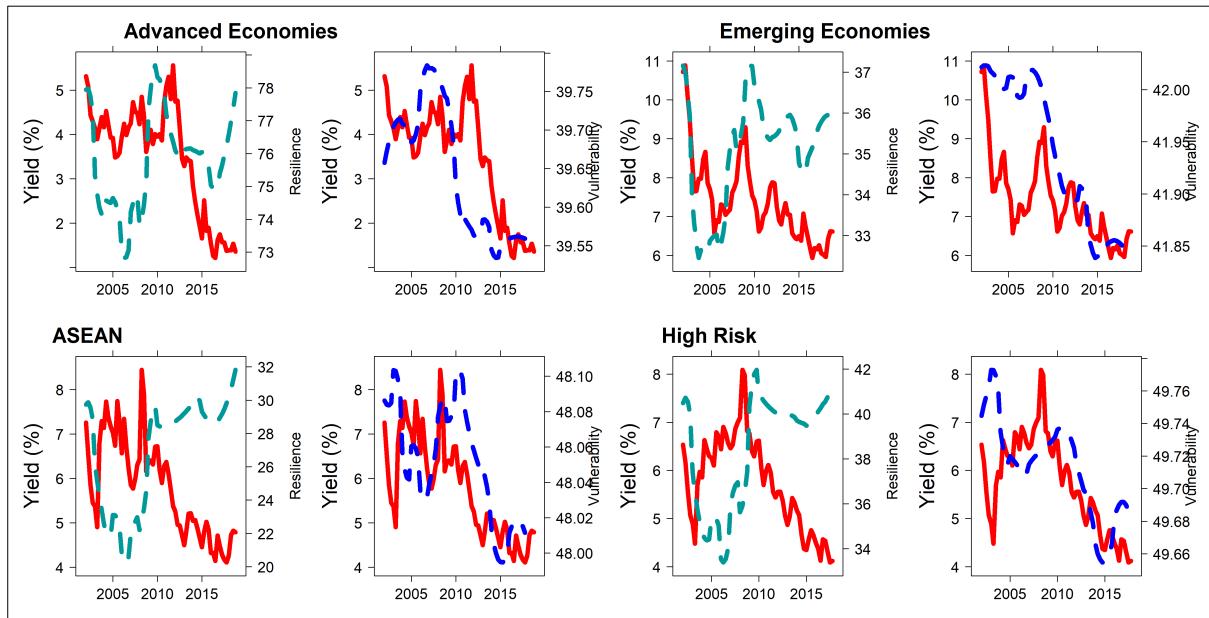
Note: High-risk countries denote those countries that are in the highest quartile for exposure to climate risk.

Source: Compiled by authors with data from Bloomberg, FTSE Russell, ND-GAIN (2020), and Kling et al. (2020).

dependent upon sectors that are particularly sensitive to climate change; and (iii) the extent of an economy's adaptive capacity to climate change. This measure can therefore be interpreted as an overall measure reflecting both physical and transition climate-related risks. We use the refined measure by Kling et al. (2020) which strips out measures that are highly correlated with macroeconomic variables, so that the new vulnerability index is less correlated with countries' financial or economic conditions, which might cause endogeneity.

Figure 37 shows that vulnerability to climate risk is positively related to sovereign bond yields. This appears to be particularly the case for emerging economies (EMEs) in the high-risk category, i.e. countries in the top quartile for climate risk exposure. In Figure 37 also displays a negative relationship between yields and resilience. Economies that have in place measures that enable them to combat the negative effects of climate change tend to have lower sovereign bond yields. The positive relationship between bond yields and climate risk vulnerability, and the negative relationship between bond yields and climate risk resilience, also holds across our sample of countries grouped according to region and high risk.

Figure 37: Sovereign bond yields, climate risk, and resilience by country grouping



Note: **Red** line refers to the government bond yield in percent. **Blue** dashed line refers to the vulnerability. **Dark Green** dashed line refers to the resilience.

Source: Compiled by authors with data from Bloomberg, FTSE Russell, ND-GAIN (2020), and Kling et al (2020).

Having established the directional priors for the relationship between sovereign bond yields and climate risk vulnerability, and climate risk resilience, we then conduct a formal econometric analysis, based on the methodology described in Box 3.

5.3 Empirical results

The results from our empirical analysis provide evidence that the cost of sovereign borrowing is particularly exposed to climate risk vulnerability, while resilience to climate risk has only a very small (but statistically significant) effect on sovereign bond yields. Figure 38 plots, for the full sample of 40 countries as well as sub-groups, the coefficients of the two climate risk measures from the panel model estimation described in the methodology.³⁷

³⁷ For purposes of exposition, we present only the coefficients of the climate risk measures. Please refer to Table A.2 in the Appendix for the full set of coefficients across all regressors.

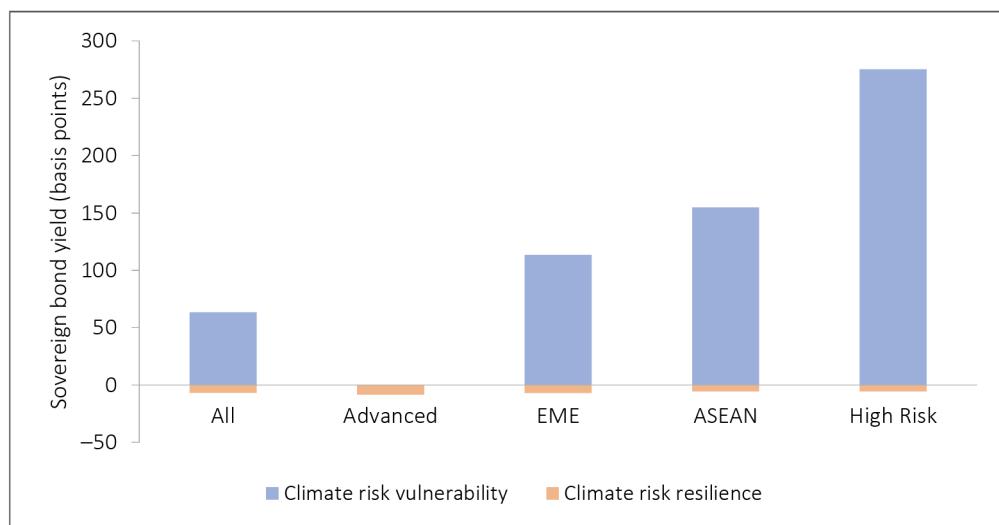
Box 3: Methodology and data

In order to empirically test the relationship between the cost of sovereign borrowing and climate risk, we employ two econometric approaches. First, using a quarterly data frequency, we use a fixed effects panel model over the period from 2002Q1 to 2018Q4 across 40 developed and emerging economies. As well as a subpanel for the member countries of ASEAN, we also examine a subpanel based on economies characterized as having high climate-related risks, defined as being in the top quartile for risk exposure. The panel model estimated enables us to assess the effect of climate risk vulnerability and resilience to climate risk on sovereign bond yields, controlling for a large set of domestic macroeconomic factors and two global factors. Second, a structural panel vector autoregression (VAR) is used to examine the response of sovereign bond yields to shocks to climate vulnerability and resilience. Crucially, these shocks also control for a range of macroeconomic fundamentals and global factors. The panel SVAR is implemented across the same 40 countries as in stage one, but over the period from 2007Q1 to 2017Q4 in a balanced setup.

Drawing on the literature that examines the drivers of sovereign bond yields and the price of sovereign risk, the domestic macroeconomic controls include the current account balance/GDP, public debt/GDP, the fiscal balance/GDP, GDP per capita, GDP growth, and a domestic crisis dummy. The global factors comprise the Chicago Board Options Exchange's Volatility Index (VIX) as a measure of global financial market uncertainty and US sovereign bond yields. These variables have been attained from Bloomberg, the IMF International Financial Statistics, the OECD, and China Economic Database (CEIC). Regarding the climate vulnerability indicator, data for vulnerability to climate risk are taken from a refined version of the ND-GAIN vulnerability index developed by Kling et al. (2020). The refined vulnerability measure comprises all of the components from the ND-GAIN vulnerability index that are not highly related to economic variables in order to mitigate against endogeneity concerns. Data for climate resilience are from FTSE Russell. This indicator refers to the extent to which an economy has measures in place to address exposure to climate risks.

For further details on the methodology employed and data used, please refer to the Appendix. In addition, a technical background paper upon which the analysis is based is available (Beirne, Renzhi, and Volz 2020a). For country-specific analysis for ASEAN countries see Beirne, Renzhi, and Volz (2020b).

Figure 38: The impact of climate risk vulnerability and climate risk resilience on the cost of sovereign borrowing



EME = emerging economies.

Note: The y-axis refers to the climate risk coefficients from the estimation of the panel model on sovereign bond yields, expressed in basis points.

Source: Authors' estimations.

Across all countries as a whole, controlling for domestic and global factors, it is clear that vulnerability and resilience to climate risks have significant effects on sovereign bond yields. Increases in vulnerability and lower resilience to climate risks lead to rises in bond yields. As shown in Figure 38, the premium on sovereign bond yields from rising climate risk vulnerability is highest for the high-risk group at 275 basis points, compared to 155 basis points for ASEAN and 113 basis points for other EMEs. The effect of vulnerability on bond yields for developed economies is not statistically significant. As regards climate risk resilience, the magnitude of the effect on bond yields is substantially lower than that of climate risk vulnerability, with higher resilience associated with declines in bond yields by fewer than 10 basis points across all country groups.

The results are striking in two main ways. First, it is apparent that vulnerability to climate risk matters substantially more for the cost of sovereign borrowing than resilience to climate risk. In other words, exposure to the direct effects of climate change remains key, with a sizable and significant impact on the cost of sovereign debt for developing and emerging economies. Improving resilience efforts further may help to combat exposure to these direct effects and hence bring down the cost of sovereign financing. Second, it is clear that the magnitude of the effect on bond yields is notably higher for economies that are more exposed to climate risks. In particular, the effect on bond yields for the high risk group is higher than for EMEs as a whole by a factor of about three, and higher than for ASEAN by a factor of around two. Our findings therefore suggest that those economies that are particularly exposed to climate change and have the greatest need for resilience investment face the highest climate risk premium on their sovereign borrowing costs. Given that a significant share of the financing of adaptation and vulnerability reduction measures would have to be borne by the public sector, a higher cost of borrowing could severely hamper these crucial investments. The results from our empirical analysis are also robust to alternative measures of climate risk vulnerability, namely the FTSE Russell measures for physical and transition climate risks.

As regard to the results from the impulse response analysis, we find that across the sample of 40 countries, sovereign bond yields respond positively to a positive shock imposed on climate risk vulnerability, and negatively to a positive shock on resilience, in line with economic intuition. The shock becomes permanent after around 12 quarters. The direction of the effect of the shocks on bond yields is consistent across each of our sub-panels. Moreover, and in line with our stage one analysis, the magnitude of the effect on bond yields is notably larger for economies in the high risk category.³⁸

For the high-risk economies, the upward effect on yields of the vulnerability shock peaks at around six quarters, while for ASEAN and other EMEs, the peak is reached at a longer duration of around 15–18 quarters, albeit with lower magnitudes. The upward reaction of developed economy bond yields also peaks after around six quarters. For shocks to climate risk resilience, the downward response of yields is most pronounced after around six quarters for EMEs, ASEAN, and the high risk group, with developed economy bond yields peaking downward much more quickly after around two quarters. Given that the effect of climate risk vulnerability and resilience to climate risk on sovereign bond yields is not transitory and does not subside over time, this underscores the importance for policy makers to ramp up efforts aimed at mitigating the effects of physical climate risks. Without such action, the negative ramifications for fiscal sustainability and, as a result, economic growth could be substantial.

³⁸ Please refer to Figure A.1 in the Appendix for further details on the SVAR impulse response results.

6. What Are the Implications for Macrofinancial Governance?

From the preceding analysis it should be clear that climate change can have a material impact on sovereign risk. However, both the analysis of the various transmission channels in Chapter 3 and the illustration of these risk channels for the countries of Southeast Asia in Chapter 4 have shown the complexity of the nexus between climate change and sovereign risk. Just as it is impossible to capture these medium- to long-term risks adequately in a handful of indicators or develop a comprehensive model that will reliably forecast sovereign risk, there are no easy policy fixes. Appropriate public policy responses will have to comprise a broad range of measures to minimize macrofinancial risk, while at the same time building capacities to better manage risk and developing contingency plans. Efforts have to involve all parts of government, including monetary and financial authorities.

The five areas in which climate-related financial risks should be addressed in a coordinated manner are:

1. conduct a comprehensive vulnerability assessment and develop a national adaptation plan;
2. mainstream climate risk analysis in public financial management;
3. adjust monetary and prudential frameworks to account for climate risks;
4. implement financial sector policies to scale-up investment in climate adaptation and resilience and develop insurance solutions; and
5. provide international support to mitigate and manage climate-related sovereign risk.

6.1 Conduct a comprehensive vulnerability assessment and develop a national adaptation plan

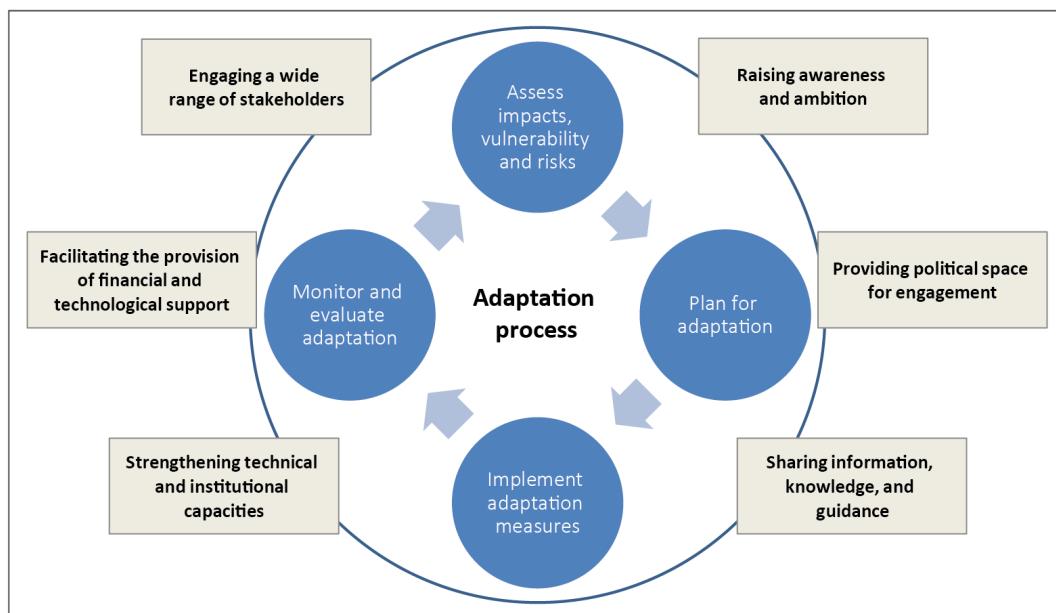
The starting point ought to be a comprehensive vulnerability assessment, where all sources of vulnerability for the macroeconomy, the financial system, and public finances are systematically assessed and possible actions are considered. A vulnerability assessment should comprise a scenario analysis of climate and socioeconomic change and address both physical and transition risks. Importantly, it needs to consider short-term and long-term risks, including those usually beyond the horizon of policy makers. Such an assessment could be conducted by a dedicated national climate risk board that should include the central bank and supervisor along with key government departments responsible for finance, economy, planning, agriculture, among others. It should also seek input from science and civil society. The vulnerability assessment should form the basis for a number of subsequent, coordinated actions aimed at mitigating and managing climate-related sovereign risks.

Vulnerability to climate change is defined by the IPCC as “[t]he degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.” (McCarthy et al. 2001, 995). Vulnerability is dynamic and depends on adaptation strategies taken in response to the exposure. A vulnerability assessment shall help to recognize the degree to which a system is subject to potential risks, the likely impacts, and how capably it can cope with these. A vulnerability assessment needs to identify the major macrofinancial risks discussed in Chapter 3, their likelihood under different scenarios, and the priority with which they should be dealt. Vulnerability assessments ought to be a continuous process that will get refined over time as methodologies and data availability improve. Indeed, trying to improve the availability and accuracy of various climate vulnerability indicators needs to be a key component of the vulnerability assessment process. Based on an assessment of the

level of exposure to the various risks, it needs to consider possible responses that will help to minimize or avoid risk. These will form an adaptation strategy.

Many countries have already established a national climate change commission or committee on climate change policy that has developed or is working toward a national adaptation plan (NAP). The NAP process was established by the United Nations Framework Convention on Climate Change (UNFCCC) under the Cancun Adaptation Framework to feed into nationally determined contribution (NDC) adaptation goals. NAPs are meant “as a means of identifying medium- and long-term adaptation needs and developing and implementing strategies and programmes to address those needs” (UNFCCC 2020b). Adaptation processes are continuous, progressive, and iterative (Figure 39). The bodies developing NAPs usually include finance ministries, given the fiscal implications, but in most cases central banks and supervisors are not involved as climate change was until recently considered to be outside their remit. However, it is crucial that monetary and financial authorities contribute to the development of NAPs to make sure that macrofinancial risks are properly accounted for in vulnerability assessments and also that appropriate strategies to reduce and manage macrofinancial risks are adequately included in the NAPs.

Figure 39: Adaptation cycle under the United Nations climate change regime



Source: Compiled by authors based on UNFCCC (2020a).

6.2 Mainstream climate risk analysis in public financial management

Climate change requires extending time horizons in public administration. To this end, it is of crucial importance that financial planning extends beyond the annual budgeting cycle, and that administrations consider the potential impacts of climate change on the medium- to long-term quality and sustainability of public finances. To mitigate climate-related sovereign risks, climate risks need to be considered at all levels of public financial management.

Vulnerability assessments should feed into macroeconomic impact analysis and forecasting, which are an integral part of the annual budget process. However, it is important that the analysis and the budget planning goes beyond the short term and includes also medium- and long-term risks to the budget, so that potential risks on both the expenditure and revenue side are identified. As in the vulnerability assessment, both physical and transition risks should be considered. Moreover, finance ministries need to enhance transparency, develop their budgetary instruments, enhance public sector funding and debt management strategies, and diversify government revenue streams away from high-risk sectors.

Disclose and analyze climate risks

As part of its recommendations for fiscal risk analysis and management, the IMF's (2019b, 3) Fiscal Transparency Code recommends that "governments should disclose, analyze, and manage risks to the public finances and ensure effective coordination of fiscal decision-making across the public sector". Among the specific risks to public finances that "should be regularly monitored, disclosed, and managed", the IMF lists "the volume and value of major natural resource assets under different price and extraction scenarios", as well as "the main fiscal risks from natural disasters" (IMF 2019b, 14–15). Regarding the former, it will be important to include stranded asset risk facing resource rich countries. More broadly, all of the risk channels discussed earlier need to be considered.

The IMF recommends the systematic incorporation of natural disaster risks into the budget process with a medium-term perspective (Cevik and Huang 2018). It also recommends the analysis of disaster risks in the context of a fiscal risk statement as part of the Medium-Term Fiscal Framework (Cevik and Huang 2018).³⁹ The IMF's Fiscal Transparency Code also recommends that governments regularly publish "multiple scenarios for the sustainability of the main fiscal aggregates and any health and social security funds over at least the next 30 years using a range of macroeconomic, demographic, natural resource, or other assumptions" as part of a Long-term Fiscal Sustainability Analysis (IMF 2019b, 13). Going forward, all major climate risks should become a central part of such a long-term fiscal sustainability analysis, which should become standard procedure for all countries. For the time being, only a few countries conduct meaningful long-term fiscal sustainability analysis, and many countries lack the capacity and expertise to do so. Hence, it will be important that the IMF and other international financial institutions contribute to the development of such capacities.

Develop budgetary instruments to account for climate risk

Building on fiscal risk analysis, budget planning should build in fiscal buffers for climate-related risks. The most commonly used budgetary instruments for *ex ante* disaster financing are contingency lines and disaster, reserve or contingency savings funds (Cevik and Huang 2018, Schuler et al. 2019). Contingent credit lines are offered by international financial institutions to support relief, recovery, and reconstruction efforts after natural disasters. Contingency savings funds have been created in countries facing high risk of natural disasters. Countries may also seek insurance and risk transfer solutions, for example through parametric insurance for weather-related risks or catastrophe insurance schemes that spread risks across countries.⁴⁰

³⁹ The World Bank also recommends incorporating forward-looking assessments of future climate shocks into the scenario analysis that provides the basis of fiscal risks statements (Schuler et al. 2019).

⁴⁰ Parametric insurance pays a fixed amount when a qualifying event occurs. A prominent example of a multi-country catastrophe insurance scheme is the Caribbean Catastrophe Risk Insurance Facility. However, a weakness of such regional schemes is that countries tend to face the same risks, which make it important to broaden risk pools (Schuler et al. 2019).

Mainstream and integrate climate framework, policies, and laws into national and sectoral budgets

Going further, long-term budget planning needs to account for the estimated costs of NAPs and climate policies more broadly, including for mitigation, as laid out in country NDCs. Public financial management should mainstream and integrate national climate policies and legislation in the budgetary process (EFI, CPI, and UNDP 2019). In particular, it needs to ensure that spending is redirected from activities that are not aligned with the national climate finance strategy to activities that are consistent. Two tools that can support the mainstreaming of climate policies in budgets are climate budget tagging, where all climate-relevant budget expenditures are marked, and climate public expenditure and institutional reviews, which are a systematic qualitative and quantitative assessments of a government's public expenditures, policies, and institutional frameworks regarding climate change (EFI, CPI, and UNDP 2019).

Develop public sector funding and debt management strategies

Climate risks should also be integrated in public sector funding and debt management strategies. For developing countries, international climate finance is an important source of funding for adaptation and mitigation investment. In countries that are vulnerable to climate hazards or other natural shocks, governments can issue debt instruments with risk-sharing features that would help them to better manage risks. For instance, governments can include natural disaster or "hurricane" clauses in new public debt instruments. These stipulate that capital and/or interest payments are deferred in the event of a pre-defined disaster. During a debt restructuring in 2015, Grenada was the first country to pioneer a hurricane clause in its bonds. Barbados has also included a natural disaster clause in most of its new public debt to increase financial resilience (Anthony, Impavido, and van Selm 2020; Shutter 2020). Together with the IMF and the World Bank, the International Capital Market Association, a trade association for participants in the capital markets, has developed indicative terms and conditions for sovereign hurricane-linked bonds and loans (IMF 2020, ICMA 2020). Disaster clauses could be promoted as the new standard in sovereign debt. Governments could also issue GDP-linked bonds (Benford, Ostry, and Shiller 2018), a risk-sharing debt instrument that extends beyond disaster risks.

Diversify government revenue streams away from high-risk sectors

Last but not least, public finance needs to fund, support, and incentivize investment in adaptation and resilience that will help to reduce a country's exposure and vulnerability to climate risks (Forni, Catalano, and Pezzolla 2019). An important area are public investments in climate-resilient infrastructure (OECD, World Bank, and UN Environment 2018). Moreover, fiscal policy should help to advance structural change to diversify the economy out of climate-sensitive activities (Schuler et al. 2019). This is particularly relevant for economies whose prosperity depends to a large extent on fossil fuels that are likely to be stranded (Cust, Manley, and Cecchinato 2017). Governments also need to develop effective social safety nets to cushion adverse physical and transition impacts on the population, especially more vulnerable groups. Governments should also seek to climate-proof public assets to reduce the direct exposure to possible future losses (Bonen et al. 2016) and lessen the dependency of their own revenue streams on climate-sensitive activities.

For the time being, most governments are in early stages of climate-proofing public finances. But awareness is rising, as shown by the formation of the Coalition of Finance Ministers for Climate Action, which was launched in April 2019 and which now comprises 52 countries that represent 30% of global GDP and that are responsible for 16% of global CO₂ emissions. In the Helsinki Principles, the Coalition of Finance Ministers for Climate Action (2019) has committed to “[t]ake climate change into account in macroeconomic policy, fiscal planning, budgeting, public investment management, and procurement practices”.⁴¹ Likewise, the finance ministries of the Climate Vulnerable Forum—a group of 48 countries vulnerable to climate change—work together to address climate-related challenges and mobilize support from the international community.

6.3 Adjust monetary and prudential frameworks to account for climate risks

Central banks and financial supervisors need to play an important role in supporting governments in analyzing macrofinancial risks arising from climate change. But they also need to address climate-related risks in their monetary and prudential frameworks and operations. Mainstreaming climate-financial risk assessment in financial contracts is crucial for aligning finance flows with a pathway toward low greenhouse gas emissions and climate-resilient development, as stipulated in Article 2.1c of the Paris Agreement. Financing the global energy transition and low-carbon, sustainable development requires the mainstreaming of climate-financial risk assessment in financial contracts and substantial changes in financial governance (UNEP Inquiry 2016; Volz 2017; Battiston, Mandel, and Monasterolo 2019; Dikau and Volz 2020). Importantly, monetary and financial authorities need to fully integrate climate risks into their prudential and monetary frameworks.

Central banks and supervisors need to implement a comprehensive agenda for addressing climate-related risks (Monasterolo and Volz 2020). Such an agenda should include the mandatory disclosure of climate and other sustainability risks across the financial sector to help with better risk analysis, require financial institutions to conduct regular climate stress-testing that considers multiple transition scenarios, and the integration of climate-related financial risks into prudential supervision. The implementation of prudential instruments that account for climate risks is imperative to minimize the potential build-up of additional risks in portfolios.

Table 22 shows a toolbox with three broad categories of measures—monetary, prudential, and other—covering nine types of tools that central banks and supervisors could employ to minimize climate-related risks for individual financial institutions and the financial system at large and to support the scaling-up of investment in climate adaptation and mitigation (Dikau, Robins, and Volz 2020). Not all instruments will be adequate for all countries, but a discussion is needed among central banks and supervisors on how their operational frameworks and policy tools can be adapted to mitigate climate risks and support a low-carbon transition of the economies they serve.

⁴¹ The shared Principles of the Coalition of Finance Ministers for Climate Action were drafted in Helsinki in February 2019. The six Helsinki Principles are: 1. Align our policies and practices with the Paris Agreement commitments; 2. Share our experience and expertise with each other in order to provide mutual encouragement and promote collective understanding of policies and practices for climate action; 3. Work towards measures that result in effective carbon pricing; 4. Take climate change into account in macroeconomic policy, fiscal planning, budgeting, public investment management, and procurement practices; 5. Mobilize private sources of climate finance by facilitating investments and the development of a financial sector which supports climate mitigation and adaptation; and 6. Engage actively in the domestic preparation and implementation of Nationally Determined Contributions (NDCs) submitted under the Paris Agreement (Coalition of Finance Ministers for Climate Action 2019).

Table 22: Toolbox of sustainable monetary policy, prudential, and other measures for central banks and supervisors

	Conventional (sustainability-blind) calibration	Sustainability-enhanced calibration
1. Monetary policy		
(1) Collateral frameworks	<ul style="list-style-type: none"> Collateral credit quality is assessed based on conventional methods, perpetuating exposure to and market mispricing of climate risks and carbon bias and maintaining financing conditions for industries not aligned with the Paris Agreement. 	<ul style="list-style-type: none"> Collateral frameworks become carbon-neutral, take climate- and other sustainability-related financial risks into account and apply haircuts to account for these risks. Collateral frameworks exclude asset classes that are not aligned with sustainability goals such as the Paris Agreement.
(2) Implement monetary policy: indirect instruments (open market operations, standing facilities, reserve requirements)	<ul style="list-style-type: none"> Standard instruments such as refinancing operations and programs are calibrated without sustainability considerations, leading to a potential carbon bias. 	<ul style="list-style-type: none"> Align refinancing operations with sustainability goals such as the Paris Agreement. Differentiated reserve requirements, risk weights, accounting for carbon footprint, climate-related financial risk (particularly transition risks), or other sustainability factors. Interest rates based on sustainability criteria.
(3) Nonstandard instruments	<ul style="list-style-type: none"> Asset purchase programs ignore climate- and other sustainability-related financial risks, perpetuating financial markets' exposure to climate risks and carbon bias. Direct (short-term) credit to the government to support standard fiscal spending. Helicopter money without conditionality. 	<ul style="list-style-type: none"> Asset purchase programs exclude carbon-intensive assets. Direct (short-term) credit to the government to support sustainable and/or Paris Agreement-aligned fiscal policies. Purchase of green sovereign bonds. Helicopter money conditioned on sustainable and/or Paris Agreement-aligned spending.
(4) Direct credit allocation instruments*	<ul style="list-style-type: none"> Direct controls on interest rates (e.g. minimum and maximum interest rates, preferential rates for certain loan categories). Credit ceilings (at aggregate level or on individual banks). Directed lending policies (e.g. preferential central bank refinance facilities to direct credit to priority sectors). Window guidance and/or moral suasion to promote priority sectors. 	<ul style="list-style-type: none"> Credit interest rate ceilings for sustainable priority sectors, asset classes, and firms. Minimum and/or maximum allocation of credit through credit ceilings or quotas to restrict and/or promote lending to carbon-intensive and/or sustainable sectors Targeted refinancing lines to promote credit for sustainable sectors. Window guidance and/or moral suasion to promote lending to sustainable sectors.
2. Financial stability: Regulation and supervision		
(5) Microprudential instruments	<ul style="list-style-type: none"> Conventional stress testing and/or excessive delay of climate-stress testing. No disclosure requirements for climate-related financial risks. Standard supervisory review process. Conventional calibration of other Basel III instruments. 	<ul style="list-style-type: none"> Stress testing frameworks that acknowledge climate and other sustainability risks and help firms take into account longer-term risks. Mandatory disclosure requirements for climate-related financial risks or other sustainability risks. Supervisory review process that highlights management of climate-related financial risks or other sustainability risks. Climate risk-sensitive calibration of other Basel III instruments, distinguishing between low-carbon and carbon-intensive and/or high-exposure assets to create buffers against climate-related losses (e.g. differential risk-based capital requirements, lower required stable funding factor for green loans).

continued on next page

Table 22 *continued*

	Conventional (sustainability-blind) calibration	Sustainability-enhanced calibration
(6) Macroprudential instruments	<ul style="list-style-type: none"> • Conventional system-wide stress testing. • Calibration of instruments along the cyclical dimension without explicit acknowledgment of climate-related financial risks. • Calibration of instruments along the cross-sectional dimension without explicit acknowledgment of climate-related financial risks. 	<ul style="list-style-type: none"> • System-wide stress testing that acknowledges and assesses systemic climate-related financial risks. • Cyclical instruments calibrated to account for and mitigate systemic risk implications of climate change and restrain the build-up of risk-taking during the recovery and/or expansion phase (e.g. countercyclical and higher capital buffer in order to protect the financial sector from periods of excessive carbon-intensive credit growth, loan-to-value ratios and loan-to-income ratios to limit the extension of credit by banks to carbon-intensive industries and investment in non-sustainable asset classes). • Cross-sectional instruments calibrated to account for and mitigate systemic risk implications of climate change and to mitigate individual institutions' contribution to systemic risk (e.g. large exposure restrictions to limit financial institutions' exposure to high carbon-intensive assets, capital surcharges for systemically important financial institutions and institutions with high exposure to carbon-intensive assets).
3. Other policies		
(7) Further financing schemes and other initiatives	<ul style="list-style-type: none"> • Corporate financing facilities or loan guarantees without climate or sustainability conditionality. • Financial sector bailouts without climate or sustainability conditionality. 	<ul style="list-style-type: none"> • Corporate financing facilities or loan guarantees subject to reduction of CO₂ emissions or sustainability enhancing activities. • Incorporation of sustainability considerations into bailout packages in case of partial or full nationalization of financial institutions. • Funding sustainable lending and/or investment schemes by public banks and development finance institutions (e.g. for renewable energy or retrofitting of buildings) through refinancing credit lines or purchase of bonds under asset purchase programs in secondary market or direct refinancing operations. • Tailoring of supervisory frameworks for development banks to enhance their public policy capacity to bear risk, promote economic transformation.
(8) Management of central bank portfolios	<ul style="list-style-type: none"> • Management of central bank portfolios without consideration of climate change and other sustainability risks. 	<ul style="list-style-type: none"> • Disclosure of climate-related financial risks in own portfolios. • Adopting sustainable and responsible investment principles for portfolio management.
(9) Supporting sustainable finance		<ul style="list-style-type: none"> • Sustainable finance roadmaps and/or guidance for financial institutions. • Advice and dialogue with other parts of the government. • Research and publication of handbooks and resources (e.g. reference scenarios, risk assessment methodologies). • Capacity building programs in sustainable finance for the financial sector, convening role of central banks.

Note * Direct instruments, which are mostly relevant in the emerging market and developing economy context where underdeveloped financial markets permit the effective employment of indirect instruments, operate by setting or limiting either prices or quantities through regulations and may also be used to allocate credit. Furthermore, it is important to note that the calibration of many central banking and supervisory instruments can have intended or unintended consequences for the allocation of credit.

Source: Dikau, Robins, and Volz (2020).

Reconsider the prudential treatment of sovereign exposures in financial regulation

With respect to the prudential treatment of climate-related sovereign risks, it is important to highlight the relevance of sovereign assets for systemic financial stability. In many countries, a significant share of banking assets is invested in domestic sovereign debt, and exposures are twice as large when lending to subnational governments, loans and receivables, and sovereign guarantees are considered (Jobst and Oura 2020). Sovereign exposures of banks tend to be higher in developing and emerging economies (Jobst and Oura 2020)—where climate risks tend to be higher too. As previously discussed, sovereign risk can directly affect financial stability, and a worsening of sovereign risk can lead to a doom loop between worsening sovereign risk and banking risk, as seen during the euro crisis. It is therefore important to integrate sovereign risk into macroprudential solvency stress testing (Jobst and Oura 2020). For the reasons discussed throughout this report, such stress testing needs to integrate various climate scenarios.

What is more, supervisors need to reconsider the treatment of sovereign exposures. As noted by the Basel Committee on Banking Supervision, under the current Basel regulatory framework for banks (Table 23), “[i]n most cases, the existing treatment of sovereign exposures is more favourable than [of] other asset classes” (BCBS 2017, 18). In particular, the risk-weighted framework allows supervisors to exert discretion “to apply a preferential risk weight for sovereign exposures denominated and funded in domestic currency” (BCBS 2017, 18). Moreover, the large exposures framework exempts banks’ exposures to sovereigns and central banks. Last but not least, no limits or haircuts are applied to domestic sovereign exposures that are deemed high-quality liquid assets as part of the liquidity standards. In other words, sovereign debt is in most cases treated as a safe asset, which in many cases is not a reflection of actual risk.

Table 23: Summary of current regulatory treatment of sovereign exposures under the Basel regulatory framework

Credit risk: standardized approach
Ratings-based look-up table.
National discretion to apply a preferential default risk weight for sovereign exposures denominated and funded in domestic currency.
Credit risk: internal ratings-based approach
Exemption of 0.03% probability of default floor for sovereign exposures.
Credit risk: credit risk mitigation framework
National discretion to apply a zero haircut for repo-style sovereign transactions with core market participants.
Revised market risk framework
Standardized approach: national discretion to apply a preferential default risk charge for sovereign exposures denominated and funded in domestic currency.
Internal models approach: sovereign exposures included in models, including default risk models.
Large exposures framework
Exemption of sovereign exposures.
Leverage ratio framework
Inclusion of sovereign exposures.
Liquidity standards
No limits on amount of domestic sovereign debt eligible as high-quality liquid assets, with no haircuts applied.

Source: BCBS (2017).

Even in the absence of climate risk, the treatment of sovereign debt as risk free assets is highly problematic. Climate change is making this even more perilous. The high-level Task Force on Climate-related Financial Risks, which was established by the Basel Committee on Banking Supervision in October 2019, should consider how climate-related risks could be adequately reflected in the Basel framework. Likewise, regulation for the treatment of sovereign exposure for institutional investors should adequately reflect climate risks.

6.4 Implement financial sector policies to scale-up investment in climate adaptation and resilience and develop insurance solutions

As discussed, to minimize exposure to climate-related risks and to support the mobilization of private capital for adaptation and mitigation finance, financial sector activities need to be aligned with climate goals. Financial authorities need not only to play a role in incorporating climate risks in prudential and monetary policy, they also need to support the scaling-up of sustainable finance and, especially in developing economies, the mobilization of domestic resources for financing sustainable infrastructure and adaptation.

While foreign aid and foreign private capital can be an important source of finance for development, it is important to acknowledge the limits to the role of foreign capital in financing infrastructure and the financial vulnerability risks associated with foreign private financial flows (Chen and Volz 2020). It is also important to make better use of domestic savings in developing and emerging economies, many of which invest significant amounts of their savings in low-yielding assets in the financial centers of developed economies. Strengthening domestic resource mobilization is therefore crucial, and concerted efforts to this effect are needed.

Since the emerging market crises of the late 1990s and early 2000s, progress has been made in developing local currency bond markets (Burger, Warnock, and Cacdac Warnock 2012; Berensmann, Dafe, and Volz 2015; Dafe, Essers, and Volz 2018). Yet, these are in part still very dependent on foreign investors. The large-scale withdrawal of international capital from emerging economies' bond markets in March 2020 has once again highlighted the vulnerabilities associated with a shallow domestic investor base and a heavy reliance on international portfolio investors (Hofmann, Shim, and Shin 2020; Beirne et al. 2020). There clearly is a need to further develop local currency capital markets with a strong domestic investor base. Monetary and financial authorities can play an important role in building these markets, and make sure that these can be used for long-term financing of sustainable infrastructure. They can also support the development of fintech in mobilizing domestic savings and channeling these into sustainable investments (Chen and Volz 2020; Task Force on Digital Financing of the Sustainable Development Goals 2020).

Monetary and financial authorities can play a supportive role in developing insurance markets. The need for governments to provide support for recovery and reconstruction will be greater if large parts of the economy lack insurance. Greater insurance coverage will enhance the financial resilience of households and businesses. As pointed out by Mechler (2014, 185), awareness has been growing that "there is a need for more holistically tackling commercial insurance as part of disaster risk management in order to address some of the primary barriers and gaps: inadequate insurance infrastructure, limited risk awareness, lack of solid risk management techniques, lack of insurance regulation and disaster laws, and a scarcity of solid information on losses as well as risks." In the absence of significant public intervention, market-based insurance mechanisms are unlikely to meet the aspirations of loss reduction and equitable compensation as set out in the Warsaw International Mechanism for Loss and Damage (Linnerooth-Bayer et al. 2019). Financial authorities can help build the infrastructure for insurance services and make them affordable to poorer clients. This will help recovery when disasters strike—and take a burden off public finances. Financial authorities can also provide an enabling environment for fintech based insurance solutions. It should be emphasized, however, that not all risks can be insured.

6.5 Provide international support to mitigate and manage climate-related sovereign risk

International financial institutions—including the IMF, multilateral development banks, and regional financing arrangements—have a special role to play in supporting member countries to address climate-related sovereign risks and strengthen adaptive capacity and macrofinancial resilience. Support is needed in technical assistance and training, surveillance and risk monitoring, financing adaptation and resilience, the development of insurance solutions, emergency lending and crisis support, and the development of an international debt resolution mechanism.

Technical assistance and training

International financial institutions, along with other international bodies and development agencies, can help develop approaches for the various policy responses discussed in this chapter, and support their implementation through technical assistance and training. To this end, the IMF and others need to strengthen their own capacity in analyzing the macrofinancial risks of climate change and lead by example in developing best practices for integrating climate risks in all aspects of their own operations. The IMF, in particular, could support its member countries' financial and monetary authorities, where needed, in developing capacity to better assess climate risks, e.g. via climate stress testing to inform the design of prudential policies, and in mainstreaming climate risk analysis in public financial management. The IMF and others could also provide support to member countries in strengthening public debt management to enable them to better account for climate risks in public budgets. Importantly, governments should be supported in developing contingency plans and securing pre-arranged contingent financing facilities from different sources, as well as insurance-based solutions.

Surveillance and risk monitoring

Conducting assessments of macrofinancial risk is at the core of the IMF's work. In its surveillance and monitoring operations, which are carried out at the global, regional, and country levels, the IMF seeks to identify potential risks to macroeconomic and financial stability and puts forward policy adjustments that should support economic growth, promote financial and economic stability, and prevent the buildup of financial risks. At the country level, surveillance centers around the annual Article IV consultations. The IMF has only recently started to address climate change in some of its Article IV consultations with its member countries (Volz 2020a). Since the early 2010s, when climate change was still virtually absent from Article IV consultations, a small number of Article IV reports each year included substantial references to climate change. A large increase was recorded in 2019. However, in the vast majority of Article IV consultations, climate change and climate-related macroeconomic and fiscal risks still play no role. The IMF needs to make climate risk a core part of its surveillance and monitoring operations, and a mandatory component of all Article IV consultations.

Moreover, the IMF could add a mandatory section on climate-related financial risks to the Financial Sector Assessment Program assessments it conducts together with the World Bank. Likewise, the joint World Bank–IMF Debt Sustainability Framework for Low-Income Countries could be enhanced by an analysis of the impact of climate-related risks on debt sustainability. The IMF should also include climate risk in its stress testing exercises (Adrian, Morsink, and Schumacher 2020).

Financing adaptation and resilience and developing insurance solutions

International financial institutions need to ramp up support to climate-vulnerable countries. A rapid scaling-up of investment in climate resilience is a matter of urgency for the most climate vulnerable countries, which are also those struggling the most to finance adaptation and resilience. As shown in Chapter 5, the governments of climate vulnerable countries are already facing a climate risk premium on the cost of capital. To avoid a vicious circle in which greater climate vulnerability raises the cost of debt and diminishes fiscal space for investment in climate resilience, climate-vulnerable developing countries will need more external support for investment in climate resilience, mostly in the form of grants instead of loans. Moreover, international financial institutions and other development agencies should continue to support climate vulnerable developing countries through initiatives such as the InsuResilience Global Partnership for Climate and Disaster Risk Finance and Insurance in developing insurance and risk transfer solutions (Jarzabkowski et al. 2019).

Emergency lending and crisis support

The IMF and regional financing arrangements should consider how to develop their emergency financing facilities for supporting member countries facing balance of payment difficulties or needing temporary financing because of a climate-related, adverse shock to their economy. For the IMF, one option is to raise access under the Rapid Credit Facility and a Rapid Financing Instrument, the two IMF facilities meant for catastrophe situations including climate disasters. Moreover, options should be explored to converting these facilities into grants, particularly for low-income countries eligible to concessional financial support through the Poverty Reduction and Growth Trust. A further option would be to establish an entirely new climate disaster emergency facility. The IMF could also explore ways to link a climate disaster facility to an issuance of special drawing rights, which could then benefit only countries hit by climate disasters. Multilateral development banks as well as national development banks can also assume an important role by providing countercyclical emergency support in times of distress.

Develop an international debt resolution mechanism

Last but not least, a discussion is needed around the treatment of climate debt, i.e. public debt that has been incurred as a direct result of climate disasters or necessary adaptation measures (Volz 2020b). Such a discussion should consider options for adding natural disaster clauses to sovereign debt contracts, developing instruments such as GDP-linked bonds, and developing a new framework for dealing with climate debt, including a sovereign debt restructuring mechanism and debt-for-climate swaps (Akhtar et al. 2020).

6.6 Summary

A multitude of actions is needed to climate proof the economies and public finances of countries vulnerable to climate change. Importantly, these actions need to be coordinated. Monetary and financial authorities will have to play a key role, working with other parts of the government and with international organizations in safeguarding macrofinancial stability and the sustainability of public finances. Table 24 provides an overview over the actions discussed in this chapter.

Table 24: Overview of policies to mitigate and manage climate-related sovereign risk

1. Conduct a comprehensive vulnerability assessment and develop a national adaptation plan	Systematic assessment of all sources of vulnerability for the macroeconomy, the financial system, and public finances Scenario analysis of climatic and socioeconomic change, addressing both physical and transition risks
2. Mainstream climate risk analysis in public financial management	Disclose and analyze climate risks Develop budgetary instruments to account for climate risk Mainstream and integrate climate framework, policies, and laws into national and sectoral budgets Develop public sector funding and debt management strategies, including debt instruments with risk-sharing features Diversify government revenue streams away from high-risk sectors
3. Adjust monetary and prudential frameworks to account for climate risks	Mandatory disclosure of climate and other sustainability risks Regular climate stress testing of financial institutions Integrate climate-related financial risks into prudential supervision Align monetary and prudential measures with climate goals Reconsider the prudential treatment of sovereign exposures in financial regulation
4. Implement financial sector policies to scale-up investment in climate adaptation and resilience and develop insurance solutions	Support the development of local currency bond markets for long-term financing of climate-resilient infrastructure Support the development of insurance markets
5. Provide international support to mitigate and manage climate-related sovereign risk	Technical assistance and training Surveillance and risk monitoring Financing adaptation and resilience and develop insurance solutions Emergency lending and crisis support Develop an international debt resolution mechanism

Source: Compiled by authors.

7. Summary and Recommendations

Climate change can have a material impact on sovereign risk. Global environmental change is eroding natural capital and natural services, undermining the foundation of economic prosperity and the development prospects of countries. In particular, climate change can have direct and indirect effects on public finances and threaten debt sustainability. This study has identified and scrutinized six different transmission channels through which climate change can amplify sovereign risk and worsen a sovereign's standing: the fiscal impacts of climate-related disasters; the fiscal consequences of adaptation and mitigation policies; the macroeconomic impacts of climate change; climate-related risks and financial sector stability; the impacts of climate change on international trade and capital flows; and the impacts of climate change on political stability.

The nexus between climate change and sovereign risk is complex. The various transmission channels are not independent from each other. A worsening of climate impacts in one area can magnify the transmission of risk through other channels. Just as the physical effects of global environmental change are highly complex, with tipping points and feedback loops, the socioeconomic and fiscal effects of climate change are multifaceted and depend on the policies taken or not taken to mitigate and adapt to these risks.

This report has illustrated the relevance of the six transmission channels for sovereign risk in Southeast Asia, one of the most climate-vulnerable regions of the world. Southeast Asian countries will not only be exposed to an increase in the frequency and intensity of extreme weather events, large parts of the region will also suffer from chronic physical impacts such as worsening heat and water stress and sea level rise, which are expected to significantly impact economic activity. Some countries, including Myanmar, the Philippines, Viet Nam, Thailand and Cambodia, are heavily exposed to the physical impacts of climate change and the implications these have for international commerce, output, employment, and public finances. Others face lower physical risk but are exposed to high transition risk as their exports and economies will be affected by international climate policies, technological change, and changing consumption patterns worldwide. Among Southeast Asian countries, Brunei Darussalam faces the greatest transition risk, given its reliance on fossil fuels exports. For sure, much more granular analysis of the macrofinancial risk resulting from climate change is required, but even the high-level analysis for ASEAN countries conducted in this report shows that the implications of climate change for macrofinancial stability and sovereign risk are likely to be material for most if not all of them.

The report also presents new empirical evidence on the relationship between climate vulnerability, resilience, and the sovereign cost of capital. Using a sample of 40 developed and emerging economies, our econometric analysis shows that climate risks and resilience to these risks have significant effects on the cost of sovereign borrowing. In particular, higher climate risk vulnerability leads to significant rises in the cost of sovereign borrowing. Premia on sovereign bond yields amount to around 275 basis points for economies highly exposed to climate risk, compared to 155 basis points for ASEAN, and 113 basis points for EMEs overall. In contrast, exposure to climate risk is not statistically significant for the group of advanced economies. Resilience to climate risk is statistically significant in reducing bond yields across all country groups, but with smaller magnitudes. Overall, our analysis confirms that climate vulnerability has significant implications for sovereign borrowing costs, and that the magnitude of the effect is much larger for countries highly vulnerable to climate change. Impulse response analysis suggests that shocks imposed on climate vulnerability and resilience have permanent effects on bond yields, and that economies highly exposed to climate risks experience larger permanent effects on yields than economies with lower exposure.

All branches of government will have to address climate-related risks. Monetary and financial authorities will have to play crucial roles in analyzing and mitigating macrofinancial risks. We recommend five broad policy actions to mitigate and manage climate-related sovereign risk in a coordinated manner.

First, governments need to conduct a comprehensive vulnerability assessment and develop national adaptation plans. To address and mitigate climate-related sovereign risk properly, it is important to understand the ways in which climate change can amplify sovereign risk. To this end, a systematic assessment of all sources of vulnerability for the macroeconomy, the financial system, and public finances is needed. Along with vulnerability to climate risks, this assessment should include the projected change in the country's risk exposure. This should include scenario analysis of climatic and socioeconomic change, addressing both physical and transition risks. Such an assessment could be conducted by a dedicated national climate risk board that should include the central bank and supervisor along with key government departments responsible for finance, economy, planning, agriculture, among others. Regional bodies such as ASEAN can play an important role in facilitating the exchange of best practice among member countries, as they seek to understand the scale of their relative climate risk exposure.

Second, and based on the vulnerability assessment, governments need to mainstream climate risk analysis in public financial management. This should include appropriate analysis, disclosure, and management of risks to public finances as well as coordination of fiscal decision-making across the public sector. Furthermore, governments need to develop budgetary instruments to account for climate risk, and mainstream and integrate climate framework, policies, and laws into national and sectoral budgets. Finance ministries also need to develop public sector funding and debt management strategies, including debt instruments with risk-sharing features, and diversify government revenue streams away from high-risk sectors.

Third, central banks and financial supervisors need not only play an important role in supporting governments in analyzing macrofinancial risks arising from climate change. They also need to address climate-related risks in their monetary and prudential frameworks and operations. In particular, they should make disclosure of climate and other sustainability risks mandatory and conduct regular climate stress tests of financial institutions, fully integrate climate-related financial risks into prudential supervision, and align monetary and prudential measures with climate goals. Mainstreaming climate-financial risk assessment in financial contracts is crucial for aligning finance flows with a pathway toward low greenhouse gas emissions and climate-resilient development. Importantly, supervisors should reconsider the prudential treatment of sovereign exposures in financial regulation.

Fourth, governments and financial authorities should implement financial sector policies to scale-up investment in climate adaptation and resilience and develop insurance solutions. Especially in developing economies, financial authorities should seek to facilitate the mobilization of domestic resources for financing climate-resilient, sustainable infrastructure and other adaptation measures. For instance, monetary and financial authorities can play an important role in supporting the development of local currency bond markets for long-term financing of climate-resilient infrastructure. They can also support the development of fintech in mobilizing domestic savings and channeling these into sustainable investments. Financial authorities can also help build the infrastructure for insurance services—including fintech based insurance solutions—and make them affordable to poorer clients. Developing insurance markets and broadening insurance coverage can help to enhance the financial resilience of households and businesses and take the burden off public finances.

Fifth, international financial institutions—including the IMF, multilateral development banks, and regional financing arrangements—have a special role to play in supporting vulnerable countries to address climate-related sovereign risks and strengthen adaptive capacity and macrofinancial resilience. Building on their respective strengths, they can provide technical assistance and training, support surveillance and risk monitoring, provide finance for adaptation and resilience investment, support the development of insurance solutions, and provide emergency lending and crisis support.

For the most climate vulnerable countries, a rapid scaling-up of investment in climate resilience is a matter of survival. Sadly, those who have the greatest need for investment in adaptation and resilience are also those who are struggling the most to finance it. As shown in this report, climate vulnerable developing countries are already facing a climate risk premium on the cost of capital. There is a risk that these countries enter a vicious circle, in which greater climate vulnerability raises the cost of debt and diminishes fiscal space for investment in climate resilience. As financial markets increasingly price climate risks, and global environmental change accelerates, the risk premia of climate vulnerable countries, already high, are likely to increase further. International support for increased investments in climate resilience and mechanisms to transfer financial risks is urgently needed and could help these countries to enter a virtuous circle. Greater resilience investments could reduce both vulnerability and the cost of debt, providing these countries with extra room to scale up investments to tackle the climate challenge.

As the COVID-19 crisis is worsening public finances and as debt sustainability is threatened in countries around the world, it will be even more important for governments to analyze and mitigate climate-related sovereign risks. The pandemic has hit at a time when we have about a decade left to achieve a low-carbon transition and bring the world economy onto a 1.5°C trajectory (IPCC 2018). The next years are the last chance to avoid catastrophic global warming. Regardless, most countries also face a great urgency in preparing for the effects of climate change that are already underway. The COVID-19 crisis has revealed the vulnerability of our economies and societies—with dire consequences for public finances. It is imperative that the various crisis responses aimed at protecting jobs and boosting a recovery are coupled with longer-term, strategic goals of mitigating climate change and shoring up climate change adaptation and resilience (Volz 2020b). As much as possible, economic stimulus and recovery measures should be used to strengthen the resilience of economies and support a just transition.

In many countries, climate change threatens to undermine the sustainability of public finances. Governments need to take urgent action to climate-proof their economies and public finances. If they don't succeed in this, they will be left helpless in an ever-worsening spiral of climate vulnerability and unsustainable debt burdens.

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Appendix to Chapter 5

Sample of countries

Our analysis comprises 40 developed and emerging economies, as outlined below.

Table A1: List of countries by grouping

Developed	Emerging	ASEAN	High Risk
Australia	Argentina	Indonesia	Indonesia
Belgium	Brazil	Malaysia	India
Denmark	Chile	Philippines	Japan
Finland	Columbia	Singapore	Netherlands
France	Czech Republic	Thailand	Philippines
Germany	Hungary	Viet Nam	Republic of Korea
Greece	India		Singapore
Ireland	Israel		Sri Lanka
Italy	Mexico		Thailand
Japan	Nigeria		Viet Nam
Netherlands	People's Republic of China		
New Zealand	Peru		
Portugal	Poland		
Spain	Republic of Korea		
Sweden	Russian Federation		
United Kingdom	South Africa		
United States	Sri Lanka		

Source: Compiled by authors.

Econometric approach and data

Firstly, we estimate a fixed effects panel model with the following baseline specification:

$$y_{i,t} = \beta x_{i,t-1} + \gamma Z_{i,t-1} + \chi VIX_{t-1} + \tau USY_{t-1} + CRISIS_{i,t-1} + \delta_i + \varepsilon_{i,t} \quad i=1,\dots,N, t=1,\dots,T$$

where $y_{i,t}$ represents the government bond yield; $x_{i,t}$ represents a set of domestic macroeconomic fundamentals (current account/GDP, GDP per capita, public debt/GDP, fiscal balance/GDP, GDP growth); Z_j denotes our climate vulnerability and resilience indicators; VIX stands for the Chicago Board Options Exchange (CBOE) Volatility Index, a measure of global risk aversion; USY are US long-term government bond yields; CRISIS represents the Laeven and Valencia (2018) indicator for the incidence of a crisis event for each country in the sample; δ_i are country fixed effects; and $\varepsilon_{i,t}$ is the error term. The variables are lagged by one period to mitigate against endogeneity concerns.

Secondly, a structural panel VAR is used to examine the response of sovereign bond yields to shocks to climate vulnerability and resilience. Crucially, these shocks control for a range of macroeconomic fundamentals and global factors. The panel SVAR is implemented across the same 40 countries as in stage one, but over the period from 2007Q1 to 2017Q4 in a balanced set-up. The panel SVAR can be denoted as follows in its general specification, with structural shocks identified by a recursive restriction:

$$A(L)\Delta Y_{i,t} = \varepsilon_{i,t}$$

where $A(L)$ is the matrix of lag polynomial; $Y_{i,t}$ refers to the demeaned value of X_t of country i to accommodate country-specific fixed effects; and $\varepsilon_{i,t}$ is a vector of structural disturbances. Following the setting of the previous SVAR model, we take a first-differencing form of $Y_{i,t}$ as $\Delta Y_{i,t}$. The ordering of the variables imposed in the recursive form is the same as the previous SVAR model. The panel VAR includes two lags selected by the Akaike information criterion (AIC).

Our identification strategy is based on a block recursive restriction (Christiano, Eichenbaum, and Evans 1999), which results in the following matrix A to fit a just-identified model:

$$A = \begin{bmatrix} a_{1,1} & 0 & \dots & 0 \\ a_{2,1} & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ a_{11,1} & \dots & a_{11,10} & a_{11,11} \end{bmatrix}$$

The ordering of the variables imposed in the recursive form implies that the variables at the top (such as $a_{1,1}$) will not be affected by contemporaneous shocks to the lower variables (such as $a_{2,1}, a_{11,1}, \dots$), while the lower variables will be affected by contemporaneous shocks to the upper variables. Usually, slower moving variables are better candidates to be ordered before fast-moving variables (Bruno and Shin 2015). It follows therefore that we place the climate vulnerability variable at the top in the ordering, which implies that it will only be affected by contemporaneous shock to itself. Following the vulnerability variable, we place the climate resilience variable second in the ordering, which implies that resilience will be affected by contemporaneous shocks to vulnerability and itself, but not by contemporaneous shocks to macroeconomic fundamentals or sovereign bond yields. Importantly, we put the sovereign yields in last place in the ordering, which is not only based on the assumption that climate risk will affect bond yields, but also on the consideration of our first-stage empirical results that imply the macroeconomic fundamentals that are driving bond yields. Last, we place our macroeconomic fundamentals in the middle of the ordering. The lag selection of the SVAR model is based on the AIC, which suggests that our model should be with two lags.

Baseline empirical results

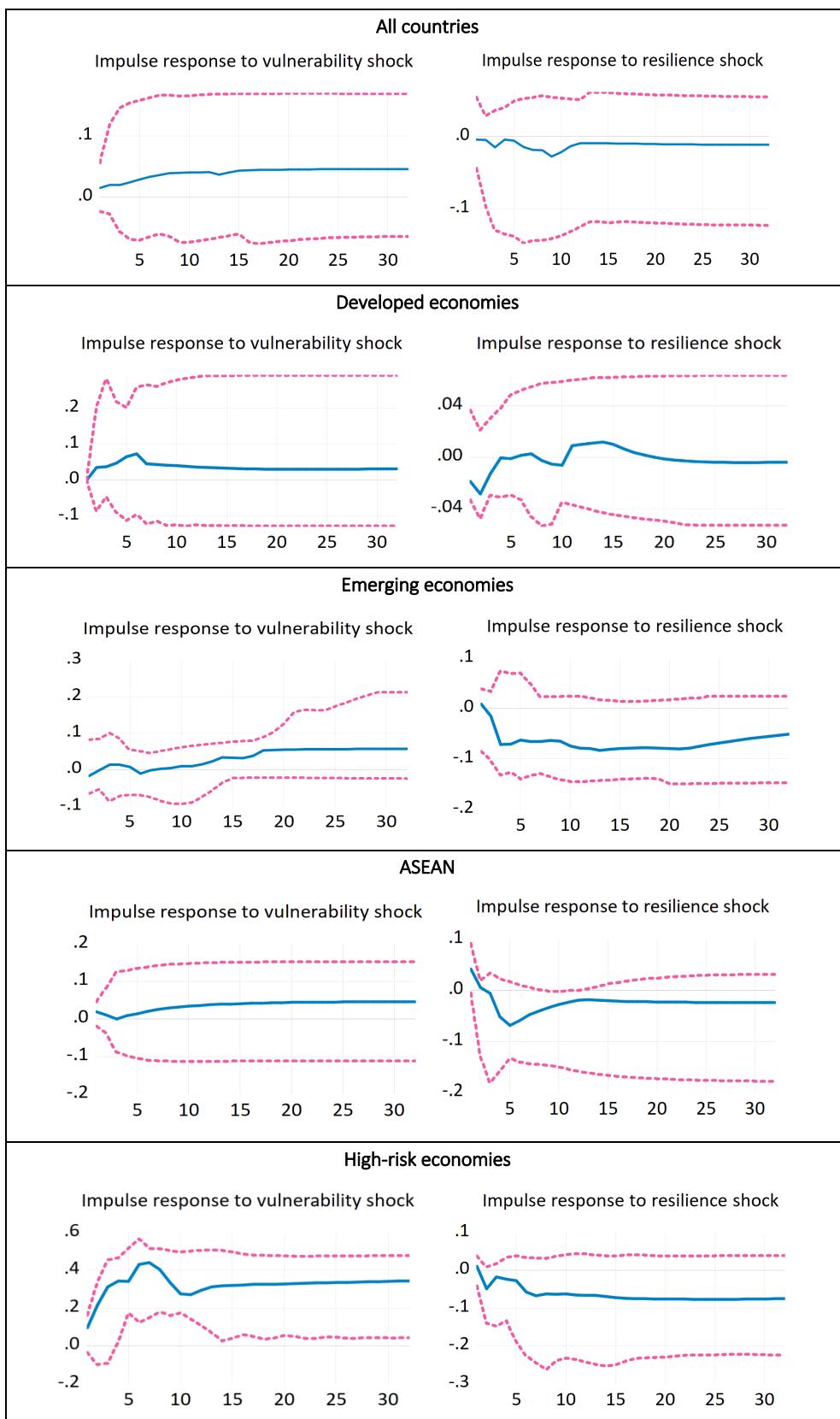
Table A2: The determinants of sovereign bond yields

	(1) All	(2) ADV	(3) EME	(4) ASEAN	(5) HRSK
Climate risk vulnerability and resilience					
Vulnerability	0.634*** (0.150)	-0.001 (0.164)	1.134*** (0.434)	1.549*** (0.328)	2.753*** (0.388)
Resilience	-0.067*** (0.009)	-0.084*** (0.013)	-0.070*** (0.016)	-0.057*** (0.015)	-0.057*** (0.016)
Domestic factors					
Current account/GDP	-0.051*** (0.011)	-0.019 (0.015)	-0.127*** (0.029)	-0.0650*** (0.013)	-0.106*** (0.015)
GDP per capita	-0.748* (0.385)	-9.181*** (0.992)	-0.265 (0.571)	-4.587*** (0.868)	1.049 (0.666)
Public debt/GDP	0.016*** (0.001)	0.013*** (0.002)	-0.0133* (0.008)	0.0294*** (0.005)	0.00991*** (0.003)
Fiscal balance/GDP	0.008 (0.008)	-0.014 (0.008)	0.172*** (0.035)	-0.015 (0.022)	-0.023 (0.020)
GDP growth	-0.180*** (0.014)	-0.142*** (0.019)	-0.242*** (0.027)	-0.042 (0.027)	-0.042* (0.023)
Crisis	0.673*** (0.203)	1.325*** (0.226)	-0.129 (0.377)	n/a	0.605 (0.743)
Global factors					
US bond yield	0.803*** (0.052)	0.832*** (0.072)	0.587*** (0.092)	0.282** (0.129)	0.861*** (0.101)
VIX	0.049*** (0.005)	0.035*** (0.007)	0.059*** (0.009)	0.006 (0.010)	0.038*** (0.009)
Constant	-14.94** (7.242)	102.3*** (13.16)	-36.96** (17.67)	-30.90* (17.54)	-142.3*** (20.95)
Observations	2,399	1,088	949	362	600
R-squared	0.296	0.430	0.236	0.573	0.411
Number of countries	40	17	17	6	10
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Time effects	No	No	No	No	No

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimations, for explanations see the technical background paper (Beirne, Rhenzi, and Volz 2020a).

Figure A1: Response of sovereign bond yields to climate risk vulnerability and climate risk resilience shocks



Note: The pink line represents the 95% confidence interval. The blue line represents the impulse response of government bond yields to shocks.

Source: Authors' estimations, for explanations see the technical background paper (Beirne, Rhenzi, and Volz 2020a).