



Climate-Related Risks for Ministries of Finance: An Overview

Nepomuk Dunz and Samantha Power (World Bank)

A product of the Helsinki Principle 5 Workstream

May 2021

Authors and Acknowledgements

This note was co-authored by Nepomuk Dunz and Samantha Power (World Bank) under the direction of the Sherpa Co-Chairs of the Coalition of Finance Ministers for Climate Action, Pekka Moren (Finland) and Masyita Crystallin (Indonesia), the Lead of the Helsinki Principle 5 Workstream, Meg Nicolaysen (UK), and Fiona Stewart (World Bank).

This note benefited from contributions from Robert Zymek, Emmanuelle Dot (UK Treasury), Joanna Tikkanen (MoF Finland), Bryan Gurhy, Sebastien Boitreaud, Cigdem Aslan, Hiroshi Tsubota, Lars Jessen, Henk Jan Reinders, Rachel Chi Kiu Mok (World Bank), Ulrich Volz (SOAS, University of London), Joaquim Levy, Carter Brandon, and Lihuan Zhou (World Resources Institute), as well as input from the Helsinki Principle 5 Workstream Members more broadly. This note also benefited from the work of the Network for Greening the Financial System (NGFS) and its members. Benjamin Holzman provided graphic design.

Disclaimer and Copyright

This work is a product of the Coalition of Finance Ministers for Climate Action ('the Coalition') and was prepared at the request of the Co-Chairs of the Coalition under the Helsinki Principle 5 Workstream on 'mobilizing private finance for climate action'. The views, findings, interpretations, and conclusions expressed, however, are those of the authors and do not necessarily reflect those of the Coalition, its Members, or the affiliations of the authors.

This work may be reproduced, in whole or in part, for non-commercial purposes provided full attribution to this work is given.

©2021 The Coalition of Finance Ministers for Climate Action

All rights reserved.

Website: www.financeministersforclimate.org

—

Suggested citation:

Dunz, Nepomuk and Power, Samantha. 2021. Climate-Related Risks for Ministries of Finance – An Overview. Coalition of Finance Ministers for Climate Action, Washington, DC. © Coalition of Finance Ministers for Climate Action.

Table of Contents

Foreword	4
Introduction	5
Climate-Related Risk Transmission Channels	7
Households.....	9
Businesses	9
Finance	10
Government	10
Macroeconomic Implications.....	10
Reinforcing Feedback Effects	11
Contingent Liability Risks for Ministries of Finance	13
Contingent Liability Risk with Ex-Ante <i>Known</i> Fiscal Costs.....	15
Contingent Liability Risk with Ex-Ante <i>Unknown</i> Fiscal Costs.....	15
Implications for Ministries of Finance	16
Endogeneity of Climate-related Risks for Ministries of Finance	17
Conclusion and Policy Actions for Ministries of Finance	19
References	22

Foreword

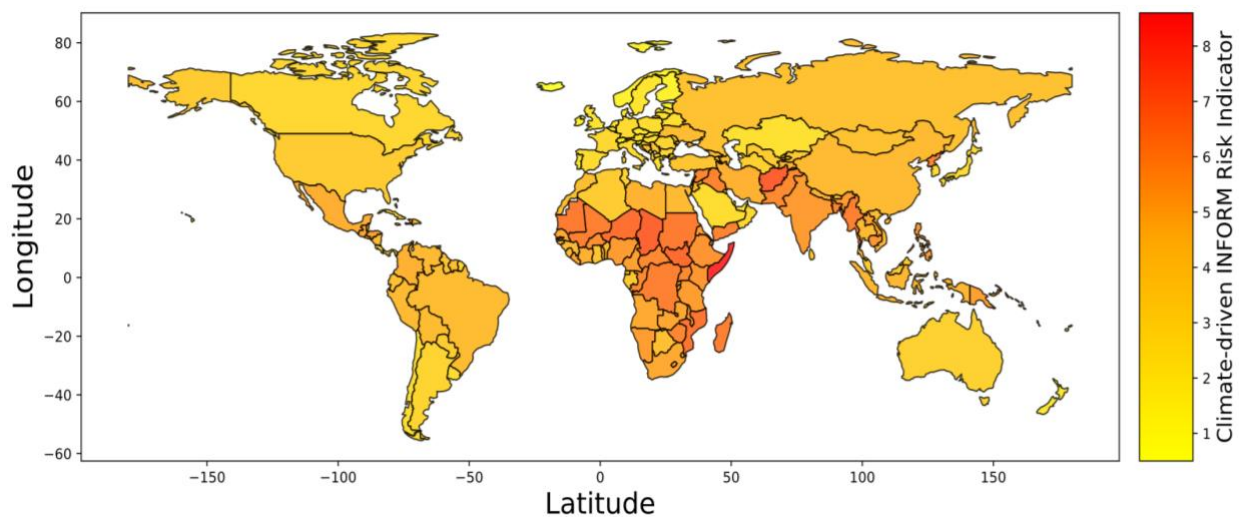
The Coalition's Santiago Action Plan stresses the importance of incorporating climate change considerations into financial decisions and identifying risks climate change poses to financial stability. In this context, the Coalition produced this note on climate-related financial risk to raise awareness and explore risk management approaches. The findings of this note will be reviewed by Coalition Members with a view to identify policy priorities and potential areas for future work.

This note provides an overview of how climate-related risks may manifest in different sectors of the economy and alter macroeconomic conditions that affect the work and responsibilities of Ministries of Finance (MoFs). The interaction of various risks may lead to reinforcing feedback effects that could gradually or abruptly cause high fiscal costs and trigger contingent liabilities of MoFs with growing climate change. However, the materiality of these risks – posing potentially high ex-ante unknown fiscal costs for MoFs – depends on the interplay of climate-related risk transmission channels, the degree of unfavorable reinforcing feedback loops, the specific country context, and climate action measures. Ambitious mitigation and adaptation measures could reduce the likelihood of severe climate-related risk impacts that could otherwise grow and potentially hinder countries' long-term economic development. The note concludes with potential policy actions MoFs can take to mitigate and manage climate-related risks.

Introduction

Climate change and its related physical impacts are becoming increasingly visible with 2016 and 2020 being the hottest years on record¹ and economic damages steadily increasing all over the world². The long-term physical consequences of unmitigated climate change, however, are highly uncertain due to the complex nature of the earth system – comprising tail risk³, tipping points⁴, and domino effects⁵. Estimates of global economic impacts range from 2.1%⁶ to 23%⁷ of annual GDP damages in 2100^a. Yet, there is general agreement amongst scientists that growing climate change will lead to more frequent and intense *acute* extreme weather events such as droughts, floods, tropical cyclones, and wildfires, potentially causing business disruption and property damage⁸. *Chronic* higher temperatures and sea-level rise could reshape entire landscapes and alter living conditions⁹, requiring large-scale adaptation investments¹⁰. *Acute* and *chronic* climate change impacts constitute climate physical risk. Figure 1 shows the climate-driven IMF INFORM risk indicator for countries in 2020, capturing climate-driven hazard and exposure vulnerability and lack of coping capacity¹¹.

Figure 1: Climate-driven IMF INFORM Risk Indicator



Note: The INFORM risk indicator assesses risk for climate-driven hazards in 2020, based on the IMF climate change dashboard. It captures three dimensions – climate-driven hazards and exposure, vulnerability, and lack of coping capacity – and can thus support the assessment of countries’ abilities in prevention, preparedness, and response to climate physical risks. The index for risk-management on INFORM risk ranges from 0-10. The higher the indicator the higher the risk.

^a Note that economic damages from climate change are computed and estimated using a wide range of methodologies, relying on different calibrations, damage functions, and assumptions regarding economic growth impacts, treatment of tail risks, feedback effects, and financial risk. For instance, Nordhaus (2017) assumes a quadratic functional form, resulting in relatively low damages at high temperatures. In contrast, Weitzman (2009) suggests an exponential damage function, where losses increase non-linearly with higher temperature changes.

Source: *INFORM Risk*; IMF staff calculations.

To mitigate and adapt to the most severe consequences of climate change, ambitious climate policies are needed to foster a low-carbon transition. Climate transition risk, however, could emerge from sudden and uncoordinated climate policies, technology disruptions, and altered consumption preferences during the transition towards a carbon-neutral economy¹². This could drive entire sectors out of business and lead to abrupt financial asset revaluation and stranded high-carbon assets with negative implications for the real economy and government budgets.

Both, climate physical and climate transition risk, could amplify macroeconomic risks¹³, with finance being a potential driver of risk amplification¹⁴. To that end, financial supervisory institutions and central banks have started to assess potential consequences for financial stability^{12,15,16}. Climate-related risk disclosure¹⁷ and climate-stress testing exercises^{18–20} are being applied to improve the understanding of the materiality and magnitude of these risks for the financial sector.

Climate-related risk implications for MoFs have so far received limited attention^b, though their impact could be substantial. Lower dividends from or potential bailout costs for state-owned enterprises, lower tax revenues, and higher debt servicing costs could directly limit MoFs' fiscal space. Contingent liability risks with ex-ante unknown fiscal costs, emerging from climate physical and climate transition risk, could be even more substantial, as MoFs are a lender of last resort for households, businesses, and financial institutions in extreme circumstances. MoFs are responsible for the design and execution of core governmental financial functions²¹. They fulfill policy (e.g., fiscal policy rule or target setting), regulatory (e.g., supervision of specific economic sectors and financial institutions), and transaction (e.g., processing budgetary payments) functions²¹. As such, they are at the center of economic and fiscal policymaking, giving them an exceptional position in respect to their exposure to climate-related risks and power to take climate action.

This note focuses on MoFs and provides clarity on how their work and responsibilities could be impacted by climate-related risks. In particular, this note intends to provide a general overview of risk transmission channels for climate-related risk and the fiscal and contingent liability risks they could trigger for MoFs. The note concludes with identifying critical policy actions MoFs can take to mitigate and manage these risks.

^b Climate change, however, receives increasing attention in national financial and non-financial risk assessments such as Financial Sector Assessment Programs (FSAPs).

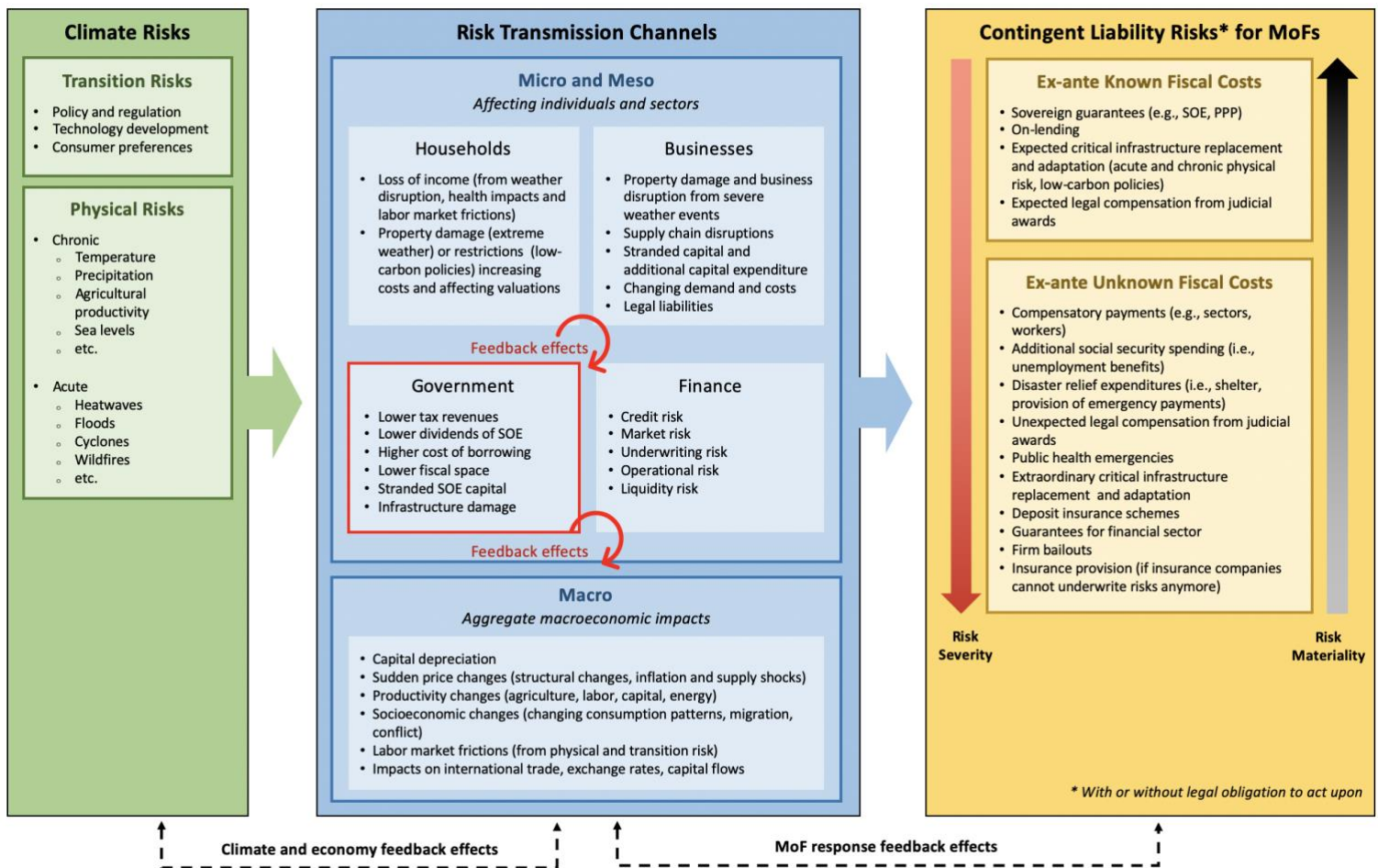
Climate-Related Risk Transmission Channels

Climate physical risks could transmit via individual, sectoral, or macroeconomic impacts, whereby different risk transmission channels interact and induce reinforcing feedback effects. This, in turn, could gradually or abruptly trigger private and public sector financial risks and impact long-run economic growth. The concrete manifestation and exposure to climate-related risks is, however, country and context dependent as geographical^c and structural differences among economies and capital markets influence the relevance of various transmission channels²². Further, manifestation depends on actions taken to mitigate climate-related risks. Importantly, climate-related physical and transition risk differ in their direct impacts on distinct sectors of the economy, thus leading to potentially different indirect impacts and feedback effects. Climate-related physical risk might play out as natural hazards, such as tropical cyclones that may destroy productive capacity, thus impeding firms' production and profitability. This could cause cascading effects on the economy with implications for both private and public finance²³. Climate-related transition risk may materialize as carbon-intensive firms facing higher production costs as a result of higher prices for fossil energy and carbon tax payments. This would lower their profitability, potentially leading to stranded high-carbon assets and further indirect impacts if not anticipated and priced by the financial sector²⁴.

This note follows the conceptualization by the Network for Greening the Financial System (NGFS) (2020)²⁵ of how climate physical and climate transition risks could affect the economy and financial markets. Figure 2 conceptualizes the climate-related risk transmission channels that could trigger fiscal risks and contingent liabilities with previously known and unknown fiscal costs for MoFs.

^c Small island states, for instance, are more strongly exposed to physical risks, as sea-level rise and tropical cyclones pose significant damages to their economies already today¹⁰⁸.

Figure 2: Climate-related risk transmission channels and Ministries of Finance



Note: The figure shows the transmission of climate-related risks (physical or transition) to different sectors of the economy (including government fiscal risk) and the macroeconomy. The interaction of these risks may lead to reinforcing feedback effects, as discussed below – potentially triggering contingent liabilities of the MoF. Contingent liabilities are defined as obligations^d that only materialize when a certain event in the future occurs²⁶. Contingent liability risks could become gradually or abruptly more severe with ongoing climate change (depending on the specific country context), as indicated by the red “risk severity” arrow. However, the materiality of these risks, posing potentially high ex-ante unknown fiscal costs for MoFs, depends on the interplay of climate-related risk transmission channels, the degree of unfavorable reinforcing feedback loops, and climate action measures – as is indicated by the grey “risk materiality” arrow.

Source: Authors’ conceptualization adapted from NGFS (2020)²⁵, Schuler et al. (2019)²⁷, Volz et al. (2020)²⁸ and IMF (2008)²⁹

^d With or without legal obligation to act upon.

Households

Households could face significant health impacts as well as income loss and property damage, tightening budget constraints. Drivers of climate change, such as fossil fuel combustion, already strongly contribute to indoor and outdoor air pollution, leading to 7 million deaths annually³⁰. Higher temperatures, extreme weather events, and sea-level rise could contribute to further detrimental impacts on people's health^{e,30,31} and impede their ability to work³². Food prices could increase as a result of more frequent extreme weather events and increased competition for arable land³³. Extreme weather events are already leading to an increasing trend in property damages², with frequency and intensity expected to increase further³⁴. Moreover, property valuations could suffer from exposure to more frequent and severe extreme weather events, sea-level rise³⁵, and changes in weather patterns, affecting household wealth and collateralized loans. With respect to climate transition risk, climate policies could lead to labor market friction due to different skillset requirements of workers in low-carbon activities. Low-carbon policy restrictions could create additional costs for households, such as higher insulation requirements for houses. Overall, lower household income, lower wealth, and higher product prices could reduce private consumption and induce debt default – constituting a demand shock³⁶. In turn, spillovers to governments, firms, and financial institutions could emerge (Figure 3).

Businesses

Businesses are exposed to revenue loss as a result of business disruptions and property damage stemming from climate-related physical and transition risk. Adapting to higher physical risk exposure and new climate policy and regulation is costly and requires access to finance. Extreme weather events could destroy production facilities, decimate harvests³⁷, and disrupt sensitive supply chains³⁸. Further, ecosystem health could decline, lowering the productivity and reliability of ecosystem services³⁹. Moreover, empirical evidence suggests that climate vulnerability increases the cost of corporate capital⁴⁰. With respect to climate transition risk, firms may not be able to pass through higher costs to customers depending on sectoral competition. As such, climate policies and technological breakthroughs could affect firms' profitability. Further, changes in consumer preferences towards low-carbon products⁴¹ and lower household income could alter demand³⁶, while investors' climate sentiments could impact financing costs⁴². Both, lower demand and profitability could drive entire firms and sectors out of business, posing a risk of stranded high-carbon assets¹⁹, impacting the financial sector and investors' probability of default⁴³. Finally, firms could face legal liability if they fail to comply with regulations and standards, or if they are forced to account for their historical contribution to climate change⁴⁴.

^e With no additional climate action, a substantial increase in mortality and morbidity with respect to climate change is expected. Direct effects on health include injuries, cardiovascular, respiratory, and mental diseases. Indirect effects on health could stem from food and water insecurity as well as climate sensitive infectious diseases.

Finance

Real economy impacts and sudden asset revaluations could translate into significant risks for the financial sector, potentially impacting financial stability^{12,19}. Lower firm revenues and profits, as well as lower household income, increase probability of default and loss – given default. In combination with the revaluation of collateral (private, corporate, and sovereign), credit risk increases. Sudden repricing and fire sales of debt, equity, and commodities pose market risk⁴⁵. The deeply uncertain nature of climate change impacts increases underwriting risk of insurance and financial products. At the same time, climate physical risks could pose operational risk in the form of office closures, breakdowns in payment systems, and the disruption of workers’ commutes. Finally, liquidity risk could materialize, if depositors and investors withdraw funds because of higher climate-related risk expenses or fears related to solvency.

Government

The government in general, and the MoF in particular, are directly affected via lower revenue streams, higher expenditures, and potentially higher borrowing costs – having direct fiscal implications. Climate-related risks for the government may transmit via fiscal impacts of climate-related disasters, fiscal consequences of adaptation and mitigation policies (or lack thereof), macroeconomic impacts of climate change, impacts on international trade and capital flows, and impacts on political stability²⁸. The exact impacts, however are difficult to predict due to non-linear feedback effects¹⁰. Lower tax revenues could result from reduced household income and reduced profits to firms. Further, state-owned enterprises (SOEs) could be strongly exposed to climate physical and climate transition risk, often being large-scale infrastructure providers or carbon intensive companies⁴⁶. Decreasing profitability of SOEs may materialize for governments via lower or more volatile dividends; in extreme cases the government might need to take over SOEs’ guaranteed debt that the company is no longer able to service. Dividends, such as from oil sector SOEs, are often an important government revenue stream⁴⁷. Climate physical risk could cause severe infrastructure damage, while climate transition risk could lead to stranded high-carbon public assets.

Macroeconomic Implications

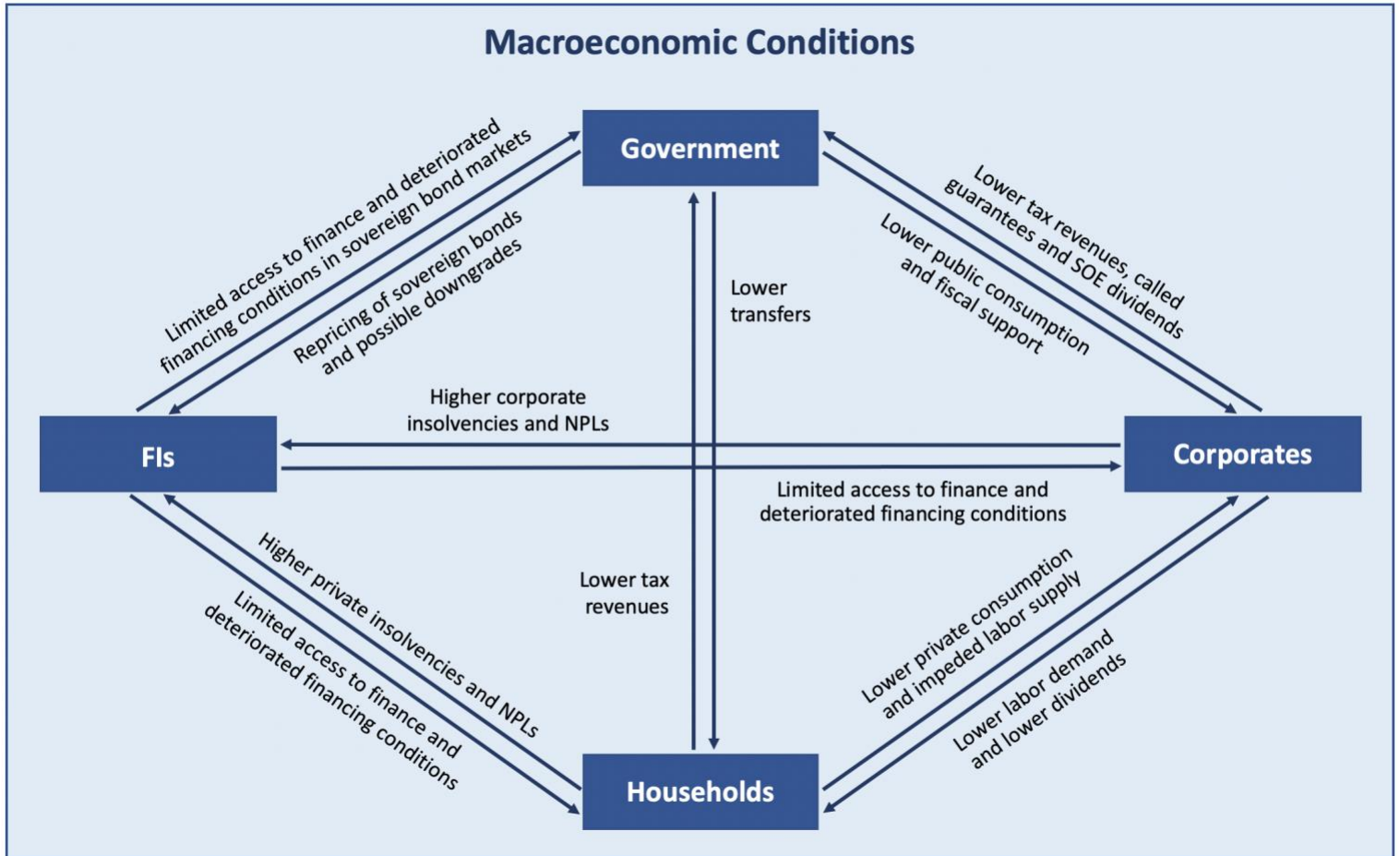
Climate physical and climate transition risk also transmit via altered macroeconomic conditions. In addition to destruction of capital stock and property, climate physical risks could decrease the lifespan of infrastructure, factories, and vehicles, thus requiring more frequent replacement and increasing depreciation rates. Labor productivity could deteriorate with higher temperatures⁷. A sudden shift in prices in response to changing consumption patterns, policies, or technology could induce fast structural changes and supply shocks – such as for labor, food, or natural capital supply – to the economy³⁶. A sudden shift in prices could also drive long-term

inflation⁴⁸. Climate-related risks are heterogeneous across countries but are generally more severe for disadvantaged people and communities across countries of all levels of development⁹. Job loss and the shift to uninhabitable conditions in certain regions could induce migration and conflict over limited natural resources^{49,50}. Climate physical risk could negatively affect international tourism and the agricultural sector⁵¹. Unilateral climate policies might affect a country's competitiveness by inducing carbon leakage⁵², thus posing climate transition risk. Resulting changes in Foreign Direct Investment (FDI) and trade patterns could weaken a country's trade position⁵¹ and increase volatility in foreign exchange markets. This in turn could threaten debt sustainability, as external debt becomes more difficult to service.

Reinforcing Feedback Effects

Climate-related risk transmission channels are overlapping, affecting different economic sectors and the macroeconomy at the same time. Importantly, the interplay of likely and recurring events and different sources of risk and sectors could gradually or abruptly turn into a vicious cycle (Figure 3). This could give rise to destabilizing feedback loops that could trigger tail risks, shifting the likelihood of their occurrence. As such, initially sector or geographically restricted climate-related risks could become systemic and affect long-run economic growth. For instance, the materialization of climate physical and transition risk could lead to a higher probability of loan default by firms. In response, the financial sector would need to tighten lending conditions⁴⁰. The prevented access to funding or higher cost of finance for adaptation, mitigation, and recovery investment could drive reinforcing feedback effects⁵³ and delay the low-carbon transition. Another risk layer emerges when climate change impacts compound with socio-economic vulnerabilities and financial risk, as has been seen during the COVID-19 pandemic⁵⁴. Such compounding could trigger non-linear amplification effects, impeding a fast recovery^{23,55}. Climate risks also strongly interact with biodiversity risks^{39,56,57}. A changing climate has widespread impacts on species and ecosystems, reducing the productivity of ecosystem services and leading to species extinction. Biodiversity loss, in turn, contributes to climate change, as terrestrial and marine ecosystems provide significant carbon sequestration services. Degradation of those ecosystems releases sequestered carbon and reduces ecosystems' ability to provide future sequestration services.

Figure 3: The Corporate-Household-Bank-Government Nexus



Note: Interlinkages between different sectors of the economy may gradually or abruptly turn into a vicious cycle of climate-related risk transmission, giving rise to destabilizing feedback loops that could trigger tail risks.

Source: Adapted from a speech by Isabel Schnabel, Member of the Executive Board of the ECB, at the LSE conference on "Financial Cycles, Risk, Macroeconomic Causes, and Consequences" (2021)⁵⁸ and authors' conceptualization.

Contingent Liability Risks for Ministries of Finance

Climate-related risks could cause direct fiscal impacts (see Figures 2 and 3), but could also trigger a wide range of contingent liabilities with ex-ante known and unknown fiscal costs. Contingent liabilities are defined as obligations that only materialize when a certain event in the future occurs²⁶. These risks can further be distinguished into *explicit* contingent liabilities, that represent obligations fixed by law or contract, and *implicit* contingent liabilities, that involve moral obligations or public responsibility not determined by legal contracts^{59,f}. Both, explicit and implicit contingent liabilities, constitute substantial fiscal costs for the government if they materialize (see Table 1). Financial sector and legal claims are most severe, in terms of both average and maximum fiscal costs^g. For instance, a substantial financial sector contingent liability for governments around the world materialized when governments bailed out banks and provided financial sector guarantees to avoid financial contagion during the financial crisis in 2008-2009 (Figure 4)^h. As such, a banking crisis can cause sovereign debt distress⁶⁰. Natural disasters have comparably low average fiscal costs; yet, they are already occurring frequently, with an increasing tendency⁸.

On the one hand, climate-related risks could gradually deteriorate public finance conditions via lower tax revenues, higher public debt levels, reallocation of funds from other development finance priorities, and the triggering of contingent liabilities with known fiscal costs (however, yet to be financed). On the other hand, climate-related risks could trigger contingent liabilities with ex-ante unknown fiscal costs, potentially exceeding previously allocated funds and thus abruptly resulting in deteriorated public finance conditions. Figure 2 provides a non-conclusive overview of contingent liability risks that MoFs face^{12,27-29}. Yet, similar to climate-related risk transmission channels, contingent liability risks from climate change are country- and context-dependent. Physical risk impacts are heterogeneous among countries. Further, economic and financial market characteristics determine climate-related risk severity and materiality²². For example, a country with a dominant fossil fuel extraction sector could be strongly exposed to climate transition risk. A country with a deep financial market might be able to absorb a certain degree of climate physical and climate transition risk.

^f MoFs will need to decide in a specific circumstance whether to act upon those outlays, with the risk of increasing moral hazard. MoFs, nevertheless, may need to intervene to prevent economic contagion.

^g A number of caveats apply, however. First, in the underlying dataset of the study (1990-2014) of the risks from PPPs appear low due to the long-term nature of these projects. Second, fiscal risks are highly correlated. Therefore, what look like isolated risks in table 1 (e.g., PPPs, SOEs, natural disasters) might actually be interlinked.

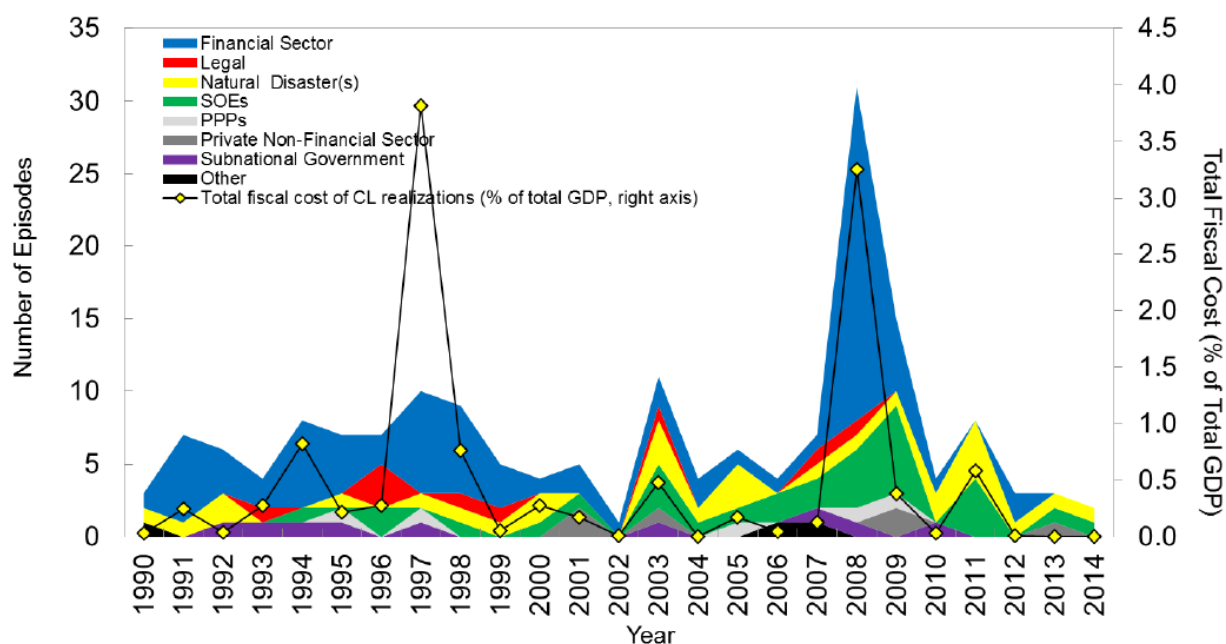
^h Though no legal obligation for governments existed.

Table 1: Average Fiscal Cost of Contingent Liability Realizations of 34 advanced Economies and 46 Emerging Market Economies from 1990-2014

Type of Contingent Liabilities	Number of Episodes	Number of Episodes with Identified Fiscal Costs	Avg. Fiscal Costs (% GDP)	Maximum Fiscal Costs (% of GDP)
Financial Sector	91	82	9.7	56.8
Legal	9	9	7.9	15.3
Subnational Government	13	9	3.7	12
SOEs	32	31	3	15.1
Natural Disaster(s)	65	29	1.6	6
Private Non-Financial Sector	7	6	1.7	4.5
PPPs	8	5	1.2	2
Other	5	3	1.4	2.5
Total	230	174	6.1	56.8

Source: Bova et al. (2016)

Figure 4: Number of Contingent Liability Realizations by Year and Type of 34 Advanced Economies and 46 Emerging Market Economies



Source: Bova et al. (2016)

Contingent Liability Risk with Ex-Ante *Known* Fiscal Costs

Contingent liabilities with ex-ante known fiscal costs could become more likely with ongoing climate change, leading to a gradual deterioration of a country's public finance conditions. Guarantees provided to SOEs or minimum revenue guarantees under Public Private Partnerships (PPPs) could be activated under pressure from climate physical and climate transition risks. Loans from the government's on-lending activities might defaultⁱ. Judicial awards could pose high costs. MoFs earmark funds for legal proceedings, and this action could also be taken for cases related to climate risks. Yet, court decisions and legal compensation for climate-related issues currently remain a legal grey zone. Businesses and citizens could claim compensation for a wide range of physical or transition risk damages^{61–63}, posing unknown fiscal costs for MoFs. Further, critical infrastructure may need to be replaced or adapted to withstand more frequent and severe extreme weather events – contingent on the high uncertainty of future climate impacts and risk materialization. Disaster-related contingent liabilities could pose a significant risk for public finance frameworks⁶⁴, whereas timing and timeliness of disbursement of funds will be crucial to contain disaster costs¹⁰. To that end, creating ex ante fiscal space, and stacking instruments such as contingency funds, credit lines, traditional insurance, and insurance in the form of catastrophe risk bonds and regional risk pools, could be used to foster fast disaster recovery and long-term resilience. With more frequent and severe extreme weather events, ex-ante funds allocated to the materialization of contingent liabilities might not be sufficient, however.

Contingent Liability Risk with Ex-Ante *Unknown* Fiscal Costs

With ongoing climate change, contingent liability risks with ex-ante unknown fiscal costs could become more likely. Physical risks that were viewed as highly unlikely tail risks, are expected to occur with greater intensity and frequency⁸, yet outcomes are difficult to predict. For instance, the COVID-19 pandemic might not be a singular event, as human exposure to zoonotic diseases is expected to increase with ongoing climate change⁶⁵. Extreme weather events are another example – they are becoming more frequent, with 2020 being the busiest year for the Atlantic hurricane season on record⁶⁶. The increasing likelihood and frequency of physical risks also increases the likelihood of compound events⁶⁷, such as tropical cyclones occurring during a pandemic, potentially resulting in economic and financial risk amplification²³.

Reinforcing feedback effects from frequent and expected climate physical and climate transition risk might increase the scope and likelihood of the occurrence of contingent liabilities with ex-ante unknown fiscal costs for MoFs. The conditions for such an event to be triggered, as well as the fiscal costs and the required government response, are uncertain⁶⁸ and would require forward-looking scenario analysis (see details below). Contingent liabilities with ex-ante unknown fiscal costs for MoFs depend on the materiality and severity of climate-related risks. Even a relatively modest impact, but likely materialization, of climate-related risks could trigger contingent liabilities with ex-ante unknown fiscal costs. Firms and sectors significantly impacted by climate policies could call

ⁱ One may argue that on-lending arrangements are contingent assets rather than liabilities, but the fiscal impact would be similar.

for compensatory payments, regions could require structural development funding, and laid-off workers could require additional social security spending^{69,j} exceeding expectations and allocated funds. Disaster impacts could require relief expenditure, such as shelter or emergency payments, where timing is critical; however, a changing climate makes those costs difficult to anticipate.

Strong impacts of reinforcing feedback effects from climate-related risk transmission channels are potentially less likely to materialize but pose high ex-ante unknown fiscal costs from contingent liabilities. More frequent public health emergencies⁶⁵, such as the COVID-19 pandemic, require relief expenditures for businesses and households affected by pandemic containment measures. Severe economic or financial crises could arise from the interplay of several climate-related risk transmission channels, the materialization of which could lead to tremendous fiscal costs^k. MoFs will need to decide under specific circumstances whether to act upon those outlays, with the risk of increasing moral hazard. In certain cases, intervention may be necessary to prevent economic contagion. To avoid bank runs, MoFs might provide a blanket guarantee on deposits or take over deposit insurance schemes. To stabilize struggling banks, MoFs might grant financial sector guarantees. Firms and banks could require bailouts. Additionally, MoFs might need to step in to provide insurance for firms and households if private sector insurance companies can no longer underwrite risk or withdraw coverage¹⁵.

Implications for Ministries of Finance

The materialization, or likely materialization, of contingent liability risks could have substantial financial implications for MoFs and act as a barrier to countries' achievement of the SDGs. The additional fiscal costs could lower the fiscal space of MoFs, potentially requiring budget cuts in critical sectors (e.g. healthcare, education), necessitating tax increases or leading to higher public debt levels. This could raise concerns related to debt sustainability, potentially deteriorating sovereign creditworthiness^{15,70,71}. As a consequence, sovereign borrowing costs could increase and access to international capital markets could even become restricted^{72,73}. Trust in financial markets by international and domestic investors might deteriorate. Financial institutions and investors holding sovereign bonds might face haircuts. This could induce a vicious cycle leading to decreases in both sovereign and financial institution creditworthiness. Further, if MoFs are impeded in their ability to react quickly and firmly to contain contingent liability risks, inaction could feed back into the economy and financial markets. Firms, banks, and investors might default; households could fall into long-term unemployment and poverty. As such, climate-related risks could impact countries' long-run economic growth paths.

^j If additional social security spending is consistent with regulation, this would pose an explicit contingent liability. If there is no legal requirement for the government to do so, it poses an implicit contingent liability for the MoF.

^k Historically, the implicit contingent liability stemming from the financial sector poses the highest fiscal costs for MoFs (Bova et al. 2016).

Endogeneity of Climate-related Risks for Ministries of Finance

Climate-related risks are not set, but are endogenous to climate action. They depend on actions to mitigate greenhouse gas emissions and advance adaptation (limiting climate physical risk), as well as actions to drive a smooth economic transition (limiting climate transition risk). This is often referred to as the double materiality of climate change¹. Whether and to what extent the above presented climate-related risks for MoFs will materialize is uncertain, in particular because government action is aimed at countering those risks. Coordinated action by central banks, line ministries, and MoFs to manage climate-related risks can shape the materialization of these risks. Country characteristics and economic structures determine whether priority policy measures should be tilted towards mitigation (e.g. OECD countries) or adaptation policies (e.g. low-income countries). The endogeneity of climate risks differs for high emitting and low emitting countries.

MoFs have strong risk management levers via budgets, policy, and regulation. Forward-looking scenario analysis and climate and disaster risk assessment for the financial sector could provide MoFs with important information on sources of climate-related risk transmission and amplification to help identify the most effective levers. Macroeconomic and financial modeling analyses of climate physical risk (including compounding events such as pandemics and tropical cyclones) and transition risk can highlight implications for tax revenues, additional expenditure and adaptation needs, sectoral winners and losers, financial risks, as well as long term considerations for public debt¹⁰. To effectively provide such information, analyses may need to explicitly incorporate climate-related risk characteristics^{14,74,75}, such as varying perceptions of climate-related risks and respective actions taken by firms, financial institutions, policymakers, and households that could result in non-linear behavior and impacts^{74,76,77}. Further, analyzing country specific risk transmission channels to understand how these could reinforce feedback loops could indicate appropriate levers for climate policy action and financial risk management. An assessment of different climate policy instruments, such as green bonds or a carbon tax, could thereby highlight potential trade-offs and policy complementarities^{78–80}.

Risk models should incorporate the ambivalent role of finance⁵³ as an enabler of or barrier to risk amplification, impacting the outcome of the low-carbon transition. Such analysis can inform assessments of risk materiality and severity. This may help MoFs and Debt Management Offices (DMOs) report to sovereign investors on climate-related risks and respective implemented or planned adaptation and resilience measures. Initial analysis has shown that investment in resilience measures can partially mitigate upward pressure on sovereign bond yields driven by climate risk^{28,81}, and reporting could help address issues related to lack of transparency on risks and resilience. Further such analysis can help countries prepare for climate-related risk enhanced IMF Article 4 consultations^{82,83}, Financial Sector Assessment Program (FSAPs), and debt sustainability analysis (DSA)⁸⁴ exercises. Central banks can provide modeling support to MoFs as they have extensive experience conducting stress-testing exercises and financial sector systemic risk assessments.

Accelerating climate change and its related financial risks are highly uncertain, however a range of impacts can already be observed^{85,86}. Ambitious mitigation and adaptation measures could reduce the likelihood of severe climate-related risk impacts that could otherwise grow and potentially hinder countries' long-term economic

¹ Robins et al. (2021) highlight this concept in the context of central banks for instance⁹²

development. Moreover, early climate action comes at a relatively low cost and could have significant co-benefits. For instance, green investments could stimulate economic growth, generate jobs, and create markets for innovative technologies that could help to mobilize green finance and ensure debt sustainability⁸⁷. Moreover, climate action has significant potential to contribute to local environmental benefits, such as reduced air and water pollution, increased biodiversity,^{88,30} and enhanced food⁸⁹ and water⁹⁰ security. The public health co-benefits from improved environmental quality could also be significant³⁰.

Conclusion and Policy Actions for Ministries of Finance

Climate-related risks pose a substantial threat for MoFs via direct fiscal impacts, increased cost of borrowing, or triggered contingent liabilities. In this context, contingent liability risks with ex-ante unknown fiscal costs and implications for MoFs could be substantial, but their materialization is context- and country-specific and depends on climate action. This note provided an overview of potential fiscal, as well as contingent liability, risks that could be triggered by the transmission and interaction of climate-related risks.

The characteristics of climate-related risks (i.e. deep uncertainty, non-linearity, and endogeneity)^{24,74}, make their identification and the assessment of their likelihood and quantitative value challenging. However, a new set of methodologies could improve the understanding and assessment of climate-related risk exposure^{14,74,91} and identify respective winners and losers of the low-carbon transition. The resulting insights could improve the design of precautionary measures to enhance resilience (fiscal, social, economic, financial, and environmental), avoiding the materialization of unpredictable worst-case scenarios. A better understanding of climate-related risks can enable MoFs to build the body of information they need to pursue policy planning, regulation, and budgeting that is aligned with sustainable development.

The uncertainty and potentially tremendous scope of climate-related risk impacts require both ambitious climate action to reduce the likelihood of impacts, and the use of new financial instruments (such as catastrophe bonds, insurance policies, and safety nets) to manage the cost of impacts when they occur. Even more so, as early climate action comes at a relatively low cost and has significant potential to trigger co-benefits. However, an orderly low-carbon transition requires coordinated and ambitious efforts across the whole public and private, financial, and economic sector domain. Central banks, supervisors, and regulators can play a signaling and market shaping role^{92–96}, leveraging sustainable finance tools and approaches. However, MoFs also play a leading role in climate action. In this context, sufficient expertise, and resources in MoFs would need to be dedicated to climate risk management. Policy experience and research suggest at least five critical policy actions MoFs can take to better mitigate and manage climate-related risks.

First, contingent liabilities from climate-related risks could be included in the fiscal planning and budget process and mechanisms that allow for quick financial response to disasters could be put in place^{10,m}. In this regard, MOFs could build in-house capacity to better cope with climate-related risks and take climate action⁹⁷. Macro-fiscal risk assessments, enhanced with climate-related risk analysis, such as through the IMF/World Bank Financial Stability Assessment Program (FSAP)^{83,98} and Debt Sustainability Analysis, can be conducted to identify system-level risks and vulnerabilities. To respond to those vulnerabilities, MoFs could further develop and make use of budgetary instruments that account for climate-related physical risks^{10,28}. Those budgetary instruments may include contingency funds, credit lines, traditional insurance, and insurance in the form of catastrophe risk bonds and regional risk pools that help to transfer risk and enable fast recovery. At the same time, risk

^m Especially potential implicit contingent liability risk could be large in extreme cases. However, with the caveat that the government might prefer to maintain the ambiguity on its willingness to act to avoid moral hazard.

management strategies should be flexible enough to quickly adapt to new scientific insights, given the uncertainty of these risks.

Second, there is a need for policy coherence on climate change. Climate considerations should be mainstreamed into the design of public policies. Green fiscal reforms implemented by MoFs could generate significant co-benefits⁹⁹, while supporting Line Ministries with the implementation of a country's long-term transition strategy. MoFs could also target the diversification of government revenue streams²⁸, as fiscal policies could foster diversifying the economy away from climate-sensitive economic activities²⁷. Green budgeting^{100,n} could be a powerful tool to monitor progress and ensure climate policy coherence. Green stimulus and supportive policies can ensure that the recovery from the COVID-19 pandemic and economic downturn sets the economy in the direction of improved climate-related risk mitigation and management^{101,102}.

Third, coordination between MoFs, Debt Management Offices (DMOs)^o, Line Ministries, Central Banks, and Development Finance Institutions (DFIs), with input from citizens, is essential²⁸. Guidelines or requirements for climate-related risk disclosure¹⁷ could reduce financial losses, as risk surveillance could help to identify and tackle sources of risk. The potential for coordination between MoFs and Central Banks lies specifically within macro-financial risk assessment and forward-looking scenario analyses that would benefit from a common and consistent approach. Central Banks have unique insights into the functioning of the macroeconomy and the financial system and are increasingly building capacity to analyze climate-related physical and transition impacts on the economy. It is hence vital that MoFs liaise closely with Central Banks, and that the latter contribute to comprehensive vulnerability assessment, where all sources of vulnerability for the macroeconomy, the financial system, and public finances are systematically assessed and possible actions are considered²⁸. Such an assessment could be conducted by a dedicated national climate risk board that would include the Central Bank and supervisor, along with key government departments responsible for finance, the economy, planning, and agriculture, among others²⁸. The vulnerability assessment could form the basis for a number of subsequent, coordinated actions aimed at mitigating and managing climate-related risks. Further, better data, regulatory consistency, and credible commitments are needed to inform climate risk reporting analysis and climate stress-testing exercises, as well as to ensure that regulatory frameworks are aligned with NDC targets. Long term transition strategies^p will be a critical source of information for MoFs and other climate-related risk managers, as they outline transition milestones for the economy, aligned with a country's NDC targets.

MoFs can also contribute by leading the design of sustainable finance roadmaps^{q,103} that mobilize private sector finance, aligned with long term strategies. MoFs play an important role in signaling the private sector and local governments. Carbon taxes and carbon markets are critical policy tools, which can also serve as a substantial revenue source to finance the transition to a low-carbon economy^r. If MoFs go credibly ahead, thereby creating certainty around policy direction, others are likely to follow. Together with DMOs, MoFs could also develop

ⁿ Green budgeting currently entails a large set of different definitions, emphasizing different aspects and methodologies (see for example the one from the OECD (<http://www.oecd.org/environment/green-budgeting/>)).

^o In cases where the DMO is located outside of the MoF.

^p Climate transition and adaptation strategies

^q Comprising an investment plan, green product labeling standards/taxonomy, and regulatory measures. The Coalition will publish a paper on sustainable finance roadmaps later this year.

^r However, as the economy decarbonizes, this revenue source will likely dry up over time.

public sector funding and debt management strategies that could entail risk-sharing features, such as a natural disaster clause^{28,104}. To finance mitigation measures, DMOs can issue sovereign green financing instruments, which also have a market signaling role¹⁰⁵. DFIs or green banks may support a green transition with innovative green financial products¹⁰⁶ and concessional lending, domestically or in low-income countries. Further, consultation with stakeholders such as businesses, NGOs, and citizens could generate insights for more effective policy levers, ensure broader support for climate action, and enhance political feasibility.

Fourth, governments in general, and MoFs in particular, can leverage their fiduciary role for SOEs, which are often large-scale infrastructure providers or carbon intensive companies⁴⁶. MoF engagement in greening SOEs may thus be beneficial for MoFs and the economy in three ways. First, contingent liability risks for MoFs could be mitigated as transition risk for SOEs is reduced. Second, a profitable green business model of an SOE could signal to private companies in the same sector. Third, SOEs could become technology leaders in the low-carbon transition, creating positive spillovers for the entire economy.

Finally, MoFs can learn from best practice examples from peer countries to avoid unnecessary trade-offs and ensure effective and timely climate action¹⁰⁷. This could support a cooperative global climate agenda where national climate policies are aligned, leading to synergies, more robust policies, and cost effectiveness. The Coalition of Finance Ministers for Climate Action can play a role in supporting such experience sharing in global, regional, and bi-lateral exchanges.

References

1. NASA. 2020 Tied for Warmest Year on Record, NASA Analysis Shows. <https://www.nasa.gov/press-release/2020-tied-for-warmest-year-on-record-nasa-analysis-shows> (2021).
2. Smith, A. B. 2020 U.S. billion-dollar weather and climate disasters in historical context. *NOAA Climate.gov* <https://www.climate.gov/news-features/blogs/beyond-data/2020-us-billion-dollar-weather-and-climate-disasters-historical> (2021).
3. Weitzman, M. L. On Modeling and Interpreting the Economics of Catastrophic Climate Change. *Rev. Econ. Stat.* **91**, 1–3 (2009).
4. Lenton, T. M. *et al.* Climate tipping points — too risky to bet against. *Nature* **575**, 592–595 (2019).
5. Steffen, W. *et al.* Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci. U. S. A.* **115**, 8252–8259 (2018).
6. Nordhaus, W. D. Evolution of Assessments of the Economics of Global Warming: Changes in the DICE Model, 1992-2017. *NBER Work. Pap.* **23319**, (2017).
7. Burke, M., Hsiang, S. M. & Miguel, E. Global non-linear effect of temperature on economic production. *Nature* **527**, 235–239 (2015).
8. IPCC. *Global Warming of 1.5C - Summary for Policymakers.* (2018).
9. Intergovernmental Panel on Climate Change. *Climate Change 2014 Synthesis Report. Fifth Assessment Report (AR5)* <https://www.ipcc.ch/report/ar5/syr/> (2014).
10. Hallegatte, S., Rentschler, J. & Rozenberg, J. *The Adaptation Principles: A guide for designing strategies for climate change adaptation and resilience.* (World Bank, 2020).
11. IMF. Climate Change Dashboard. <https://climatedata.imf.org/pages/fi-indicators/#fi3> (2021).
12. NGFS. *A call for action - Climate change as a source of financial risk.* (Network for Greening the Financial System, 2019).
13. Feyen, E., Utz, R., Zuccardi Huertas, I., Bogdan, O. & Moon, J. Macro-Financial Aspects of Climate Change. *World Bank Policy Res. Work. Pap.* (2020) doi:10.1596/1813-9450-9109.
14. Monasterolo, I. Embedding Finance in the Macroeconomics of Climate Change: Research Challenges and Opportunities Ahead. *CESifo Forum* **21**, 25–32 (2020).
15. FSB. *The Implications of Climate Change for Financial Stability.* (Financial Stability Board, 2020).
16. ECB. *Guide on climate-related and environmental risks risk management and disclosure - Supervisory expectations relating to risk management and disclosure.* (European Central Bank, 2020).
17. TCFD. *Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report* (Task Force on Climate-related Financial Disclosures, 2017).
18. Regelink, M., Reinders, H. J., Vleeschhouwer, M. & van de Wiel, I. *Waterproof? An exploration of climate-related risks for the Dutch financial sector.* (De Nederlandsche Bank, 2017).
19. Battiston, S., Mandel, A., Monasterolo, I., Schütze, F. & Visentin, G. A climate stress-test of the financial

- system. *Nat. Clim. Chang.* **7**, 283–288 (2017).
20. IMF & The World Bank. *Financial Sector Assessment Program - The Philippines*. (International Monetary Fund, The World Bank, 2021).
 21. Allen, R., Hurcan, Y., Murphy, P., Queyranne, M. & Yläoutinen, S. The Evolving Functions and Organization of Finance Ministries. *IMF Work. Pap.* **232**, (2015).
 22. BIS. *Climate-related risk drivers and their transmission channels*. (Bank for International Settlements, 2021).
 23. Dunz, N., Mazzocchetti, A., Monasterolo, I., Essenfelder, A. H. & Raberto, M. Macroeconomic and Financial Impacts of Compounding Pandemics and Climate Risks. *SSRN Work. Pap.* (2021)
doi:<https://dx.doi.org/10.2139/ssrn.3827853>.
 24. Monasterolo, I. Climate Change and the Financial System. *Annu. Rev. Environ. Resour.* **12**, (2020).
 25. NGFS. *NGFS Climate Scenarios for central banks and supervisors*. (Network for Greening the Financial System, 2020).
 26. IMF. *Public Sector Debt Statistics: Guide for Compilers and Users*. (International Monetary Fund, 2011).
doi:10.5089/9781616351564.069.
 27. Schuler, P., Oliveira, L. E., Mele, G. & Antonio, M. Managing the Fiscal Risks Associated with Natural Disasters. in *Fiscal Policies for Development and Climate Action* (ed. Pigato, M. A.) (The World Bank, 2019).
 28. Volz, U. *et al.* *Climate Change and Sovereign Risk*. (SOAS Centre for Sustainable Finance, Asian Development Bank Institute, World Wide Fund for Nature Singapore, Four Twenty Seven, 2020).
 29. Cebotari, A. Contingent Liabilities: Issues and Practice. *IMF Work. Pap.* **08**, 1 (2008).
 30. WHO. *COP 24 Special Report: Health and Climate Change*. (World Health Organization, 2018).
 31. Haines, A. & Ebi, K. The Imperative for Climate Action to Protect Health. *N. Engl. J. Med.* **380**, 263–273 (2019).
 32. Watts, N. *et al.* The 2020 report of the Lancet Countdown on health and climate change: responding to converging crises. *Lancet* **397**, 129–170 (2021).
 33. IPCC. Summary for Policymakers. in *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (eds. Shukla, P. R. *et al.*) (International Panel on Climate Change, 2019).
 34. USGCRP. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. (2018) doi:doi: 10.7930/NCA4.2018.
 35. Bernstein, A., Gustafson, M. T. & Lewis, R. Disaster on the horizon: The price effect of sea level rise. *J. financ. econ.* **134**, 253–272 (2019).
 36. Batten, S. *Climate change and the macro-economy: a critical review*. *Staff Working Paper No. 706*
<https://www.bankofengland.co.uk/working-paper/2018/climate-change-and-the-macro-economy-a-critical-review> (2018).
 37. Lobell, D. B., Schlenker, W. & Costa-Roberts, J. Climate Trends and Global Crop Production Since 1980. *Science (80-.)*. **333**, 616–620 (2011).
 38. Hallegatte, S. Disasters’ impacts on supply chains. *Nat. Sustain.* **2**, 791–792 (2019).

39. Dasgupta, P. *The economics of biodiversity: The Dasgupta review*. (HM Treasury, 2021).
40. Kling, G., Volz, U., Murinde, V. & Ayas, S. The impact of climate vulnerability on firms' cost of capital and access to finance. *World Dev.* **137**, 105131 (2021).
41. Creutzig, F. *et al.* Towards demand-side solutions for mitigating climate change. *Nat. Clim. Chang.* **8**, 268–271 (2018).
42. Dunz, N., Naqvi, A. & Monasterolo, I. Climate Transition Risk, Climate Sentiments, and Financial Stability in a Stock-Flow Consistent Model. *J. Financ. Stab.* (2021) doi:<https://doi.org/10.1016/j.jfs.2021.100872>.
43. Battiston, S. & Monasterolo, I. On the Dependence of Investor's Probability of Default on Climate Transition Scenarios. *SSRN Work. Pap.* (2020) doi:<https://dx.doi.org/10.2139/ssrn.3743647>.
44. Frank, W., Bals, C. & Grimm, J. The Case of Huaraz: First Climate Lawsuit on Loss and Damage Against an Energy Company Before German Courts. in *Loss and Damage from Climate Change: Concepts, Methods and Policy Options* (eds. Mechler, R., Bouwer, L. M., Schinko, T., Surminski, S. & Linnerooth-Bayer, J.) (Springer Open, 2019). doi:10.1007/978-3-319-72026-5.
45. Roncoroni, A., Battiston, S., Escobar-Farfán, L. O. L. & Martinez-Jaramillo, S. Climate risk and financial stability in the network of banks and investment funds. *J. Financ. Stab.* **54**, 100870 (2021).
46. The Guardian. What do we know about the top 20 global polluters? *The Guardian Online* (2019).
47. Baum, A., Medas, P., Soler, A. & Sy, M. Managing Fiscal Risks from State-Owned Enterprises. *IMF Work. Pap.* **20**, (2020).
48. Batten, S., Sowerbutts, R. & Tanaka, M. Climate Change: Macroeconomic Impact and Implications for Monetary Policy. in *Ecological, Societal, and Technological Risks and the Financial Sector* (eds. Walker, T., Gramlich, D., Bitar, M. & Fardnia, P.) 13–38 (Springer International Publishing, 2020). doi:10.1007/978-3-030-38858-4_2.
49. Carleton, T. A. & Hsiang, S. M. Social and economic impacts of climate. *Science (80-.)*. **353**, (2016).
50. Hsiang, S. M., Burke, M. & Miguel, E. Quantifying the Influence of Climate on Human Conflict. *Science (80-.)*. **341**, (2013).
51. Dellink, R., Hwang, H., Lanzi, E. & Chateau, J. International trade consequences of climate change. *OECD Trade Environ. Work. Pap.* **01**, (2017).
52. Felbermayr, G. & Peterson, S. *Economic assessment of Carbon Leakage and Carbon Border Adjustment. European Parliament - Four briefings on Trade-related aspects of carbon border adjustment mechanisms* (2020).
53. Battiston, S., Monasterolo, I., Riahi, K. & van Ruijven, B. J. Accounting for finance is key for climate mitigation pathways. *Science (80-.)*. (2021) doi:10.1126/science.abf3877.
54. Battiston, S., Billio, M. & Monasterolo, I. Pandemics, Climate and Public Finance - How to Strengthen Socio-Economic Resilience across Policy Domains. in *A New World Post COVID-19 - Lessons for Business, the Finance Industry and Policy Makers* (eds. Billio, M. & Varotto, S.) (2020).
55. Mahul, O. & Signer, B. Commentary The Perfect Storm : How to Prepare against Climate Risk and Disaster Shocks in the Time of COVID-19. *One Earth* **2**, 500–502 (2020).
56. IPBES. *The global assessment report on biodiversity and ecosystem services: summary for policymakers*.

- (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019).
57. World Bank Group. *Mobilising Private Finance for Nature*. (The World Bank Group, 2020).
 58. Schnabel, I. The sovereign-bank-corporate nexus – virtuous or vicious? *Speech by Isabel Schnabel, Member of the Executive Board of the ECB, at the LSE conference on “Financial Cycles, Risk, Macroeconomic Causes and Consequences”* <https://www.ecb.europa.eu/press/key/date/2021/html/ecb.sp210128~8f5dc86601.en.html> (2021).
 59. Bova, E., Ruiz-Arranz, M., Toscani, F. & Ture, H. E. The Fiscal Costs of Contingent Liabilities: A New Dataset. *IMF Work. Pap.* **16**, 1 (2016).
 60. IMF. From Banking to Sovereign Stress - Implications For Public Debt. *IMF Policy Pap.* **December**, (2014).
 61. Mathiesen, K., Aarup, S. A. & Oroschakoff, K. EU governments whipsawed by climate and coal lawsuits. *Politico* (2021).
 62. Chazan, G. German court rules utilities can claim for nuclear shutdown decision. *Financial Times* (2016).
 63. Schwartz, J. Court Quashes Youth Climate Change Case Against Government. *The New York Times* (2020).
 64. Gamper, C., Signer, B., Alton, L. & Petrie, M. Managing disaster-related contingent liabilities in public finance frameworks. *OECD Work. Pap. Public Gov.* **27**, (2017).
 65. Gibb, R. *et al.* Zoonotic host diversity increases in human-dominated ecosystems. *Nature* **584**, 398–402 (2020).
 66. NOAA. 2020 Atlantic Hurricane Season takes infamous top spot for busiest on record. *NOAA National Centers for Environmental Information* <https://www.noaa.gov/news/2020-atlantic-hurricane-season-takes-infamous-top-spot-for-busiest-on-record> (2020).
 67. Zscheischler, J. *et al.* Future climate risk from compound events. *Nat. Clim. Chang.* **8**, 469–477 (2018).
 68. Bachmair, F. F. Contingent Liabilities Risk Management: A Credit Risk Analysis Framework for Sovereign Guarantees and On-Lending: Country Experiences from Colombia, Indonesia, Sweden, and Turkey. *Policy Res. Work. Pap. - World Bank Gr.* **7538**, (2016).
 69. Buck, T. & Chazan, G. Germany plans to phase out coal-fired power stations by 2038. *Financial Times* (2019).
 70. Cevik, S. & Jalles, J. T. Feeling the Heat: Climate Shocks and Credit Ratings. *IMF Work. Pap.* **20**, (2020).
 71. Boehm, H. Physical Climate Change Risks and the Sovereign Creditworthiness of Emerging Economies. *SSRN Electron. J.* (2020) doi:10.2139/ssrn.3663846.
 72. Kling, G., Lo, Y., Murinde, V. & Volz, U. Climate Vulnerability and the Cost of Debt. *SSRN Electron. J.* (2018) doi:10.2139/ssrn.3198093.
 73. Cevik, S. & Jalles, J. T. This Changes Everything: Climate Shocks and Sovereign Bonds. *IMF Work. Pap.* **20**, (2020).
 74. Bolton, P., Despres, M., Pereira da Silva, L. A., Samama, F. & Svartzman, R. *The green swan - Central banking and financial stability in the age of climate change*. (BIS, Banque de France, 2020).
 75. Campiglio, E. *et al.* Climate change challenges for central banks and financial regulators. *Nat. Clim. Chang.* **8**, 462–468 (2018).

76. Sharpe, S. *et al.* *Deciding how to decide : Risk-opportunity analysis as a generalisation of cost-benefit analysis.* UCL Institute for Innovation and Public Purpose <https://www.ucl.ac.uk/bartlett/public-purpose/publications/2021/jan/deciding-how-decide-risk-opportunity-analysis-generalisation-cost-benefit> (2021).
77. Battiston, S. The importance of being forward-looking. Managing financial stability in the face of climate risk. *Financ. Stab. Rev. Banq. Fr.* **23**, 39–48 (2019).
78. Stiglitz, J. E. Addressing climate change through price and non-price interventions. *Eur. Econ. Rev.* **119**, 594–612 (2019).
79. Dafermos, Y., Nikolaidi, M. & Galanis, G. Climate Change, Financial Stability and Monetary Policy. *Ecol. Econ.* **152**, 219–234 (2018).
80. Monasterolo, I. & Raberto, M. The EIRIN Flow-of-funds Behavioural Model of Green Fiscal Policies and Green Sovereign Bonds. *Ecol. Econ.* **144**, 228–243 (2018).
81. Buhr, B. *et al.* *Climate Change and the Cost of Capital in Developing Countries.* (Imperial College London; SOAS University of London; UN Environment, 2018).
82. IMF. *Articles of Agreement of the International Monetary Fund.* vol. March <https://www.imf.org/external/pubs/ft/aa/index.htm> (2020).
83. Gallagher, K. P., Ramos, L., Stephenson, C. & Monasterolo, I. Climate Change and IMF Surveillance The Need for Ambition. *GEGI Policy Br.* **014**, (2021).
84. IMF. Review of the Debt Sustainability Framework for Market Access Countries. *IMF Policy Pap.* **January**, (2021).
85. Stott, P. A. *et al.* Attribution of extreme weather and climate-related events. *Wiley Interdiscip. Rev. Clim. Chang.* **7**, 23–41 (2016).
86. Chiang, F., Mazdiyasi, O. & AghaKouchak, A. Evidence of anthropogenic impacts on global drought frequency, duration, and intensity. *Nat. Commun.* 1–10 (2021) doi:10.1038/s41467-021-22314-w.
87. Batini, N., Serio, M. Di, Frassetto, M., Melina, G. & Waldron, A. Building Back Better: How Big Are Green Spending Multipliers? *IMF Work. Pap.* 47 (2021).
88. New Climate Economy. *Unlocking the Inclusive Growth Story of the 21st Century: Accelerating Climate Action In Urgent Times.* (New Climate Economy, 2018).
89. FAO. *Climate change and food security: Risks and responses.* (Food and Agriculture Organization of the United Nations, 2015). doi:10.1080/14767058.2017.1347921.
90. IUCN. *Water and Climate Change Issues Brief.* (International Union for Conservation of Nature, 2015).
91. Smith, P. *The Climate Risk Landscape: A comprehensive overview of climate risk assessment methodologies.* (UNEP FI, 2021).
92. Robins, N., Dikau, S. & Volz, U. *Net-zero central banking : A new phase in greening the financial system.* (Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science, and Centre for Sustainable Finance, SOAS, University of London, 2021).
93. Campiglio, E. Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a

- low-carbon economy. *Ecol. Econ.* **121**, 220–230 (2016).
94. Battiston, S. & Monasterolo, I. How could the ECB's monetary policy support the sustainable finance transition? *FINEXUS Work. Pap. (input to Posit. Money Veblen's policy Rep. "Aligning Monet. Policy with EU's Clim. Targets")* 1–18 (2019).
 95. Oustry, A., Erkan, B. & Svartzman, R. Climate-related Risks and Central Banks' Collateral Policy: A Methodological Experiment. *SSRN Electron. J.* (2021) doi:10.2139/ssrn.3771299.
 96. Dikau, S. & Ryan-Collins, J. Green Central Banking in emerging market and developing country economies. *New Econ. Found.* 1–50 (2017).
 97. Georgieva, K. The IMF is placing climate change at heart of its work. *Remarks by IMF Managing Director at the Climate Adaptation Summit* <https://www.imf.org/en/News/Articles/2021/01/25/sp012521-md-remarks-at-the-climate-adaptation-summit> (2021).
 98. Adrian, T., Morsink, J. & Schumacher, L. *Stress Testing at the IMF. Departmental Papers / Policy Papers* vol. 20 (International Monetary Fund, 2020).
 99. Heine, D. & Black, S. Benefits beyond Climate: Environmental Tax Reform. in *Fiscal Policies for Development and Climate Action* (ed. Pigato, M. A.) (World Bank Group, 2019). doi:10.1596/978-1-4648-1358-0.
 100. Bain, N., Nguyen, L. & Baboyan, K. *Knowing what you spend: A guidance note for Governments to track climate finance in their budgets.* (UNDP, 2017).
 101. The Coalition of Finance Ministers for Climate Action. *Better Recovery, Better World: Resetting climate action in the aftermath of the COVID-19 pandemic.* vol. July (The Coalition of Finance Ministers for Climate Action, 2020).
 102. Levy, J., Brandon, C. & Studart, R. *Designing the COVID-19 Recovery for a Safer and More Resilient World.* (World Resources Institute, 2020).
 103. PRI & World Bank Group. *How policy makers can implement reforms for a sustainable financial system.* (Principles for Responsible Investment, World Bank Group, 2020).
 104. Anthony, M., Impavido, G. & Selm, B. van. Barbados' 2018-19 Sovereign Debt Restructuring – A Sea Change? *IMF Work. Pap.* **20/34**, (2020).
 105. Boitreaud, S., Gratcheva, E. M., Gurhy, B., Paladines, C. & Skarnulis, A. *Riding the Wave : Navigating the ESG Landscape for Sovereign Debt Managers.* (World Bank Group, 2020).
 106. Silva, A. C. & Stewart, F. My word is my bond: Linking sovereign debt with national sustainability commitments. *World Bank Blogs* <https://blogs.worldbank.org/climatechange/my-word-my-bond-linking-sovereign-debt-national-sustainability-commitments> (2021).
 107. The Coalition of Finance Ministers for Climate Action. *Long-Term Strategies for Climate Change: A review of Country Cases.* (The Coalition of Finance Ministers for Climate Action, 2020).
 108. International Monetary Fund. *Small States' Resilience to Natural Disasters and Climate Change - Role for the IMF. IMF Policy Paper* (2016).