

Macro-Financial Aspects of Climate Change

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Abstract

This paper examines the interaction between macro-financial and climate-related risks. It brings together different strands of the literature on climate-related risks and how these relate to macro-financial management and risks. Physical impacts of climate change as well as the transition toward a resilient low-carbon economy pose significant challenges for macro-financial management, as they can damage the balance sheets of governments, households, firms, and financial institutions due to the adverse and possibly abrupt impacts on investment and economic growth,

fiscal revenue and expenditure, debt sustainability, and the valuation of financial assets. In turn, macro-financial risks translate into weakened resilience to physical climate risks and constrained capacity for climate adaptation and mitigation efforts. The paper finds that many countries face the “double jeopardy” of simultaneous elevated climate-related and macro-financial risks. Reducing macro-financial risks in countries under double jeopardy is an important component of international efforts to tackle climate change to complement and support country-specific efforts.

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Introduction and Conceptual Framework

Introduction

Climate change is one of the greatest global challenges. Unless adequate measures are taken to reduce greenhouse gas (GHG) emissions, adverse climate change impacts are projected to accelerate, with a serious risk of uncontrollable, catastrophic developments. The developing world, and in particular, the poorest segments of society, are likely to bear the worst impacts of climate change, given their high exposure, vulnerability, and limited means to prepare, cope and recover from climate-related catastrophes. Climate change thus puts the achievement of global poverty reduction and progress towards the Sustainable Development Goals at risk. Strong action to mitigate climate change and to adapt to its impacts is essential, as reflected in the 2015 Paris Agreement on Climate Change, which has been signed by 194 states and the European Union.

This paper examines the interaction between macro-financial and climate-related risks. It brings together different strands of the literature on climate-related risk and how these relate to macro-financial management and risks. As such, it seeks to provide a broad overview of issues and presents data on countries' exposure to both types of risks.

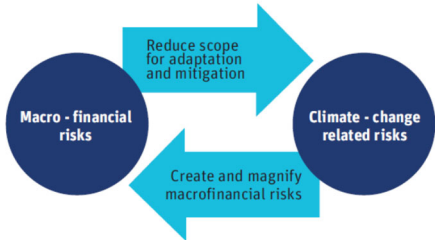
This paper is organized as follows: The remainder of this section lays out the conceptual framework used to examine these interactions. The second section examines in detail some of the linkages between climate change-related risks and macro-financial developments and management, with a focus on growth and structural transformation and fiscal, monetary, and financial sector linkages. Section 3 uses various indicators of macro-financial risk together with indicators of climate-related risks to identify countries that may be at particularly elevated risk levels due to the co-existence of climate related risks and macro-financial vulnerabilities. We conclude with a brief summary of key issues and implications for policy and analytic work.

Conceptual framework

Our conceptual framework links climate change to macro-financial risks and developments. Climate change-related risks magnify macro-financial risks, while at the same time macro-financial vulnerabilities limit the scope for effective action for climate change mitigation and adaptation (Figure 1). The interaction between these two sets of risks can give rise to either vicious or virtuous cycles.

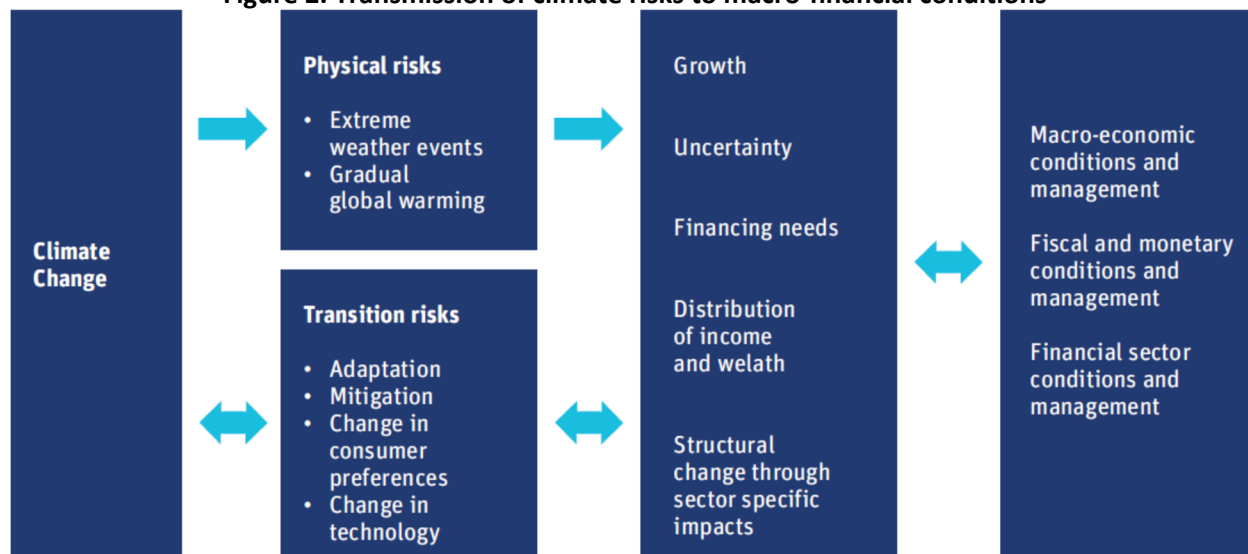
Climate change-related risks can be grouped into two categories: physical risks which are a consequence of changes in climate, and transition risks which derive from the transition to a low-carbon economy (Figure 2). Physical risks relate to the climate impacts from weather events such as tropical cyclones, droughts, heat waves, or flooding which are projected to increase in frequency and intensity and from the gradual effects of global warming. For example, sea-level rise could significantly reduce the productivity of coastal land (and lead to the submersion of entire atoll countries in the Pacific, such as Kiribati and Tuvalu), while

Figure 1. Interaction between macro-financial and climate related risks



temperature increases and changes in precipitation patterns would affect the productivity of agricultural land.

Figure 2. Transmission of climate risks to macro-financial conditions



Transition risks derive from the move towards a more resilient, low carbon economy, which is induced by climate policies as well as shifts in technology and consumer preferences which may occur abruptly. The transition to resilient, low-carbon economies implies that carbon-intensive sectors will face changes in their asset values and the economy might face higher costs of production, particularly those associated to energy prices due to changes in the energy mix. In addition, transition risks cover the impact on public and private balances caused by policies designed for the adaptation to climate change (i.e., adaptation of existing infrastructure and expansion of new types of infrastructure, research and development of technology for adaptation, etc.). Finally, changes in regulatory policy about climate change could encourage shifts in the private sector’s consumption and investment decisions. Transition risks capture the uncertainties related to the timing and speed of the adjustment to a low-carbon economy. While the net benefits of such measures should be positive, they generate very significant financing needs and result in structural changes in the transition to a low-carbon economy.²

These two sets of risks have direct economic impacts, including on economic growth, increased levels of uncertainty regarding the medium to long-term macro-economic outlook, increased public and private sector financing needs, structural changes to the economy, and the distribution of wealth and income. While physical risks reduce the productivity of all types of capital (human, physical, natural, social...) and thus impact economic growth, the impact of transition risks on economic growth is less clear cut. On the one hand, adaptation and mitigation measures create significant financing needs, which may crowd out public and private investment, but on the other, could also provide new growth impulses towards a green economy (The New Climate Economy, 2018). Climate change-related risks create multiple “deep

² Physical and transition risks are not independent with complex interaction between these two types of risks and over time. For example, delayed action on mitigation not only results in increased physical risks, but also an increased risk of economic collapse (Carney, 2019).

uncertainties” regarding medium- to long-term prospects (Hallegatte et al., 2012), which are likely to have an adverse effect on private sector investment.³

Thus, the economic impacts of climate change have a direct bearing on macro-financial stability and management. Lower economic growth coupled with large climate-related financing needs and increased levels of uncertainty will have a detrimental impact on the balance sheets of all sectors – public, financial, corporate, and households. At the same time, weaknesses in the balance sheets of these entities will also reduce their ability to take time-appropriate actions for climate change mitigation and adaptation.

Linkages between Climate Change and Macro-Financial Conditions

This section examines the interaction between macro-financial and climate change-related risks. Table 1 provides an illustration of how climate related risks would add to risks in the nine areas that are at the core of MFR monitoring. The subsequent discussion focuses on three specific areas of macro-financial and climate related risk interactions, namely: (a) economic transformation and economic growth; (b) fiscal and monetary policy and management; and (c) the financial sector.

Structural change and economic growth

Climate change will have significant macroeconomic implications for most economies, be it through the physical impacts or through the transition to a more resilient low-carbon economy. These changes will affect, inter alia, the structure of economies, economic growth, as well as prices and interest rates. These macroeconomic changes will have significant impacts on the balance sheets of key economic entities and thus on the level of macro-financial risks. The following paragraphs outline some of the key macroeconomic changes that can come about due to climate change.

Structural change

Climate change will entail significant structural changes for most economies in the medium to long term. Physical impacts, climate adaptation, and climate mitigation affect the productivity of existing investments as well as decisions on new investments. In the following section we discuss four channels through which climate change will lead to structural changes in economies, namely, productivity changes due to physical risks, crowding out of productive investments by investments in adaptation and mitigation measures, transition to a low carbon economy, and finally, innovation and the emergence of green sectors.

³ The nature of uncertainty underlying physical and transition risks may be different. Although in both cases underlying uncertainty is deep (i.e. difficult to assign probabilities), the sources of transition risks (that is faster decarbonization) are “more” deeply uncertain, because most of them are endogenous, i.e. are dependent on decisions not yet taken by billions of consumers, firms and governments. Transition risk can see temporary reversals (with policy and technology twists and turns), while physical risk can go slower or faster, but only in one direction.

Table 1. Interactions between macro-financial and climate related risks

Macro-financial risks		Examples of linkages with climate change	
Risk	Description	Physical	Transition
Spillover risks from the external environment outside the region	<ul style="list-style-type: none"> Exposure to external shocks through trade and financial channels Exchange rate market pressures Buffers against external shocks (i.e., level of international reserves) 	<ul style="list-style-type: none"> Global commodity and food prices Cross-border trade 	<ul style="list-style-type: none"> Global commodity prices, including for agricultural products and energy Availability of green capital flows
Macroeconomic risks	<ul style="list-style-type: none"> Macroeconomic and sovereign credit performance Macroeconomic outlook Market perception of sovereign risk 	<ul style="list-style-type: none"> Productivity and economic growth outlook, due to impacts on health and labor productivity, population displacement and destruction of infrastructure and assets Inflation dynamics due to food and energy shortages 	<ul style="list-style-type: none"> Productivity and economic growth outlook, particularly in agricultural and carbon-intensive sectors Inflation dynamics due to changes in energy mix Climate-linked sovereign creditworthiness
Banking risks	<ul style="list-style-type: none"> Banks' exposure to the corporate, household, and public sectors Bank risk indicators (leverage, asset quality, currency and maturity mismatches) Banks' buffers against shocks 	<ul style="list-style-type: none"> Damages to financial infrastructure Collateral damages Loan defaults 	<ul style="list-style-type: none"> Valuation of climate-change exposed assets Demand for green loans
Public sector risks	<ul style="list-style-type: none"> Public debt level Fiscal position 	<ul style="list-style-type: none"> Acute financing needs and debt sustainability issues 	<ul style="list-style-type: none"> Expenditure related to climate adaptation and mitigation policies Revenue potential from carbon taxes
Corporate sector risks	<ul style="list-style-type: none"> Corporate debt level Maturity mismatch Profitability and stock market returns 	<ul style="list-style-type: none"> Collateral damages Lower demand 	<ul style="list-style-type: none"> Viability of climate-change exposed business models and assets Transition costs
Household risks	<ul style="list-style-type: none"> Household debt Unemployment property price growth Stock market returns 	<ul style="list-style-type: none"> Employment Damages of household assets 	<ul style="list-style-type: none"> Impact on labor productivity and employment associated with structural shifts towards a low-carbon economy
Market and liquidity risks	Market and bank funding and liquidity conditions	<ul style="list-style-type: none"> Re-pricing of financial assets Financial market volatility 	<ul style="list-style-type: none"> Sudden re-evaluation of carbon-intensive assets and industries
Monetary and financial conditions	<ul style="list-style-type: none"> Monetary policy stance Availability of bank credit 	<ul style="list-style-type: none"> Acute need for monetary stimulus Ability of banks to lend counter-cyclically 	<ul style="list-style-type: none"> Green finance Increased economic volatility and uncertainty regarding banks' balance sheets exposure to climate impacted assets
Risk appetite	<ul style="list-style-type: none"> Market prices of sovereign bonds and equities Volatility of market prices Portfolio and FDI flows 	<ul style="list-style-type: none"> Investor risk aversion 	<ul style="list-style-type: none"> Risk aversion towards carbon-intensive assets and industries Higher demand for green assets

The physical impacts of climate change affect the relative productivity of sectors and regions, which may lead to shifts away from activities, sectors, and regions that are most affected by climate change. Agriculture is predicted to be among the sectors that would be most affected by climate change, where changes in the frequency and intensity of extreme weather events and changes to temperature and precipitation patterns will have significant impacts on the productivity of particular crops and areas. Sea-level rise is also expected to have major impacts on the productivity of low-lying coastal areas, including through flooding and saline contamination. Potential reactions to these developments include the pre-emptive switch to more resilient, but typically lower yield crops, the intensification of agricultural inputs to maintain production, and the movement of people from agriculture to other activities.

Countries that are highly dependent on a limited number of export products, such as tourism, fish, and copra for many small island economies, or agricultural exports in many African countries, are particularly vulnerable to even small changes in relative prices or comparative advantages. If their main sector is lost, it is extremely difficult for them to diversify into other products and “reinvent” themselves.

However, sectoral impacts of climate change can be complex. For example, if climate change reduces the physical yield of a particular crop, the price of the crop may increase, potentially more than offsetting the decline in physical yield. This is indeed a likely outcome for food production: while climate change is expected to reduce physical agricultural productivity, the low elasticity of food consumption means that prices may increase, making agriculture a more productive (in economic terms) activity (although relocation of agricultural activity to regions less impacted by climate change would still be expected). In this case, the impact of climate change would fall on consumers in the form of higher food prices.

Internal and international migration will accompany these changes, leading to shifts in labor supply (Carleton and Hsiang, 2016). Burzynskia et al. (2019) estimate that climate change will induce the voluntary and forced displacement of 100 million to 160 million workers (200 million to 300 million climate migrants of all ages) over the course of the 21st century. To the extent that climate change also results in conflict, the numbers of climate migrants could be significantly higher.

The cost of climate adaptation and mitigation measures is high and risks crowding out other investments and consumption. Climate change adaptation entails public and private expenditure on reduction and prevention of physical risks, preparation, and restoration (GCA, 2019). UNEP (2016) estimates the global annual cost of adaptation to range from US\$140 billion to US\$300 billion by 2030 and from US\$280 billion to US\$500 billion by 2050. Rozenberg and Fay (2019) show that annual spending on new infrastructure to the tune of 4.5 percent of GDP would “enable LMICs to achieve the infrastructure-related Sustainable Development Goals and stay on track to limit climate change to 2°C. Such defensive expenditure (Olson, 1977) has to be undertaken by all economic agents (public, private and financial sectors, households), crowding out productive investment or consumption, and thus directly affecting the growth outlook and welfare of a society.

A low-carbon transition (LCT) brings qualitatively new macrostructural challenges to countries that rely on fossil fuels’ value chains. An LCT carries the possibility of a structural decline in fossil fuel-based industries, with associated systemic risks to the countries, firms, financial institutions, and communities that depend on them. This low-carbon transition risk, recognized by financial sector regulators,⁴ can be

⁴ See for example: Carney, M. (2015), Bank of England (2018), ESRB Advisory Scientific Committee (2016), DG Trésor, Banque de France and ACPR (2017), European Central Bank (2019), Regelink et al. (2017) or Schotten et al. (2016).

conveyed to fossil-fuel dependent countries through many intertwined channels of impacts, such as disruptive clean technologies, policies to address environmental problems, and shifts in public sentiments.

Innovation and green growth. The projected negative impacts of climate change and the need to transition towards a low carbon economy also serve as an important stimulus for innovation and economic growth (Gruebler et al., 2002). Investment in R&D on low-carbon technologies is an important element of climate mitigation efforts and has already generated significant innovation in recent decades. Key elements of a growth agenda that holds the prospect of delivering economic growth, development while meeting climate objectives would include the following (The New Climate Economy, 2018): clean energy systems; smarter urban development; sustainable land use; wise water management; and a circular economy.

Economic growth

There is large uncertainty and disagreement on the economic costs of climate change. One of the main tools to assess the economic cost of climate change is Integrated Assessment models (IAMs). They seek to estimate the potential economic losses due to climate change as well as the impact of mitigation measures on GDP. For example using an IAM, Nordhaus (2017) projects that by 2100, .."the damages are 2.1% of global income at a 3°C warming, and 8.5% of income at a 6°C warming." While IAMs tend to find small impacts on GDP, other approaches such as projections based on the aggregation of micro-evidence on the impact of climate change have generated more pessimistic results. For example Hsiang et al (2017) estimate that for the United States, "...the very likely (5th to 95th percentile) range of losses at 1.5°C of warming is -0.1 to 1.7% GDP, at 4°C of warming is 1.5 to 5.6% GDP, and at 8°C warming is 6.4 to 15.7% GDP annually." Economic losses arising from the implementation of climate mitigation measures needed to provide a two-thirds (66 percent) chance of achieving the 2 percent goal are estimated at between 2.9 and 11.4 percent of consumption by 2100 (NGFS 2019a).

There is, however, increasing recognition that existing models may significantly underestimate the economic impact of climate change and overestimate the cost of mitigation measures (Stern, 2016). In particular, most current models fail to consider the catastrophic and irreversible impacts of unmitigated climate-change which could be triggered by the crossing of global and local tipping points (Box 1). The mounting evidence on the impact of climate change on factors of production is either not or only inadequately included in IAMs through damage functions. Therefore, IAMs are not able to capture direct economic growth impacts of climate change. Similarly, most IAMs do not account for the distributional impacts of climate change and their potentially severe consequences in terms of migration and conflict. There is also considerable debate on the appropriate discount rate, where higher discount rates give less weight to the welfare of future generations. In addition, accumulating micro-evidence provides a better understanding of the impacts of climate change on productivity. For example, natural hazards and higher temperature have a negative impact on children's physical and cognitive development (through undernutrition and stress) and educational achievement (because learning is more difficult in high temperatures and because children tend to drop out of schools in disaster aftermaths and in response to reduced agricultural yields). There is also a direct link between temperature and outdoor labor productivity (e.g., for agriculture or the construction industry) (Hallegatte et al., 2016).

Box 1. The risk of tipping points

The damages from climate change are rising and may spiral out of control. Scientifically, there is “very high confidence in the potential for state shifts” (U.S. Global Change Research Program, 2017) in which the climate system passes tipping points to unleash positive feedback mechanisms of escalating damages, meaning that beyond certain threshold warming levels, the costs of climate change may accelerate abruptly. If human action increases earth’s temperature beyond certain levels, these increases may trigger positive feedback mechanisms in the climate system which cause additional, autonomous warming. This additional warming may spiral out of control, implying that these tipping points could be points-of-no-return. Such tipping points could be the melting of the Antarctic and Greenland ice shields or a shift in the El-Nino Southern Oscillation.

In addition to global tipping points, there is also the risk of local tipping points where local limits to adaptation (limits to the adaptation of local eco systems or human beings) are crossed. Examples of such local tipping points would be that summer temperatures in the Gulf countries become too high for human being to survive outside, or the death of the local forests due to fires in California or the Russian Federation. Even though such local tipping points are less dramatic than global tipping points and geographically contained, such local tipping points may be crossed earlier and the impacts difficult to manage for individual countries.

It is critical to avoid crossing climate tipping points. At which levels of temperature increases these tipping points lie is not certain; based on the scientific consensus (e.g., IPCC, 2014), the international community has agreed to translate its objective to “avoid dangerous anthropogenic interference with the climate system” (UNFCCC, 1992, Art. 2) into the commitment to contain global warming to “well below 2°C” (Paris Agreement 2015). From a macroeconomic perspective, the concept of a tipping point is familiar. It is important to contain the risk of unleashing crises, knowing that, once triggered, a crisis can be much more expensive to stabilize than the costs of policies to prevent it. For climate change, stabilization might even be impossible (IPCC, 2014), leading to a fat-tailed probability distribution of disastrous outcomes (Weitzman, 2009), so there is a clear logic of avoiding such tipping points.

A particular shortcoming of IAMs is that they typically do not include money, finance, and banking. As pointed out by Farmer et al. (2015), this may be a significant shortcoming, as “... the financial sector is crucial for understanding cycles of economic activity and hence climate change emissions and mitigation policies.” This also omits the potential impacts of stranded assets and the increasing role of climate finance for green projects. Work is underway to address the shortcoming of IAMs (e.g., Piontek et al., 2018; Burke et al., 2015; or Mitnik et al., 2019).

The focus on aggregate GDP losses also fails to take into account important distributional aspects of the economic impacts of climate change. GDP impacts at the global level do not capture well what happens in poor countries (and to poor people in all countries). Tropical countries are projected to feel the brunt of climate change impacts and the poor in developing countries tend to be more exposed to and have only very limited means to deal with climate change risks. Climate change thus slows down poverty reduction, but the disproportional effect on poor countries and on the poor can also magnify negative impacts on economic growth. While better off countries and people are better equipped to recover from climate impacts, the poor typically lack this ability and temporary impact can have permanent effects, if for example these temporary effects result in children quitting school or households having to sell income earning assets.

A successful transition to a low-carbon economy will not only avert the negative impact of climate change but can become a new engine of growth for the 21st century. Regarding climate mitigation measures,

most estimates of their cost do not consider the potential positive impacts that a shift to a low carbon economy could entail, including the possibility of positive impacts on low-carbon related innovation as a source of cost reductions and an engine of growth. The New Climate Economy (2018) estimates that bold action could yield a direct economic gain of US\$26 trillion through 2030 compared to a business as usual scenario. The OCED (2017) estimates that the combination of economic reforms with ambitious climate policies could spur economic growth in the G20 countries by 2.8 percent (or 4.7 percent, if the avoided climate impacts are taken into account).

Fiscal linkages

What are the impacts of climate change on the public sector?

Physical impacts of climate change generate significant revenue and expenditure pressures and add uncertainty to fiscal management. Climate-related risks can affect public sector balance sheets in many ways, some of which are illustrated in Table 2. For example, physical risks will have a direct impact on fiscal revenue by hurting the revenue base, on public expenditure for outlays on disaster relief and reconstruction, or on the net-income of SOEs if their activities are impacted by natural disasters.

However, even in the slow onset scenario, long-term impacts of climate change can have immediate impacts on fiscal management and sustainability. To the extent that climate change is expected to impact a country's growth trajectory, this can have an impact on the country's debt sustainability, borrowing space, and borrowing cost.

Transition risks are particularly high for countries that generate a significant share of public revenue from carbon intensive industries. Lower-income and conflict-affected oil and gas exporters (mostly in Africa and the Middle East) are more vulnerable and less able to manage an LCT. They have not yet converted hydrocarbon rents into other sources of export revenues needed to grow and diversify. They also often face major challenges attracting commercial investors and raising affordable finance, although some of them, for example, Mozambique and Ghana, have heavily borrowed against expected extractive revenues and are already burdened with the high cost of debt service (Cust, J. and D. Mihalyi, 2017). Climate policy leaders could help these countries adjust to an LCT through technology, financial cooperation, and trade agreements that would provide them with revenue visibility to invest in low-carbon growth and diversification.

Coal producers and users face local and social, rather than national and systemic, challenges. Unlike oil and gas exporters, even the largest coal producing countries do not depend on coal revenues and rents for national growth and prosperity, so the macro-fiscal risk of low-carbon transition to coal countries is small. The value of coal per energy unit is simply too small to generate foreign exchange large enough to cause Dutch disease. However, some regions that depend on coal mining to create jobs and local income face social challenges because of sticky "stranded labor" and disrupted cultural identities (Stanley et al. 2018; Sartor, 2018). Stranded assets are less of a problem in coal producing countries because coal mining has traditionally been more labor intensive, rather than capital intensive. The systemic risk of an LCT can be transmitted through overreliance on coal-fired electricity generation (as is the case in Botswana, China, India, Kosovo, Mongolia, Poland, Serbia, and South Africa). Coal mining in OECD countries is already a declining industry that is experiencing massive structural changes, asset repricing, and bankruptcies. However, Australian and Asian coal producers are not yet fully affected by an LCT due to the robust demand for coal in Southeast Asia and Africa. Coal-dependent industrial sectors, such as iron and steel or

cement, are more resilient to LCT impacts because substituting for coal as the feedstock in manufacturing processes is more difficult than in electricity generation.

Table 2. Climate change risks for the public sector

Risk factor	Examples	Climate-change channels
Economic growth	Weaker-than-expected economic performance reduces tax revenue and increases the cost of unemployment insurance and other social protection programs	Environmental changes and extreme weather events threaten to disrupt activity across a wide range of economic sectors
Commodity prices	Sudden changes in commodity prices affect government spending, customs duties, and energy, agricultural, or food subsidies.	The increased frequency and severity of extreme weather events increase the volatility of global commodity prices
State-owned enterprises (SOEs)	The poor financial or commercial performance of SOEs may generate contingent liabilities	Climate change intensifies risks to SOE performance
Public-private partnerships (PPPs)	PPPs may entail contractual obligations and/or implicit public guarantees with important fiscal implications	Climate change threatens the financial viability of PPPs
Natural disasters	Disasters can disrupt production in fiscally important sectors and may require large-scale relief and reconstruction spending	Climate change increases the frequency and severity of natural disasters
Public health emergencies	Epidemic disease can radically increase health spending and may adversely affect employment, production, and trade	Rising temperatures and extreme weather events increase the risk of epidemics
Judicial awards	Court judgments against the government may result in unexpected spending	Courts may determine that a government is liable for climate-adaptation measures

Source: Pigato (2019)

What is the role of the public sector in addressing climate change?

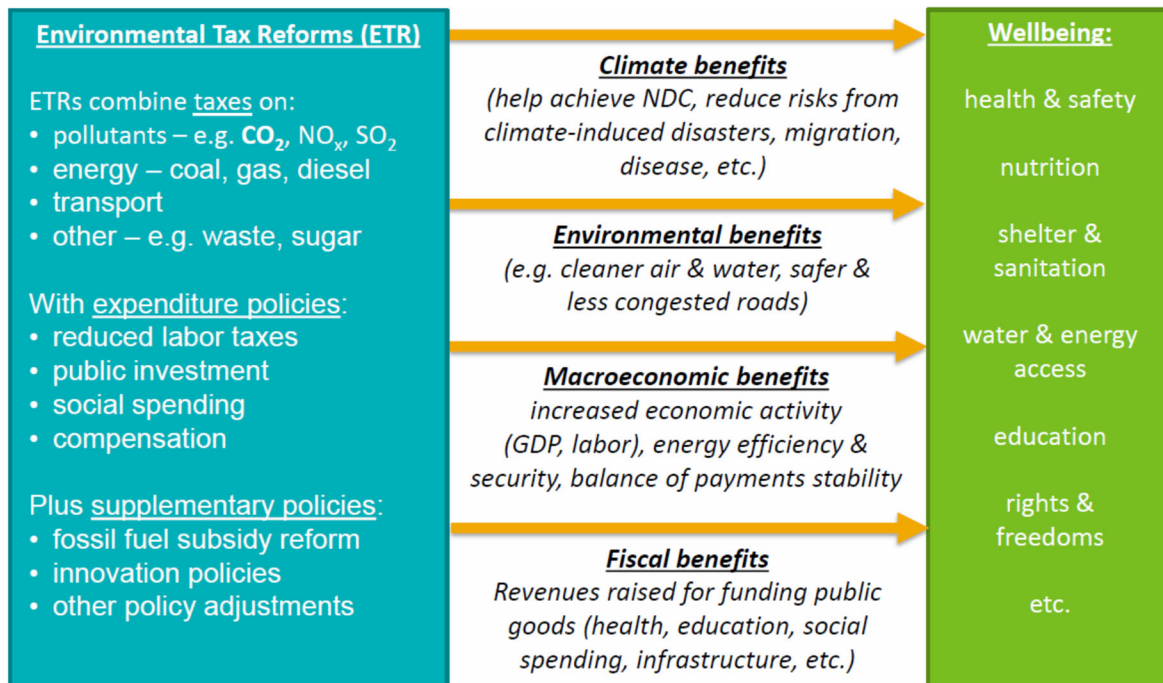
Fiscal instruments are a critical and necessary component of the package of policies needed to reduce emissions. The IPCC (2018) finds that by 2030, GHG emissions must be 45 percent lower than the levels in 2010 to contain the global temperature increase to 1.5°C. However, markets cannot deliver the required mitigation on their own due to market failures. Fiscal tools, such as: (i) price policies (e.g., carbon taxation, subsidies for mitigation action and low-carbon investment); (ii) spending and investment; and (iii) public guarantees to secure private-sector participation, are critical.

Carbon pricing seeks to ensure that the social cost of GHG emissions is captured in energy prices through carbon taxes, cap and trade schemes, or a combination thereof. Carbon taxes represent an efficient means to reduce carbon emissions while collecting revenues, generating significant development co-benefits, such as improved air quality and public health or reduction in traffic congestion and road accidents (Pigato, 2019). The World Bank’s State and Trends of Carbon Pricing 2019 report indicates that by mid-2019, 57 carbon pricing initiatives were either being implemented or scheduled for implementation. They consist of 28 ETSs in regional, national and subnational jurisdictions, and 29 carbon taxes, primarily applied on a national level. So far, 96 countries have indicated that they are planning or considering the use of carbon pricing as a tool to meet their commitments under the Paris Agreement.

Environmental tax reforms (ETR) which combine environmental taxes, expenditure policies and supplementary policies are an effective tool to pursue climate objectives (Figure 3). ETRs emphasize that the revenue generated through carbon taxes can be used to reduce other taxes that have a negative

impact on the economy’s competitiveness (tax shifting), fund adaptation and mitigation measures, or increase socially targeted transfers and services to ensure that lower income households do not experience a decline in well-being through the increase in carbon taxes.

Figure 3. Environmental tax reforms



Source: Pigato (2019)

A range of complementary policies and measures are necessary to achieve global climate targets. Complementary policies that the world’s largest economies implement to mitigate global environmental challenges include direct regulations, such as low-carbon fuel and product standards (for example in California and EU); infrastructure investments, especially in power and transport sectors, and new networks that lock-in new clean technologies offer increasing returns to scale; and softer measures, such as labeling, and information campaigns, can speed up consumers’ and investors’ behavioral response to policy incentives. The use of several policy levers for climate mitigation not only helps to address different aspects of climate mitigation, but they also often mutually reinforce each other. For example, Avner et al (2016) show that investments in public transit can double the price elasticity of transport carbon emissions, implying that public investments can make pricing solutions twice as efficient. In addition, countries implementing unilateral climate policies are increasingly considering border carbon adjustment measures to protect their trade-exposed energy-intensive industries from unfair competitiveness effects of asymmetric climate policies.⁵ Trade measures would especially adversely affect export of manufacturing products and services with a high footprint of GHG emissions. It cannot be ruled out that

⁵ See [Economists’ statement on carbon dividends \(The Wall Street Journal, January 17, 2019\)](#) or the [mission letter](#) from Ursula von der Leyen, President-elect of the European Commission to Phil Hogan, Commissioner-designate for Trade (European Commission, September 10, 2019).

a group of large countries will even consider plain trade sanctions to encourage noncooperating countries to share the burden of the global effort to stabilize the climate (Nordhaus, 2015).

Public (as well as private) spending on climate adaptation carries high returns. According to the GCA (2019), the overall rate of return on adaptation investments is very high, with benefit-cost ratios ranging from 2:1 to 10:1, and in some cases even higher. Priority investments need to focus on key systems affected by climate change, namely, food, water, the natural environment, cities, infrastructure, disaster risk management, and finance (Global Commission on Adaptation, 2019). Also these costs are expected to rise over time, partly because greater warming causes disproportionately greater damages and partly because “the physical and socioeconomic impacts of compound extreme events (such as simultaneous heat and drought, wildfires associated with hot and dry conditions, or flooding associated with high precipitation on top of snow or waterlogged ground) can be greater than the sum of the parts.” (U.S. Global Change Research Program, 2017).

What needs to be done?

The key fiscal policy action for climate mitigation is to use environmental tax reform (ETR) to align energy prices to fully reflect climate externalities. For such policy action to be effective in mitigating climate change, it is necessary to increase the number of countries that implement ETR, as well as to adjust environmental taxes to ultimately cover the social cost of greenhouse gas emissions.

As the physical and transition risks of climate change add to countries’ fiscal vulnerabilities, strengthening fiscal resilience is essential. Enhancing the financial resilience of the public sector requires a combination of purchasing insurance, enlarging sovereign borrowing space, and building financial buffers (Nishizawa et al., 2019). In addition, implementing measures that enhance the flexibility of revenue and expenditures to adjust to external shocks is also important to reduce fiscal stability risks.

A range of financing instruments will need to be mobilized to accommodate climate change-related financing needs. Financing needs for climate adaptation and mitigation are large, requiring comprehensive financing strategies. Such strategies would: (i) consider priorities for public financing and options for private sector solutions; (ii) examine increasing revenue, especially through environmental taxes; (iii) mainstream climate change considerations into the design, appraisal, and selection of public investment projects; and (iv) examine the scope and rationale for the use of debt financing.

Given that climate-related risks can generate significant fiscal risks, governments should incorporate and quantify climate-related risks into the fiscal risk statements that accompany the budget presentation (Pigato, 2019). Enhanced analysis and transparency of climate related risks in the budget process would enable decision makers to make informed decisions on fiscal sustainability and climate actions. It would also enable decision makers to provide important information on fiscal risks to other economic agents.

Monetary linkages

What are the impacts of climate change on monetary policy?

Climate change creates challenges for monetary policy as it adds significant volatility and uncertainty to the economic outlook. Climate change and climate policies create temporary and permanent primarily supply-side shocks to the economy, affecting both output and prices (McKibbin et al., 2017). However,

demand for money and credit is also impacted. Research on the interactions between climate change, climate policies, and monetary conditions and management is relatively nascent.

The impact of climate change on economic growth and structural transformation affects a range of variables that are typically monitored and targeted by monetary policy instruments. These include credit spreads, precautionary savings, real interest rates, and financial instability, which in turn affect inflation, often the target of monetary policy.

What is the role of monetary policy in addressing climate change?

Monetary policy should take into account climate-related risks, as the implications for the achievement of monetary policy objectives are significant. Most monetary authorities are charged with pursuing one or several policy objectives (macro-economic stability, economic growth, inflation, or employment targets) through the use of monetary policy instruments. Many Central Banks have thus invested significant resources to understand the economic impact of climate change on these objectives. In comparing the impact of climate change to other forces that affect economic outcomes, Guy Debelle (2019), Deputy Governor of the Reserve Bank of Australia notes, "... few of these forces have the scale, persistence, and systemic risk of climate change."

McKibbin et al. (2017) highlight the importance of choosing climate and monetary policies jointly, given important interactions between the two sets of policies. They note that the impacts of climate change tend to have opposite impacts on inflation and output. As such, a monetary policy rule that targets the level or growth of nominal income instead of inflation may achieve superior outcomes as it incorporates both real economic conditions and inflation, while being a less volatile aggregate than a price index. Such a policy rule would also be more suitable in an environment of increased uncertainty, where it is difficult to forecast output gaps and inflation. Economides et al. (2019) show that losses due to climate shocks are smaller under a flexible exchange rate regime than under a fixed exchange rate regime. In addition, a flexible exchange rate regime provides Central Banks with greater scope to deal with increased volatility due to climate shocks. There are also important interactions between the design of climate policy and monetary policy. In particular, a cap and trade scheme is associated with greater price volatility which makes inflation forecasting more difficult. A carbon tax or a hybrid between a cap and trade scheme and a carbon tax may thus be preferable (McKibbin et al., 2017).

As Central Banks typically hold large asset portfolios, adequately assessing and reflecting climate risks in their portfolios is critical to reducing their exposure to climate risks. Improved assessment of climate risk in Central Bank portfolios could also affect the price of carbon intensive assets and provide incentives for investors to increase their portfolio allocation to low carbon assets (Krogstrup et al., 2019).

A more direct intervention to foster climate change mitigation efforts would include the explicit targeting of low carbon assets in Central Banks' asset sales and purchases. However, such interventions are often constrained by Central Banks' narrow mandates and could risk politicizing these institutions (Krogstrup et al., 2019).

Financial sector linkages

Overview

How do climate-related financial risks compare to other financial vulnerabilities?

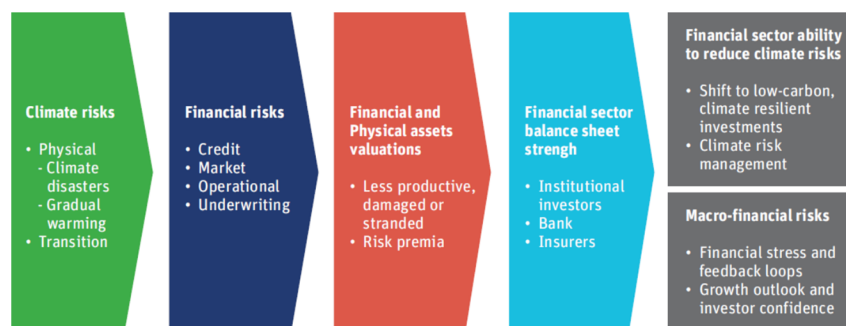
Climate change is an increasingly recognized source of risk to the financial sector. Climate-related physical and transitions risks have significant, adverse, direct and indirect impacts on the financial sector, which manifest themselves in both sudden and gradual ways. Over 50 central banks and supervisory agencies have come together to form the Network for the Greening of the Financial System (NGFS) aiming to manage climate change risks and support the transition to a low-carbon economy (NGFS 2019).

Climate-related financial risks are distinct from other financial vulnerabilities – they are structural and shrouded in uncertainties and data gaps. Climate risks differ from other financial sector vulnerabilities in their potentially systemic and irreversible nature (Bank of England 2018). Moreover, there are deep uncertainties and data gaps regarding the impact and timing of transition and physical risks on the financial sector, as well as their interactions with the broader economy. Climate-related risks may still be underpriced if they materialize beyond investor horizons, are not adequately measured and disclosed, and when social and environmental externalities are not properly accounted for. To reduce information asymmetries, the Financial Stability Board created the private-sector led Task Force on Climate-related Financial Disclosures (TCFD) to provide recommendations for comparable and consistent disclosures by individual firms (both nonfinancial and financial) of the financial risks they face from climate change (TCFD 2017).

What are the impacts of climate change on the financial sector?

In light of these uncertainties, and due to the short time horizons of many investors, there is a significant risk that climate-related financial risks are not yet adequately recognized by financial markets. Carbon-intensive assets and fossil fuel reserves may become obsolete and ultimately stranded. This shift could occur gradually or abruptly, depending on policies, technology, and consumer preferences. In an adverse scenario, the recognition of unusable carbon-intensive assets is abrupt and amplified by underinvestment in low carbon, climate-resilient assets and technologies. The way this transition unfolds will thus have important implications for financial institutions and markets. For example, in terms of only equity market capitalization, oil and gas companies represent nearly \$5 trillion, mostly held on financial sector balance sheets.⁶

Figure 4. Impacts of climate risks on the financial sector



⁶ Bloomberg New Energy Finance.

Physical and transition risks for the financial sector manifest themselves through four financial risk channels, which impact physical and financial assets, thus affecting financial sector balance sheets (Figure 4):

- **Operational risk.** This includes damages to financial infrastructure, branches, and office buildings (*physical risks*) as well as reputational impacts of not adjusting to “green” investment policies and potential green-washing (*transition risks*).
- **Market and liquidity risk.** The re-assessment of financial projections and risk premia will impact asset valuations. This re-assessment could trigger pro-cyclical materialization of losses and tighter funding and liquidity conditions, particularly when it is due to, for example, a disaster (*physical risks*) or a sudden policy, technology, or consumer preferences shock (*transition risks*). Droughts and disasters (*physical risks*) as well as necessary shifts in the energy mix (*transition risks*) may drive up commodity and energy prices.
- **Credit risk.** Borrower repayment capacity could be adversely affected due to, for example, damages (*physical risks*), higher energy prices or lower productivity (physical and transition risks). Lower collateral prices amplify credit risk, particularly when uninsured. The quality of credit exposures to carbon-intensive sectors may deteriorate (*transition risks*). In carbon-intensive and natural disaster-prone economies, sovereign credit risks could adversely interact with the financial sector risks.
- **Underwriting risk.** *Physical risks* can impede pricing accuracy of (re-)insurance liabilities causing losses to insurers, raising premiums or even rendering some activities or geographies uninsurable, which would raise fiscal costs as governments would be forced to backstop losses. Lower availability of insurance may have important repercussions on investments and loans.

Climate-related financial risks may weaken financial sector balance sheets and induce or amplify macro-financial risks, particularly in the case of shocks. Such shocks could stem from disasters or sudden changes in policy, technology, or consumer preferences. The resulting financial sector losses and volatility in financial and commodity markets can adversely impact funding, liquidity, and lending conditions and weaken financial sector balance sheets, giving rise to negative feedback loops with macro-fiscal implications. Emerging markets and developing economies may be particularly affected, given that their financial markets are less resilient to such shocks.

The impact of climate change risks on housing poses a particular risk for the financial sector. Housing-related loans represent a large share of bank balance sheets, and housing prices are affected both by climate policies (e.g., policies to favor public transit could lead to price changes in remote suburbs dependent on individual cars) and climate impacts (e.g., coastal areas in places like Florida are seeing a decrease in housing prices as the vulnerability to sea level rise and hurricanes becomes better priced).

What is the role of the financial sector in addressing climate change?

The financial sector should play a central role in making financial flows more consistent with the transition towards a climate-resilient and low-carbon economy and managing associated risks. The financial sector is the economy’s main engine to allocate resources to their most productive use and to distribute risks efficiently. In light of a sizeable climate finance gap and public finance constraints, it is hence incumbent on the financial sector to redirect financial flows to better align them with this necessary economic transition. The ability of the financial system to support this transition is underpinned by, inter alia,

adequate price signals to appropriately reflect risks in financial markets to inform risk management, investment, lending, and insurance underwriting decisions.

Box 2. Examples of estimated climate-related losses, from the academic literature

Financial Institutions

- **Transition risks.** Delis et al (2019) find that recently banks price climate policy exposure to syndicated loans to fossil fuel firms. Vermeulen et al. (2019) stress tests transition risks for industry exposures by Dutch banks, pension funds and insurance companies. The results suggest that the regulatory capital (CET1) ratio of banks could decrease by 4 percentage points due to abrupt changes in policy and technology. For pension funds and insurers, the study estimates a potential loss of up to 10 percent of bond and equity values. By introducing the element of contagion and feedback loops in the financial sector, Battiston et al. (2017) find even more severe impacts for a set of European banks from an abrupt energy transition.
- **Physical risks.** For a sample of 160 countries, Klomp (2014) finds that weather-related and other natural disasters increase the likelihood of a bank's default. Noth and Schüwer (2018) find evidence for impacts on non-performing loans and foreclosure rates for US banks operating in disaster-prone regions. Brei, Mohan, and Strobl (2019) document that following a hurricane strike, banks in the Eastern Caribbean face deposit withdrawals and negative funding shocks. Regelink et al. (2017) model the impact of severe flood scenarios on mortgages, commercial real estate, and SME loan portfolios of Dutch banks, predicting several billion in financial losses.

Asset prices

- **Transition risks.** Bernardini, et al. (2019) show that, following the progressive introduction of economic incentives by the European Union to stimulate investment in renewable energy, the profit of electric utility companies using non-renewable energy inputs fell sharply.
- **Physical risks.** Kruttli et al. (2019) find that within the 120 trading days after the landfall of a hurricane, the stock returns for firms operating in the disaster region are significantly lower than the returns of other firms in the United States. Duan and Li (2019) find that unusually hot weather in US counties is associated with a mortgage volume reduction by 7 percent. The effect is greater for counties with higher awareness of climate change, counties more exposed to the risks of sea-level rise, and during periods of elevated media attention.

Banks

What are the impacts of climate change on the banking sector?

The physical impacts of climate change can lead to heightened operational, credit, market, and liquidity risks for banks. The limited empirical literature provides some evidence for the materiality of the impact of physical risks on banks (Box 2). Climate change-induced weather-related shocks could trigger losses due to higher defaults and lower collateral valuations – particularly if uninsured. Agricultural and real estate exposures could be at particular risk from weather related shocks. Liquidity could also tighten, due to lower savings and higher withdrawals as demand for cash surges. Weather-related shocks can also damage payment systems and bank branches.

Exposures to carbon-intensive sectors and assets create material transition risks for banks. Given the lack of historical precedent on how these risks manifest themselves, studies are beginning to estimate

potential transition impacts using scenario analysis and stress testing models. Banks are facing risks from loan and investment exposures to highly carbon intensive sectors, as well as non-sustainable real estate exposures, including sizable mortgage portfolios that are tied to buildings with a low energy efficiency scores (Regelink et al., 2017; DNB, 2019).⁷ If credit and market portfolio exposures to carbon-intensive sectors are mostly short term in nature, banks may have the ability to adapt smoothly to a low-carbon economy - given alternative investment opportunities are available. Providing finance for carbon-intensive industries and assets also exposes banks to reputational risks, in the face of changing public opinion.

What is the role of banks in addressing climate change?

Not only does climate change affect risks in the banking sector, it also provides opportunities for banks to contribute, and therewith profit from, a transition to a climate-resilient and low-carbon economy. IFC (2019) estimates that there is a US\$23 trillion investment opportunity until 2030 for a group of 23 emerging markets from implementing their Nationally Determined Contributions to the Paris Agreement (NDCs). Identified opportunities include those in real estate, transport, renewable energy, and energy efficiency. To reach necessary investment volumes, IFC estimates that bank balance sheets need to 'green' from around 7 percent today, to 30 percent in 2030 (Stein et al., 2018). Significantly expanding green loans will be important to reach this target. Though still small in overall volume and not well tracked, green credit flows are increasing. The 7 percent of green credit in the portfolios of Sustainable Banking Network (SBN) members currently represents an estimated \$3 trillion. However, SBN estimates that with the 30 percent green assets goal and current growth in membership, green SBN assets will be valued at \$15 trillion by 2030.

What needs to be done?

Banks need to build capacity and integrate climate factors into all aspects of their operations. This includes integrating risks and opportunities relevant to climate change and the energy transition in bank strategy, risk management procedures and pricing models, governance structures, disclosure practices, and loan origination processes.

During the 2019 United Nations General Assembly, The Principles for Responsible Banking were launched. Under this initiative, 130 financial institutions, representing US\$47 trillion in 49 countries, have committed to standards which better align their business activities with sustainability goals.

Policymakers and supervisors need to play a key role in supporting better management of climate-related financial risks:

- **Risk surveillance.** Supervisors should map, quantify, and monitor climate-related financial risks, including through developing and implementing macro-level stress testing methodologies. Impacts on the micro-finance sector should also be studied. Anecdotal evidence suggests that micro-finance institutions, and the community-based lending system it relies on, face significant climate risks.
- **Supervisory approaches.** Supervisors should integrate identified risks in supervisory approaches and potentially prudential frameworks. This includes requirements regarding risk management,

⁷ In a recent bulletin, DNB (2019) highlighted the materiality of energy efficiency certificates for housing prices in the Netherlands.

governance, and disclosure of climate risks. Moreover, supervisors should monitor and supervise the uptake of such requirements and the integration of climate risk management, governance, and disclosure into their supervisory scoring models. Discussions have also emerged on how climate risks should be assessed under the Basel 3 framework, including the supervisory review process (pillar 2), which allows for additional capital charges in the case of risky exposures. Whether risk weights (pillar 1) should be adjusted to account for climate-specific risks of certain exposures, is an area that supervisors are currently cautiously reviewing (UNEP Financing Initiative, 2014).

- **Crisis management frameworks.** Existing frameworks appear poorly suited to address climate risks, however research on this is limited. Regulators from countries that frequently deal with the impacts of natural hazards (e.g., Philippines), have issued specific guidance to banks in the aftermath of high-impact natural disasters.
- **Disclosure and taxonomies.** There is a need for internationally comparable disclosure standards for climate risks. Firms should be encouraged to disclose in line with the FSB TCFD framework. Moreover, there is a need for the development of taxonomies that would help to identify green and sustainable economic activities, as well as climate and environmental risks. Such taxonomies can help financial institutions and regulators to measure green financial flows, assess and identify risks, and label green financial products.
- **Green policy strategies.** Various authorities have successfully deployed holistic policies, strategies, and instruments to expedite the greening of banking sectors (e.g., EU - see Box 3, UK, and China). Some regulators have also started to facilitate the development of green loan markets (e.g., China, Bangladesh). Several countries are exploring ways to expand the role for national development banks as catalyzers for green finance.

Box 3. EU Action Plan for Sustainable Finance

The EU Action Plan is among the most far reaching and supported by legislative actions, compared to other comparable roadmaps. In order to reorient capital flows, make the financial sector more climate resilient, and facilitate transparency, the action plan lays out a strategy based on 10 high-level actions. These actions include creating of a taxonomy, enforcing mandatory disclosure, and developing prudential requirements.

A technical expert group is tasked with implementing the plan. The group recently launched a draft version of the sustainability taxonomy, which provides banks with a framework to identify and measure their portfolio allocation to green assets.

The Action Plan contemplates climate-linked capital requirements. The Commission will “explore the feasibility of recalibrating capital requirements for banks (the so-called green supporting factor) for sustainable investments, when it is justified from a risk perspective, while ensuring that financial stability is safeguarded.”

Box 4. Assessing climate risks and opportunities in the Financial Sector Assessment Program (FSAP)

Recently, the World Bank and the IMF began to pilot assessments of the impacts of climate change and related environmental risks and opportunities on financial sectors as part of the Financial Sector Assessment Program (FSAP). The assessment provides financial sector policy makers and supervisors with insights on climate-related risks, appropriate supervisory responses to those risks based on global good practices, and advice on how to foster green finance.

Although early days, and not public yet, the first pilot assessments in Bangladesh and the Philippines provide insights into the high materiality of, particularly, physical climate risks for these countries. In both cases weather-related disasters, particularly floods and cyclones, have led to the materialization of operational and credit risks for banks. Institutions with exposures in rural and agricultural areas have been most affected. At the same time, bank exposures in these two countries are heavily concentrated in urban areas, which are exposed to worst-case natural hazards that could put financial stability at risk.

Institutional investors

What are the impacts of climate change on institutional investors?

Institutional investors – such as pension funds and life insurance companies – will be disproportionately affected by climate change given their much longer-term investment horizons. In addition to the climate risks that affect financial stability, second-tier impacts from climate change (such as food security, social, and political unrest, and biodiversity loss) are likely to be nonlinear, characterized by tipping points, and material over the long-term. The investment strategies of institutional investors, therefore, should be designed to manage long-term risks.

EIU (2015) estimates the expected losses to institutional investors at \$4.2 trillion in discounted, present value terms at 2015 prices. However, losses are much higher in more adverse scenarios. Notwithstanding methodological uncertainties, the tail risks are estimated to be much larger, up to \$43 trillion in a warming scenario of 6 degrees Celsius, and using lower, public sector discount rates. In the latter scenario, estimated losses represent approximately 30 percent of the global stock of assets under management.

Evidence on the impact of climate change on various asset classes is still lagging – including on sovereign bonds, which make up most of the investment portfolios of institutional investors. Without clear frameworks through which investors can assess climate risk to sovereigns, assets may be mispriced which impedes institutional investors from effectively managing risks.

What is the role of institutional investors in addressing climate change?

Although climate change poses risks to institutional investors' portfolios, it also provides investment opportunities – particularly in the areas of mitigation and adaptation. There is a \$2.5 trillion annual funding gap between the investment flowing to sustainable infrastructure and what is needed to meet the Paris Agreement goal and the SDGs (UNCTAD 2019). Yet, despite owning almost \$100 trillion in assets (OECD 2019), institutional investors jointly contributed just 1% of the \$455 billion global climate finance flows in 2016 (Climate Policy Initiative 2018).

What needs to be done?

To shift more capital to climate-related investments – particularly in emerging markets and developing economies – both better risk management and new investment instruments will be required, and both the public and private sectors will have a role to play. Emerging markets and developing economies face a lack of investment due to higher country risk, regulatory uncertainty, shallow local capital markets, and the absence of strong local investor bases. In some of these countries, “brown” investment, such as in coal plants, continues.

Relevant regulatory measures include:

- **Regulatory frameworks.** Regulations will have to be adapted to encourage or require investors to incorporate climate-related criteria into their risk assessments as part of their fiduciary duty, as documented by the UN Principles of Responsible Investment (UN RPI 2015). In the past year, some regions and jurisdictions have imposed requirements and responsibilities of institutional investors to incorporate environmental, social, and governance (ESG) factors into their investment processes. However, other jurisdictions have increased regulatory hurdles, which could disincentivize, or create barriers for, institutions working to adapt their investment processes. Supervisors should follow the recommendations issued by IOSCO regarding sustainable financial instruments and disclosure requirements of ESG-specific risks.⁸ Regulators should ensure the recommendations are enforceable and establish requirements for the offerings of sustainable instruments. The requirements should include criteria for the use and management of the funds raised and the processes used by issuers for project evaluation and selection (IOSCO 2019).
- **Industry capacity.** Even with a supportive regulatory environment, institutional investors will have to adapt to new investment processes and develop appropriate tools. Major institutional investors will need to act proactively in order to shift capital to the degree necessary to avert the worst impacts of climate change.
- **Coordination.** Policy makers and development financial institutions will have to work closely with investors to develop further financial mechanisms which can both fill the climate financing gap and meet institutional investors’ risk and return needs. Innovative climate finance tools, mechanisms, and approaches are being developed to allow institutional investors to take advantage of climate investment opportunities. The new instruments aim to reduce risk, blend public and private finance, and facilitate investment across a project’s life-cycle. They include concessionary finance, loan guarantees, policy insurance, foreign exchange liquidity facilities, pledge funds, and subordinated equity.

Insurers

What are the impacts of climate change on insurers?

Climate change has implications for insurance companies on both sides of the balance sheet: as investors and as underwriters. As investors, insurance companies face largely similar transition and physical risks as

⁸ These recommendations include ensuring the following: agreed-upon definitions of sustainable instruments are applied, projects and activities are deemed eligible, proper documentation is developed, issuers are obliged to meet ongoing disclosure requirements, and external reviews are considered.

other asset managers. In line with institutional investors, insurers may also be disproportionately affected due to the long-term nature of their equity and infrastructure investments. As underwriters, pricing risks may arise from changing risk profiles to insured assets. For example, climate-change trends may affect the size of segments in the insurance market (e.g., some risks may become hard to insure) but may also offer opportunities for innovative insurance offerings. Moreover, climate change increases the complexity of catastrophe models, making it harder to make valid predictions about expected and unexpected losses and increasing the uncertainty in estimates (e.g., due to hard to model climate-change trends and knowledge gaps). Finally, insurance companies may be affected by increased liability risks due to climate-change, among others as part of negligence policies. (IAIS/SIF, 2018; Bank of England, 2015).

Insured losses from climate-related natural disasters reached a record high in 2017, while industry estimates (Lloyds of London 2017) suggest weather-related losses have increased to US\$200 billion in the past decade. Lloyd's attributes these losses to both climate change and development patterns which are leading to a rise in concentration of people and assets in high-risk regions such as coastal and urban areas. So, while these losses cannot necessarily be fully attributed to climate change, changing weather patterns and sea-level rise, as well as climate change-related disasters, can give rise to higher damages and losses due to changing risk profiles of insured assets and property, as well as changing mortality and demographics. If insured losses resulting from climate-related events are sufficiently large and concentrated, they could lead to distress or failure of insurance companies.

What is the role of insurers to address climate change?

The insurance sector has a valuable role to play as risk manager, underwriter and investor to build economic resilience and entrepreneurial pathways for addressing climate targets. The industry is contributing significantly to building financial resilience to extreme events and other physical risks by providing risk information and risk pricing expertise, offering innovative risk transfer products and services, and improving the efficiency of distribution channels and payout mechanisms. It is also supporting the transition to a low-carbon economy through its underwriting business, investment strategies, and active reduction of its carbon footprint (Geneva Association, 2019).

There is some evidence that countries utilizing market-based insurance coverage may recover faster from the financial impacts of extreme weather events, although there is no consensus in the literature. The widening protection gap indicates that the benefits of risk transfer measures are yet to be fully utilized and that countries with lower levels of insurance penetration experience larger declines in economic output and more considerable fiscal losses from disasters. Findings by Von Peter et al. (2012) suggest that the growth response to insured losses is close to zero, while that to uninsured losses was clearly negative (2.3 percent or more), suggesting that it is the uninsured part of catastrophe-related losses that drives the macroeconomic cost. Melecky and Raddatz (2011) also find that countries with higher insurance penetration are able to contain the real impacts of natural disaster without the need for significant fiscal expansion. Hsiang and Jian (2014) on the other hand, find that tropical cyclones result in a long-run decline in national incomes relative to their pre-disaster trend and post disaster interventions such as borrowing, transfers, and insurance have only a limited long-run impact.

The insurance sector is an important source of finance and innovation in building resilience. Regional catastrophe risk insurance pools such as in the Caribbean and in the Pacific transfer their excess catastrophe risk to the international reinsurance markets cost-effectively. The Philippines, with the help of the World Bank, secured \$590 million in reinsurance markets for its catastrophe risk insurance program

for local governments. Chile, Colombia, Mexico, and Peru issued a \$1.3 billion cat bond, through the World Bank, to protect against major earthquakes.⁹

Insurance markets can generate the benefits one can expect from them only if there is a good cooperation between governments, regulators, and private actors. Countries with high penetration of disaster insurance typically have a public system to cope with the largest risks and mandatory disaster risk insurance. With climate change creating more uncertainty and thus making the pricing of insurance more difficult, the need for public-private partnership will become even bigger. It is also important that many climate change impacts are likely to remain uninsurable, either because they are too big or because they are too frequent.

What needs to be done?

In addition to adopting similar measures for banks¹⁰ (e.g., governance, risk surveillance, supervisory approaches), key challenges to adapt to climate change for the insurance sector include:

- **Data, knowledge, and modeling limitations.** Limited data on hazard, vulnerability, and exposure impedes the development of cost-effective insurance-based solutions. The complex nature of disasters creates volatility and uncertainty surrounding loss estimation which can only be addressed through improved data. Further, when risk-based premiums are applied, this paucity of data can impact the affordability of cover due to the positive correlation between risk and pricing. For infrastructure investments, insurers require data to assess the climate resilience and carbon-intensity throughout its lifecycle (Geneva Association, 2018).
- **Disaster planning and budgeting.** In many countries, the policy and regulatory environments, institutional capacities and mandate, lack of coordination, and sometimes willingness to share data within and across government, hamper the implementation of disaster risk finance and insurance measures. Additional support is required to build understanding and improve quantification of socio-economic risk.
- **Market failures and innovation needs.** The limited uptake of catastrophe risk insurance by households or firms is the result of a market failure that reduces the incentive to adapt, including to purchase insurance. It can be attributed to a combination of limited demand to purchase such products, and at times weaknesses within the domestic insurance market to supply these products – demonstrating that capacity building is needed on both the demand and supply side. Innovation within the insurance sector can help address existing domestic market failures with support from governments and the international re/insurance markets.

⁹ The World Bank is supporting Jamaica to issue a cat-bond to insure against hurricanes, floods and earthquake.

¹⁰ Also see IAIS (2018).

Box 5. Developing domestic catastrophe risk insurance markets in Fiji

TC Winston highlighted a major protection gap: 94 percent of houses are uninsured against tropical cyclones. The building stock in Fiji comprises approximately 240,000 residential homes (Pacific Risk Information System – PacRIS). With only 15,000 homes (or 6 percent of the housing stock) purchase coverage against tropical cyclone, a significant gap in insurance coverage emerges. The supply of TC coverage within the domestic insurance industry is limited because insurers are unable to secure reinsurance capacity. Insurance companies can only supply property catastrophe insurance for houses of a high construction standard and a current engineer’s certificate which is required by the international reinsurers to provide reinsurance.

Most low-income households do not meet the standard required to purchase an engineer’s certificate which demonstrates that there is market failure creating a major contingent liability for the GoF. Uninsured households create an implicit liability or social obligation for the GoF to provide financial assistance in the aftermath of a disaster, as was seen in the case of TC Winston where GoF has spent FJ\$80 million to support the reconstruction of housing.

The World Bank and the IFC have been developing two pilot catastrophe risk insurance schemes to test the viability of market-based insurance solutions to provide household coverage against tropical cyclones. The first product is property insurance for houses of low-build quality that are still deemed insurable with some basic reinforcement, such as roof strapping. Such houses are estimated to represent half of the housing stock, or approximately 121,000 households, in Fiji. The second product is a parametric-based livelihoods (protection) insurance product for households with non-insurable assets, which account for approximately 68,000 households.

Empirical Assessment of Linkages

This section reviews countries’ exposure to macro-financial and climate related risks. We start with a discussion of physical and transition risks and then seek to identify countries that are subject to “double jeopardy” due to the simultaneous presence of both risks. The data and analysis presented in this section are subject to a range of caveats and should thus be considered as an initial illustration of macro-financial – climate risk linkages. The chosen climate risk indicators provide a broad indication of countries’ vulnerability. However, there is ongoing work on some of these risks (e.g., transition risks) to develop better indicators. Second, country coverage is limited for some of the indicators. The listing of countries that are subject to both elevated macro-financial and climate related risks can thus not claim to capture all countries that may face high twin risks. Another caveat is that the classification of countries according to climate related risks is very simple, dividing countries for each indicator into two groups, depending on whether they are above or below the median of the indicator. Additional work will be required to identify more appropriate thresholds for risk categories. Further analysis will be required to deepen the understanding of macro-financial – climate risk linkages and to address some of these caveats.

Measuring climate-related and macro-financial risks

This section presents information on four sets of indicators used to measure climate change-related physical (linked to extreme weather events and gradual global warming) and transition risks (linked to high carbon intensity or high fossil fuel exports). For the measurement of macro-financial risks, we use macro-financial risk indicators generated by the Economist Intelligence Unit (EIU).

Extreme weather events

We use data from the Emergency Events Database (EM-DAT) compiled by the Centre for Research on the Epidemiology of Disasters (CRED) as the measure of countries’ vulnerability to extreme weather events.

EM-DAT provides data on over 22,000 mass disasters around the world since 1900.¹¹ We use for our analysis the ratio of damages to GDP (30-year median) as the indicator of countries' vulnerability to extreme weather events. Even though this is a backward-looking measure which is silent on the attributability of these events to climate change, it is a good indicator of countries' exposure to the impact of climate change through increased frequency and intensity of extreme weather events.

Floods and storms are the most frequent severe weather events, with the East Asia and Pacific region showing the highest number of events (Figure 5). EM-DAT data show that since the 1980s 45 percent of all incidents were floods, while storms accounted for 34 percent. The rest of the extreme weather conditions such as droughts, heat waves, landslides and wildfires accounted for 20 percent of events (Figure 5B). While all regions faced an increase in extreme weather events since the 1980s, East Asia and the Pacific experienced considerably more disasters than any other region (Figure 5D). The second most affected region is Latin America and the Caribbean, closely followed by Europe and Central Asia.

As countries faced an increase in disasters over time (Figures 5A and C),¹² the associated fatalities fell around the globe, suggesting that countries adopted disaster response and emergency strategies to minimize the number of human casualties. Simultaneously, the total number of affected people (including those who became homeless or were injured) increased over time, though disproportionately more in EAP and SA, reflecting the overall large populations of those regions. Sub-Saharan Africa also experienced a rise in total victims since the 1980s.

Extreme weather events result in material damages that also rose over time and were not equally distributed around the globe with EAP affected most. For instance, since the 1980s, median annual economic losses due to disasters totaled about US\$18 billion in EAP and US\$5 billion in ECA (Figure 5E).

Gradual global warming

Analysis of countries' vulnerability to the effects of gradual global warming and readiness to adapt to climate change is based primarily on the Notre Dame-Global Adaptation Index (ND-GAIN) (Figure 6). This index shows countries' vulnerability to climate disruptions and their readiness to leverage private and public sector investment for climate action. The vulnerability indicator covers the vulnerability of six life-supporting sectors to climate change: food, water, health, ecosystem service, human habitat, and infrastructure. The indicator of readiness to improve resilience covers economic, governance, and social readiness. The vulnerability and readiness indicators cover 182 and 184 countries, respectively for the period 1995 to the present.

Since 1995, countries' vulnerability to climate change, as measured by the ND Vulnerability Index, declined overall and across all regions (Figure 6B). This decrease in vulnerability reflects an increase in adaptive capacity in many countries. Yet, some countries are disproportionately more vulnerable to climate risks, such as those in SA, EAP, and SSA. These regions also are the most exposed to climate-related risks in the form of extreme weather events.

¹¹ <https://www.emdat.be/>

¹² It is worth noting that part of the increase in events could be due to improved measurement and tracking of extreme weather conditions around the world over time.

The ND readiness index shows an upward trend since 1995 based on improvements in economic, governance, and social readiness. This observation is particularly evident for the ECA region, followed by MENA (Figure 6D and E). In contrast, countries in the most vulnerable region, EAP, do not seem, on average, to get more resilient to extreme climate shocks, as their ND readiness indicator remained flat for the period under study.

Transition risks – high carbon intensity

Countries with a large carbon footprint face significant transition risks arising from the move towards low-carbon economies. We use CO₂ emissions intensity (kg per kg of oil equivalent energy use) from the World Development Indicators to track countries' exposure to transition risks.

Countries' exposure to transition risks, as measured by their CO₂ emissions intensity, has hardly changed since 1995. The data on CO₂ emissions show that between 1995 and 2014, median CO₂ intensity across countries has been fairly stable (Figure 7A and B). Moreover, MENA appears to be the most exposed, but its CO₂ intensity declined over time. In particular, Jordan and Morocco face high transition risk. Many economies in the region try to diversify their economies, even though they are still heavily dependent on hydrocarbons.

Whereas countries in the MENA and in ECA reduced their carbon footprint in the past 20 years, those in Asia (both Eastern and Southern) increased their CO₂ emissions (Figure 7B). Yet, for some countries in ECA, such as Poland and Kazakhstan, transition risk has increased over time.

Transition risks – fossil fuel exporters

Fossil fuel export dependent economies face particularly significant transition risks. Global efforts to reduce GHG emissions and fossil fuel consumption will affect demand and prices of fossil fuels. Revenue from fossil fuels is the main source of revenue for many fossil fuel exporters which thus face significant fiscal risks. The MENA region is the most exposed while dependence is rising for some countries in the ECA region (Figure 7D). Diversification away from fuel exports will become more urgent, bringing additional challenges and uncertainties to these economies. In our analysis, we use the ratio of fossil fuel exports to GDP as the indicator for this type of transition risk.

Macro-financial conditions

We analyze macro-financial conditions using the EIU country risk index and its subcomponents (macroeconomic, banking, and sovereign debt). The EIU Country Risk Index is part of the EIU Country Risk Model and measures the build-up of sovereign, currency, and banking risks in 131 countries since 1997, using 77 quantitative and qualitative variables. In each category, countries are assigned a score from 0 to 100, where 0 is the lowest risk and 100 is the highest risk.¹³

Linking climate and macro-financial risk measures

This section highlights countries and regions that face the double jeopardy of elevated macro-financial and climate related risks. We discuss the results for the four main categories of risks. Countries are classified as being at higher macro-financial or climate-related risk if they are above the sample median for the particular climate-related or macro-financial indicator. We also examine systematic relations

¹³ Using the MFR indices of macro-financial risks yields broadly similar results. However, due to the confidentiality of these ratings these results are not shown in this paper.

between macro-financial and climate-related variables through regression analysis (the methodology and quantitative results are presented in Annex 1).

Risks from extreme weather events

About 30 percent of countries in the East Asia and Pacific, Latin America and Caribbean, South Asia, and Africa regions face the double jeopardy of elevated risks from extreme weather events and macro, debt, and banking sector risks (Figure 10, Table 3). In these countries, recovery from disaster-induced physical damages is likely to be constrained by limited ability to mobilize significant amounts of resources quickly, while the cost of funds is likely to be elevated due to these weaknesses. Financial sector vulnerabilities that are relatively frequent in East and South Asia also pose the risk that an extreme weather event could lead to a further weakening of the financial sector, if repayment of loans is affected or large insurance pay-outs required. Most countries in the MENA have limited risks from extreme weather events.

Table 3. Countries with higher extreme weather event risk and at least one elevated macro-financial risk

EAP	ECA	LAC	MENA	SAR	SSA
Cambodia	Bosnia and Herzegovina	Bolivia	Oman	Bangladesh	Malawi
China	Herzegovina	Costa Rica	Tunisia	Sri Lanka	Mozambique
Myanmar	Croatia	Dominican Republic			Namibia
Papua New Guinea	Serbia	Jamaica			Sierra Leone
Vietnam		Nicaragua			South Africa
		Uruguay			

Our regression analysis suggests that the occurrence of a significant natural disaster is associated with a weakening of fiscal, banking, and macro positions, even one year after the shock (Table A1.2). Using a Panel Data framework with country and year fixed effects (see more details in Annex 1), we find that countries that faced natural disasters with losses equivalent to at least 1 percent of GDP tend to have the following characteristics:

- **Weaker fiscal conditions:** i) Debt of the general government is 2.4 percent of GDP higher after one year of the shock. The increment starts during the year of the shock and continues after one year. ii) Sovereign ratings are lower two years later for countries that faced extreme weather shocks, consistent with the significant rise of public debt level after one year.
- **More vulnerable banking sector:** Non-performing loans are 1.17 percent of total assets higher in countries that experience a natural disaster. In addition, bank provisions are 9.7 percent of NPLs lower in those countries in the year they face the shock.
- **Macroeconomic risks are higher:** Macroeconomic risks indicators are higher for countries that faced extreme weather-related shocks. This effect appears in the year of the disaster and still visible two years after the disaster.

Risks from gradual global warming

For Sub-Saharan Africa, high climate change vulnerability coincides in most countries with elevated levels of macro, financial, and debt risks, which leaves the region in a weak position to confront climate

vulnerabilities (Figure 11, Table 4). For East and South Asia, in many countries elevated climate vulnerability coincides with elevated banking sector risks, suggesting that climate change could lead to a deepening of financial sector risks. Many countries in the East Asia and Pacific region are also vulnerable to climate change, but countries in the region differ significantly with respect to their macro-financial resilience to physical risk and their macro-financial capacity for adaptation and mitigation. A relatively large share of countries has strong macro-financial resilience and capacity. Countries in the LAC and MENA regions have a smaller share of countries that face the double jeopardy of high climate vulnerability and macro financial risks. The ECA countries have the lowest vulnerability to climate change among all regions, with no countries that are assessed as having both elevated climate vulnerability and macro-financial risks.

Table 4. Countries with global warming risk and at least one elevated macro-financial risk

EAP	ECA	LAC	MENA	SAR	SSA	
Cambodia		Bolivia	Bahrain	Bangladesh	Angola	Nigeria
Myanmar		Cuba	Egypt, Arab	Sri Lanka	Congo, Rep.	Seychelles
Papua		Dominican	Rep.		Ghana	Sierra
New		Republic	Iraq		Kenya	Leone
Guinea		Ecuador	Syrian Arab		Malawi	Sudan
Vietnam		Jamaica	Republic		Mozambique	Tanzania
		Nicaragua			Namibia	Zambia

Regression analysis confirms that countries that are vulnerable to gradual global warming also show macro-financial vulnerabilities that could affect their ability to respond to the disruptions generated by climate change (Table A1.3). The “sensitivity” component of the Notre Dame Vulnerability Index is the main channel of transmission between climate change distortions and macro-financial vulnerabilities, while the “adaptive capacity” component of the index offsets the effects of the “sensitivity” channel.

- **Fiscal position:** Countries with higher “sensitivity” to climate change impacts tend to have higher levels of public debt and lower sovereign ratings. This result means that countries that could be more affected by physical-gradual risks of climate change have less fiscal space to respond to the challenges of that phenomenon. Countries with higher “exposure” also show higher public debt levels, while countries with more “adaptive capacity” show lower public debt.
- **Banking sector:** Countries that are more vulnerable to climate change show lower bank provisions (% of NPLs). Even though we find no statistical association between NPLs (% total assets) and the Notre Dame vulnerability index, provisions show a negative and significant relationship with the vulnerability index via its “sensitivity” component.
- **Macro-financial risks:** Countries with higher vulnerability to climate change also show higher macro-financial risks, particularly in the public sector bucket, based on the EIU Index. Consequently, the ability to respond to the challenges of climate change is limited in countries with weaker macro-financial conditions. At the same time, there is a negative correlation between country risk and countries’ readiness to adapt to climate change (Figure 9). The negative correlation between country risk and readiness to adapt may partly reflect the fact that there is some overlap in what the two concepts measure.

Transition risks for CO2 intensive economies

MENA is not only the region with the highest level of transition risks due to the dependence of many countries on fossil fuel exports, but this elevated transition risk coincides often with elevated levels of macro, banking sector, and debt risk (Figure 12, Table 5). EAP, ECA, and LAC are the other regions with relatively high transition risks. Among these three regions, EAP has the strongest macro-financial resilience to transition risks, while in ECA and LAC several countries with high transition risks also have high macro, banking sector, and debt risks. Countries in the South Asia and Sub-Saharan Africa regions (for which data are available) show relatively low exposure to transition risks.

Table 5. Countries with higher transition (carbon intensity) risk and at least one elevated macro-financial risk

EAP	ECA	LAC	MENA		SAR	SSA
China	Azerbaijan Bosnia and Herzegovina Greece Kazakhstan Russian Federation Serbia Turkey	Bolivia Cuba Dominican Republic Ecuador Jamaica	Algeria Egypt, Arab Rep. Iran, Islamic Rep. Iraq Jordan Lebanon	Libya Morocco Oman Qatar Syrian Arab Republic Tunisia United Arab Emirates		Angola South Africa

Our regression analysis (Table A1.4) suggests that countries with higher CO2 intensity tend to have a higher share of non-performing loans. However, it is quite likely that this higher risk in the banking sector also reflect other characteristics of carbon-intensive economies and not primarily the transition risk.

Transition risks for fossil fuel exporters

As to be expected, MENA countries are the most exposed to this source of transition risk (Figure 13, Table 6). A significant share of MENA countries also faces twin risks, as this risk often coincides with macro-financial vulnerabilities. Many of these economies also have developed down-stream, carbon-intensive industries. They will thus not only have to find alternative sources of foreign exchange and fiscal revenue, but their industries will also have to undergo significant transition if they want to pursue low-carbon objectives.

Our data also show that that in most regions about 20 percent of countries also face twin risks from the combination of fossil fuel exports and macro-financial risks.

Our regression analysis (Table A1.4.) suggests that higher fossil fuel exports are associated with lower sovereign ratings, and higher macro, banking, and debt risks. While this would be consistent with the expected impact of high exposure to transition risks, it is likely that this also captures other vulnerabilities that are signaled by a high share of fossil fuel exports, especially vulnerability to swings in commodity prices and Dutch disease effects.

Table 6. Countries with higher transition (fossil fuel exports) risk and at least one elevated macro-financial risk

EAP	ECA	LAC	MENA		SAR	SSA
Vietnam Myanmar Papua New Guinea	Azerbaijan Bosnia and Herzegovina Kazakhstan Russian Federation Ukraine Greece Croatia Hungary	Bolivia Venezuela, RB Jamaica Ecuador	Bahrain Tunisia Qatar Algeria Egypt, Arab Rep. Libya	Oman Iraq Iran, Islamic Rep. Syrian Arab Republic United Arab Emirates		Mozambique Sudan Nigeria Angola Ghana Kenya Congo, Rep. South Africa

Conclusions

The analysis shows that a significant number of countries face a double jeopardy due to the simultaneous presence of climate related and macro-financial risks. Even though elevated climate-related risks indicate the need for adaptation and mitigation measures, these countries have limited macro-financial capacity to act. Especially, high public sector and financial sector vulnerabilities limit these countries' ability to mobilize necessary financing. As physical risks such as natural disasters materialize, high macro-financial risks mean low macro-financial resilience and a high risk of prolonged crisis and hardship.

The analysis also suggests that there is a systematic relationship between macro-financial and climate related risks, with countries facing higher climate related risks typically also facing higher macro-financial risks. This may to some extent reflect the role of climate related risks as a source of macro-financial risks. However, further analysis will be necessary to understand this systematic relationship.

The presence of twin risks underlines the importance of reducing macro-financial risks in order to enhance countries' macro-financial resilience to the physical impacts of climate change and their macro-financial capacity for climate adaptation and mitigation. In the first instance, country specific reforms will be at the core of building macro financial resilience and capacity to deal with climate related risks. However, given that there appears to exist a systemic relationship between macro-financial and climate-related risks, there may also be need for the international community to consider strengthening the macro-financial resilience and capacity of the most exposed countries as an element of international efforts to tackle climate change.

Figure 5. Physical climate change risks due to natural disasters

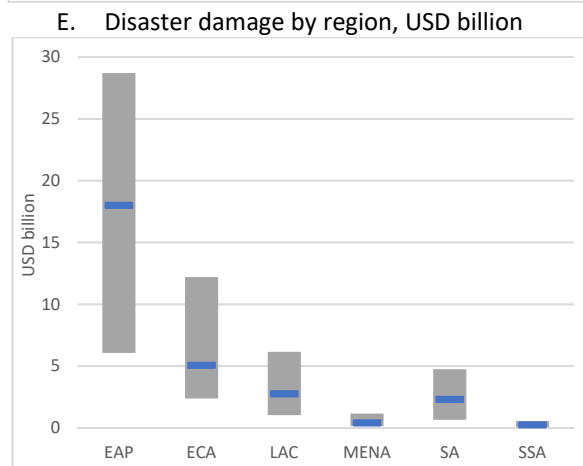
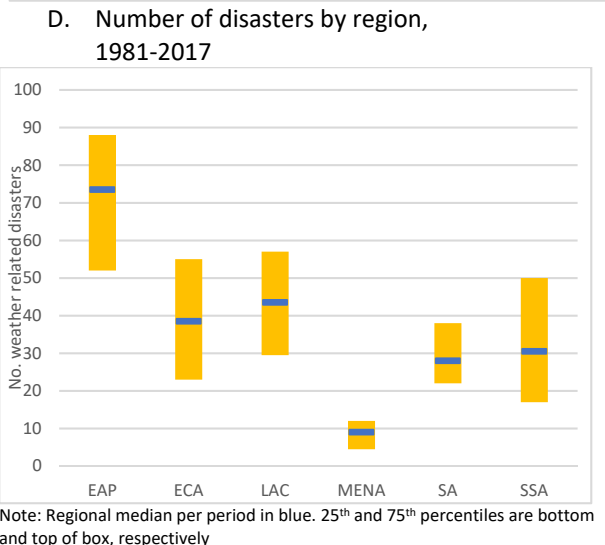
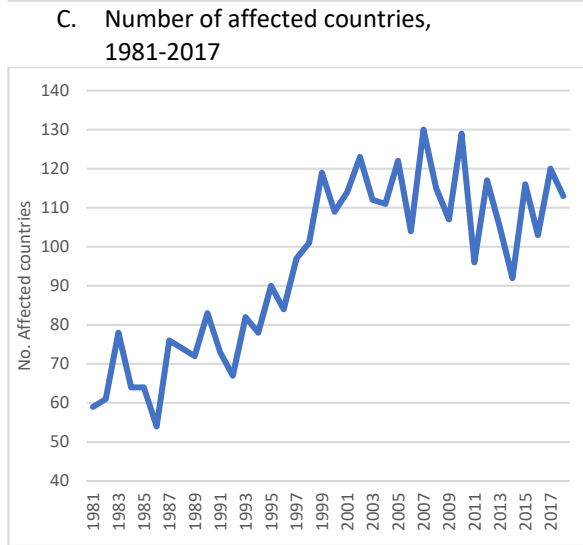
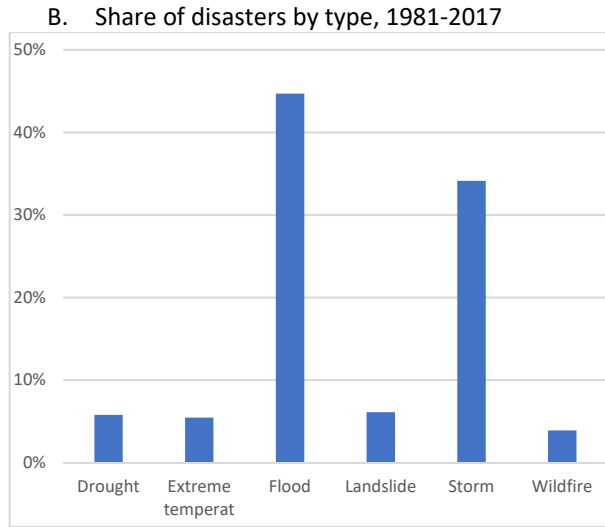
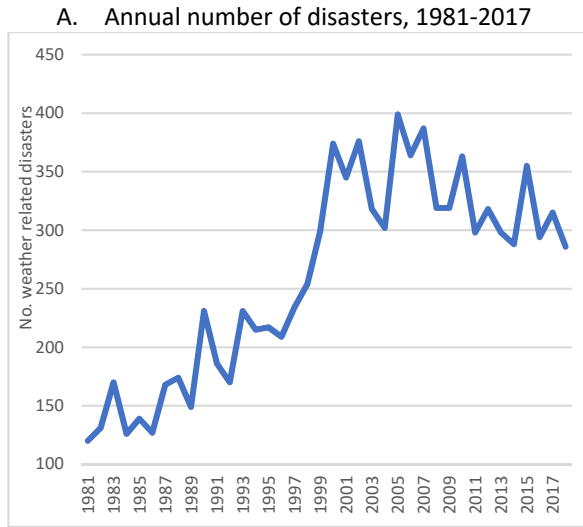
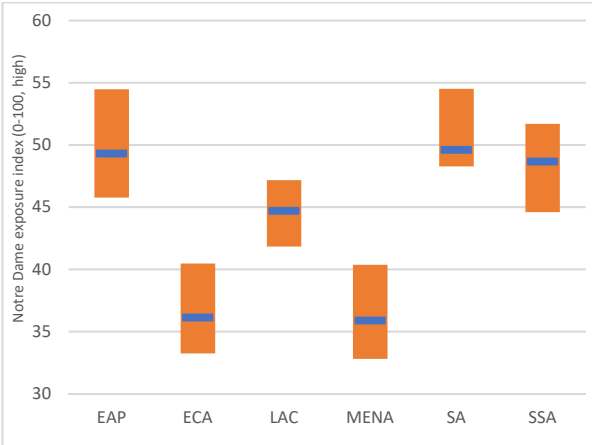


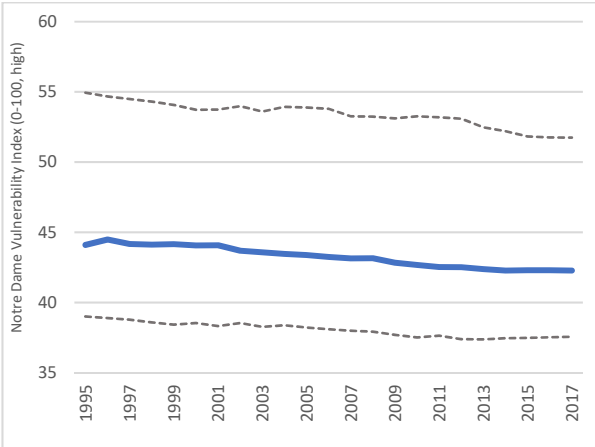
Figure 6. Notre Dame GAIN indicators of vulnerability to climate change

A. Climate change exposure by region



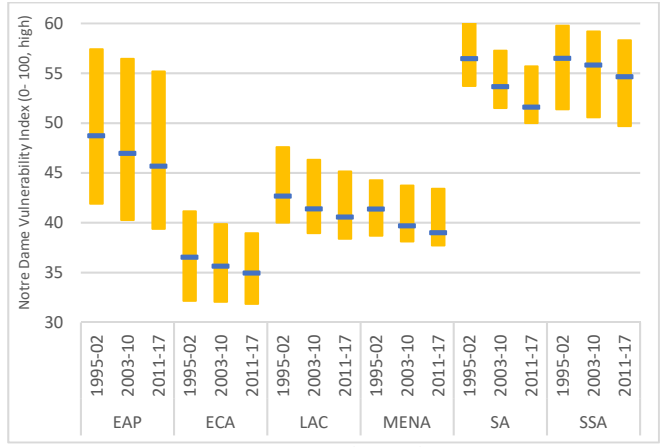
Note: Regional median per period in blue. 25th and 75th percentiles are bottom and top of box, respectively

B. Vulnerability index, 1995-2017



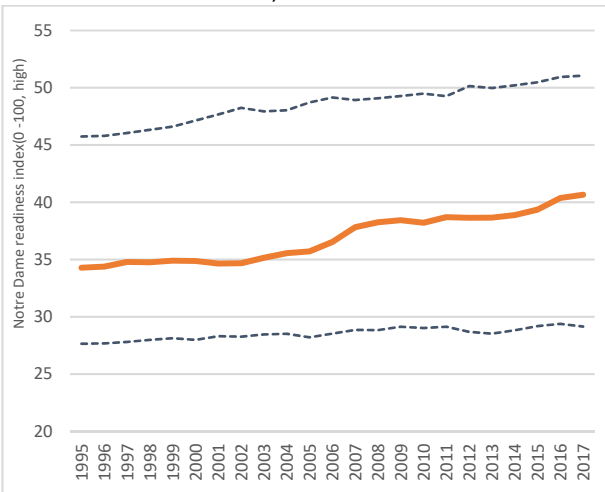
Note: Country median per year. 75th and 25th percentiles in dotted lines

C. Vulnerability index by region



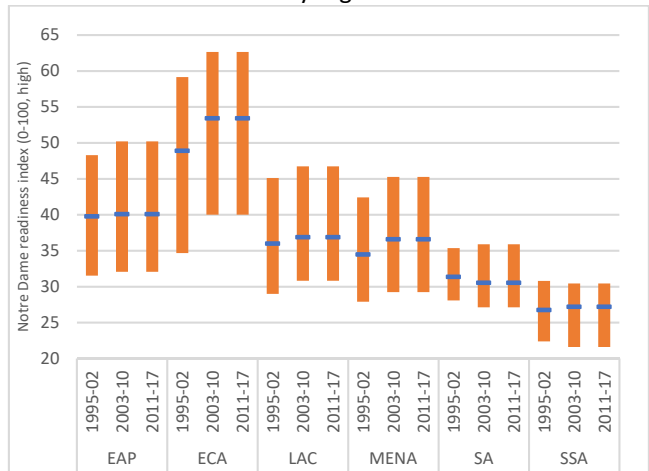
Note: Regional median per period in blue. 25th and 75th percentiles are bottom and top of box, respectively

D. Readiness index, 1995-2017



Note: Country median per year. 75th and 25th percentiles in dotted lines

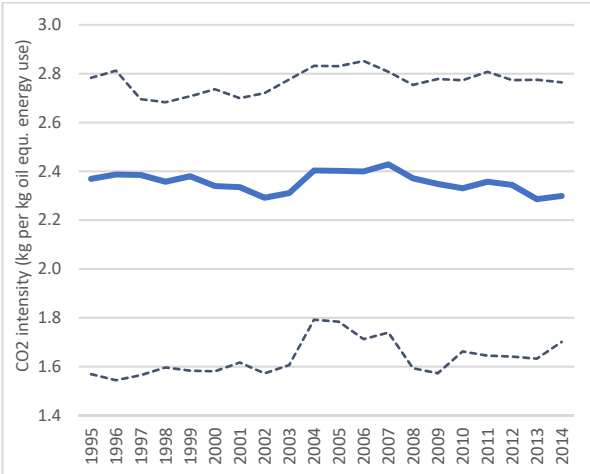
E. Readiness index by region



Note: Regional median per period in blue. 25th and 75th percentiles are bottom and top of box, respectively

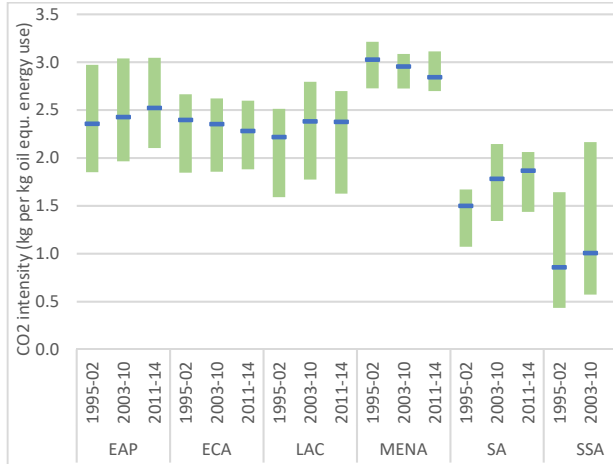
Figure 7. CO2 intensity and fuel exports as indicators of exposure to transition risks

A. CO2 intensity, 1995-2014



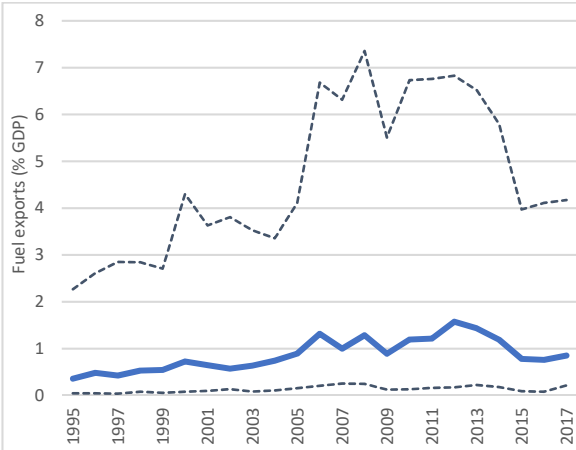
Note: Country median per year. 75th and 25th percentiles in dotted lines

B. CO2 Intensity by region



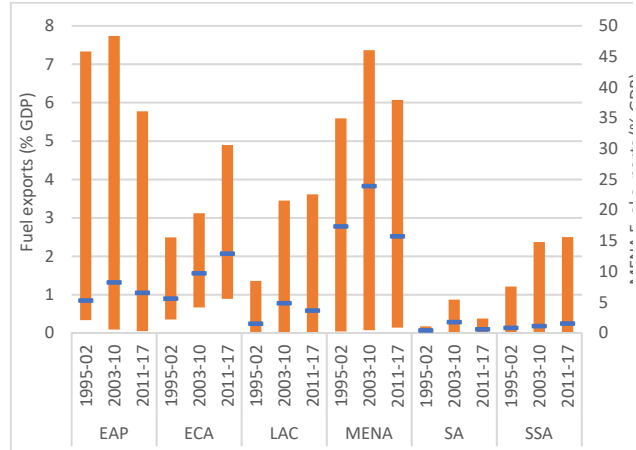
Note: Regional median per period in blue. 25th and 75th percentiles are bottom and top of box, respectively

C. Fuel exports (% of GDP), 1995-2017



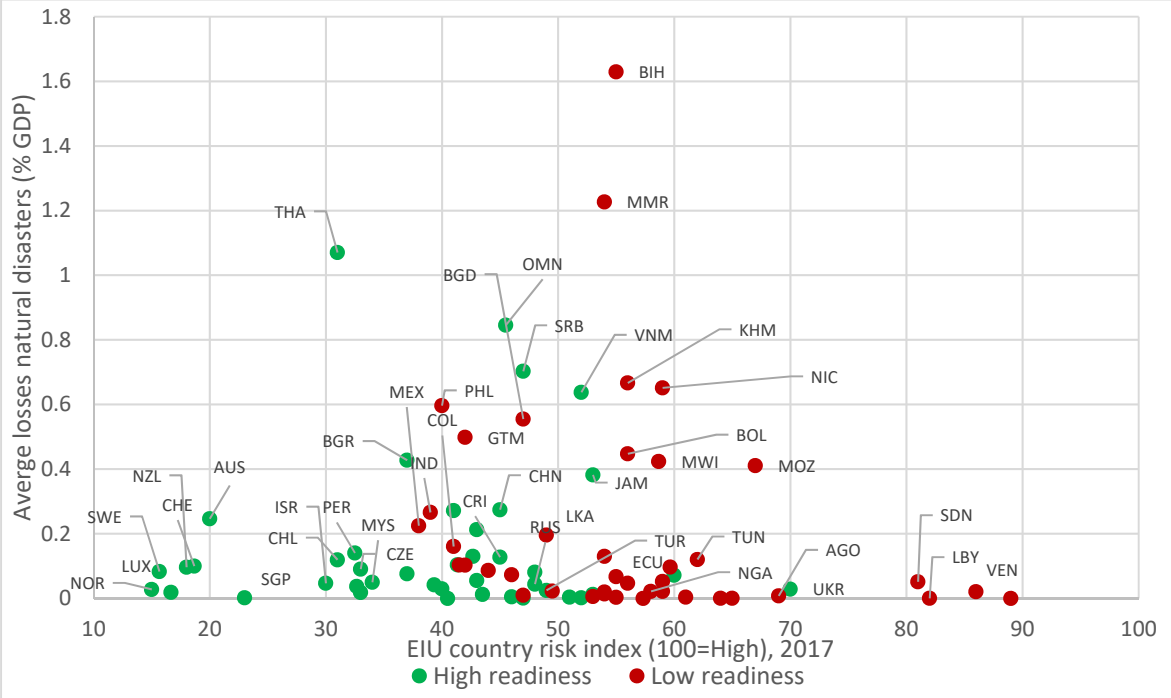
Note: Country median per year. 75th and 25th percentiles in dotted lines

D. Fuel exports (% of GDP) by region



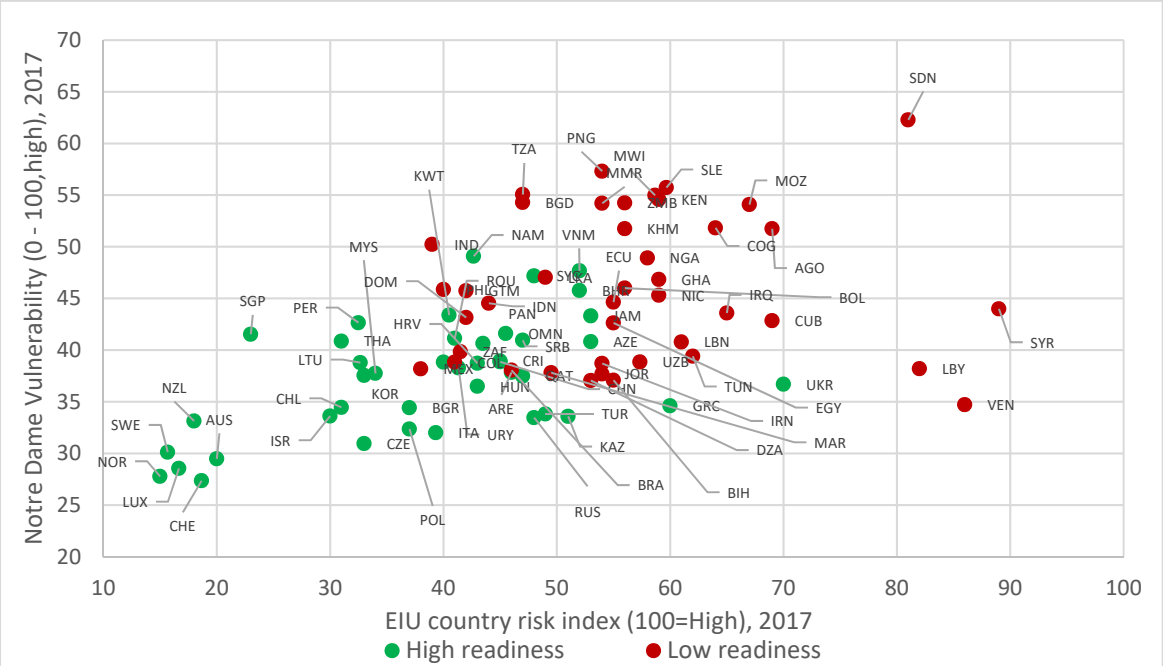
Note: Regional median per period in blue. 25th and 75th percentiles are bottom and top of box, respectively

Figure 8A. Physical (disaster) risk vs. EIU country risk



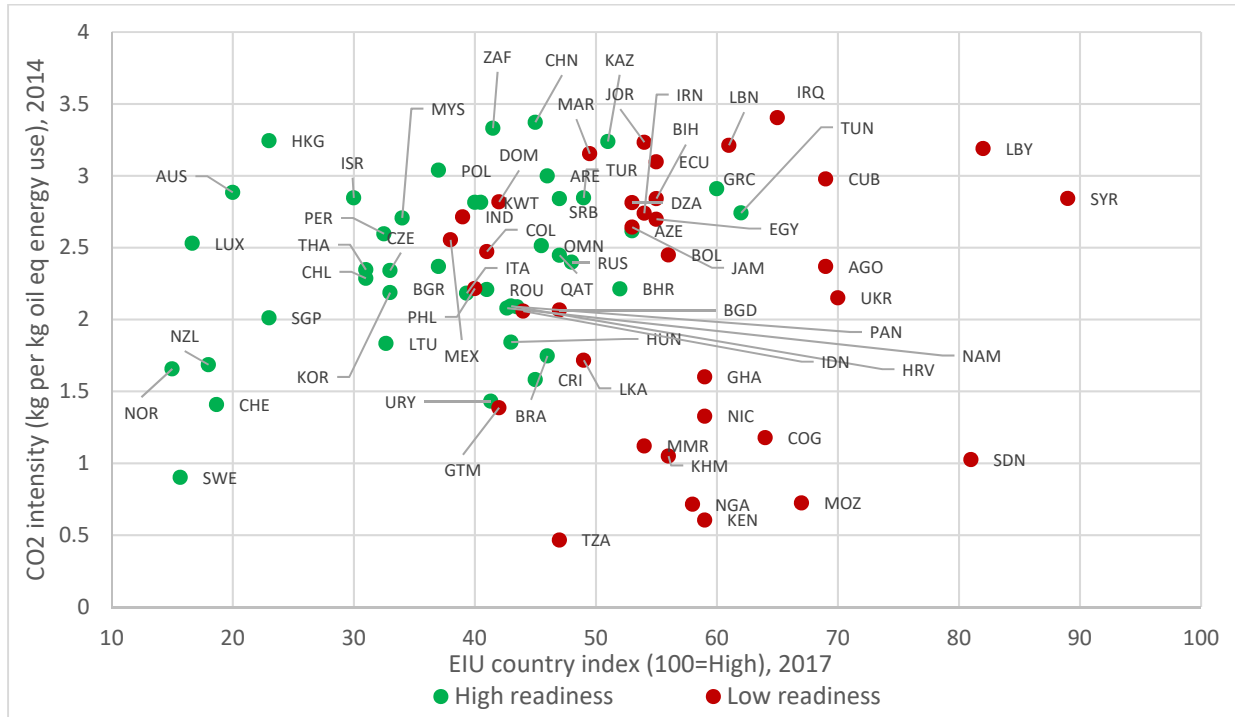
Note: Average losses natural disasters (% GDP) between 2005 and 2017. Countries above (below) country median in Notre Dame Readiness indicator in green (red).
 Source: EIU Credit Risk Model, GermanWatch. Staff calculations

Figure 8B. Physical (gradual vulnerability) risk vs. EIU country risk



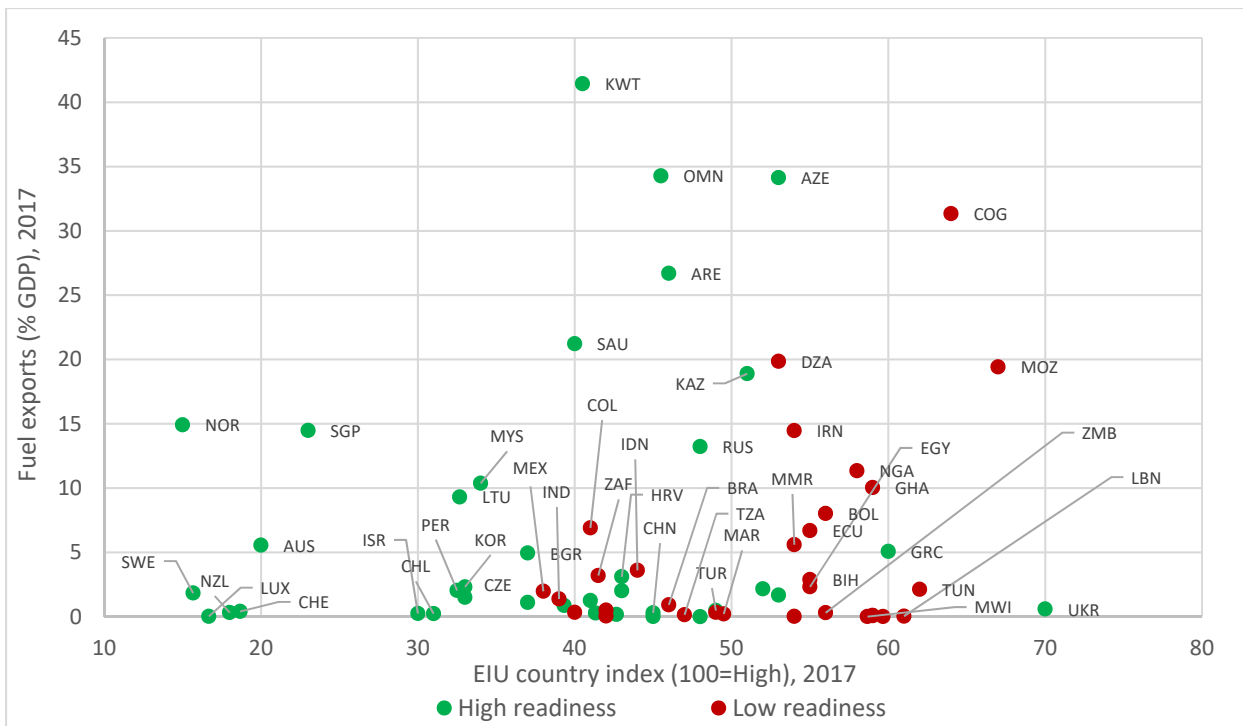
Note: Countries above (below) country median in Notre Dame Readiness indicator in green (red). EIU data for Saudi Arabia as of 2016.
 Source: EIU Credit Risk Model, Notre Dame GAIN. Staff calculations

Figure 8C. Transition risk (CO2 intensity) vs. EIU country risk



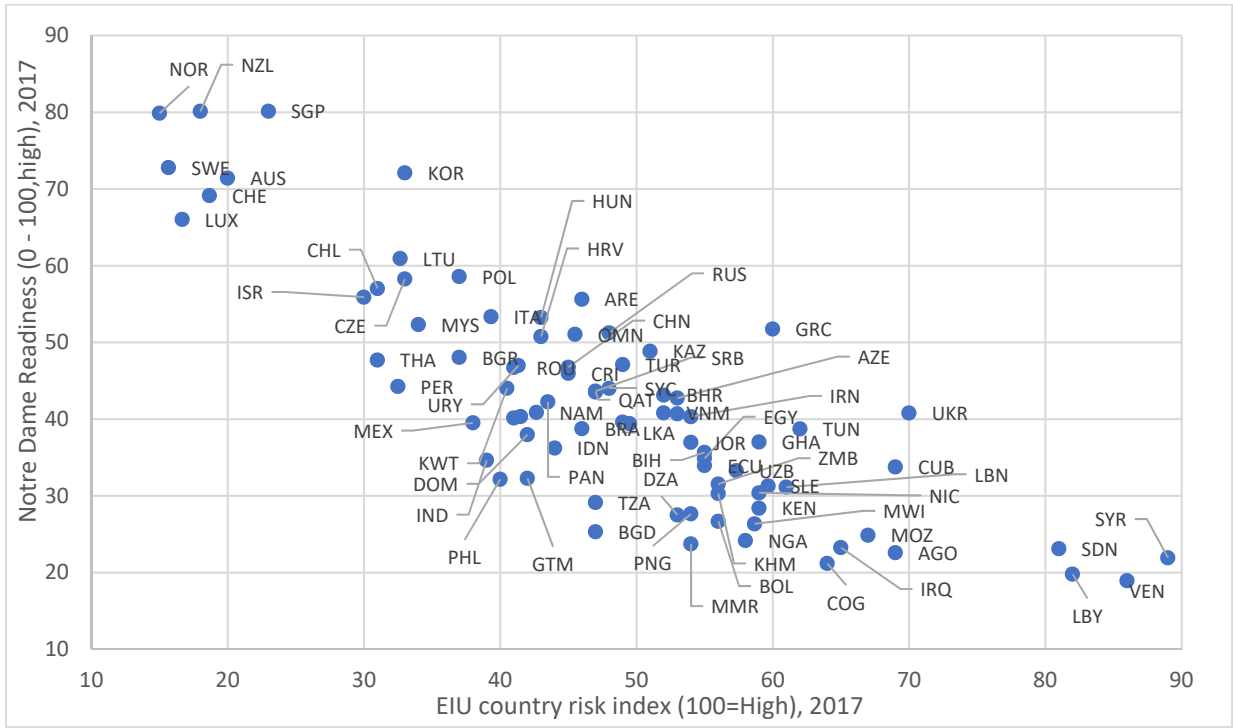
Note: Countries above (below) country median in Notre Dame Readiness indicator in green (red). EIU data for Saudi Arabia as of 2016.
 Source: EIU Credit Risk Model, World Development Indicators. Staff calculations.

Figure 8D. Transition risk (fuel exports % GDP) vs. EIU country risk, 2017



Note: Countries above (below) country median in Notre Dame Readiness indicator in green (red). EIU data for Saudi Arabia as of 2016.
 Source: EIU Credit Risk Model, World Development Indicators. Staff calculations.

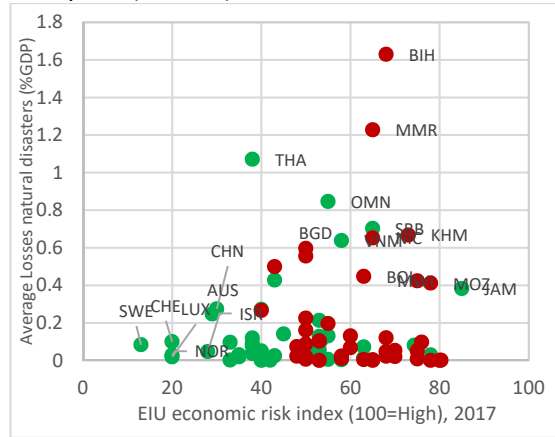
Figure 9. Notre Dame readiness index vs. EIU country risk, 2017



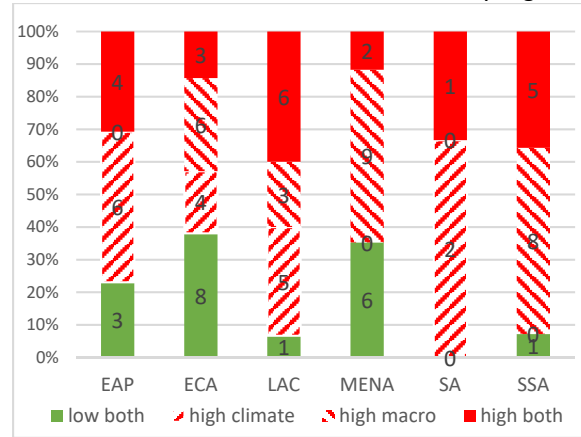
Source: EIU Credit Risk Model, Notre Dame GAIN. EIU data for Saudi Arabia as of 2016. Staff calculations.

Figure 10. Extreme weather event risks and macro-financial risks

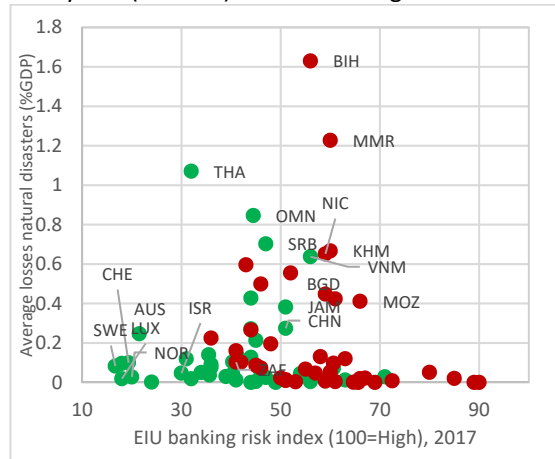
A. Physical (disaster) risk vs. macroeconomic risk



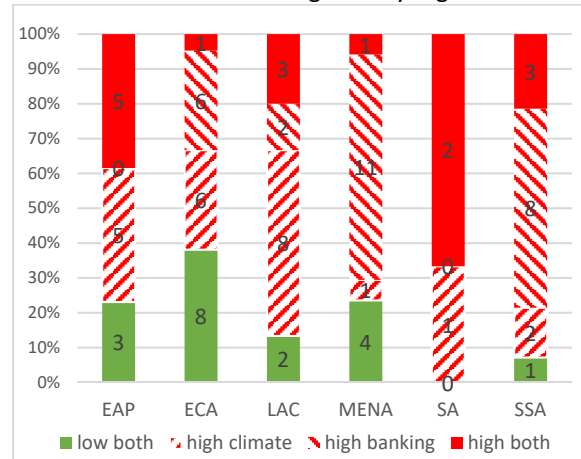
B. Weather event & macroeconomic risks by region



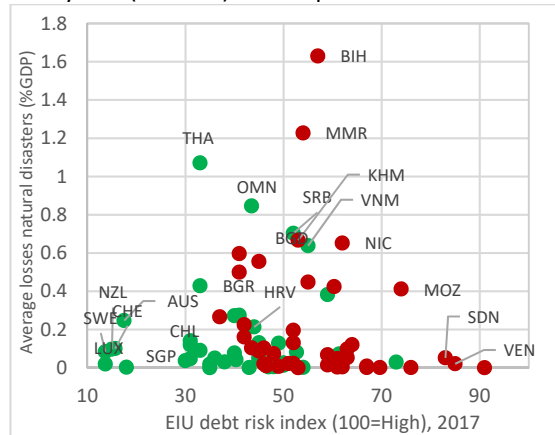
C. Physical (disaster) risk vs. banking risk



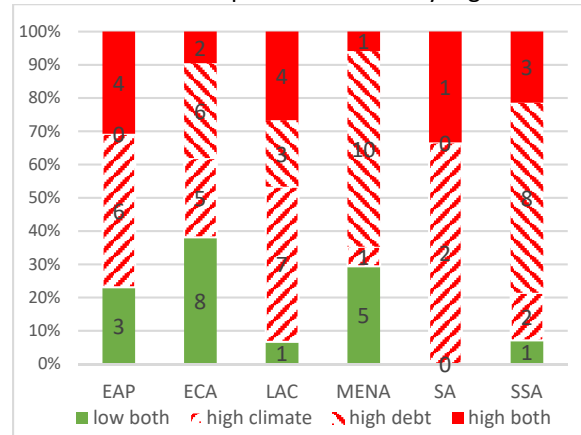
D. Weather event & banking risks by region



E. Physical (disaster) risk vs. public debt risk



F. Weather event & public debt risks by region



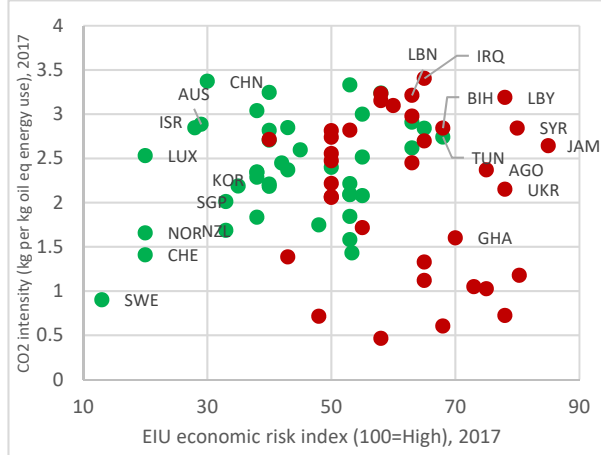
Note: Panels A, C, and E: Countries above (below) country median in Notre Dame Readiness indicator in green (red). Panel A: average losses (% GDP) between 2005 and 2017.

Panels B, D, and F: columns show proportion of countries in each category (i.e., low climate and macro-financial risks, high climate-low macro-financial risks, low climate-high macro-financial risks, high climate and macro-financial risks) by region. Thresholds are country median values of EIU indicator or climate variable as of 2017 (historical country median for the case of fuel exports). Numbers in columns are the number of countries in each category. EIU data for Saudi Arabia as of 2016.

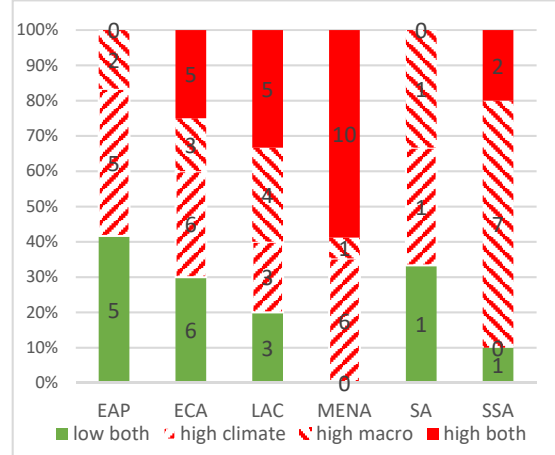
Source: EIU Credit Risk Model, GermanWatch, Notre Dame GAIN, WDI. Staff calculations.

Figure 12. Transition risks (carbon intensive production) and macro-financial risks

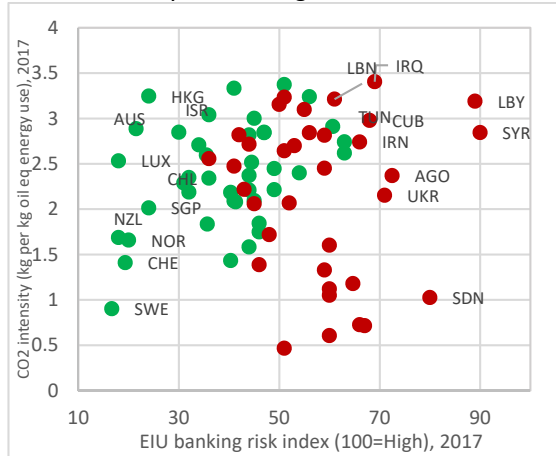
A. CO2 intensity vs. macroeconomic risks, 2017



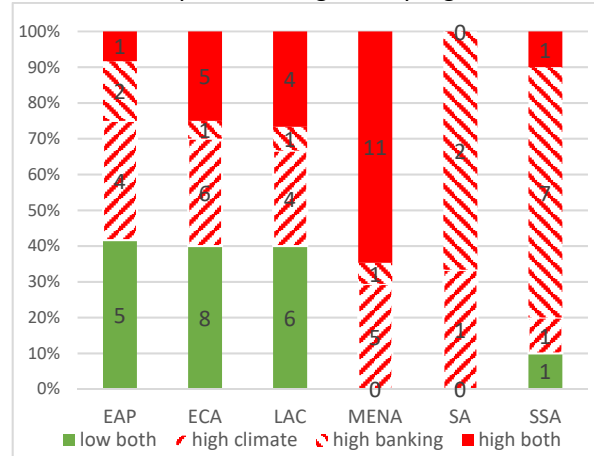
B. CO2 intensity and macroeconomic risks by region



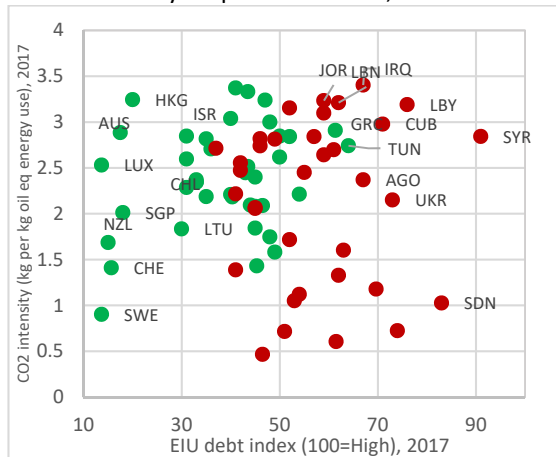
C. CO2 intensity vs. banking risks, 2017



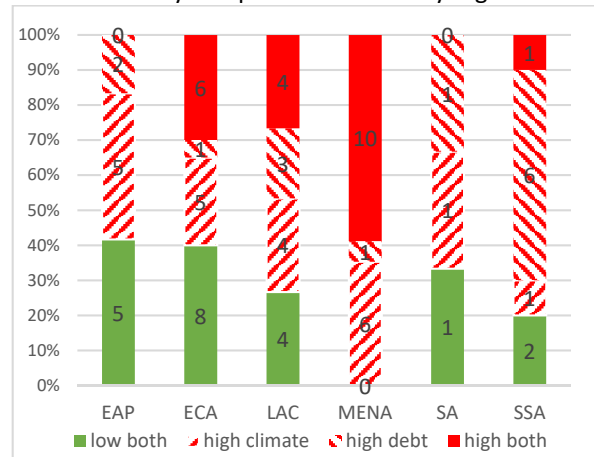
D. CO2 intensity and banking risks by region



E. CO2 intensity vs. public debt risk, 2017



F. CO2 intensity and public debt risks by region



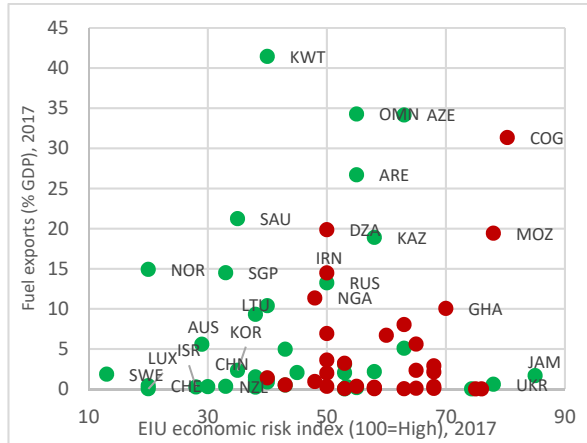
Note: Panels A, C, and E: Countries above (below) country median in Notre Dame Readiness indicator in green (red). Panel A: average losses (% GDP) between 2005 and 2017.

Panels B, D, and F: columns show proportion of countries in each category (i.e., low climate and macro-financial risks, high climate-low macro-financial risks, low climate-high macro-financial risks, high climate and macro-financial risks) by region. Thresholds are country median values of EIU indicator or climate variable as of 2017 (historical country median for the case of fuel exports). Numbers in columns are the number of countries in each category. EIU data for Saudi Arabia as of 2016.

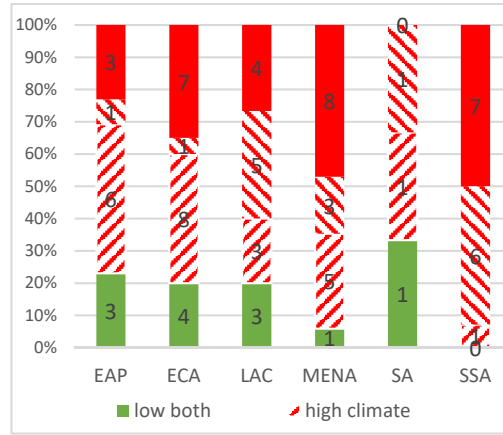
Source: EIU Credit Risk Model, GermanWatch, Notre Dame GAIN, WDI. Staff calculations.

Figure 13. Transition risks (fossil fuel exports) and macro-financial risks

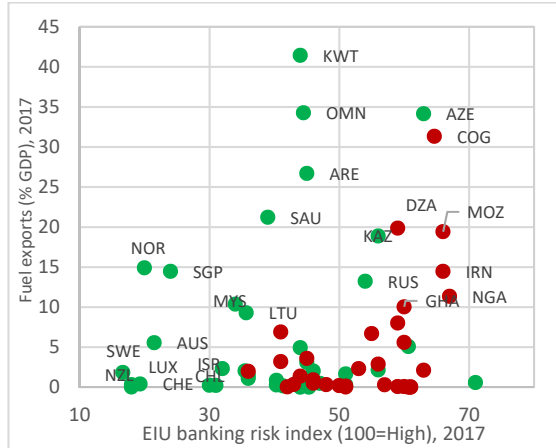
A. Fuel exports (% GDP) vs. macroeconomic risks, 2017



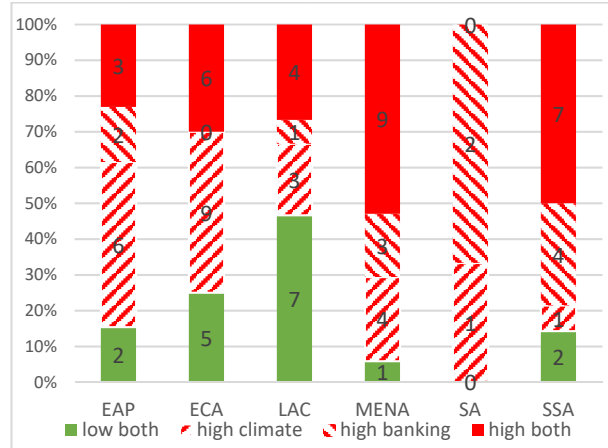
B. Fuel exports and macroeconomic risks, by region



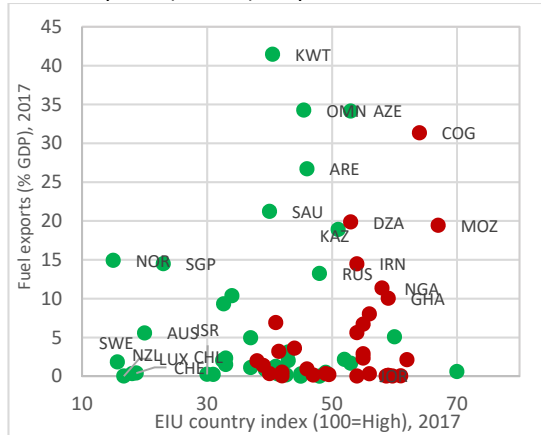
C. Fuel exports (% GDP) vs. banking risks, 2017



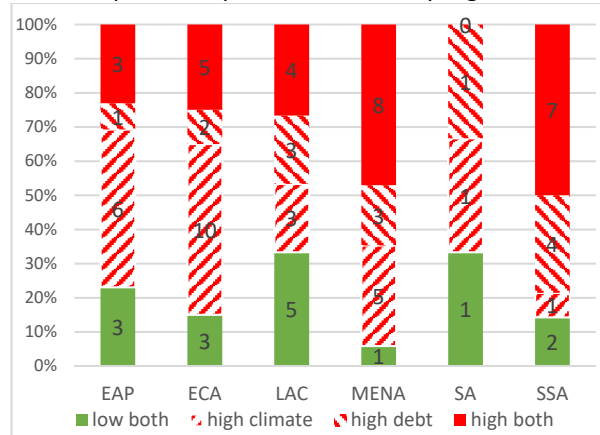
D. Fuel exports and banking risks, by region



E. Fuel exports (% GDP) vs. public debt risk, 2017



F. Fuel exports and public debt risks, by region



Note: Panels A, C, and E: Countries above (below) country median in Notre Dame Readiness indicator in green (red). Panel A: average losses (% GDP) between 2005 and 2017.

Panels B, D, and F: columns show proportion of countries in each category (i.e., low climate and macro-financial risks, high climate-low macro-financial risks, low climate-high macro-financial risks, high climate and macro-financial risks) by region. Thresholds are country median values of EIU indicator or climate variable as of 2017 (historical country median for the case of fuel exports). Numbers in columns are the number of countries in each category. EIU data for Saudi Arabia as of 2016.

Source: EIU Credit Risk Model, GermanWatch, Notre Dame GAIN, WDI. Staff calculations.

Policy Considerations

Based on the analysis, we offer nine policy considerations.

1. There is increasing awareness that climate change poses significant macro-financial risks (see Box 6). Climate change poses physical risks stemming from the potential economic losses of more frequent and intense natural disasters as well as transition risks arising from the uncertain adjustment process towards a more resilient, low-carbon economy. These risks pose significant challenges for macro-financial management: if realized, they can damage the balance sheets of governments, households, firms, and financial institutions due the adverse impacts on investment and economic growth, fiscal revenue and expenditure, debt sustainability, and the valuation of financial assets.
2. Macro-financial risks in turn may restrain the ability of policy makers and financial markets to implement and finance climate mitigation and adaptation measures. Climate change mitigation and adaptation require strong public and private balance sheets. For example, a weak fiscal position reduces the scope for implementing disaster management strategies, for reducing the dependence on carbon-entangled fiscal revenues, and for financing climate-resilient public infrastructure. Similarly, these risks could impede the flow of finance to green financial instruments which would slow down the transition to a low-carbon economy.
3. Economic risks and costs are likely underestimated in current models, and new approaches to capture “deep risks” are needed. Current projections significantly underestimate the economic cost of climate change. New work is underway to address some of the shortcomings of existing work, including doing a better job of capturing potential non-linearities, irreversibility in environmental stocks, and tipping points, which when crossed would lead to self-feeding accelerating temperature increases with catastrophic outcomes for humanity.
4. Climate-related risks may still be underpriced, thus hampering the transition to a low-carbon economy and efficient risk management. This may be the case because they materialize beyond investor horizons; are not adequately measured and disclosed; and social and environmental externalities are not properly accounted for.
5. Fiscal policy and the financial sector are key actors in climate mitigation and adaptation efforts. Pricing carbon to adequately reflect the damages caused by greenhouse emissions is a key lever to curb greenhouse emissions. Public expenditure on activities that support climate mitigation and adaptation are needed, such as investments in research on the low-carbon transition and alternative energies. Given the long-time horizon of investments, it is particularly important to make financial flows consistent with low-carbon and climate-resilience objectives. The financial sector can play an important role in mobilizing longer-term funding for these “green” investments while providing investors with assets that match their long-term liabilities. But there is a need for regulatory action and market-making at the domestic and international levels to mobilize these financial streams as well as to protect the financial sector from climate risks.
6. There are potentially important interactions between monetary policy and climate change risks. Policy makers and academics are only starting to explore these interactions and more work is needed in this area.
7. Many countries face the double jeopardy of elevated climate related and macro-financial risks. The simultaneous presence of elevated climate related and macro-financial risks implies that these countries have limited macro-financial resilience to physical climate risks and limited macro-financial capacity for adaptation and mitigation. This underlines the urgency for policy makers to reduce macro-financial risks. As there appears to be a positive correlation between macro-financial and

climate related risks, reducing macro-financial risks in countries under double jeopardy may need to be considered in the context of international efforts to tackle climate change.

8. Climate-related risks are not yet widely integrated into macro-financial management. Even though there is increasing recognition of the macro-financial risks posed by climate change, these risks are not yet widely reflected in monetary, fiscal and financial management practices. The first step in this process would be an explicit assessment and reporting of such risks, followed by the design and implementation of strategies on how to reflect these risks in fiscal and financial sector management. A number of initiatives – most prominently, the Coalition of Finance Ministers for Climate Action and the Network for Greening the Financial System – have recently been established to support countries in mainstreaming climate change in policy frameworks. However, the optimal balance of macro, fiscal, and financial policies is currently unclear and requires further analysis, given complementarity and substitution effects.
9. Transition to low carbon-economy should be better integrated into growth analytics and strategies. Climate change will result in significant structural transformation of economies and therefore impact economic growth. Accumulating evidence suggests that the implementation of climate mitigation and adaptation measures could be a significant driver of economic growth. However, the later climate actions are adopted, the more costly and disruptive the transition will be.

Box 6. Selected examples of global and regional macro-financial initiatives on climate change

Several initiatives are underway at the global and regional levels to manage risks and to support the deployment of macro-financial instruments to address climate mitigation and adaptation needs:

- **Finance Ministries.** *The Coalition of Finance Ministers for Climate Action* is a group of 44 Finance Ministers who have committed to take collective action to address climate change, encourage ambition, and sharing knowledge and best practices. In 2019, the Coalition endorsed the “Helsinki Principles,” which identify steps member countries will take to achieve the Paris Agreement goals.
- **Central Banks.** *The Network for Greening the Financial System (NGFS)* is a group of Central Banks and Supervisors from 42 countries that exchange experiences, share best practices, contribute to the development of environment and climate risk management in the financial sector, and mobilize mainstream finance to support the transition toward a sustainable green economy. Its purpose is to define and promote best practices to be implemented within and outside the NGFS Membership and to conduct or commission analytical work on green finance. The NGFS published a report in April 2019 which offers recommendations to better integrate climate-related risks into financial stability surveillance and prudential frameworks.
- **G20.** The *Green Finance Study Group*, later renamed the *Sustainable Finance Study Group*, was launched by G20 members to identify barriers to green finance and to develop voluntary options to mobilize private capital for green investment.¹ Currently, this group is no longer active.
- **Financial Stability Board (FSB).** The private sector-led *Task Force on Climate-related Financial Disclosures* was created in 2017 by the FSB, given the importance of internationally comparable and consistent disclosures. The Task Force developed a framework to create more effective financial disclosures for financial and non-financial firms on climate-related risks and opportunities. Several countries have implemented guidance or mandates for public corporations to use the framework for their climate-related disclosures. However, adoption is still quite limited. The TCFD will deliver its third status report in 2020 on the adoption of its recommendations.
- **Disclosure Standards.** The *Climate Disclosure Standards Board (CDSB)* is a non-profit organization working to provide material information for investors and financial markets through the

integration of climate change-related information into mainstream financial reporting. The CDSB standards feed into the TCFD framework.

- **Accounting Standards.** The *Sustainability Accounting Standards Board (SASB)* formulated standards which are designed to help businesses identify, manage, and report on the sustainability topics that are material to investors. SASB's standards were developed with input from a wide range of market participants and are tailored for specific industries. The SASB standards feed into the CDSB framework.
- **Securities Regulators.** The *International Organization of Securities Commissions (IOSCO)* is an association of organizations that regulate the world's securities and futures markets. In 2019 IOSCO issued a specific set of recommendations on how its members can better regulate sustainable finance activities, "given the significance of the associated risks and opportunities."¹ IOSCO's Sustainable Finance Network aims to foster exchange of information and best practices.
- **The Insurance Sector.** The *Sustainable Insurance Forum* and *The International Association of Insurance Supervisors (IAIS)*, jointly published in 2018, an issues paper that highlighted that climate-related risks present significant material challenges for the insurance sector through underwriting and investment activities and that insurance supervisors should increase their understanding of climate risks and develop supervisory capabilities. The IAIS and the Sustainable Insurance Network will also prepare a report on TCFD implementation and disclosure practices in the insurance sector.
- **The Insurance Development Forum (IDF).** The IDF is a public/private partnership led by the insurance industry and supported by international organizations. It aims to optimize and extend the use of insurance and its related risk management capabilities to build greater resilience and protection for people, communities, businesses, and public institutions that are vulnerable to disasters and their associated economic shocks. The IDF was first announced at the United Nations Conference of the Parties (COP21) Paris Climate Summit in 2015 and was officially launched by leaders of the United Nations, the World Bank, and the insurance industry in 2016.
- **The Banking Sector.** The *Sustainable Banking Network (SBN)* is a community of financial sector regulatory agencies and banking associations from emerging markets committed to advancing sustainable finance in line with international good practice. The 38 member countries represent \$43 trillion (85 percent) of the total banking assets in emerging markets. The IFC serves as the SBN Secretariat.
- **The Private Sector.** The *Climate Finance Leadership Initiative (CFLI)* convenes companies to mobilize and scale private capital for climate solutions. Michael Bloomberg formed the CFLI at the request of UN Secretary-General António Guterres. CFLI members explore, test, and scale products, services, and investment approaches to help drive the transition to a low-carbon economy.
- **Investors.** The *United Nations-supported Principles for Responsible Investment (UNPRI)* is an international network of investors working together to put the six UNPRI principles into practice. The principles offer a menu of possible actions for incorporating ESG issues into investment practice.
- **Europe.** As follow-up to its Action Plan, the EU launched a Technical Expert Group to support the European Commission (EC) with the design and implementation of a taxonomy for sustainable economic activities. The *European Systemic Risk Board (ESRB)* is also taking important steps towards developing a monitoring framework for climate-related risks. The EC has developed a taxonomy that aims to help investors increase their capital allocation to sustainable activities.
- **Megacities.** C40 is a network of the world's megacities committed to addressing climate change. C40 supports cities to collaborate effectively, share knowledge, and in so doing, drive meaningful, measurable and sustainable action on climate change. The Global Covenant of Mayors for Climate and Energy unites more than 7,100 cities in 119 countries in the shared goal of fighting climate change through coordinated local climate action.

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Annex 1: Methodology, data, and estimates

Methodology and data

For each type of climate change risk (i.e., physical-weather related, physical-gradual, and transition risks), we established a quantitative framework that allows us to capture potential associations between climate change indicators and macro-financial variables. We use country-level annual information between 2005 and 2017 for physical-weather related risks, and information for 2017 or the latest information for both physical-gradual and transition risks. These illustrative econometric exercises have the purpose to indicate potential statistical relationships between climate change indicators and macro-financial indicators, but they do not pretend to illustrate any causality between those two sets of indicators.

Physical (weather-related disaster) risk vs. Macro-Financial Indicators: We use a panel data framework with country and year fixed effects and robust errors, with annual information from 2005 to 2017. The sources of information are GermanWatch, WDI, FinStats, and EIU. In order to identify extreme climate change-weather related shocks with potential macro-financial effects, we created a dummy variable that equals 1 for weather-related events with losses equivalent to 1% of GDP or more, and 0 otherwise. As the distribution of the variable “losses (% GDP)” has a large tail to the right of the distribution (i.e., weather events with large losses but low probability of occurrence), the threshold 1% of GDP is equivalent to the 95th percentile of the distribution.¹⁴ Table A1.2 shows the results of the econometric framework.

Physical (gradual) risk vs. Macro-Financial Indicators: Given the slow movement over time of the Notre Dame Vulnerability Index and its components, we use an OLS cross-country regression framework with robust errors in order to capture variability across countries in our estimations. The sources of information are the Notre Dame-GAIN index, WDI, FinStats, and EIU. Table A1.3 shows the results of the econometric framework.

Transition risk vs. Macro-Financial Indicators: Similarly, given the slow movement over time of the CO2 intensity and fossil fuel exports (% GDP), we use an OLS cross-country regression framework with robust errors in order to capture variability across countries in our estimations. The sources of information are WDI, FinStats, and EIU. Table A1.4 shows the results of the econometric framework.

¹⁴ We estimate similar econometric exercises using losses equivalent to 3% and 5% GDP as thresholds with similar results.

Table A1.1. Descriptive Statistics

	Obs	Mean	Std. Dev.	Min	Max	25th pctile	75th pctile
General Government Debt (% GDP)	1527	50.4	33.9	0.113	245.5	28.3	64.3
Primary Balance (% GDP)	1,502	-0.97	4.8	-35.1	49.1	-2.9	0.82
Sovereign Rating (1=lowest, 21=highest)	1,137	12.2	5.1	1	21	7.8	16.4
Non-performing loans (% Total Assets)	1,062	6.4	6.8	0	54.5	2.2	8.4
Provisions (% NPLs)	1,036	70.1	46.3	0	604.1	43.9	79.8
EIU Country Risk Index (0-100)	893	47.7	13.5	12	84.3	38.5	57.3
Macro	893	51.2	15.2	8	91	40	63
Banking	893	49.9	13.8	16	83	40	60
Debt	893	47.5	15.1	5	87.7	38	57.7
Dummy disaster loss	1,527	0.053	0.22	0	1	0	0
GDP percapita (PPP US dollar)	1,527	17,351.8	18,287.2	622.7	120,366.3	3849	25,382
Vulnerability (100=highest)	1,499	43.9	9.5	25.9	68.3	36.8	68.4
Exposure (100=highest)	1,525	43.8	7.3	27.3	72.2	38.6	49
Sensitivity (100=highest)	1,443	38.9	10.1	11.9	62.6	31.3	46.7
Capacity (100=highest)	1,493	48.7	16.5	16	87.3	37.1	62.5
CO2 intensity (kg per kg oil equivalent)	803	2.1	0.79	0.09	3.6	1.6	2.7
Fossil Fuel Exports (%GDP)	1,527	6.1	12.2	0	70.1	0.11	4.6

Table A1.2: Physical (weather-related disaster) risk vs. Macro-Financial Indicators

VARIABLES	General Government Debt (%GDP)				Primary Balance (% GDP)	Sovereign Rating (1=lowest, 21=highest)	Non-performing loans (% Total Assets)	Provisions (% NPLs)	EIU Country Risk Index			
	Level	Change		Index					Macro	Banking	Debt	
		Annual Change	Cumulated after 1 year									
Dummy disaster loss	0.016	1.855**	3.183**	-0.048	-0.207	1.173**	-9.694*	1.099	1.552**	1.016	1.637**	
	(0.010)	(2.534)	(2.502)	(-0.075)	(-1.240)	(2.200)	(-1.813)	(1.621)	(2.037)	(1.469)	(2.203)	
Dummy disaster loss (-1)	2.422**	1.124*	-0.007	-0.507	-0.240	0.495	-8.189	1.752**	2.147**	1.693**	1.918**	
	(2.029)	(1.685)	(-0.006)	(-0.963)	(-1.475)	(1.096)	(-1.186)	(2.405)	(2.178)	(2.472)	(2.260)	
Dummy disaster loss (-2)	0.832	-0.483	-0.933	-0.626	-0.329*	-0.040	-0.848	1.570**	0.370	1.546**	1.174	
	(0.764)	(-0.696)	(-0.747)	(-1.492)	(-1.944)	(-0.081)	(-0.270)	(2.102)	(0.339)	(2.157)	(1.451)	
Observations	1,527	1,525	1,524	1,519	1,146	1,063	1,037	903	903	903	903	
Country Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Year Effects	Y	Y	y	Y	Y	Y	Y	Y	Y	Y	Y	
No. Countries	179	179	179	177	135	136	134	123	123	123	123	

Note: Panel data estimation with country and year fixed effects. Annual information 2005-2017. Dummy disaster loss is equal 1 if disaster loss is 1% of GDP or higher, 0 otherwise.

Data of disaster losses from GermanWatch. Controlled by GDP percapita

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A1.3: Physical (gradual warming) risk vs. Macro-Financial Indicators

VARIABLES	Gen. Gov. Debt (%GDP)		Sovereign Rating (1=lowest, 21=highest)		Non-performing loans (% Total Assets)		Provisions (% NPLs)		EIU Country Risk Index							
									Index		Macro		Banking		Debt	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Vulnerability (100=highest)	-0.668*		-0.166***		-0.170		-1.173**		0.697***		0.868***		0.687***		0.729***	
	(-1.920)		(-3.217)		(-0.949)		(-2.089)		(3.316)		(4.640)		(3.270)		(3.229)	
Exposure (100=highest)		0.925*		0.016		-0.103		-0.122		-0.350*		-0.270		-0.440*		-0.256
		(1.935)		(0.424)		(-0.988)		(-0.227)		(-1.683)		(-1.485)		(-1.929)		(-1.277)
Sensitivity (100=highest)		1.030***		-0.114***		0.148		-1.552**		0.377***		0.348***		0.337**		0.473***
		(2.987)		(-3.385)		(1.429)		(-2.557)		(2.779)		(2.688)		(2.270)		(3.411)
Capacity (100=highest)		-1.278***		-0.059*		-0.175		0.345		0.405**		0.476***		0.462**		0.326*
		(-3.642)		(-1.760)		(-1.271)		(0.758)		(2.456)		(3.074)		(2.628)		(1.896)
Observations	172	162	128	124	78	75	77	74	80	79	80	79	80	79	80	79
R-squared	0.024	0.162	0.657	0.684	0.044	0.080	0.100	0.170	0.436	0.534	0.498	0.568	0.417	0.526	0.475	0.551

Note: OLS estimation with robust errors. Data for 2017 or latest available. Notre Dame - GAIN Vulnerability Index, and subcomponents (Exposure, sensitivity and adaptive capacity). Controlled by GDP percapita

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A1.4. Transition risk vs. Macro-Financial Indicators

VARIABLES	General Government Debt (%GDP)		Sovereign Rating (1=lowest, 21=highest)		Non-performing loans (% Total Assets)		Provisions (% NPLs)		EIU Country Risk Index								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Index		Macro		Banking		Debt		
									(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	
CO2 intensity	3.766		0.041		2.131**		8.243		0.029		-2.206		0.347				-0.018
	(0.977)		(0.102)		(2.049)		(1.306)		(0.020)		(-1.174)		(0.210)				(-0.011)
Fossil Fuel Exports (%GDP)		-0.703		-0.094***		0.121		0.649		0.467***		0.479***		0.579***			0.387***
		(-1.497)		(-3.387)		(1.636)		(1.563)		(5.117)		(4.010)		(6.094)			(3.321)
Observations	126	133	111	109	105	68	103	67	85	67	85	67	85	67	85	67	67
R-squared	0.012	0.028	0.572	0.684	0.063	0.033	0.071	0.131	0.465	0.620	0.435	0.528	0.403	0.649	0.508	0.596	

Note: OLS estimation with robust errors. Data for 2017 or latest available. Controlled by GDP percapita. CO2 intensity (kg per kg of oil equivalent energy use) as of 2014. Source: World Bank -World

Development Indicators

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A1.5. Climate Change indicators by type of risk vs. Macro-Financial risk Indicators

Year: 2017 or latest available

Country	Physical Risks						Transition risks ^c		Readiness ^b	Macro-Financial Risks, 2019			
	A. Weather related risks (average 2005-2017) ^a		B. Gradual risks ^b Vulnerability (0-100, higher more vulnerable)				CO2 intensity in 2014 (kg per kg of oil equivalent energy use)	Fuel Exports, 2017 (% GDP)	(0-100, higher better positioned)	EIU Country Risk Index (100=high) ^d			
	Fatalities (% population)	Losses (%GDP)	Index	Exposure	Sensitivity	Capacity				Index	Debt	Banking	Macro
Aruba													
Afghanistan	1.3	0.2	59.5	48.1	54.0	71.3			22.4				
Angola	0.2	0.0	51.7	54.3	30.5	70.4	2.4	27.1	22.6	64	61	70	68
Albania	0.1	0.1	42.3	40.8	36.5	50.0	2.4	0.1	43.5	53	53	57	60
Andorra				24.7									
UAE	0.0	0.0	37.8	36.7	37.0	39.1	3.0	26.7	55.6	37	38	38	50
Argentina	0.1	0.1	36.8	47.0	25.3	38.0	2.4	0.3	40.7	57	64	53	65
Armenia	0.0	0.0	41.4	33.7	42.3	45.1	1.9	0.8	48.9				
Antigua and Barbuda	0.4	5.5	48.7	47.2	42.7	54.8		0.0	43.5				
Australia	0.3	0.2	29.5	48.0	12.2	27.2	2.9	5.6	71.4	19.5	18	20	29
Austria	0.1	0.1	31.3	35.0	35.1	29.5	1.8	0.8	72.3				
Azerbaijan	0.0	0.0	40.8	35.1	38.9	42.4	2.6	34.1	42.7	54	49	64	63
Burundi	0.3	0.2	58.1	52.2	54.9	71.1		0.0	22.8				
Belgium	0.4	0.0	36.1	34.0	42.2	31.6	1.8	6.9	59.5	29	31.5	26.5	25
Benin	0.1	0.1	57.4	44.7	56.9	72.1	1.5	0.6	28.7				
Burkina Faso	0.1	0.2	57.2	52.9	47.3	68.7		0.3	27.6				
Bangladesh	0.1	0.6	54.3	51.9	48.2	62.8	2.1	0.1	25.3	50	48	56	53
Bulgaria	0.2	0.4	34.4	38.2	27.5	37.1	2.4	4.9	48.1	36	32	43	43
Bahrain	0.0	0.0	45.8	41.8	53.1	44.8	2.2		43.1	55	58	53	53
Bahamas	1.1	2.0	37.6	42.7	0.0	45.4			43.1				
Bosnia and Herzegovina	0.1	1.6	37.1	35.7	34.2	41.6	2.8	2.9	35.7				
Belarus	0.0	0.0	34.2	32.6	31.9	38.3	2.3	12.4	48.9				
Belize	0.6	1.1	47.4	47.2	46.5	50.5		1.5	32.1				
Bermuda													
Bolivia	0.3	0.4	46.0	44.8	35.5	59.6	2.4	8.0	26.7	54	54	57	60
Brazil	0.1	0.1	38.1	50.1	25.5	38.5	1.7	0.9	38.8	46	49	45	48
Barbados	0.0	0.1	38.1	39.6	46.6	35.1		0.5	47.3				
Brunei Darussalam	0.0	0.0	39.5	40.5	23.4	53.7	2.6	41.2	50.7				
Bhutan	0.5	0.2	49.3	48.5		56.0			42.3				
Botswana	0.0	0.1	47.1	35.6	46.3	56.4	2.6	0.0	42.7	30	28	33	43
CAR	0.0	0.0	58.0	49.5	55.9	74.8		0.0	13.0				
Canada	0.0	0.1	29.6	43.3	17.9	26.8	1.9	5.8	67.2				
Switzerland	0.1	0.1	27.4	30.9	28.2	23.0	1.4	0.4	69.1	17	15	17	18
Chile	0.1	0.1	34.5	38.4	27.0	37.9	2.3	0.2	57.0	30	30	29	40
China	0.1	0.3	38.9	44.8	32.3	39.4	3.4	0.3	46.8	41	37	47	25
Côte d'Ivoire	0.1	0.0	51.4	45.1	43.0	66.7	0.8	4.2	27.1	47.5	51.5	47.5	68
Cameroon	0.0	0.0	48.3	46.2	36.1	65.5	0.9	4.0	26.6				

Climate Change indicators by type of risk vs. Macro-Financial risk Indicators (continued)

Year: 2017 or latest available

Country	Physical Risks						Transition risks ^c		Readiness ^b	Macro-Financial Risks, 2019			
	A. Weather related risks (average 2005-2017) ^a		B. Gradual risks ^b Vulnerability (0-100, higher more vulnerable)				CO2 intensity in 2014 (kg per kg of oil equivalent energy use)	Fuel Exports, 2017 (% GDP)	(0-100, higher better positioned)	EIU Country Risk Index (100=high) ^d			
	Fatalities (% population)	Losses (%GDP)	Index	Exposure	Sensitivity	Capacity				Index	Debt	Banking	Macro
D.R. Congo	0.1	0.0	58.8	49.4	44.6	81.5	0.2		18.0	70	69	72	60
Congo	0.1	0.0	51.8	48.7	40.5	70.8	1.2	31.3	21.2	57	61.5	60.5	78
Colombia	0.3	0.2	38.8	50.1	19.5	46.8	2.5	6.9	40.1	40	42	40	50
Comoros	0.4	0.1	47.9	47.1	41.4	60.5			26.4				
Cape Verde	0.1	0.0		38.5					45.4				
Costa Rica	0.1	0.1	38.9	45.1	29.7	42.0	1.6	0.0	46.0	43	47	42.5	50
Cuba			42.8	49.7	35.5	42.4	3.0		33.8	66	70	65	60
Curaçao							3.0						
Cayman Islands													
Cyprus	0.1	0.0	36.0	34.1	39.0	35.2	3.1	4.7	52.1				
Czech Republic	0.1	0.1	31.0	27.3	31.9	32.6	2.3	1.5	58.3	33.5	33.5	34.5	39
Germany	0.0	0.1	29.2	34.7	30.1	22.9	2.4	0.7	67.8				
Djibouti	0.0	0.0	50.0	41.3	46.7	66.3			27.8				
Dominica	9.1	29.0	40.3	36.9	27.2	43.1			53.7				
Denmark	0.0	0.1	34.4	44.1	36.4	18.4	2.1	1.3	75.6	19	15	22	20
Dominican Republic	0.1	0.1	43.2	44.7	35.4	49.3	2.8	0.0	38.0	40	44	40	53
Algeria	0.1	0.0	37.1	32.7	32.4	45.4	2.8	19.9	27.5	53	53	57	53
Ecuador	0.2	0.1	44.6	53.2	32.9	47.9	3.1	6.7	34.0	59	63	59	63
Egypt	0.0	0.0	42.6	36.0	54.8	37.1	2.7	2.3	34.9	52	57	50	58
Eritrea	0.0	0.0	59.6	45.9	49.4	80.2	0.9		12.1				
Spain	0.0	0.1	30.8	36.1	30.8	24.7	2.0	1.2	56.0	35	34	35	38
Estonia	0.1	0.2	37.6	37.9	29.6	44.9	3.2	4.9	62.3				
Ethiopia	0.2	0.1	56.6	51.1	49.1	70.7	0.2		26.7				
Finland	0.0	0.0	30.8	44.3	25.6	22.9	1.4	2.1	74.7	21	20	20	28
Fiji	0.9	1.8	45.2	46.0	38.0	52.9		0.0	42.8				
France	0.5	0.1	29.6	39.7	25.0	24.2	1.2	0.6	62.9	23	23	25	25
Faroe Islands													
Micronesia	2.2	3.1	63.8	59.8		63.8			36.7				
Gabon	0.1	0.0	44.0	46.3	30.0	59.3	1.0		28.7				
United Kingdom	0.1	0.1	29.9	39.0	26.3	24.3	2.3	1.4	68.1	25	26	23	35
Georgia	0.1	0.0	41.0	40.6	37.6	45.0	2.0	0.9	55.7				
Ghana	0.2	0.1	46.8	44.4	42.9	53.2	1.6	10.0	37.0	54	53	59	63
Gibraltar							2.7						
Guinea	0.0	0.0	54.3	43.6	41.1	73.3			28.0				
Gambia	0.2	0.0	53.9	47.4	57.4	64.5		0.0	30.5				
Guinea-Bissau	0.1	0.0	62.6	50.5	61.6	76.0			26.9				
Equatorial Guinea	0.0	0.0	47.9	44.5	28.4	60.4			20.5				
Greece	0.1	0.1	34.6	42.5	35.4	26.5	2.9	5.1	51.8	58	59	58	68
Grenada	0.1	0.3	39.1	38.2	29.0	50.9			52.0				
Greenland													
Guatemala	0.9	0.5	45.7	47.9	41.0	48.3	1.4	0.5	32.3	44	44	47	43

Climate Change indicators by type of risk vs. Macro-Financial risk Indicators (continued)

Year: 2017 or latest available

Country	Physical Risks						Transition risks ^c		Readiness ^b	Macro-Financial Risks, 2019			
	A. Weather related risks (average 2005-2017) ^a		B. Gradual risks ^b Vulnerability (0-100, higher more vulnerable)				CO2 intensity in 2014 (kg per kg of oil equivalent energy use)	Fuel Exports, 2017 (% GDP)	(0-100, higher better positioned)	EIU Country Risk Index (100=high) ^d			
	Fatalities (% population)	Losses (%GDP)	Index	Exposure	Sensitivity	Capacity				Index	Debt	Banking	Macro
Guyana	0.1	2.1	48.0	40.4	46.8	54.5		0.0	32.8				
Hong Kong							3.2			26	22	28	40
Honduras	0.4	0.5	46.2	44.5	40.2	53.8	1.8	0.3	28.7	51	53	52	68
Croatia	0.0	0.2	38.7	40.3	36.9	37.9	2.1	3.1	50.8	41	42.5	43.5	50
Haiti	1.1	2.3	55.6	44.1	48.1	74.6	0.7		18.4				
Hungary	0.0	0.1	36.5	34.9	41.3	35.2	1.8	2.0	53.2	39	42	41	48
Indonesia	0.1	0.1	44.5	51.8	28.5	53.3	2.1	3.6	36.2	48	49	47	50
India	0.2	0.3	50.2	57.2	38.2	55.4	2.7	1.4	34.6	42	39	48	43
Ireland	0.0	0.1	34.5	41.1	36.0	26.8	2.7	0.3	64.0				
Iran	0.0	0.0	38.7	34.7	34.5	46.7	2.7	14.5	40.3	64	55	75	53
Iraq	0.0	0.0	43.6	43.7	43.4	44.7	3.4		23.3	59	60	65	70
Iceland	0.0	0.0	31.2	44.8	19.9	25.6	0.3	0.2	69.9				
Israel	0.1	0.0	33.6	28.4	46.4	26.6	2.8	0.2	55.9	30	33	28	28
Italy	0.1	0.0	32.0	44.1	34.6	17.5	2.2	0.9	53.4	38	39.5	39.5	39
Jamaica	0.1	0.4	43.3	44.8	40.3	46.3	2.6	1.7	40.7	53	58	52	80
Jordan	0.0	0.0	37.7	28.9	42.0	42.3	3.2	0.0	37.0	53	56	51	55
Japan	0.1	0.0	37.2	52.0	38.8	21.2	2.7	0.2	67.4				
Kazakhstan	0.0	0.0	33.6	35.1	31.5	34.6	3.2	18.9	48.9	51	46.5	56.5	59
Kenya	0.2	0.0	54.6	50.8	49.2	63.7	0.6	0.1	28.4	60	60	64	63
Kyrgyzstan	0.3	0.0	39.1	32.6	47.7	38.5	2.5	1.9	39.2				
Cambodia	0.3	0.7	51.7	39.4	50.5	67.4	1.0		30.3	54	52	58	68
Kiribati	0.0	0.8		61.8					42.2				
Saint Kitts and Nevis	0.0	1.4	41.8	43.5	0.0	47.1		0.0	49.1				
Korea	0.0	0.0	37.5	49.4	31.9	31.1	2.2	2.3	72.1	28	29	30	33
Kuwait	0.0	0.0	43.4	39.7	52.8	38.7	2.8	41.4	44.0	36	33	38.5	42
Laos	0.2	0.3	53.7	39.4	47.8	65.0			32.5				
Lebanon	0.1	0.0	40.8	33.2	44.8	44.2	3.2	0.0	31.1	63	63	64	63
Liberia	0.0	0.1	61.7	48.8	54.3	75.9			26.4				
Libya	0.0	0.0	38.2	28.6	34.1	52.9	3.2		19.8	72	66	81	75
Saint Lucia	0.4	0.7	39.1	38.6	31.6	50.5		0.4	45.4				
Liechtenstein			0.0	25.5	0.0	0.0			65.1				
Sri Lanka	0.3	0.2	47.0	49.9	38.1	53.0	1.7	0.3	39.6	51	55	48	55
Lesotho	0.0	0.1	50.9	36.5	46.2	69.7		0.0	31.0				
Lithuania	0.1	0.0	38.8	36.5	35.9	46.3	1.8	9.3	60.9	32	27	36	38
Luxembourg	0.0	0.0	28.5	28.2	34.8	21.4	2.5	0.0	66.0	17.5	15	19	20

Climate Change indicators by type of risk vs. Macro-Financial risk Indicators (continued)

Year: 2017 or latest available

Country	Physical Risks						Transition risks ^c		Readiness ^b	Macro-Financial Risks, 2019			
	A. Weather related risks (average 2005-2017) ^a		B. Gradual risks ^b Vulnerability (0-100, higher more vulnerable)				CO2 intensity in 2014 (kg per kg of oil equivalent energy use)	Fuel Exports, 2017 (% GDP)	(0-100, higher better positioned)	EIU Country Risk Index (100=high) ^d			
	Fatalities (% population)	Losses (%GDP)	Index	Exposure	Sensitivity	Capacity				Index	Debt	Banking	Macro
Latvia	0.3	0.3	39.3	37.4	37.4	41.3	1.6	1.9	60.9	33	30	36	35
Macao													
Morocco	0.0	0.0	37.8	33.8	33.1	46.4	3.2	0.2	39.4	48	51	49	55
Monaco				43.2					77.3				
Moldova	0.0	0.8	41.7	33.6	44.8	47.4	1.5	0.0	42.7	52	50	54	55
Madagascar	0.2	0.7	58.4	50.0	50.1	78.1		0.4	24.2				
Maldives	0.0	0.0	56.0	72.2	41.3	42.2		0.0	36.9				
Mexico	0.1	0.2	38.2	48.7	25.2	40.7	2.6	2.0	39.5	34	39	32	43
Marshall Islands	0.0	0.1		58.7					35.6				
N. Macedonia	0.2	0.2	36.6	31.5	34.2	43.7	2.9	0.8	46.8	46	48	46	55
Mali	0.1	0.1	60.9	52.5	49.1	73.1		0.0	28.1				
Malta	0.1	0.0	35.6	31.0	37.5	38.2	3.0		49.4	28	24	32	25
Myanmar	12.1	1.2	54.2	56.5	43.6	61.9	1.1	5.6	23.7	54	56	58	65
Montenegro	0.1	0.0	38.8	32.9		43.5	2.3	1.1	46.5				
Mongolia	0.3	0.1	40.7	26.7	33.7	61.0	3.9	25.7	46.1				
Mozambique	0.3	0.4	54.1	43.3	51.3	67.6	0.7	19.4	24.9	74	80	72	83
Mauritania	0.1	0.4	56.7	36.4	60.4	72.7			28.8				
Mauritius	2.0	0.0	43.8	48.5	41.1	44.8	3.0	0.3	55.0	47.5	47.5	48.5	55
Malawi	0.1	0.4	55.0	49.3	47.9	63.3		0.0	26.4	62	64	62	78
Malaysia	0.1	0.0	37.7	44.3	29.5	39.1	2.7	10.4	52.3	36	38	36	35
Namibia	0.9	0.1	49.1	42.1	43.4	61.7	2.1	0.2	40.9	45.5	46	44.5	56.5
New Caledonia													
Niger	0.2	0.3	67.0	63.3	60.0	76.9	0.7		28.9				
Nigeria	0.1	0.0	48.9	45.5	36.2	65.1	0.7	11.3	24.2	58	52	66	50
Nicaragua	0.3	0.7	45.3	49.3	38.0	48.6	1.3	0.1	30.4	63	67	64	70
Netherlands	0.0	0.0	35.1	39.7	42.7	23.0	2.3	7.4	68.1	21	17	24	20
Norway	0.0	0.0	27.8	38.9	25.2	19.5	1.7	14.9	79.9	10	2.5	15	20
Nepal			51.6	47.7	47.6	60.2	0.7	0.0	31.3				
Nauru	0.7	0.3		58.6					41.4				
New Zealand	0.1	0.1	33.1	45.2	28.7	24.7	1.7	0.3	80.1	18	15	19	30
Oman	0.3	0.8	41.6	41.0	34.8	51.9	2.5	34.3	51.1	42.5	42.5	42	55
Pakistan	0.4	0.7	50.7	49.3	50.5	52.4	1.9	0.1	28.6	58	62	57	60
Panama	0.2	0.0	40.6	44.6	35.5	41.8	2.1		42.3	44	47	41	58
Peru	0.2	0.1	42.6	45.7	29.3	53.0	2.6	2.0	44.3	33.5	31.5	37	45
Philippines	1.2	0.6	45.9	49.2	36.6	51.8	2.2	0.3	32.2	41	42	43	50
Palau	0.0	0.0		53.2				0.0	42.2				
Papua New Guinea	0.2	0.1	57.3	49.1	39.2	79.9			27.7	48.5	47.5	53	60
Poland	0.2	0.1	32.4	33.4	27.9	35.8	3.0	1.1	58.6	33	36	32	30
D.R. Korea				54.2			3.4		20.2				
Portugal	0.2	0.2	34.7	39.4	36.3	28.6	2.1	1.9	58.0	38	37	39	45

Climate Change indicators by type of risk vs. Macro-Financial risk Indicators (continued)

Year: 2017 or latest available

Country	Physical Risks						Transition risks ^c		Readiness ^b	Macro-Financial Risks, 2019			
	A. Weather related risks (average 2005-2017) ^a		B. Gradual risks ^b Vulnerability (0-100, higher more vulnerable)				CO2 intensity in 2014 (kg per kg of oil equivalent energy use)	Fuel Exports, 2017 (% GDP)	(0-100, higher better positioned)	EIU Country Risk Index (100=high) ^d			
	Fatalities (% population)	Losses (%GDP)	Index	Exposure	Sensitivity	Capacity				Index	Debt	Banking	Macro
Paraguay	0.1	0.8	38.5	42.3	31.0	42.4	1.1	5.5	33.6				
French Polynesia													
Qatar	0.0	0.0	37.5	39.7	35.0	36.1	2.4	30.8	43.5	43	40	46	53
Romania	0.2	0.3	41.1	44.5	37.0	40.8	2.2	1.3	46.7	41	40	45	40
Russia	3.3	0.0	33.5	44.0	20.4	35.8	2.4	13.2	51.2	43	38	53	53
Rwanda	0.1	0.0	55.5	50.9	56.5	60.8			40.7				
Saudi Arabia	0.3	0.0	38.8	35.8	32.3	51.3	2.8	21.2	47.4	36	35	35	38
Sudan	0.1	0.1	62.3	54.2	59.5	73.1	1.0		23.1	84.5	89.5	82.5	90
Senegal	0.0	0.0	53.5	51.1	50.0	59.5	2.2	2.4	33.2				
Singapore	0.0	0.0	41.5	53.8	38.3	34.7	2.0	14.5	80.1	23	17	25	30
Solomon Islands	0.8	0.4	65.8	55.7		65.9		0.0	42.0				
Sierra Leone	1.0	0.1	55.7	48.5	45.9	74.6		0.0	31.3	63	67	64	78
El Salvador	0.5	0.7	44.8	46.9	37.8	49.7	1.5	0.7	34.8				
San Marino				27.0					53.1				
Somalia	0.7	0.0	67.8	52.6	45.2	87.1			8.3				
Serbia	0.1	0.7	40.9	36.3	39.4	47.2	2.8	0.5	43.6				
South Sudan	0.1	0.0					2.1						
Sao Tome and Principe	0.0	0.0	47.8	47.7		47.4		0.0	32.5				
Suriname			40.4	41.8	32.2	43.1	2.9	26.5	30.5				
Slovakia	0.0	0.0	36.4	33.5	40.3	37.8	1.9	3.9	52.7	26.5	24.5	27	38
Slovenia	0.1	0.2	33.9	33.1	38.6	31.5	1.9	3.9	64.9				
Sweden	0.0	0.1	30.1	41.0	23.9	25.4	0.9	1.8	72.8	15	14	15	13
Swaziland	0.0	0.1	54.6	44.6	55.6	67.8		0.5	35.1				
Seychelles	0.0	0.1	47.2	59.4		36.3		0.0	44.0	47	53	44	73
Syria	0.0	0.0	44.0	37.2	42.0	51.5	2.8		21.9				
Turks and Caicos Islands													
Chad	0.1	0.1	65.1	54.1	60.9	85.0			16.5				
Togo	0.0	0.0	53.9	40.9	46.8	74.1	0.8	0.5	29.8				
Thailand	0.3	1.1	40.9	45.8	38.4	38.4	2.3	1.4	47.7	37	37	37	38
Tajikistan	0.2	1.2	43.8	36.1	52.2	42.9	1.9		29.2				
Turkmenistan	0.0	0.0	42.5	30.9	49.8	42.9	2.6		23.1				
Timor-Leste	0.0	0.0	55.8	52.4	46.5	68.0		0.0	38.0				
Tonga	0.1	0.8	57.3	54.5		47.0			39.6				
Trinidad and Tobago	0.0	0.0	40.5	40.4	32.1	48.9	2.4		37.6	43	44	46	65
Tunisia	0.0	0.1	39.4	33.0	41.5	43.8	2.7	2.1	38.7	60	63	61	70
Turkey	0.0	0.0	33.8	41.5	27.3	32.6	2.8	0.5	47.1	51	53	49	48
Tuvalu	0.0	8.3		63.1					55.3				

Climate Change indicators by type of risk vs. Macro-Financial risk Indicators (continued)

Year: 2017 or latest available

Country	Physical Risks						Transition risks ^c		Readiness ^b	Macro-Financial Risks, 2019			
	A. Weather related risks (average 2005-2017) ^a		B. Gradual risks ^b Vulnerability (0-100, higher more vulnerable)				CO2 intensity in 2014 (kg per kg of oil equivalent energy use)	Fuel Exports, 2017 (% GDP)	(0-100, higher better positioned)	EIU Country Risk Index (100=high) ^d			
	Fatalities (% population)	Losses (%GDP)	Index	Exposure	Sensitivity	Capacity				Index	Debt	Banking	Macro
Tanzania	0.0	0.0	55.1	49.9	46.8	68.0	0.5	0.1	29.1	47	46	52	58
Uganda	0.1	0.0	58.0	52.0	58.2	64.7		0.3	29.6				
Ukraine	0.2	0.0	36.7	40.4	32.3	38.3	2.2	0.6	40.8	70	74	69	75
Uruguay	0.1	0.1	38.3	45.4	32.2	37.0	1.4	0.3	47.0	42	43.5	43	49
United States	0.2	0.4	33.9	48.1	27.0	26.5	2.4	0.8	69.7	20	15	21	28
Uzbekistan	0.0	0.0	38.8	31.9	55.5	34.3			33.3	54	53	60	58
Saint Vincent	0.9	0.8	37.8	41.0	30.2			0.0	49.4				
Venezuela	0.0	0.0	34.7	42.2	25.2	36.8			18.9	91	94	89	93
Viet Nam	0.2	0.6	47.7	49.1	45.1	48.9		2.2	40.8	50	54	53	55
Vanuatu	1.5	5.1	56.9	48.7	53.6	56.9			35.5				
Samoa	0.5	2.4	48.3	47.8		52.1		1.5	41.3				
Kosovo	0.1	0.1											
Yemen	0.2	0.1	55.5	45.2	45.0	75.1			22.4	87	90	89	98
South Africa	0.1	0.1	39.8	43.1	29.6	48.8	3.3	3.2	40.3	42	44.5	41	51.5
Zambia	0.0	0.0	54.2	54.9	48.4	58.0		0.3	31.5	63	68	62	73
Zimbabwe	0.3	0.6	54.3	51.7	55.2	59.2		0.1	20.5				
Taiwan										27	28	27	35

a. Source: GermanWatch

b. Source: Notre Dame Adaptation Risk Index

c. Source: World Bank World Development Indicators

d. Source: Economist Intelligence Unit. Information as of 2018 for Argentina, Bulgaria, Bahrain, Bolivia, Brazil, Colombia, Guatemala, UK, France, India, Italy, Jordan, Lebanon, Oman, Thailand, Tanzania, and Ukraine.