Network for Greening the Financial System

Technical document

Overview of Environmental Risk Analysis by Financial Institutions

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As the world grapples with the biggest public health emergency in generations, the climate and environmental emergency has been pushed out of the headlines. Yet the impacts of this emergency, such as rising sea levels, more frequent flooding and droughts and biodiversity loss to name but a few, will pose far greater challenges to our societies and continued existence in remainder of this century.

Regardless of when the Covid-19 crisis is finally contained, a transition to a green, low-carbon economy is still imperative. Not as a niche, or something that is just "nice to have" — we simply cannot go back to "business as usual." The economic response to the pandemic should therefore be not to rebuild the old economy with its inherent climate risks, but to act now to lay the groundwork for an orderly transition to a more sustainable economy and climate-resilient financial system. A green recovery.

Being environmentally responsible is not only a virtue: it is necessary for a business to operate as a going concern as it navigates increasing risks from both the natural and the regulatory environment. This is also necessary for financial institutions as they need to accurately assess the climate and environmental risks to which they are exposed. Underestimating these risks leads to excessive allocation of financial resources to polluting or high carbon sectors, which not only exacerbates pollution and climate change, but threatens financial institutions own balance sheets and financial stability.

Over the past few years, some institutions have attempted to gauge the financial risks arising from climate and environmental exposures through Environmental Risk Analysis (ERA). However, the integration of climate and environment-related factors into decision making remains limited. Some of the most significant barriers include a lack of publicly available ERA methodologies, assumptions, and data, in addition to institutional problems such as lack of regulatory expectations, incentives and capacity building networks.

This Overview of Environmental Risk Analysis by Financial Institutions*, and the accompanying* Occasional Paper on Case Studies of Environmental Risk Analysis Methodologies*, provides important references to the tools and methodologies used by some banks, asset managers and insurance companies for measuring their exposure to environmental risks (encompassing both environment-related and climate-related risks) and for assessing the financial implications of these risks in a forward looking manner, including via stress testing and scenario analysis. We hope that the methodologies presented in these documents will bridge an important knowledge gap in the public domain and may inspire many other institutions and research organizations to devote resources to developing and applying such methodologies.*

We encourage all central banks and supervisors to promote the development and adoption of ERA by financial institutions. Actions can be taken to raise awareness of the value of ERA, to require them to measure and report their exposures to environmental and climate risks, to disseminate knowledge, and to encourage research projects. As many of the ERA methodologies are still at a very early stage of application, collective efforts will be needed between institutions, regulators, academic institutions, and NGOs to refine the tools and methodologies and to enhance the public availability of data and assumptions.

This "Overview of Environmental Risk Analysis by Financial Institutions" was prepared under the auspices of NGFS' supervision workstream (WS1) chaired by Dr. Ma Jun, special advisor to the Governor of the People's Bank of China, with substantial inputs from more than a dozen NGFS members, and drawing extensively from case studies contained in the Occasional Paper as well as other NGFS publications. We hereby thank all the contributors as well as the efforts made by the NGFS secretariat for arranging the publication.

The Covid-19 crisis has halted the world's mightiest economies, but also demonstrated the capabilities of technology and human tenacity when faced with unprecedented challenges. It may just be the pivotal moment for humankind to rethink its relationship with nature and create a greener and healthier future. We trust we will grasp this precious opportunity together.

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Executive summary

As an essential task of financial institutions (FIs), risk management forms the basis of financial stability. Conventionally, FIs manage risks – including credit risk, liquidity risk, market risk, underwriting risk and operational risk – through a framework often under regulated prudential requirements. However, environmental risks (encompassing both environment- and climate-related risks) have not yet been explicitly recognized and effectively addressed by many financial institutions. Our consultation meetings with a few dozen FIs indicate that only a fraction of large FIs in OECD countries and China have begun to utilize some environmental risk analysis (ERA) methods for assessing environmental risks, and many of these applications remain at the experimental stage. Many FIs are not yet engaged, and most small FIs, especially those from developing countries, have limited awareness of ERA. For these institutions, one reason for the lack of environmental risk analysis and management is the limited understanding of the transmission mechanism between environmental risks and financial risks, and the ability to quantify these risks.

This NGFS publication, *Overview of Environmental Risk Analysis (ERA) by Financial Institutions,* provides an extensive list of examples of how environmental risks are transmitted to financial risks, and a comprehensive review of the tools and methodologies for ERA used by financial institutions (FIs) including banks, asset managers and insurance companies. Based on the detailed case studies in the NGFS Occasional Paper titled *Case Studies of Environmental Risk Analysis Methodologies,* this document provides a less technical review of the tools and methodologies developed by FIs, third-party service providers, research institutions and NGOs. These tools and methodologies cover wide-ranging environmental/climate scenario analyses and stress tests, as well as ESG analysis and natural capital risk assessment, that can be used to analyze the potential impact from transition and physical risks associated with climate and other environmental factors on FIs.

Three aspects of the ERA methodologies and their applications are reviewed. First, the major steps for analyzing environmental risks are summarized; second, the methodologies for scenarios analysis and stress test are classified by the types of users including banks, asset managers and insurance companies, and by types of risks including physical and transition risks; third, alternative methodologies used by FIs in measuring environmental risks and opportunities are presented, including ESG ratings and the natural capital risk assessment approach. This document also contains a few boxes that describe technical details of several ERA methodologies, including frequently used climate scenarios.

This document also identifies several major barriers to wider adoptions of ERA by the financial services industry. These barriers include: 1) lack of awareness of environmental risks and appreciation of their relevance; 2) inadequate environmental and loss data; 3) limited capacity to develop ERA methodologies; 4) limited application to environment-related risks and emerging market economies; 5) gaps in methodologies and data quality.

It is concluded that collective efforts are needed from regulators, FIs, IOs, third party vendors, and academic institutions to promote the wider adoptions of ERA. These efforts are: 1) central banks and financial supervisors should strive to enhance ERA awareness among FIs; 2) industry associations, central banks and supervisors, IOs, NGOs and academic institutions could organize seminars and training activities on ERA methodologies, with some results delivered as public goods to the financial industry; 3) the NGFS, IOs, central banks and supervisors should consider supporting demonstration ERA projects in key sectors and for key regions exposed to substantial environment- and climate-related risks; 4) central banks and supervisors can encourage disclosures of FIs' exposures to environmental risks and their ERA results in line with TCFD recommendations; 5) the NGFS and relevant IOs can conduct research and encourage market bodies to develop key risk indicators to identify and measure the most important environment- and climate-related risks; 6) policymakers should bring together the relevant stakeholders and experts to develop a taxonomy of economic activities sensitive to environment- and climate-related risks.

We hope that, by showcasing the availability of ERA methodologies and application of ERA by some FIs, this publication will serve as an important inspiration for the global financial community to recognize its usefulness and strive to further improve and expand its adoption. **It should be noted that while this publication made references to several ERA methodologies, they are illustrative in nature and the NGFS does not endorse or recommend any particular service or vendor.**

1 Introduction

This *Overview of Environmental Risk Analysis (ERA) by Financial Institutions,* prepared by the Central Banks and Supervisors Network for Greening the Financial System (NGFS), provides a comprehensive review of the tools and methodologies for ERA used by *financial institutions* (FIs) including banks, asset managers and insurance companies. It directly follows the previous publication for supervisors[1] and is a continuation of the NGFS work on financial sector's exposure assessment. Based on the detailed case studies in the NGFS Occasional Paper titled *Case Studies of Environmental Risk Analysis Methodologies,* this document provides a less technical review of the tools and methodologies developed by FIs, third-party service providers, research institutions and NGOs. These tools and methodologies cover wide-ranging environmental/climate scenario analyses and stress tests, as well as ESG analysis and natural capital risk assessments, that can be used to analyze the potential impact from transition and physical risks associated with climate and other environmental factors on FIs. This document also identifies major barriers to wider adoptions of ERA by the financial services industry and proposes several options for the stakeholders to help enhance the awareness of the need for ERA, develop the capacities and ERA databases, support pilot projects, and promote the disclosures of ERA results (including stress tests and scenario analyses).

The term "**environmental risks**" used in this document refers to both environment-related risks and climate-related risks. Climate-related risks are a subset of the broader category of environmental risks.[2] Depending on the context, we use "environmental risks" and "environment- and climate-related risks" interchangeably.

As stated in the April 2019 NGFS Comprehensive Report, **environment-related risks** refer to risks (credit, market, operational and legal risks, etc.) posed by the exposure of financial firms and/or the financial sector to activities that may potentially cause or be affected by environmental degradation (such as air pollution, water pollution and scarcity of fresh water, land contamination, reduced biodiversity and deforestation) and actions taken to address these environmental challenges. **Climate-related risks** refer to risks posed by the exposure of financial firms and/or the financial sector to physical or transition risks caused by or related to climate change (such as damage caused by extreme weather events or a decline in asset value in carbon intensive sectors).

The levels of understanding of environmental risks are very uneven within the global financial community. As a matter of fact, the NGFS *Status Report on financial institutions' experiences from working with green, non-green and brown financial assets and a potential risk differential* highlighted the fact that overall, most FIs are not yet able to effectively track the specific risks associated with green or brown assets (NGFS, 2020d). This reflects many institutional, policy and technical problems that contribute to the difficulties in measuring and pricing environment- and climate-related risks. In areas of green finance, these problems include, to name a few, the lack of clear definitions of green and brown assets, inadequate or lack of user friendly environmental and climate data, the lack of public knowledge and capacity to conduct ERA.

The rest of this report is divided into four sections. **Section 1** presents a classification of environmental risks, explains how these risks may translate into credit, market, underwriting, and operational risks for financial institutions (FIs), and highlights the importance of these risks by reviewing literature on the potential magnitude of financial losses they may cause. **Section 2** reviews the ERA tools and methodologies that have been developed by financial institutions, third party services providers, research institutions, and NGOs. **Section 3** discusses the major gaps between research and application of ERA tools. **Section 4** proposes a number of options for "stakeholders", including FIs, central banks and regulators, industrial associations, NGOs and academic institutions to consider on how to promote ERA in the financial industry.

1 For details, please refer to NGFS (2020a).

2 For a detailed discussion on the connection between environment-related risks and climate-related risks, please refer to *Guide for Supervisors – Integrating climate-related and environmental risks into prudential supervision* (NGFS, 2020a).

1.1 Classification of environmental risks

According to the G20 Green Finance Study Group (2017), NGFS (2019a), and other literatures such as Ma et al. (2018), the environmental and climatic sources of financial risks can be mapped to two key risk categories – physical and transition risks:[3]

1) **Physical risks** that arise from the impact of extreme climatic events (such as exacerbated extreme weather events), rises in sea levels, losses of ecosystem services (e.g., desertification, water shortage, degradation of soil quality or marine ecology), as well as environmental incidents (e.g., major chemical leakages or oil spills to air, soil and water/ocean);
2) **Transition risks** that arise from human efforts to address environmental and climate challenges, including changes in public policies, technology breakthroughs, shifts in investors or public sentiments and disruptive business model innovations.

Physical and transition risks have many categories and subcategories. For instance, "extreme weather events" as a physical risk includes tropical cyclones and typhoons, floods, winter storms, heat waves, droughts and hailstorms, among others. Public policy changes, as a category of transition risks, include carbon-trading systems, carbon taxes, green certificates, subsidies for renewable energy or electric vehicles (EVs) and energy saving projects. There are numerous examples of physical and transition risks that may have financial implications for firms and the financial institutions that finance their operations. Table 1 below presents a brief taxonomy of environmental and climatic sources of risks under the headings of physical and transition risks. A more detailed description of these risks and illustrative examples are given in Appendix 1.

Table 1. **Sources of environmental risks**

Physical Risks	**Sub-categories/examples**
Extreme weather events	Tropical cyclones/typhoons, floods, winter storms, heat waves, droughts, wildfires, hailstorms
Ecosystem pollution	Soil pollution and degradation, air pollution, water pollution, marine pollution, environmental accidents
Sea-level rise	Chronic sea-level rise or sea surges
Water scarcity	Drought or insufficient supply of water
Deforestation/desertification	Deforestation caused extinction of species, changes to climatic conditions, desertification, and displacement of populations
Transition Risks	**Sub-categories/examples**
Public policy change	Energy transition policies, pollution control regulations, resource conservation regulations
Technological changes	Clean energy technologies, energy saving technologies, clean transportation, and other green technologies
Shifting sentiment	Changes in consumer preference for certain products, changes in investor sentiment on certain asset classes
Disruptive business models	New ways to run businesses that can rapidly gain market shares from traditional businesses (e.g., virtual meetings that significantly reduce business travels; vertical farming that challenges traditional farming)

Source: Caldecott et al. (2013); CICERO (2017); G20 Green Finance Study Group (2017); Ma et al. (2018); NGFS (2019a).

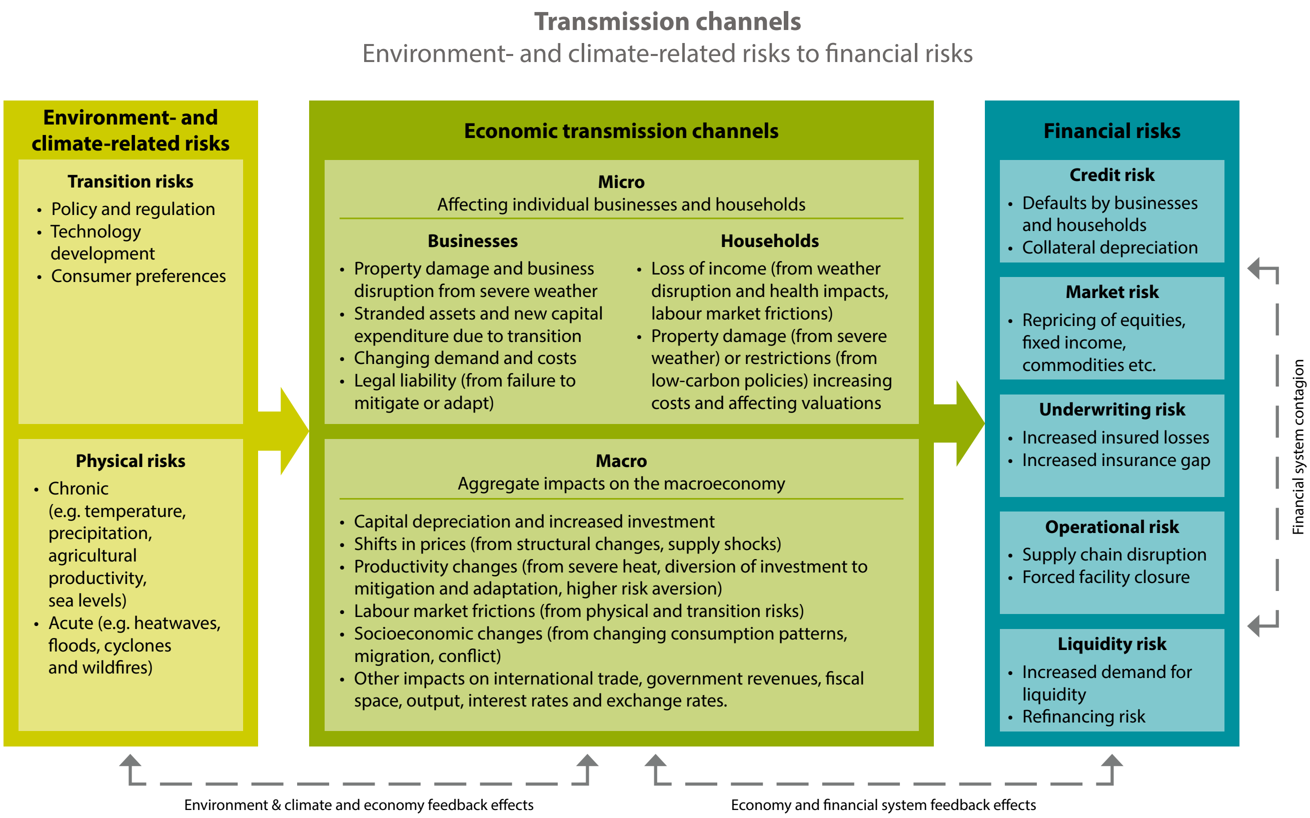
3 Note that the following descriptions of physical and transition risks are broader than those used in the NGFS Comprehensive Report (NGFS, 2019a), as we now cover both environment-related physical and transition risks and climate-related physical and transition risks, while the NGFS 2019a report focused only on climate-related risks.

1.2 Transmission from environmental risks to financial risks

As an essential task of FIs, risk management forms the basis of financial stability. Conventionally, FIs manage risks through a framework often under regulated prudential requirements. They include credit risk, liquidity risk, market risk, underwriting risk[4] and operational risk. Risks arising from environmental factors have not been explicitly recognized and effectively addressed by many FIs, especially those in developing countries. One reason for the lack of ERA and management is the limited understanding of the transmission mechanisms between environmental risks and financial risks. This section elaborates on how financial firms' exposures to environment- and climate- related risks are transmitted to financial risks.

While FIs may have direct exposures to environment- and climate-related risks (e.g., headquarters of some FIs may be located in coastal areas under risks of a sea-level rise), most exposures are indirect and arise from their clients' and investees' exposures to these risks. As illustrated in Figure 1 (NGFS, 2020c), **transition risks** will affect the operations of businesses and the wealth of households, thereby creating financial risks for lenders and investors. They will also affect the broader macroeconomy through investment, productivity and relative prices channels, particularly if the transition leads to stranded assets. **Physical risks** affect the economy in two ways. Acute impacts from extreme weather events can lead to business disruption and damages to property. Historically these impacts were considered transient but this will change with increased global warming. These events can increase underwriting risks for insurers and impair asset values. Chronic impacts, particularly from increased temperatures, sea levels rise and precipitation, may affect labour, capital and agriculture productivity. These changes will require a significant level of investment and adaptation from companies, households and governments.

Figure 1. **Schematic illustration of transmission from environmental risks to financial risks**



Source: Adapted from NGFS (2020c).

4 For detailed decriptions of underwriting risks, see by FSA Japan (2020); Kumar (2014).

Table 2 describes 24 categories and sub-categories of environmental risks. Each may result in financial risks such as credit (default) risk, market risk (valuation loss), and liquidity risk, as well as operational risk with FIs.[5] There are therefore numerous scenarios for environmental risks to transmit to financial risks. Table 2 shows over 100 possible scenarios of environmental risk transmission to financial risks; we select 10 cases to illustrate how such transmissions could work. Note that these are just examples of how physical and transitional risks can lead to selected financial risks and operational risks, and that it does not mean that these events would not also lead to one of the other types of risks. For instance, typhoons and floods may have implications at the same time for credit, market, liquidity and operational risks of financial institutions.

Table 2. **Examples of environmental risks transmitted to FI financial risks**

Financial Risks for FIs / Environmental risks		Market Risk	Credit Risk	Liquidity Risk	Other risks
Physical Risks	**Sub-categories**				
Extreme weather events	Tropical cyclones/Typhoons	1	1		1
	Floods		2	2	2
	Winter storms				
	Heat waves		3		3
	Droughts		4		
	Wildfires		5		
	Hailstorms				
Ecosystems pollutions	Soil degradation and pollution		6		
	Water pollution				
	Marine pollution				
	Environmental accidents	7	7		7
Sea-level rise					
Water scarcity					
Deforestation					
Desertification					
Transition Risks	**Sub-categories**				
Public policy change	Energy transition policies	8	8		
	Pollution control regulation				
	Polices on resource conservation				
Technological changes	Clean energy technologies	9	9		
	Energy saving technologies				
	Clean transportation				
	Other green technologies				
Shifting sentiment		10	10	10	
Disruptive business model					

Sources: adapted from G20 Green Finance Study Group (2017); NGFS (2019a); Ma et al (2018); CICERO (2017); Caldecott et al. (2013); EIOPA (2019).
Note: Examples of other risks include operational risk, legal risk, underwriting risk and liability risk.[6]

5 For formal definitions of these financial risks, please see BCBS' publications (BCBS, 2000, 2008, 2011, 2016).

6 Note that legal risk is included in the definition of operation risk by the Basel Committee (BCBS, 2011, Page 3). For liability risk, please see the report of Bank of England (2015).

Case 1: Transmission from tropical cyclone/ typhoon risk to market risk, credit risk and underwriting risk

1) Climate change exacerbates the intensity and frequency of tropical cyclones/typhoons (physical risk);
2) Higher intensity and frequency of tropical cyclones/ typhoons lead to more severe damages to real estate assets located in coastal areas, reducing the value of properties (market risk);
3) Lower property values reduce collateral values of mortgage loans, and increase Loss Given Default (LGD);
4) Lower collateral values of mortgage loans and disruption to economic activities (e.g., income) due to extreme weather events increase mortgage default rates, and higher default rates and LGD increase expected losses of banks (credit risk) (Sun & Ma, 2020);
5) For insurers that provide property insurance for real estate assets in coastal areas, larger than expected damage losses of property could result in unexpectedly high claims (underwriting risk).[7]

Case 2: Transmission from floods risk to operational risk, credit risk and liquidity risk

1) Climate change will result in more severe and frequent floods (physical risk) (Blöschl et al., 2019);
2) Floods disrupt supply chains and plant operations of some non-financial firms (e.g., due to power and transportation disruption) that are banks' clients, or threaten banks' business continuity by damaging their buildings (operational risk);
3) Business disruptions reduce revenue and increase repair/ maintenance cost, thus reduces profit of the affected non-financial firms;
4) Reduced revenue and profit of these firms weaken their ability to repay bank loans and increase loan default rates and LGD (credit risk).
5) Insurers that provide flood insurance may be under pressure to liquidate assets at a loss in order to cover claims due to major flooding (liquidity risk).

Case 3: Transmission from high temperatures/heat waves to credit risk and operational risk

1) Climate change results in longer, more frequent and more dangerous heatwaves (physical risk) (Pierre-Louis, 2019);
2) Heatwaves decrease labor productivity (Deryugina & Hsiang, 2014), and may disrupt transportation, power generation (e.g. due to lack of cooling water) of non-financial firms that are banks' clients;
3) Decline in productivity and business disruption reduce revenues and increase facility maintenance and repair costs of these non-financial firms;
4) The decline in profitability of these firms will increase default rates and LGD for banks (credit risk);
5) Damages to transportation and power facilities may cause disruption of banking services (operational risk) (Euronews, 2019).

Case 4: Transmission from drought to credit risk

1) Climate change causes more severe drought conditions and water shortages (physical risk) (Calanca, 2007; Loukas et al., 2008);
2) Water scarcity may lead to power shortages;
3) Water scarcity and power shortages reduce revenues and increase operating costs of non-financial firms that depend heavily on water (such as those in agriculture, food manufacturing, textile & dyeing, and other water intensive industries) and power;
4) These changes in revenue and cost of non-financial firms may result in higher default rates of loans to the companies (credit risk).

Case 5: Transmission from wildfire to legal risk and credit risk

1) Climate change leads to global warming and more frequent and intensive droughts (Herrera et al., 2017);
2) Exacerbated droughts increase the probability of wildfires (physical risk);

7 Hurricane Andrew in 1992 in Florida, caused an estimated $15.5 billion (1992 dollars) in total insured losses, resulted in the insolvency of 11 insurance companies, link: *https://www.air-worldwide.com/news-and-events/press-releases/Twenty-Five-Years-after-Hurricane-Andrew--AIR-Analyzes-the-Impact-if-it-Were-to--Strike-Again-Today/*.

3) Wildfires destroy infrastructure and equipment, thus lowering productivity and decreasing revenues of some non-financial firms. Wildfires may also increase their repairment costs.
4) Losses incurred from more wildfires could also be in the form government penalties or legal claims to liable companies that caused or exacerbated the wildfires;
5) From a lender's perspective, higher cost, lower revenue and impairment of collaterals could reduce the affected non-financial firms' ability to repay bank loans and increase default rates and LGD (credit risk).

Case 6: Transmission from soil degradation to credit risk

1) Land degradation (physical risk) lowers agricultural yields (UNDP, 2019; Young, 1994);
2) Expenditure for remediation measures lead to lower profitability of agricultural firms;
3) For banks lending to these agricultural firms, lower firm profitability may result in higher default rates and LGD (credit risk) (Ascui & Cojoianu, 2019; UNEP FI, 2018).

Case 7: Transmission from environmental accidents to legal risk and market risk

1) Environmental accidents by non-financial firms (e.g. BP's oil spill) may result in serious water and land pollution (physical risk);
2) Litigation may result in heavy penalties for these companies and associated reputation risk;
3) Lawsuits and penalties lead to extra costs and tarnish these companies' reputation and reduce their future sales;
4) From an investor/lender's perspective, the above-mentioned changes in revenue and cost as well as reputational losses of the non-financial firms could lead to a fall in their valuation (market risk) and an increase in their probability of loan default and LGD (credit risk).
5) From an insurer's perspective, these could result in an increase in environment-related claims under liability policies (liability risk).[8]

Case 8: Transmission from energy transition policies to market and credit risks

1) Energy transition policies may include measures (e.g. carbon tax/pricing scheme) to limit utilization of fossil fuels (transition risk);
2) These measures may result in higher costs for oil & gas companies, coal mining companies, and coal-fired power producers, meanwhile reducing market demand for their products;
3) Higher costs and reduced revenues cut profits and reduce the future cash flows of these companies;
4) From a FI perspective, these result in lower asset valuation (market risk) and/or higher loan default rates and LGD of carbon-intensive companies (credit risk).

Case 9: Transmission from technological changes to market risk and credit risk

1) Technological innovation that results in a decline in renewable energy costs (transition risk) reduces the market share and pricing power of "brown" companies such as oil & gas companies, coal mining companies, and coal-fired power producers;
2) From a FI perspective, the reduced sales and profits of "brown" companies lead to decreased asset value (market risk) and/or higher default rates and LGD (credit risk).

Case 10: Transmission from shift in market sentiment to market, credit and liquidity risks

1) Market sentiment towards carbon-intensive assets could change suddenly (transition risk) due to the introduction of new climate policies such as carbon taxes, carbon trading mechanisms, reduction in quota for fossil fuel energy, and regulatory restrictions on fossil fuel financing, and new technology developments in the form of a sharp decline in renewable energy costs and energy saving technologies.
2) For FIs, such sentiment shifts could lead to a sudden decline in price/valuation of carbon-intensive assets they hold (market risk); for banks, such a decline in price/valuation could increase the default risk and LGD if these assets are held as loan collaterals (credit risk); it may also result in difficulties in selling such assets by FIs (liquidity risk).

8 For details, please refer to the BoE's report, Bank of England (2015).

1.3 Financial impact of environmental risks

A lack of recognition and pricing of environmental risks could lead to significant financial losses for corporates and FIs that provide financing to those exposed to such risks. It also implies an under-estimation of the potential costs (or externalities) of financing or investing in brown assets (including polluting and high carbon assets) by FIs, thus leading to excessive allocation of capital into brown sectors and delaying the green transition of the global economy.

To convince senior managers of FIs to take action to manage environmental risks, it is critical for them to get a sense of the potential magnitude of the financial impact of their FIs' exposure to environmental risks. **This section reviews literature that estimate the potential financial losses that may be caused by environmental risks.**

As stated earlier, physical risks such as sea level rise and extreme weather events could seriously damage or destroy physical assets like real estate in coastal areas, leading to declines in property valuation, increases in non-performing Loans (NPLs), and heavy insurance losses. Examples of such losses estimated in the literature are:

1) A Blackrock study estimates that the financial losses of 15 US cities could amount to USD8 trillion due largely to sea level increase and more frequent extreme weather events, as a result of climate change (BlackRock, 2019).
2) An EIU study estimates that, from a private sector investor's perspective, global warming of around 4°C could result in a present value loss of US$4.2 trillion of financial assets globally, 5°C warming could result in a present value loss of US$7 trillion, while 6°C of warming could lead to a present value loss of US$13.8 trillion. These losses are caused by direct and indirect harms to portfolios' growth and returns derived from more destructive floods, droughts and severe storms. However, from the public-sector perspective, which implies the employment of a lower discount rate, 6°C of warming could lead to a present value loss of US$43 trillion (EIU, 2015).
3) A DNB report entitled *Waterproof* estimates that, in case of 1.5°C to 3.5°C of warming, the number of claims on property insurance in 2085 would rise to 131% of that in 2016 (Regelink et al., 2017).
4) Swiss Re estimated insured losses in 2016 amounted to less than one-third of the approximately $175 billion in total disaster-related losses, leaving a protection gap of $121 billion. The global protection gap has widened by about 20%[9] over the past 25 years (EESI, 2018; Swiss Re, 2016).

Transition risks, arising from the process of policy- and technology-driven adjustment towards a greener and low-carbon economy, could take the following forms:

1) **Technology innovation,** leading to a sharp fall in renewable energy costs and thus reduced pricing power and market share for fossil fuels. For example, Bloomberg New Energy Finance (Bloomberg NEF, 2019) estimates that the global average wind and solar power costs would fall to 87% of coal fired power prices by 2027 and to 73% of that by 2030;
2) **Policy changes,** including those leading to a sharp increase in carbon prices. Based on World Bank estimate Ramstein et al., 2019 current global average carbon price is at USD2 a ton, a mere fraction of estimated USD75 a ton in 2030 required to achieve a 2-degree target;
3) **Change in consumer preference:** according to an Accenture survey in 2019 (Long et al., 2019), around 72% of respondents indicate that they are currently buying more environmentally friendly products than they were five years ago, and this shift in consumer preference will likely strengthen going forward.

These significant transition forces will likely lead to sizeable financial impacts on carbon intensive assets in many countries and markets. According to the IEA's *World Energy Outlook 2012* (Van der Hoeven, 2013), it was estimated that to have a 50% chance of limiting the rise in global temperature to 2°C, only a third of current fossil fuel reserves can be burned before 2050. Another study published in *Nature Climate Change* (McGlade & Ekins, 2015) found that, globally, a third of oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2°C. In other words, if the world is to meet the Paris climate targets, these unburnable fossil fuels must become stranded assets. Another example of such a risk is the potential sharp decline in demand for coal-fired power generation in a few years when renewable energy prices become even more competitive, undercutting the economics of new as well as existing coal fired power plants

9 The protection gap here refers to the ratio of total uninsured losses to total economic losses.

and resulting in stranded assets in the coal mining and coal-fired power sectors.

The following summarizes the preliminary findings of other studies conducted on the financial impact of transition risks:

1) A study by Tsinghua University estimates that the non-performing loan ratio of representative coal-fired power companies could exceed 20% by 2030, up from the current less than 3%, due to the expected fall in clean energy costs and the resulting downward pressure on the pricing power of the coal-fired power companies, the rise in carbon prices, a decline in demand, and an increase in funding costs for pollution and carbon intensive companies (Ma and Sun, 2020).
2) A study by HSBC Global Research estimated unburnable fossil fuels may result in more than a 40%~60% decrease of enterprise valuations EBITDA for some major resource-focused global companies, including Shell, BP, Total and Statoil (Robins et al., 2013).
3) Studies on the transition risks of climate change have estimated the potential for losses as ranging from USD 1 trillion to USD 4 trillion when considering the energy sector alone Mercure et al., 2018, or up to USD 20 trillion when looking at the economy more broadly (NGFS, 2019a).[10]
4) Summarizing the results of 31 models, the IPCC concludes that the mitigation costs of limiting warming to 2°C, including consumption losses due to risks of food and water security, loss of livelihoods and income, breakdown of infrastructure networks and critical services and alike, would be between 1-4% of global aggregate consumption by 2030 compared to current economic forecasts under cost-effective scenarios with all key mitigation technologies available and no delay of mitigation (Allen et al., 2014).
5) A climate stress-test of the financial system that examines the impact of transition risk for the top 20 listed banks in Europe finds, even focusing only on the banks' portfolio of equity holdings, the Value at Risk amounts to about 1% of the banks' regulatory capital, while losses vary between 8% to over 30% of capital across banks under "severe" scenarios (Battiston et al. 2017).

2 Overview of ERA tools for financial institutions

This section reviews the framework for ERA and various ERA methodologies. Many of these methodologies are developed by specialized third-party vendors and research institutions and are used by FIs on a pilot basis due to their complexity and resource intensity.

Three aspects of the ERA methodologies and their applications are reviewed:[11] First, the major steps for analyzing environmental risks are summarized; second, the methodologies for scenarios analysis and stress test are classified by the types of users including banks, asset managers and insurance companies, and by the types of risks including physical and transition risks; third, alternative methodologies used by FIs in measuring environmental risks and opportunities are presented, including ESG ratings and the natural capital risk assessment approach. This section also includes a few boxes that describe technical details of several ERA methodologies, including frequently used climate scenarios.

2.1 Steps for environmental risk analysis and management

The framework for environmental risks analysis and management typically involves four steps[12]:

- **Risk identification:** conducting strategic assessment of the types of environmental factors that may cause financial risks (e.g., value impairment from sea-level increases, extreme weather events, declining demand for or prices of fossil fuels, devaluation of associated infrastructure, interruption of supply chains, increased natural capital cost, and increased emission and pollution costs);
- **Risk exposure:** measuring the sizes of FIs' exposures to these risks (e.g., 15% loans exposed to certain risks);

10 In the NGFS 2019a report that figure reffered to: IEA and IRENA (2017). See IEA and IRENA (2017). There is also a difference in the methodology used. The IEA estimates stranded capital while IRENA estimates stranded value. For instance, in the upstream oil and gas sector, the IEA considers investments that oil & gas firms have made into exploration, which may not be recouped. IRENA, on the other hand, considers the potential priced-in market value of explored reserves, which, as one might expect, is higher than the cost of exploration.

11 There could be more dimensions for classifying the ERA methodologies, e.g., by micro/sectoral/macro perspective, or by dynamic/static approach.

12 As indicated by the "Guide to climate scenario analysis for central banks and supervisors, NGFS (2020b)", it must be recognized that this field is still relatively in its infancy and that there is no universally agreed approach.

- **Risk assessment:** estimating probabilities and magnitudes of financial losses arising from these risks (using ERA methods such as scenario analysis and stress test). The results of these ERA could feed into risk pricing;
- **Risk mitigation:** taking actions to reduce risks via introducing internal policies and processes that discourage exposures to environmentally risky assets. For example, FIs can reduce their exposures to carbon-intensive infrastructure assets now to avoid carbon lock-ins and the risks of holding stranded assets in the longer term; they can also assist the green transition and environmental risk management of non-financial companies via more active shareholder engagement, requesting better information disclosure and providing risk management products.

2.2 Models used for assessing different types of risks

This subsection reviews the various models used to assess, on a forward-looking basis, the financial impact of environmental risks in the forms of scenario analysis and stress tests.

2.2.1 Models for assessing physical risks

Most ERA models assessing physical risks first capture the impact on company financials due to environmental risks. The financial impact, such as declining revenues or rising costs, can be the direct result of environmental or climate events that cause property and other damages, or an indirect or secondary effect of physical events. The most common secondary impact is business interruptions and reduced economic activities. Examples include electricity outages, disruptions to supply chains and declining demand for the company's products due to an economic slowdown. The resulting changes in financial statements are then integrated into financial models (e.g., PD and LGD models or securities' valuation models) to quantify the financial risks (e.g., credit risks for lenders and market risks for institutional investors) both on a portfolio basis and individual transaction/client basis. Results of these analyses are typically presented as a scenario analysis or a stress test.

In the following boxes we present the analytical approaches of two case studies that quantify the impact of physical risks on corporates' financial performance and the resulting financial risks to FIs and investors. Specifically, **Box 1** illustrates the Tsinghua University modelling framework for assessing the impact of future trajectories of Typhoon on default probability of mortgage loans in Chinese coastal cities under various climate scenarios. **Box 2** describes the work done by a research team supported by GIZ on the impact of water stress on corporate bonds' credit risks. Similar approaches should be applicable to analyzing impact on stocks and other securities.

Box 1

Quantifying the impact of climate physical risks on property values and bank loans

Tsinghua University developed a climate physical risk assessment framework for banks to analyze credit risks arising from the impact of physical risks under various climate scenarios. This framework could be used to a wide range of hazards including typhoons, floods, heat waves, drought etc., and can be used for a large variety of sectors, especially those that are vulnerable to natural disasters, for instance housing, agriculture, energy and transportation sectors.

The analytical framework

The general analytical framework is composed of two major components: a disaster loss model and a group of financial models, as illustrated in the figure below.

The disaster loss model is used to estimate the value loss of physical properties due to damages or the financial loss due to business interruptions by natural disasters.

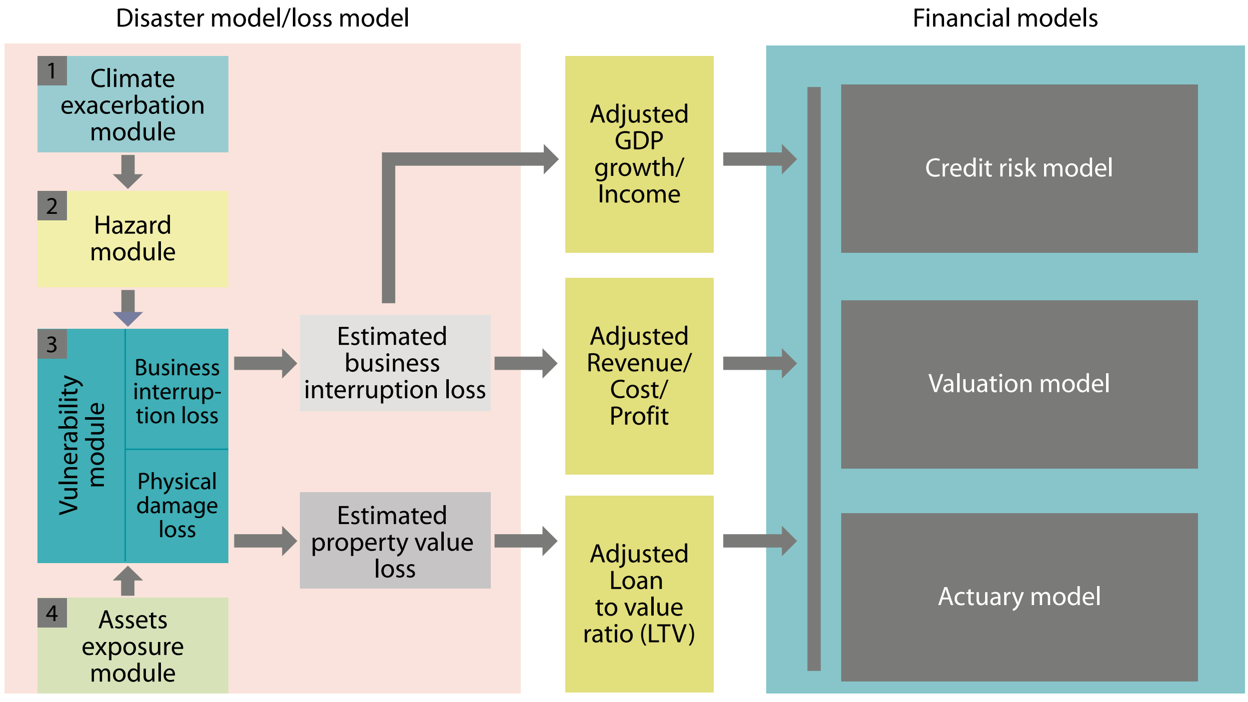
The output of the disaster model is then fed into the financial models as an input to adjust their estimates of the financial statements of an entity (be it a company, a bank, or a local government), such as assets, liabilities, revenues, costs and profits/losses. These adjusted variables are then used to estimate the various financial ratios such as the loan-to-value ratio, return on equity, asset/liability ratio and interest coverage ratio.

Disaster loss model

The disaster loss model applied by this framework is largely built on the on-going python package CLIMADA, which is developed by a group of researchers at ETH Zurich (Aznar Siguan & Bresch, 2019). The disaster loss model consists of four modules: the exacerbation module, the hazard module, the asset exposure module and the vulnerability module.

…/…

Figure 2. **The general physical risk assessment framework**



1. The exacerbation module addresses the exacerbated effect of global warming on typhoons' and other natural disasters' intensities and frequencies. Specifically, it correlates the incremental change of intensity and occurrence probability of a hazard and a rise in temperature caused by higher carbon concentration in the atmosphere.

2. The hazard module, by taking the output of the exacerbation module, projects the future hazard profiles under climate scenarios defined by IPCC (Allen et al., 2014). For our case study, this is done through combining historical typhoons' tracks obtained from the National Oceanic and Atmospheric Administration (NOAA) and the output of climate exacerbation module.

3. The asset exposure module describes the geographical locations and value distribution of the concerned assets/properties exposed to natural disaster events. These assets/properties are identified by the latitudes, longitudes and altitudes and their corresponding monetary values at specific sites.

4. The vulnerability module builds the correlation between the value damages to assets and the intensity of a hazard.

The financial models

Many financial models could be used to analyze the "disasters" impact on financial variables related to insurance, asset management and banking operations, taking the output of the "disaster loss model" as input.

The Expected Loss (EL) model is widely used by banks to estimate potential credit risks. Usually, EL could be calculated as the product of three risk-measure components, namely Probability of Default (PD), Exposure at Default (EAD) and Loss Given Default (LGD), as suggested by Internal Ratings Based (IRB) Approach of Basel III Capital Framework (BCBS, 2017):

$$\sum EL_i = \sum PD_i * LGD_i * EAD_i \quad \text{[1]}$$

In this case study, future exposure (EAD) is assumed to remain unchanged, so only impacts of natural disasters on PD and LGD need to be evaluated to derive the disasters' impact on EL. The models for estimating the PD and LGD are integrated to calculate the expected loss fraction of asset , expressed in a percentage of EAD in formula 2 as follows,

$$\textit{Percentage Loss of } EAD_i = PD_i * LGD_i \quad \text{[2]}$$

Two explanatory variables, household income and loan-to-value ratios (LTV), are identified as the key determinants of the mortgage PD model. Note that such a model structure for mortgage PD estimates is widely adopted in literature and practice (Calem & LaCour-Little, 2004; Zhang et al., 2010). For LGD model, LTV is used as the key explanatory variable, which is also in line with general banking practices. Via Equation 2, household income and LTV become the two key drivers for the potential loss to EAD due to natural disasters.

An application to mortgage loans in Chinese coastal cities

In one of the applications of the above-mentioned methodologies, we assessed the impact of future typhoons on the PD, LGD, and EL of mortgage loans for properties in 40 coastal cities in China under various stress scenarios. The 40 Chinese coastal cities are located in the most impacted eight provinces exposed to typhoons. We first estimated the outstanding amounts of mortgages loans in these cities, then mapped the geographical locations of the properties to potential disaster damages. For this purpose, an online tool is applied to geocode the center of municipal districts as the location of the properties. The output includes the latitudes and longitudes for the properties in the municipal districts of the 40 cities, which are then taken as inputs into the model for simulations.

Simulations are then conducted under various climate scenarios with different assumptions of exacerbation effects. Under the severe scenario, which involves RCP8.5 climate scenario and the 99th percentile of exacerbation effect,[1] our result shows that the expected loss (EL) of mortgage loans in 2050 could increase by 260% compared with the base-line scenario (assuming no change in climate conditions). *Source: Chapter 6 of NGFS Occasional Paper on Case Studies of ERA Methodologies.*

1 Scientific findings regarding impact of climate change on typhoon's intensity and frequency involve considerable uncertainty, and are often demonstrated as a distribution. The result estimated here applies the 99 percentile of the exacerbation effect distribution from the summarized results by Knutson et al. (2019).

Box 2

Analyzing the impact of water stress on corporate bonds

Companies that depend on water and operate in locations where water withdrawals are high relative to available water supply are exposed to water risk. Climate change and the resulting drought conditions, could push up water costs significantly, and negatively impact these firms' profitability, competitiveness and finally their ability to repay their debt.

The water risk model

A new financial model to integrate water stress into corporate bond credit analysis has been developed through a partnership between the Natural Capital Declaration (NCD), GIZ, the German Association for Environmental Management and Sustainability in Financial Institutions (VfU) and seven financial institutions from Europe, the U.S. and Latin America. By combining data on the quantity of corporate water use per production location with cost based on site-specific water supply and demand conditions, the GIZ/NCD/VfU tool allows financial analysts to quantify corporate water risk and assess the potential impact of water stress on a company's credit ratios. Fixed income analysts and portfolio managers can use the Corporate Bonds Water Credit Risk Tool to benchmark companies and assets in water-intensive industries, such as mining, power and beverages industries on exposure to water stress.

The tool incorporates newly available data from the World Resources Institute on water stress at any location globally into a traditional financial model. Thereby, it enables users to integrate a company's exposure to water stress into its credit risk analysis. Users of the tool can then benchmark companies on the potential impact of water stress on their credit ratios.

Share price of water

The model uses a shadow price for water as a proxy for exposure to potentially increasing costs for water resulting from water stress. In the absence of market prices that reflect resource constraints, shadow prices provide a proxy for the magnitude of exposure to water stress. The calculation of these shadow prices is based on a total economic value (TEV) framework – a concept taken from environmental economics. Shadow water prices are calculated by considering the value of the alternative uses to which this water could be put, if it were not used by the companies analyzed (opportunity costs).

Application to 24 companies

The study applies the model to 24 companies, eight each from the mining, power and beverages sectors. The model investigates how these firms' credit ratios could be impacted by water stress, based on the potential costs associated with their water use under current and projected water supply conditions.

The model calculates company credit ratios before and after integrating the shadow price of the water used at their production locations. For some firms, the integration of the full value of water use that takes account of scarcity and population factors has the potential to have a significant impact on their credit ratios, which could lead to a rating downgrade and an adjustment in the value of their bonds.

Key findings

- Of the eight mining firms analyzed, Barrick Gold and Vedanta are most exposed. Barrick Gold could see its Net Debt/EBITDA ratio rise by 20 percent to 3.30x in 2017 if it were to fully internalize the costs of its water use. This could cause Barrick Gold's BBB rating to fall to High BB. However, this could be prevented by Barrick Gold's robust EBITDA/ Revenue margins.

- This scenario of full cost internalization would see Vedanta's Net Debt/EBITDA ratio or leverage rise by 65 percent to 3.85x in 2017. Although Vedanta's leverage rises quite sharply in our model, Vedanta is already rated Ba3/BB-, so its rating may not change.

…/…

- Of the power companies analyzed, Eskom (Ba1/BB+Neg), the South African utility, already has extremely high leverage before water costs are added, with Net Debt/ EBITDA of 9.41x in 2017. Once Eskom faces the actual cost of its water use, its financial position deteriorates drastically, with its Net/Debt ratio almost tripling.
- Sempra, RWE and The Southern Company see their leverage rise quite sharply, when they internalize the full cost of their water use.
- Sempra Energy could see its High BBB rating fall to a non-investment grade rating: perhaps to High BB, because its leverage.

Source: Chapter 9 of NGFS Occasional Paper on Case Studies of ERA Methodologies.

2.2.2 Models for assessing transition risks

Like physical risk models, typical ERA models assessing transition risks try to first capture the financial statement impact of policy and technological changes at the company level driven by environmental and climatic factors under various scenarios.

In a climate-related transition risk analysis, the typical first step is the creation of temperature-based or event-based scenarios using underlying models, such as sector-specific models, macroeconomic models or Integrated Assessment Models (IAM)[13] (see Box 3). Given these scenarios, the financial models can then quantify the impact of energy transition policies (e.g., increasing carbon prices and contracting demand for fossil fuel products) and technology changes (e.g., causing downward pressure on the sales and prices of fossil fuel products) on companies' revenues and costs in carbon-intensive sectors such as oil & gas, coal mining, coal-fired power generation, steel, cement and transportation (see Table 3 for a case study on oil and gas). These changes in corporate financial statements are then integrated into risk models by FIs to assess financial risks (e.g., credit and market risks) both on a portfolio basis and an individual transaction/client basis.

A major challenge in modelling climate-related transition risks is handling the interactions between economic variables, energy sector parameters and corporate reactions. IAM provide input to tackle these challenges. Among many methodologies incorporating IAM included in the Occasional Paper, two examples are CLIMAFIN methodology in Chapter 4 that explains how to use the outputs of IAM (across scenarios) to assess transition risks for investor portfolios (Battiston et al. 2017), and the methodology in Chapter 11 that uses an IAM – incorporating both energy and land-use systems into a macro model – to translate the assumptions under different transition scenarios into key economic variables. The IAM approach produces a series of outputs on the energy sector, which are then used to translate scenario outputs into shocks on the real economy. Shocks are divided into two types: direct shocks (e.g., carbon price increases), which affect asset value streams through a company's operations or costs, and indirect shocks (such as a decline in demand and a resulting change in commodity prices), which affect asset value streams through changes in demand or selling prices.

ERA methods have also been developed to analyze the financial impact of other environment-related transition risks (such as pollution and water stress), albeit the number of such studies are significantly fewer than those on climate-related risks. For pollution-related transition risk analysis, a typical first step is to construct scenarios related to environmental-policy and regulatory changes, which would have an impact on the costs and/or revenues for companies in high-polluting sectors. For example, an ICBC environmental stress test models the impact of possible increases in government levies on air pollution. The impact of such policy changes on companies' financial statements are estimated, and the resulting changes in financial variables, such as costs, revenues, profits, and asset/liability ratios are fed into valuation models or PD models to quantify the changes in market and credit risks of the affected companies and/or investment portfolios (see Box 4).

13 For more information of IAMs that can be used for the purpose of transition risk assessment, please refer to NGFS's earlier publication (NGFS, 2020c).

Box 3

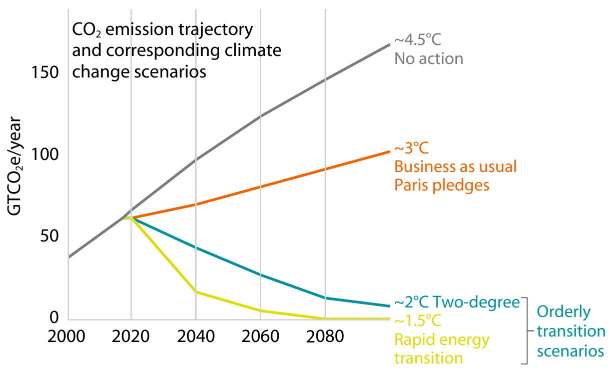
Climate-related transition scenarios

A scenario describes a path of development leading to a particular outcome. They are intended to highlight core elements of a possible future and to draw attention to the key factors that will drive future developments (TCFD, 2017b). Different scenarios allow financial institutions to conduct 'what-if' analyses of how different transition pathways could affect their assets and/or portfolios, and to explore the resilience and vulnerabilities of a firm's business model to a range of outcomes.

Two types of climate scenarios that financial institutions could consider when selecting an appropriate methodology, as identified by Oliver Wyman,[1] are:

- **Temperature-based scenarios:** these often describe a smooth and orderly transition to a low carbon economy, and have a long-term view. However, they can also describe a disorderly transition where stringent policies kick off at a later date to meet climate commitments. Temperature-based scenarios are comprehensive and holistic scenarios analyzing how the world might develop, and the corresponding impacts that these pathways have on average global temperature and climate change.
- **Event-based scenarios:** these are often used to illustrate aspects of an abrupt or a disorderly transition to a low-carbon economy, and take a short-term outlook when compared to temperature-based scenarios. Event-based scenarios focus on the potential impacts of one triggering event, such as a sudden change in government policy or the introduction of a disruptive energy technology.

Figure 3. **Temperature and Event-based climate transition scenarios**



- *Holistic scenarios/cross-sector*
- *Often developed for policy purposes to describe an* orderly transition, not a stress scenario
- *Requires long-term modeling and assumptions*
- *Explicitly refers to the TCFD and the 2°C scenario*

Event-based scenarios / Disorderly transition scenarios

Triggering event	Type of risk	Key metric	Example exposed sector
Carbon price regulation	Transition (policy)	Carbon price	Oil & Gas
Breakthrough in energy storage	Transition (technology)	Battery capacity	Car manufacturers

- *Scenarios focused on potential impact of one triggering event (e.g. carbon price regulation)*
- *Focus on understanding current portfolio exposure to the specific event – timing considered as "near-term" for simplification of analysis*

1 Oliver Wyman (2019), Climate Change: Managing a New Financial Risk.

…/…

Currently, the financial industry at large is increasingly looking into longer-term, orderly, temperature-based scenarios. This is in-line with the TCFD's recommendation that organizations use a 2°C or lower scenario in addition to two or three other scenarios most relevant to their circumstances (TCFD Financial Stability Board, 2016). Though event-based scenarios are not common in transition risk assessment methodologies at the moment, they may be relevant to consider as some FIs are interested in abrupt and disorderly transition scenarios, which may result in higher stress for financial entities as they do not provide the time horizon for a planned movement out of exposed sectors to lower carbon assets.

Temperature-based scenarios are underpinned by models which translate underlying assumptions around climate, the economy, and societies into scenario outputs. For transition risk assessments, the most relevant types of underlying models used in scenarios are:

- **Sector-specific models:** energy system models (e.g. looking at interlinked energy and transport systems) and land-use models (e.g. looking at agriculture and forestry) explore how different economic sectors evolve based on changing policy, technology and market conditions. Popular developers of scenarios using these models are the International Energy Agency (IEA) and the International Institute for Applied Systems Analysis (IIASA) respectively.
- **Macroeconomic models:** these are often computable general equilibrium (CGE) models and cover various macroeconomic variables, including an economy's resources (e.g. capital and labor), sectoral composition, and international trade. They look at how changes in one part of the economy affect the whole system. Examples of developers of macroeconomic models for transition risk assessments are Vivid Economics and E3ME.
- **Integrated Assessment Models (IAMs):** consider the socioeconomic factors that affect the earth systems to determine how these then affect human welfare. These are based on the best available science and underpin policymaking and the Intergovernmental Panel on Climate Change (IPCC)'s assessments, particularly, IAMs aligned to the use of Shared Socioeconomic Pathways (SSPs) will be used for the upcoming IPCC assessment. Scenarios using IAMs are developed by IIASA, the Potsdam Institute for Climate Research (PIK), and the Joint Global Change Research Institute (JGCRI), among others.

Source: Chapter 3 and Chapter 36 of NGFS Occasional Paper on Case Studies of ERA Methodologies.

Table 3. **Impact of climate-related transition scenarios on key drivers – the case of oil and gas exploration and production**

Driver	Expected Scenario Impact	Modelling approach
Volume	Some of the additional costs borne by the producers will be passed onto the consumers; increased price will lead to a decrease in demand/production	Decrease production of high cost producers to account for the decreasing demand
Unit Cost	The marginal of cost of extraction will be impacted by the cost of emissions: • Released when oil and natural gas products are used • Generated during the production process	Shift cost curves upwards to reflect the additional costs of emissions due to the carbon tax
Price	The price paid by consumers will increase due to the carbon tax, however the margin for the producer will become smaller	Assess scenario price and demand based on carbon intensity and elasticities of the sector
Capital Expenditure	Capital expenditure is expected to decrease reflecting the lower demand Represents investments to maintain current production or grow future production	Link level of capital expenditure to prices

Source: Chapter 3 of NGFS Occasional Paper on Case Studies of ERA Methodologies.

Box 4

Stress testing bank's credit risk on pollution-related transition risks

In 2013-14, China faced very serious air pollution and the government announced a series of anti-pollution measures and its intention to adopt even tougher measures in the following years. In 2015, the Industrial and Commerce Bank of China (ICBC) developed its first environmental stress test to analyze the impact of environmental policy changes – a type of transition risk related to environmental policy change – on banks' credit risk. It was first applied to loans extended to sectors such as thermal power and cement that generate significant air pollution. This box briefly describes ICBC's modelling approach.

Setting of scenarios

The scenarios constructed by ICBC research group consist of a range of new environmental policies and standards that were expected to be adopted in coming years and would have financial impact on the bank's corporate clients in the polluting sectors. The stress scenarios were set on three levels, namely heavy stress, medium stress, light stress. With regards to the thermal power industry, the three scenarios were set according to expected tougher emission standards and the higher emission levies likely to be adopted by the environmental authorities. These new standards are translated into four, three and two times increase in emission charges for thermal power generators.

With respect to the cement industry, the stress scenarios were set based on expected new policies and standards concerning pollution control, co-treatment and pollutant discharges. Given that most cement customers of ICBC were midstream and upstream firms in the industry, the unit/cost increases associated with these new policies were determined on consultation with industrial specialists.

Modelling the transmission of environmental policies to credit risks

The research group estimated the changes in corporate financial statements under the various stress scenarios, and then derived their impact on PD and NPL ratios as well as impact on clients' credit ratings using ICBC's internal rating model. The modelling process can be divided into four steps:

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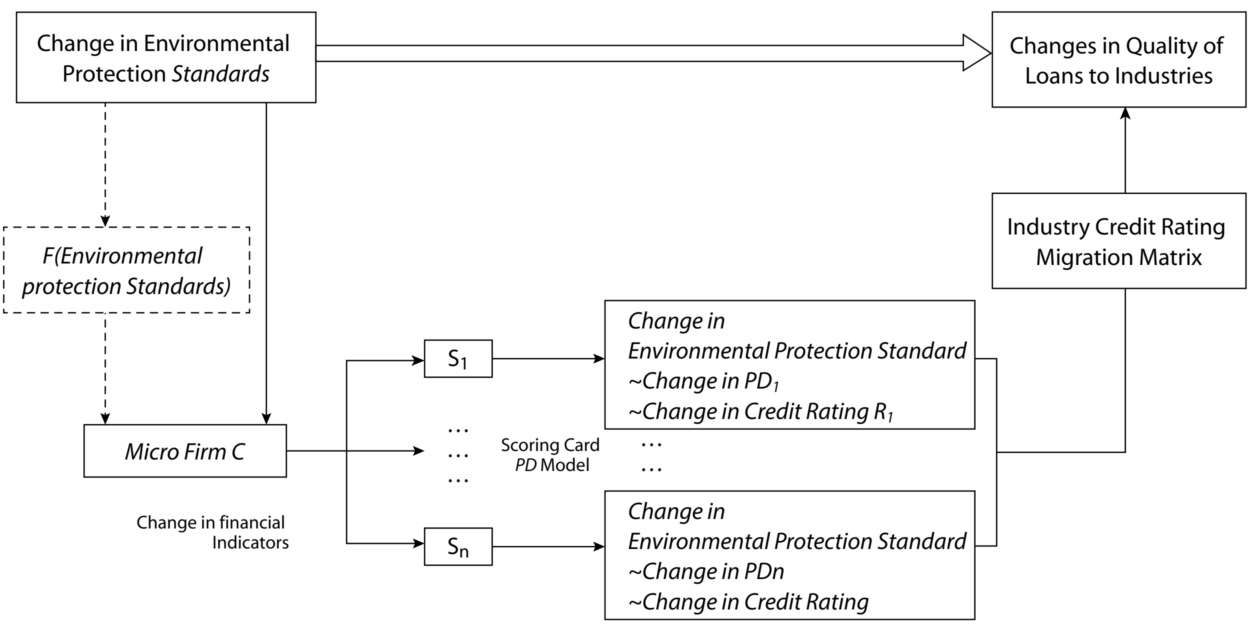
Figure 4. **Schematic diagram of financial transmission model**



Step 1: Establishing the cost function of environmental policy/stand changes in the thermal power and cement industries. Taking thermal power industry as an example, the increase in prime operating costs is calculated based on the increased cost per kilowatt hour under the stress scenarios.

Step 2: Estimating the balance sheet and income statement impact according to the unit cost increase under various scenarios. The study derived the impact on "revenue", "cost of goods sold" and "profit" in the income statement, and the resulting impact on equity, assets and liabilities in the balance sheet, as well as impact some cash flow implications.

Step 3: Estimating the impact of the above changes in financial indicators on clients' PD, and translate the change in PD into impact on clients' credit scores and credit ratings, based on the bank's existing PD model as well as credit scoring and rating methodologies.

Step 4: Constructing the credit rating transition matrix for the respective industries by summarizing the changes in credit ratings.

Findings of the stress tests

The environmental stress tests show that, for both the thermal power and cement industries, tougher environmental standards would impose cost pressure on firms, especially on small- and medium-sized firms, and would generate impact on their credit risk. For those thermal power companies currently with a AA rating or above, 81% would experience a rating downgrade under the heavy stress scenario, 75% would experience a rating downgrade under the medium stress scenario, and 68% would experience a rating downgrade under the light stress scenario. For the cement industry, under the heavy, medium and light stress scenarios, percentages of credit rating downgrades of firms that currently have a rating of AA or above might amount to 81%, 62% and 48%, respectively.

Source: Chapter 5 of NGFS Occasional Paper on Case Studies of ERA Methodologies.

2.3 Models used by different types of FI

This subsection reviews a few typical ERA models used by banks, asset managers and insurance companies for assessing the financial impact of their environment- and climate-related risks.

2.3.1 Models used by banks

Most ERA models for commercial banking business assess the impact of environmental factors on credit risk metrics, such as probabilities of default (PD) and Loss Given Default (LGD) (see example in Box 5). These models – including transition risk models and physical risk models – work by first estimating the environment-related losses or changes of some metrics that constitute explanatory variables for the loan-related risk models, then using these results as inputs for banks' credit risk models to generate adjusted risk measures including PD, LGD and credit ratings. Thus, the adjusted risk metrics produced from the second step have incorporated environmental factors, i.e., translated environmental risks into credit risks.

The above-mentioned ERA methodologies apply to banks' lending business. Banks engaged in securities and investment businesses also apply ERA models to analyze the impact of various environmental and climate factors on the performance of bonds, equities, other securities and their portfolios. These models are in principle the same as those described in the following subsection on models used by asset managers.

2.3.2 Models used by asset managers

ERA models for asset management first estimate the changes induced by environmental risks or factors to metrics that later constitute the determinant variables of valuation models of assets such as equities, bonds, real estate and infrastructure. Very often, the direct determinant variables of valuation models are dividends or cash flows. In a typical ERA model used by asset managers, environmental factors (e.g., energy transition policies) lead to declining revenues and increasing costs for a carbon-intensive company or portfolio, which in turn reduce the present values of their future dividends or cash flows. The estimated changes in the valuation of a security, an asset (e.g., stock, bond, property or infrastructure) or a portfolio under various scenarios are the typical "output" of the ERA model.

Box 5

Modelling the impact of physical risks on banks' agriculture, energy and real estate portfolios

In July 2018, 16 leading banks convened by the UNEP FI and supported by the consultancy Acclimatise released a methodological framework on physical climate risk analysis (UNEP FI, 2018). They seek to help banks make in-house estimates of the financial physical climate risks in their loan portfolios, expressed as key credit risk metrics: PD and LTV. The methodological framework is piloted specifically for agriculture[1], energy[2] and real estate portfolios[3].

On agriculture and energy sector portfolios

The framework provides guidance for recalculating the PD of borrowers accounting for climate impacts. The output can be generated per time period (2020s and 2040s) and climate scenario (2°C and 4°C) on sectoral borrowers or portfolios. The output builds on:

- Estimates of impacts from incremental climate change (temperatures and precipitations) on production (agriculture and energy) and prices (agriculture) per sub-sector and region/country, sourced from peer-reviewed impact studies. These impacts are translated into equivalent percentage of annual revenue loss for all borrowers in a sub-sector and region/country; and

- Estimates of impacts from extreme weather events in terms of production loss (proportion of crops lost in agriculture sector; electricity production downtime or reduced level in energy sector). They are estimated from empirical evidence on observed losses and projected into the future with high-level estimates of future change in frequency of categories of extremes. These impacts are translated into equivalent percentage of annual revenue loss. Using RMS models, the variation in annual revenue is also used to estimate changes in cost of goods sold.

The methodology stresses directly the variables in PD modelling that have revenues and cost components. In order to assess PD variations in a bank's specific portfolio, the methodology assesses a sample of borrowers that is representative of sector portfolio's PD, range of debt and geographic distribution. This requires data from the bank on the borrower's annual revenue, cost of goods sold, key operating assets and their location and output. The methodology extrapolates results of this representative sample to the sectoral portfolio.

On real estate portfolios

It provides guidance to revise LTV ratios per climate scenario (2°C or 4°C) and time period (2020s and 2040s). The output builds on high-level estimates of impacts of extreme climate-related events on property value, sourced from high-level observed losses and projected into the future (see the agriculture and energy methodology above).

The estimated sectoral impact on property value is used as a basis for calculating impact on the LTV for the bank's portfolio. The bank calculates the average remaining mortgage term for its portfolio and it is multiplied by the probability of hazards to occur in this period. This is combined with the high-level estimated change in property value to provide a "risk to property value" factor. Then the bank combines it with the original property value and locations in its portfolio as well as outstanding loan amounts to arrive at revised LTV ratios.

Insurance is excluded due to uncertainties on present-day coverage and future changes in insurance availability and pricing. The methodologies do not account for adaptation actions that borrowers may undertake.

Source: UNEP FI (2018) and Chapter 13 of NGFS Occasional Paper on Case Studies of ERA Methodologies.

1 With 3 sub-sectors: crop production, livestock farming, timber production

2 With 5 sub-sectors: thermal power production, hydropower production, power transmission, oil and gas upstream (exploration and production), oil and gas midstream and downstream (liquefied natural gas, gas-to-liquids, refining, petrochemicals)

3 Applicable to retail mortgages, income-producing real estate

Other outputs of the ERA exercise could take the forms of Value-at-Risk metrics (e.g., 5% probability of over X% drawdown), as illustrated in Chapter 23 of the *Occasional Paper* by AVIVA, or a sensitivity analysis (e.g., a X% share/bond price decline for a 1% increase in carbon price), as introduced in Chapter 16 of the *Occasional Paper* by CUFE. Table 4 shows an example of climate risk exposure analysis for a total portfolio. It includes the return attribution across asset classes for a selected global warming pathway relative to the climate-uninformed baseline. It quantifies climate risk exposure (i.e. Lower/higher expected cumulative median and 5% VaR returns) of the different asset classes to the transition and physical risks at play in a Paris disorderly transition pathway (red indicates higher level of expected negative impacts compared to baseline while green indicates positive impacts compared to baseline).

Some researchers have used regressions to derive "Carbon-Beta" to capture the "risks and opportunities" of stocks or other assets arising from the climate transition, based on stock market prices and carefully constructed "brown" and "green" portfolios. The Carbon Beta estimates the impacts or effects on firms, and their values or stock prices, of possible changes in expectations that may occur as the present economy moves towards a green economy (see Box 6). The Carbon Beta can be determined for different asset classes such as stocks, corporate bonds, loans, portfolios, and funds. In portfolio management, the Carbon Beta can be integrated into investment strategies, such as Factor Investing and Best-in-class approaches, and can be used for hedging carbon risks.

Table 4. **Cumulative return differences to climate-uninformed baseline expectation for several asset classes under Paris Disorderly Transition pathway**

Cumulative Impact Paris *disorderly* transition pathway (ratio to climate-uninformed baseline)	**2020-2024 Median**	**2025-2029 Median**	**2030-2039 Median**	**2040-2049 Median**	**2050-2059 Median**	**2020-2059 Median**
Fixed Income						
FI Government Bonds						
Index-Linked Gilts UK	-1%	1%	-1%	-1%	-4%	-6%
Gilts UK	0%	1%	0%	1%	1%	1%
Credits						
Credits GB	-1%	2%	0%	0%	-1%	-1%
Equity						
Equity Developed Markets	-7%	-12%	-2%	-2%	-4%	-25%
Equity Emerging Markets	-9%	-13%	-3%	-4%	-5%	-30%
Equity United Kingdom	-8%	-10%	-2%	-4%	-4%	-26%
Property						
Direct Real Estate UK	-7%	-7%	-4%	-4%	-5%	-24%
Direct Real Estate Residential UK	-5%	-4%	-2%	-3%	-4%	-16%
Direct Real Estate Offices UK	-8%	-7%	-4%	-5%	-5%	-25%
High Yield						
Corporate Credits HY US	-3%	8%	0%	-1%	-1%	2%

Source: Chapter 18 of NGFS Occasional Paper on Case Studies of ERA Methodologies.
Notes: Results are merely for illustrative purposes and should not be used to inform investment decision making. Conditional formatting is applied per time period (e.g. median return for years 1-5) to highlight the differences per (sub) asset class within that time period. Negative and positive returns are coloured in green and blue respectively. Dark green indicates a more intense climate shock than light green. White represents a muted net climate impact. Returns are calculated using (1 + median cumulative return climate pathway) / (1 + median cumulative return baseline) -1.

Box 6

CARIMA - A capital market-based approach to quantify transition risks to investment portfolios

Carbon Risk Management (CARIMA) was a research project funded by the German Federal Ministry of Education and Research (BMBF) and was completed in 2019. CARIMA aims to quantify the existing risks and opportunities for the values of financial assets and respective portfolios in light of climate change and the transition towards a green economy. Compared to other approaches, the advantage of CARIMA was that only the (freely available) return time series of the Carbon Risk Factor BMG (Brown-Minus-Green) is required for the analysis. There is therefore no need for detailed fundamental climate change-relevant information (e.g., financial statements and emissions data) about firms, which is often difficult and expensive to obtain or may not even be available.

The methodology

The CARIMA concept presents a capital market-based approach with which the risks and opportunities of the economy's transition process towards a Green Economy can be quantified comparatively easy, as carbon risks are simply "extracted" from the historical returns of global stock prices using a Carbon Risk Factor BMG in a factor model. CARIMA involves four modules:

Module A: Master Dataset

The starting point for developing and practically implementing the CARIMA concept is a comprehensive master dataset. It is crucial that the data allow a sufficiently accurate assessment of a firm's change in value in the event of unexpected changes in the transition process of the economy. Data from different databases, namely Thomson Reuters ESG, MSCI ESG-Stats and IVA-Ratings, Sustainalytics ESG Ratings, and CDP is used. The master dataset generated comprises a large number of ESG and capital market variables for around 40,000 listed firms worldwide.

Module B: Scoring Concept

Module B describes 55 Carbon Risk Proxy Variables, which are selected to support a fundamental assessment of whether the value of firms (and thus their stock prices) are influenced positively or negatively by unexpected changes in the transition process towards a green economy. Information from these 55 variables is condensed into the three group indicators via a scoring concept in order to calculate a so-called Brown-Green-Score (BGS) for each firm. The BGS represented a fundamental assessment of the direction and strength of the changes in – or in other words risks to firms' values that may occur as a result of unexpected changes in the transition process of the economy towards a Green Economy.

.../...

Figure 5. **Assignment of the 55 carbon risk proxy variables to group indicators**

VALUE CHAIN

Carbon Emissions (MSCI)
Carbon Intensity (SUST)
Clean Technology (TR)
Climate related Opp. Sources (CDP)
Climate related Risks Sources (CDP)
CO_2 Equivalents Emission Total (TR)
Energy Efficiency (MSCI)
Energy Use Total (TR)
Greenhouse Gas Emissions (CDP)
Opportunities in Clean Tech (MSCI)
Opportunities Renewable Energy (MSCI)
Regulatory Compliance (MSCI)
Regulatory Opportunities Sources (CDP)
Regulatory Risks Sources (CDP)
Renewable Energy Use (SUST)
Renewable Energy Use Total (SUST)
Supplier Environmental Programmes (SUST)
Sustainable Products & Services (SUST)
Sustainable Supply Chain (TR)

PUBLIC PERCEPTION

Climate Change Controversies (MSCI)
Disclosure Score (CDP)
Emission Reduction Score (TR)
Emissions Score (TR)
Environmental Score (TR)
ESG Score (SUST)
Industry-adjusted Overall Score (MSCI)
Performance Band (CDP)
Resource Reduction Score (TR)
Scope of GHG Reporting (SUST)

ADAPTABILITY

Air Emissions Programmes (SUST)
Carbon Emissions Score (MSCI)
Climate Change Risks/Opportunities (TR)
Climate Change Theme Score (MSCI)
Climate related Opportunities (CDP)
Climate related Risks (CDP)
Emission Reduction Prod. Process (TR)
Emission Reduction Target (CDP)
Emission Reduction Target/Objective (TR)
Energy Efficiency Policy (TR)
Energy Efficiency Target/Objective (TR)
Environmental Expenditures (TR)
Environmental Expenditures Investm. (TR)
Environmental Investments Initiatives (TR)
Environmental Management System (SUST)
Environmental Partnerships (TR)
Environmental Pillar Score (MSCI)
Environmental Policy (SUST)
Environmental Provisions (TR)
Environmental R&D Expenditures (TR)
Green Procurement Policy (SUST)
Innovation Score (TR)
Policy Emissions (TR)
Regulatory Opportunities (CDP)
Regulatory Risks (CDP)
Renewable Energy Programmes (SUST)

Brown-Green-Score
BGS

MSCI: MSCI ESG Dataset
SUST: Sustainalytics ESG Ratings
CDP: (formerly Carbon Disclosure Project)
TR: Thomson Reuters ESG (formerly ASSET4)

Module C: Carbon Risk Factor BMG

In the next step, suitable firms for the factor construction are selected. Only firms that are represented in all four databases and for which data is available for at least five Carbon Risk Proxy Variables are used for factor construction. These conditions are necessary to minimize distortions in the database-specific data collection methodology. Based on their average BGS, 1,108 firms (624 "brown" and 484 "green" firms) are assigned to one of two mimicking stock portfolios: the first portfolio consists of stocks of "brown" firms and the other of stocks of "green" firms.

Subsequently, the Carbon Risk Factor BMG can be formed from the historical returns of the four corner portfolios described, each of which is value-weighted by market capitalization, according to the following Formula:

$$BMG_t = 0.5\,(SH_t + BH_t) - 0.5\,(SL_t + BL_t) \quad [1]$$

The Carbon Risk Factor BMG thus reflects a hypothetical portfolio that is invested long in "brown" and short in "green" stocks.

…/…

Module D: Factor Model

Since stock market prices at any time reflect the speed of the transition process that market participants currently assume is occurring and thus which transition path is expected by society, the return time series of the Carbon Risk Factor BMG, constructed as a mimicking portfolio for carbon risk, contains such information in a condensed form. For a concrete assessment of the carbon risk, a simple regression analysis is applied. Only the historical returns of the financial assets or portfolios, for which the users seek to quantify the carbon risk, are necessary as the dependent variable. The return time series of the explaining variables, such as the Carbon Risk Factor BMG and the remaining factors, are available free of charge on the project website and further websites, respectively. The Carbon Beta as a measure of carbon risk is the result of a regression analysis. The Carbon Beta reflects the capital market's assessment of the carbon risk of the respective financial asset or portfolio.

The Carbon Beta estimates the impacts or effects on firms, and their values or stock prices, of possible changes in expectations that may occur as the present economy moves towards a Green Economy. It is thus the central measure for quantifying risks. Sudden changes in expectations regarding the transition process of the economy are reflected in the Carbon Beta. The higher the absolute Carbon Beta value, the greater the impact (either upward or downward) on the stock price.

Applications

A variety of potential applications for the Carbon Beta is included in Module E. The Carbon Beta can be determined for different asset classes such as stocks, corporate bonds, loans, portfolios, and funds. Furthermore, various country and sector aggregations and corresponding analyses are possible. Scenarios for stress testing the values of financial assets and portfolios can be generated based on the Carbon Beta. In portfolio management, the Carbon Beta can be integrated into investment strategies, such as Factor Investing and Best-in-class approaches, and can be used for hedging carbon risks.

Source: Chapter 34 of NGFS Occasional Paper on Case Studies of ERA Methodologies.

2.3.3 Models used by insurance companies

Insurers' business consists of two categories: (i) underwriting business providing insurance services and solutions to policyholders; and (ii) investment business acting as a major institutional investor. For the **underwriting business,** insurance companies mainly face risks of increased liabilities from physical risks, such as more frequent and severe weather events. Most ERA methodologies applied to the insurance sector (especially by property & casualty insurance and re-insurance companies) in this context use catastrophe models (see Box 7) to estimate potential loss and price premia. They also integrate forward-looking climate scenarios in such models to represent the changed patterns of possible future losses compared to historical records. For insurers' **investment business,** ERA models for general asset management (discussed under Section 2.3.2) would be applicable.

Box 7

Catastrophe models used by insurers

The impact of climate change, or in other words the changing intensity and frequency of natural disasters caused by climate change, is mostly not explicitly reflected in current natural catastrophe models. In addition, many catastrophe models used by the insurance industry are designed to support risk assessments for the next 12 months, and a forward-looking approach would therefore not necessarily be supported by these models. Against this backdrop, the insurance industry has recognized that its approach to climate risk modelling and management has to change. Some new models are investigating how climate change can explicitly be modelled. Examples include RMS studies with the OECD in 2007, which looked at the risk of sea level rise to port cities around the world; in 2014, RMS partnered with the Risky Business initiative to examine the effect of sea level rise along the East Coast of the U.S., projected through to 2100. These projects and others looked to establish the economic cost of the effects of climate change.

Corelogic works as well very closely with academic partners to study the impact of climate change on European windstorms for example. They used their European windstorm catastrophe model in combination with a Global Climate Model (GCM) which allowed them to simulate future climates in line with IPCC emission scenarios .

JBA's UK Climate Change Flood Model is a catastrophe model specifically designed to provide an indication of possible future changes to flood risk across the UK. They have taken highly-detailed and complex scientific data and created a functional, forward-looking tool that insurers can use in conjunction with their UK Flood Model.

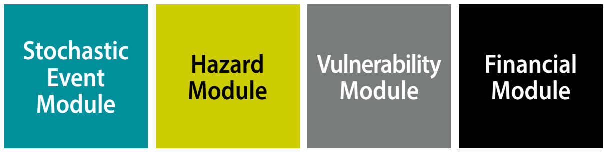
AIR completed a study, funded by the Association of British Insurers (ABI), to evaluate the impact of climate change on losses from inland floods in the United Kingdom, extratropical cyclones (wind) in the United Kingdom, and typhoons (wind and inland flood) in China.

The strategy for each of these models was to use climate change information provided by the UK Met Office Hadley Centre for Climate and Services on how precipitation and wind would change by the end of the century. This information was then used to construct climate change conditioned catalogs.

Methodology

The basic framework for modeling the impacts of climate physical risks (natural hazards) can be broken down into the following four modules, as illustrated by Figure 6:

Figure 6. **Modules of the catastrophe modelling framework by RMS**



Stochastic Event Module: Defining the Hazard Phenomena

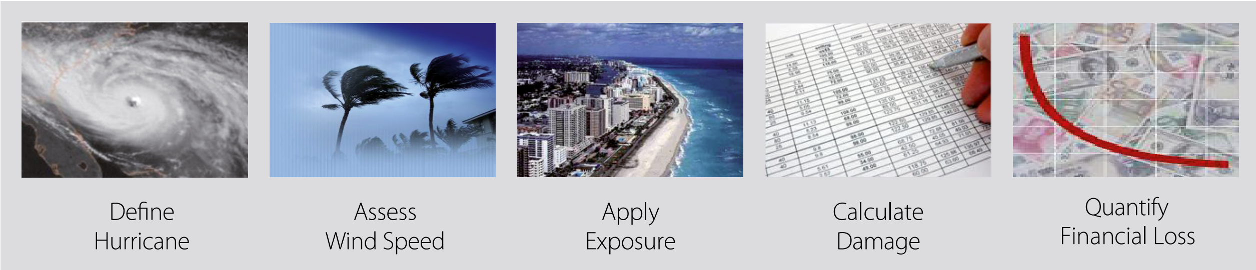
The first stage of catastrophe modeling begins with the generation of a stochastic event set, which is a database of scenario events. Each event is defined by a specific strength or size, location or path, and probability of occurring or event rate. Thousands of possible event scenarios are simulated based on realistic parameters and historical data to probabilistically model what could happen over time.

Hazard Module: Assessing the Level of Hazard

The hazard component of catastrophe models assesses the level of physical hazard across a geographical area at risk. For hurricanes, for instance, a model calculates the strength of the winds around a storm, considering the region's terrain and built environment.

.../...

Figure 7. **Steps of physical risk assessment in a catastrophe model**



Vulnerability Module: Quantifying the Physical Impact of Hazard on insured assets at Risk

The vulnerability component calculates the amount of expected damage to the insured asset at risk. Vulnerability functions are region-specific and vary by the asset at risk's susceptibility to damage. Using properties as an example, a property may be susceptible to damage from earthquake ground shaking or hurricane winds, for example. Parameters defining this susceptibility would include the property's construction material, its occupancy type, its year of construction, and its height. In catastrophe models for insurance applications, different vulnerability curves are used to estimate damage for a structure, its contents, and time element coverages such as business interruption loss or relocation expenses. Damage is quantified as a mean damage ratio, which is the ratio of the average anticipated loss to the replacement value of the building. This module also includes critical estimates of uncertainty around expected damage (i.e., standard deviations). Together, the stochastic event, hazard and vulnerability modules comprise what is traditionally known as a probabilistic risk analysis.

Financial Module: Measuring the Monetary Loss from Various Financial Perspectives

This module translates physical damage into total monetary loss. For insurers, estimates of insured losses are then computed by applying policy conditions (e.g., deductibles, limits) to the total loss estimates.

Losses from a catastrophe run much deeper than just the immediate physical damage, and modeling will also examine the longer-term losses due to business interruption, the need to restore both social and physical infrastructure, and other factors such as the need for construction labor and materials used for recovery. These factors can be as detrimental as the initial losses.

Modeled Output

The main output of a probabilistic catastrophe model is the exceedance probability (EP) curve, which illustrates the annual probability of exceeding a certain level of loss. Typically, EP curves are displayed graphically, but they can also be summarized by key return period loss levels.

For example, a 0.4% annual probability of exceedance corresponds to a 250-year return period loss (i.e., 1/250 = 0.4%). The data for this is derived from the Event or Period Loss Table, which contains a database of all possible independent events for a given peril, and a calculation of the frequency and severity of individual events – all these events are used to total up the average annual loss (AAL).

The AAL is a key risk metric – an estimate of the annual expected losses from the modeled peril(s) over time, assuming that the exposure remains constant. AAL is represented as the area under the EP curve or as the sum product of the mean loss and the annual likelihood of occurrence (i.e., the event rate) for each event in the event set, and can be used to evaluate the catastrophe load portion of an insurance rating function.

Modeled loss results provide valuable insight into the potential severity and frequency of catastrophic losses, and into the volatility of the analyzed risks. The quantification of these components can then be used to assist insurers in adjusting premium pricing.
Source: Chapter 24 of NGFS Occasional Paper on Case Studies of ERA Methodologies; EIOPA (2019c), Opinion on Sustainability in Solvency II.

2.4 Other methodologies

Two alternative methodologies are also used in ERA by FIs. One is **Environment, Social and Governance (ESG) scoring and integration,** used mainly by institutional investors in assessing the "current" ESG performance of the issuers of securities, which may have forward-looking implications. The second, **natural capital risk assessment,** focuses on assessing risk factors that fall into the ecological category, such as water availability and soil quality, and how these risks may impact financial performances of borrowers or other corporates.

2.4.1 Environmental, Social and Governance (ESG) scoring and integration

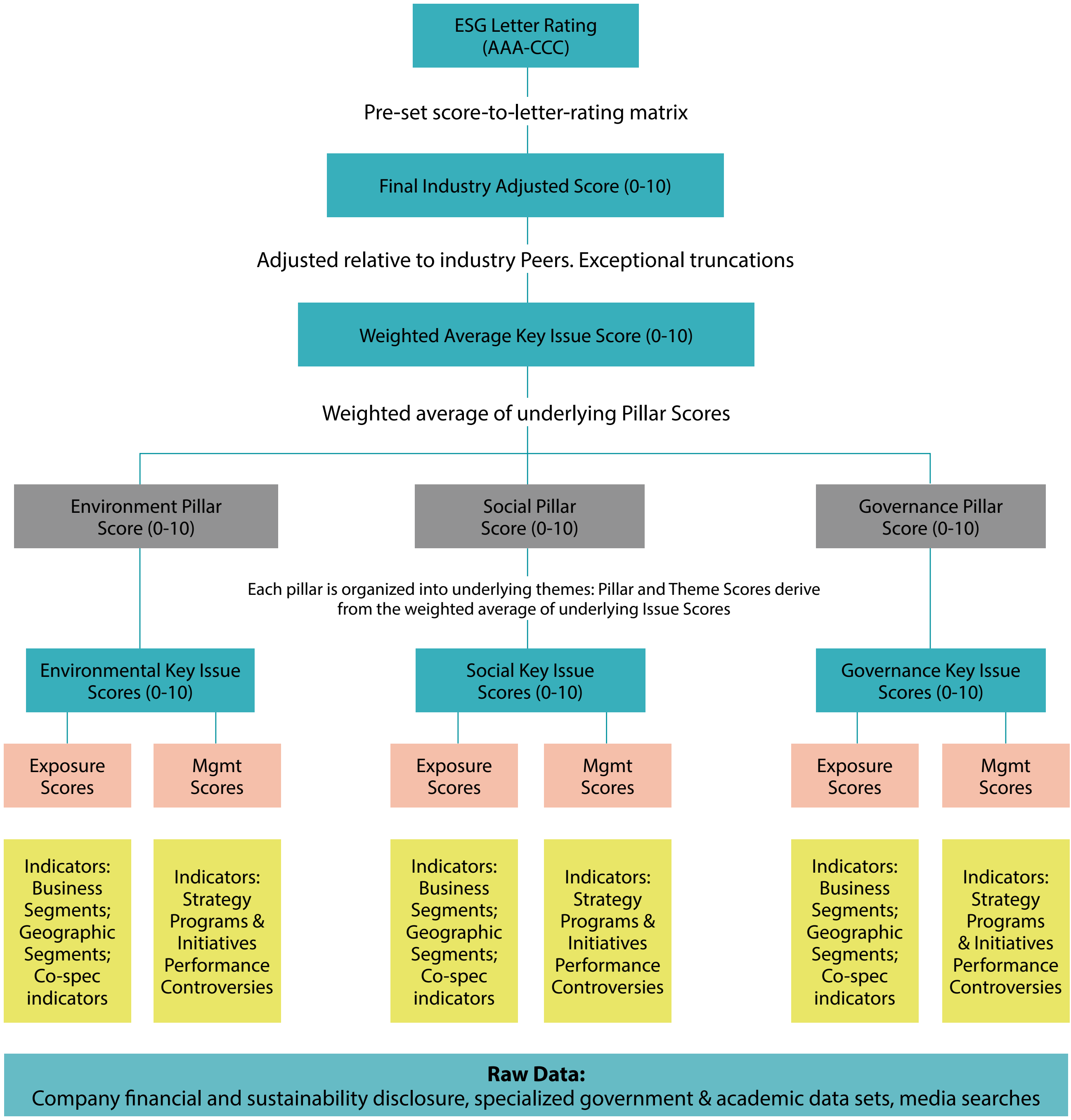
ERA methodologies, often presenting results in the form of scenario analysis and stress tests, focus on forward-looking assessments of the financial implications of environment- and climate-related risks. Investment managers and banks also evaluate the ESG performance of their clients or assets held to facilitate investment/lending decision-making. Some empirical studies show that the ESG performance of listed companies and bond issuers has a positive correlation with their long-term financial performance (BlackRock, 2020; Clark et al., 2015).

ESG scoring and integration methodology can be considered as another major category of tools for assessing environmental risks for investment holdings. The assessment of ESG performance is typically summarized in ESG scores of the securities (e.g., stocks and bonds), which are usually estimated by specialized ESG rating providers. The ESG scores are used (integrated) in the investment management practices for selecting securities with a view to managing the relevant financial risk exposure (e.g., by excluding stocks and bonds of lower ESG scores in the portfolio) and/or capturing upside opportunities (e.g., by giving preference to selecting stocks and bonds with higher ESG scores in the portfolio).

Major credit ratings agencies have incorporated "material" ESG factors in their credit analysis (see Figure 8 and Box 8). "Material" factors are those that increase the likelihood of default and credit loss currently or potential in the future. Several financial data service providers, such as MSCI and Bloomberg, have developed ESG databases that cover most listed companies and bonds. Many asset managers use ESG indicators provided by these data vendors, but some asset managers also developed their proprietary methodologies for ESG scoring and integration. For example, one asset manager constructed an ESG scoring methodology that considered six aspects of environmental performance, including "emissions and energy management", "environmental impact of production", "water management", "reputation risk", "emission reduction initiatives" and "measures of environmental impact". A growing number of banks have initiated ESG analysis of their loan applicants and other clients.

The increasing demand for reliable and timely ESG data has given rise to ESG data providers that use technology – such as artificial intelligence and machine learning algorithms – to screen vast quantities of unstructured data from sources external to a company, such as news articles, NGO reports, social media and other sources. Automated search tools using pre-defined keywords linked to specific ESG issues (e.g., climate change, water scarcity, labor relations, corporate governance) can scan vast quantities of data to identify risk incidents and controversies related to a company's ESG performance and sustainability. This data can then be used to compile ESG scores and metrics, which are used by banks, institutional investors and investment managers for due diligence and risk management (RepRisk, 2020).

Figure 8. **Hierarchy of ESG scores**



Source: Research by MSCI (2019).

Box 8

Application of ESG analysis to credit rating

Moody's Investors Service has developed a methodology to incorporate ESG consideration in credit analysis. In a follow-up to an original 2015 study,[1] Moody's presented a heat map that shows the relative exposure of rated corporate bonds in 84 sectors globally to material environmental risks. The amount of rated debt covered by this global sector review is $74.6 trillion, up 10% from its 2015 edition.

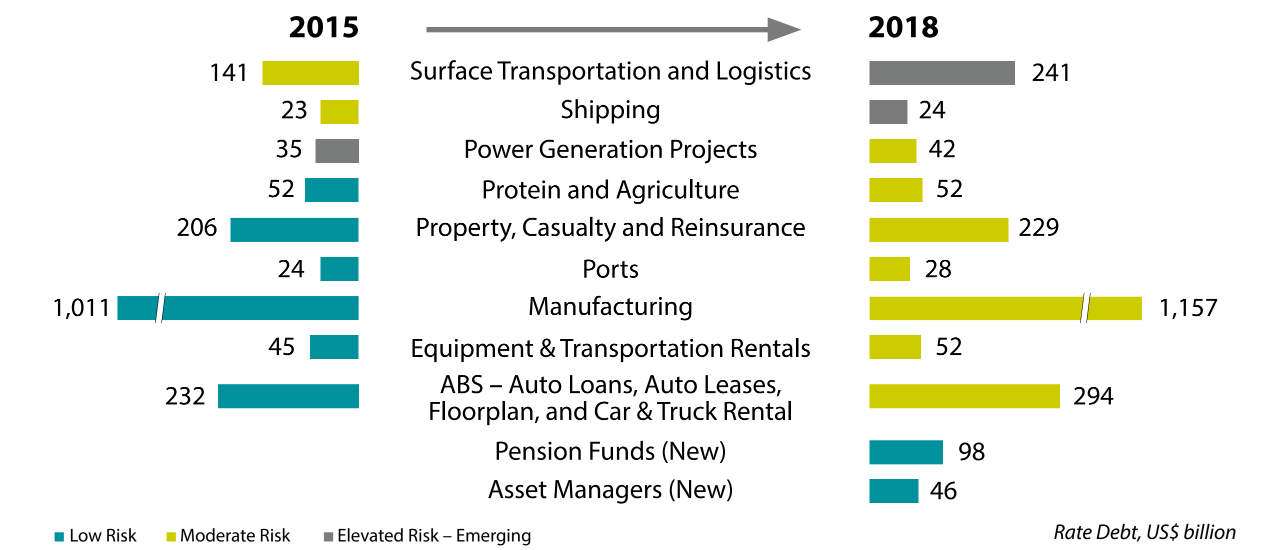
The heat map provides a high-level assessment of the materiality of environmental risks to a sector's overarching credit quality, and the nominal exposure of a sector to the five most material subcategories of environmental risks: air pollution; soil and water pollution, and land use restrictions; carbon regulations; water shortages; and natural and man-made hazards.

The heat map identifies 11 sectors, totaling roughly $2.2 trillion in rated debt, with elevated credit exposure to environmental risks. Again, this represents a 10% increase in rated debt from 2015. In Moody's view, these sectors have clear exposure to environmental risks that are either already material to credit quality or could be over the next three to five years.

The relative scoring in their 2018 environmental risks heat map remains largely stable since Moody's 2015 edition. However, there have been a number of changes in overall scoring, as illustrated in Figure 9. Shipping, and surface transportation and logistics are now scored as "Elevated Risk – Emerging," compared with "Moderate Risk" previously, reflecting a gradual tightening of environmental regulations and emissions standards. Six sectors accounting for $1.8 trillion in rated debt move to "Moderate Risk" from "Low Risk." While the rationale for these changes is sector-specific, the change to scores generally reflects the view that the potential for environmental risks to become material for these sectors over five or more years has increased. Meanwhile, power generation projects move down to "Moderate Risk" from "Elevated Risk – Emerging," as a result of a shift in their rated portfolio toward renewable generation. Finally, two new sectors – pension funds and asset managers – have been added, both scoring "Low Risk."

Figure 9. **Changes in overall sector environmental risk scores since 2015**

Heat map score and rated debt, US$ billion



Note: For 2015 heat map, see "Environmental Risks: Heat Map Shows Wide Variations in Credit Impact Across Sectors", November 2015.

Source: Chapter 27 of NGFS Occasional Paper on Case Studies of ERA Methodologies.

1 See "Environmental Risks: Heat Map Shows Wide Variations in Credit Impact Across Sectors", Moody's Investors Service, November 2015.

2.4.2 Natural capital risk assessment

In 2016, a coalition including environmental NGOs, companies and accounting organizations published the natural capital protocol, which called for the application of the natural capital risk assessment (NCRA). NCRA is a toolkit to help businesses measure and value the natural services that they rely on and their natural capital liabilities, which include the environmental damage that may result from their operations. Natural capital in this context refers to factors that fall into the ecological category that may have an impact on production activities, such as the quantity of natural capital (e.g., water availability, soil depth), quality of natural capital (e.g., water, air or soil quality) or the availability of ecosystem services (e.g. water filtration or pollination).

The aim of natural capital risk assessment is to identify the natural capital risks likely to be material to corporates and investments in securities. Currently, the most relevant and studied sector is agriculture, given its relevance to both the impacts and dependencies on natural capital. As in the case of National Australian Bank, the risk assessment model in this sector evaluates the future trend of these natural capital risks and their potential impacts on agricultural production, which in turn could determine farmers' profitability and therefore ability to repay their loans. Table 5 below presents the key risk indicators used in a case study of NCRA on Australian's wheat production for assessing credit risks for bank lending. The end result of NCRA could take the form of a 'traffic lights' system which classified loan applicants' natural capital risks into high, medium, and low risks. These risk measures can be factored into a bank's overall loan decision-making process.

Table 5. **Example risk factors, possible indicators and potential data sources for wheat farming in Australia**

Thematic area	Risk area	Risk factor	Indicator	Risk mitigation evidence
Water	Water availability	Growing season rainfall	Millimetres of rainfall during growing season for the region (historical average)	Farmer's ability to use rainfall prediction tools and adapt accordingly
		Rainfall reliability	Variability index for the above	
	Water use	Water use efficiency	Total annual millimetres of rainfall divided by tonnes of wheat yield (historical averages)	Farmer's ability to improve water use efficiency
	Water quality	*Not applicable*	*Not applicable*	*Not applicable*
Weather and climate	Temperature extremes	Heat stress	Total annual high degree hours (historical average)	Farmer's ability to use temperature prediction tools and adapt accordingly
		Frost damage	Total annual frost days (historical average)	
	Extreme weather	Floods, cyclones, hailstorms, bushfires, drought	Number of significant events in last 10 years	Farmer's ability to use extreme event prediction tools and adapt accordingly
Land and soil	Soil quality	Soil acidity	Percentage of crop area with soil pH < 4.5	Farmer's ability to monitor and actively manage these risks
		Soil salinity	Percentage of crop area with soil salinity >100 mM/L	
		Soil organic carbon	Percentage of crop area with soil organic carbon < 1% in top 10 cm	
		Soil erosion	Percentage of farm with ground cover < 50%	
	Fertiliser	Fertiliser use	Total tonnes of fertiliser used divided by application area (historical average)	Farmer's ability to monitor and actively manage these risks
			Fertiliser cost as % of total farm costs	
		Fertiliser application	Partial Nutrient Balance (kg nutrient removed from soil/kg applied)	
			Partial Factor Productivity (kg yield/kg nutrient applied)	
			Kilogrammes of nitrates released to surface water	

…/…

Biodiversity and ecosystems	Biodiversity	Extent and/or quality of biodiversity	% of land set aside for biodiversity/native vegetation	Farmer's awareness of biodiversity and implementation of conservation strategies
			Quality of biodiversity	
	Weeds, pests and diseases	Rate and/or severity of incidents	Cost per hectare of weeds, pests and diseases control (historical average)	Farmer's capacity and equipment to respond to weeds, pests or diseases outbreaks
	Animal welfare	*Not applicable*	*Not applicable*	*Not applicable*
		Cost of carbon	Greenhouse gas emissions cost as % of total farm costs	
	Other air emissions	Other emissions intensity	Total tonnes of other air emissions divided by tonnes of wheat yield	Farmer's ability to monitor other air emissions and implement emission reduction measures

Source: Ascui & Cojoianu (2019b), as quoted in Chapter 8 of NGFS Occasional Paper on Case Studies of ERA Methodologies.

3 Gaps in ERA analysis and applications

While an increasing number of financial supervisors and FIs have recognized the significance of ERA for ensuring financial stability and the resilience of FIs to environment- and climate-related risks, their application remains limited. Consultation meetings with a few dozen FIs indicate that only a fraction of large FIs in OECD countries and China have begun to utilize some ERA methods for assessing environmental risks and many of these applications remain at the experimental stage. Many FIs are not yet engaged, and most small FIs, especially in developing countries, have limited awareness of ERA. This finding is also consistent with the NGFS Status Report on Financial Insitutions Experiences from working with green, non green and brown financial assets and a potential risk differential.

The barriers to wider ERA applications may include the following:

1) A lack of awareness of environmental risks and appreciation of their relevance

Many FIs, especially those in developing countries, remain unaware of the significance of environmental risks and their potential implications on their operations. This is in part due to the lack of public knowledge, such as media coverage and education, and the lack of clear and explicit expectations from central banks and other regulators. In recent years, many FIs in OECD countries have gained awareness of climate-related risks, in part due to the efforts of the NGFS, but some of them remain largely unconcerned, partly because their investee companies or borrowers have yet to be significantly impacted by these risks, and partly because such risks are perceived to be distant and imprecise.

2) Inadequate environmental and loss data

Effective ERA requires granular data that describe the environmental aspects of companies and securities, historical patterns of environmental and climate changes, associated losses, forward-looking scenarios and assumptions for future environmental and climate changes and losses, as well as impacts of such changes on economies, sectors and companies. To a varying degree, the lack of appropriate data forms another barrier to ERA applications.

In some jurisdictions, where corporates and FIs look to regulators for developing or recommending specific green and brown taxonomies, the absence of such taxonomies becomes a key bottleneck for ERA. Without taxonomies, corporates and FIs are unable to clearly define and measure their green and brown activities, and FIs are therefore unable to clearly quantify their green and brown exposures which makes it more difficult to conduct ERA.

In some jurisdictions, there is a lack of regulatory guidance and standards for ESG information disclosure. While other jurisdictions have disclosure requirements, the reported data are not sufficiently granular nor appropriate for risk assessment purposes. There are many sources of publicly available environmental information (G20 GFSG, 2017), but many of them are not presented in a usable or friendly format for FIs, or are not easily accessible to FIs.

3) Limited capacity to develop ERA methodologies

For a typical financial firm, the development of ERA tools and models requires significant resources, including researchers specializing in economics, finance, environment, climate and statistics, and spending on manpower, data, and consultants. When the urgency or future benefits of such analysis remains unclear, the high cost of development, which is immediate, tends to deter many FIs from investing in such an effort. Another explanation for the lack of investment in ERA methodologies is that many ERA components are public goods eventually to be used widely, but there are no mechanisms for sharing the R&D spending or access to data.

4) Limited application to environment-related risks and emerging market economies

Compared with the methodologies for assessing climate risks, risk metrics and ERA methods for assessing environment-related risks (e.g., pollution, water risk, and biodiversity losses) – which are of greater concerns in many developing countries than in OECD countries – are less developed. While many developing countries (e.g., some African and ASEAN countries) are facing greater challenges due to climate change and environmental degradation, their financial sector's awareness of environmental risks and capacities for conducting ERA are much more limited than those of OECD countries.

5) Gaps in methodologies and data quality

a. Most ERA methodologies available today focus on the transmission of environmental risks to financial risks via the corporate channel, by working out the impact of environmental/climate scenarios on financial statement and then using the results for quantifying the credit and market risks for investments/loans in financial models. These approaches tend to ignore the macroeconomic feedback loop despite the fact that environmental and climate changes may well impact many macroeconomic and macro-financial variables that will drive company performance. The lack of "feedback" analysis reflects the underdevelopment of methodologies for capturing the complex mechanisms of risk transmission between the real economy, energy sector and the financial system.

b. Very few transition risk analyses have taken into account future adaptive measures of the affected entities in estimating their future financial performance (e.g., energy companies' internal efforts to allocate resources to renewable energies). This problem may result in some overestimation of financial risks arising from FIs' exposure to such entities.

c. Most physical risk analyses focus on direct physical damages on properties, infrastructure and agriculture assets, with limited reference to impact of climate events on variables affecting firms' operating environment. For example, it has been challenging for these analyses to quantify the relationships between natural disasters and the resulting damages to local economic growth, household income, unemployment rate, and supply chain conditions.

d. Most ERA studies by NGOs and academic institutions focus on listed equities and publicly traded bonds, as data for these securities are more readily available. This also means that environment- and climate-related risks are under-researched in sectors such as commercial banking, private equity, real estate and infrastructure.

e. The baseline, business-as-usual (BAU), scenario selected in many models directly impacts the magnitude of results under the policy (or transition) scenario. Selecting a baseline scenario requires an implicit assumption on the current level of policy and technical developments, which directly affects results. The fact that there is currently no widely accepted baseline scenario makes it difficult to compare results from different studies.

f. On ESG ratings, one major issue is the inconsistency in data definitions between different data vendors. A related issue is the lack of transparency on the methodologies used to develop ESG ratings. A study published by MIT and University of Zurich found that "measurement divergence" (i.e., the different ways ESG criteria are measured) explains more than 50 percent of the variations across ESG ratings (Berg et al., 2019). In terms of data used, many ESG data vendors rely heavily on counterparties' self-reported information which may not be sufficiently reliable.

4 Options for mainstreaming ERA

Given the growing recognition by NGFS members of the significance of environment- and climate-related risks to the resilience of the financial system, and the usefulness of ERA approaches in helping FIs to identify and manage such risks, some collective efforts are needed – by FIs, industry associations, central banks and financial supervisors, NGFS, international organizations (IOs), third party vendors, and academic institutions – to promote wider ERA applications in the financial sector. **In the following, we summarize several options for mainstreaming ERA,** many of which have appeared in other NGFS publications such as *A Call for Action: climate change as a source of financial risk* (NGFS, 2019a), *Macroeconomic and Financial Stability Implications of Climate Change* (NGFS, 2019b), *Guide for Supervisors – Integrating climate-related and environmental risks into prudential supervision* (NGFS, 2020a), A *Status Report on Financial Institutions' Experiences Working with Green, Non-green and Brown Financial Assets and a Potential Risk Differential* (NGFS, 2020d).

4.1 Enhancing awareness of the need for ERA

Central banks and financial supervisors should strive to enhance ERA awareness among FIs, including by: conducting ERA themselves to assess the impact of environmental factors on financial stability; clarifying the expectations for FIs to assess and manage environment- and climate-related risks; sending policy signals that FIs' disclosures of ERA results could be made a semi-compulsory or compulsory requirement in the future (NGFS, 2020a).

Industry associations servicing the financial community, NGOs and academic institutions and the media can also help to raise awareness by advocating the relevance of environment- and climate-related risks to financial stability and the green transition of the financial system via publications, seminars, and public-private sector dialogues. Such public efforts should highlight that the impact of many transition risks (e.g., those associated with energy transition) could be felt much earlier and risk hedging and mitigation are feasible even as many physical risks associated with climate change may be visible only in the longer term.

4.2 Developing analytical capacity and databases

Industry associations, central banks and supervisors, IOs, NGOs and academic institutions could organize seminars and training activities on ERA methodologies, with some results delivered as public goods to the financial industry. These organizations could host or signpost ERA-related information on their websites, including working papers, case studies, as well as publicly available environmental data, models and tools. In developing ERA tools for internal use, FIs, central banks and supervisors that lack internal resources could work with external vendors, academic institutions and NGOs that have invested substantially in this area.

4.3 Supporting demonstration projects

The NGFS, IOs, central banks and supervisors should consider supporting (by organizing and/or mobilizing research grants) a few demonstration ERA projects in key sectors such as banking, insurance and asset management, and for key regions exposed to substantial environment- and climate-related risks. For example, an ERA demonstration project for analyzing transition risks to carbon-intensive assets may prove useful to a wide range of FI users. Demonstration projects for analyzing risks associated with water shortages, pollution and biodiversity losses could also help speed up methodological progress and enhance capacities in these areas. It may also be useful to support some case studies, especially in developing countries, to understand with more granularity the potential impact of physical and transition risks on regions highly vulnerable to environment- and climate-related risks (e.g., those with heavy dependence on fossil fuels or subject to higher risks of droughts and extreme weather events).

4.4 Encouraging disclosures of environmental risk exposures and ERA results

As stated in NGFS (2019a), the NGFS emphasizes the importance of a robust and internationally consistent climate and environmental disclosure framework. In countries where tools and capacity are relatively more developed, central banks and supervisors can encourage disclosures of FIs' exposures to environment- and climate-related risks (e.g., percentages of portfolios in high carbon assets and in heavily-polluting industries) and their ERA results (including environmental stress tests and scenario analyses) in line with TCFD recommendations. Semi-compulsory (e.g., the "comply or explain" requirement) or compulsory disclosures can be considered when capacities are further enhanced.

As FIs' abilities to produce decision-useful disclosures depend critically on disclosures by firms in the real economy, central banks and financial supervisors could work with securities regulators and exchanges as well as environmental ministries to improve corporate reporting on environmental and climate-related information and to ensure the reported information is user-friendly to FIs and market participants. Industry associations and NGOs can also organize pilot projects for environmental information disclosures by corporates and FIs for demonstration purposes.

4.5 Developing Key Risk Indicators (KRI) and statistics

The NGFS and relevant IOs can conduct research and encourage market bodies and academic institutions to develop key risk indicators to identify and measure the most important environment- and climate-related risks with financial implications and enable data comparability and aggregation. Such indicators could be developed along sector lines (e.g., commercial banking, asset management, and insurance). Once developed, these indictors can be used as the basis for compiling environmental risk statistics for the financial sector at both country and global levels. Such statistics will be useful for monitoring and assessing the levels and changes of environment- and climate-related risks a country or the global financial sector is exposed to, and will enable forward looking risk analysis on an aggregate basis. They could also contribute to a better understanding of risk classifications, potential mitigants and recommended actions.

4.6 Supporting the development and adoption of green and brown taxonomies

NGFS (2019a) called for policymakers to bring together the relevant stakeholders and experts to develop a taxonomy that enhances the transparency around which economic activities (i) contribute to the transition to a green and low-carbon economy and (ii) are more exposed to environment- and climate-related risks (both physical and transition). In jurisdictions where the lack of green or brown taxonomies forms a barrier to green finance development and environment- and climate-related risk analysis, regulators could take initiatives in developing such taxonomies or encouraging the adoption of certain international taxonomies that are already available. For jurisdictions that need help in taxonomy development, IOs and NGOs could provide assistance. International platforms and relevant IOs, such as the International Platforms for Sustainable Finance (IPSF) and the ISO Technical Committee on Sustainable Finance, could explore options for harmonizing green and sustainable finance taxonomies.

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List of acronyms

AAL	Average Annual Loss
BAU	Business-As-Usual
BCBS	The Basel Committee on Banking Supervision
BGS	Brown-Green-Score
BMBF	German Federal Ministry of Education and Research
BMG	Brown-Minus-Green
CARIMA	Carbon Risk Management
CGE	Computable General Equilibrium
COGs	Cost of Goods Sold
DSCR	Debt Service Coverage Ratio
EAD	Exposure At Default
EBITDA	Earnings Before Interests, Taxes, Depreciation and Amortization
EL	Expected Loss
EP	Exceedance Probability
EPR	Extended Producer Responsibility
ERA	Environmental Risk Analysis
ESG	Environmental, Social and Governance
EVs	Electric Vehicles
FIs	Financial Institutions
GIZ	The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
IAMs	Integrated Assessment Models
IAIS	International Association of Insurance Supervisor
ICBC	Industrial and Commence Bank of China
IEA	International Energy Agency
IIASA	The International Institute for Applied Systems Analysis
IOs	International Organizations
IPCC	Intergovernmental Panel on Climate Change
IPSF	International Platforms for Sustainable Finance
IRB	Internal Ratings Based Approach
JGCRI	Joint Global Change Research Institute
KRI	Key Risk Indicators
LGD	Loss Given Default

LTV	Loan-To-Value
NCD	Natural Capital Declaration
NCRA	Natural Capital Risk Assessment
NGFS	The Network of Central Banks and Supervisors for Greening the Financial System
NPLs	Non-Performing Loans
OECD	Organization for Economic Co-operation and Development
PD	Probability of Default
PIK	Potsdam Institute for Climate Research
RCRA	Resource Conversation and Recovery Act
RMS	Risk Management Solutions
RCP	Representative Concentration Pathway
SSPs	Shared Socioeconomic Pathways
TCFD	Task Force on Climate-related Financial Disclosures
TEV	Total Economic Value
UNEP	United Nations Environment Programme
USGCRP	The U.S. Global Change Research Program
VaR	Value-at-Risk
VfU	Der Verein für Umweltmanagement und Nachhaltigkeit in Finanzinstituten e.V. (VfU) in German; in English The German Association for Environmental Management and Sustainability in Financial Institutions

Glossary[14]

Brown asset	Polluting or high-carbon asset, according to the terminology commonly used in the financial industry.
Business-as-usual (BAU)	A scenario based on the assumption that no mitigation policies or measures will be implemented beyond those that are already in force and/or are legislated or planned to be adopted.[15]
Collateral	An asset or third-party commitment that is used by a collateral provider to secure an obligation vis-à-vis a collateral taker.[16]
Credit risk	The potential that a bank borrower or counterparty will fail to meet its obligations in accordance with agreed terms.[17]
ESG integration	An SRI strategy that aims at enhancing traditional financial (risk) analysis by systematically including ESG criteria in the investment analysis to enhance risk-adjusted returns.[18]
ESG scoring	The scoring methodologies assessing a company's performance in environmental, social and governance aspects based on different approaches, such as generating a final numeric score based on weighted scores of indicators in the three dimensions.[19]
Exposure	The inventory of elements/assets exposed to a hazard or risk.[20]
Green asset	Asset that provides environmental benefits in the broader context of environmentally sustainable development.[21]
Hazard	Potential events with possibilities of occurrence and severity of any particular potential disaster, such as a tropical storm or flood, at a given location, within a specified time period.[22]
Legal risk	The risk of a loss being incurred on account of the unexpected application of a law or regulation, or because a contract cannot be enforced.[23]
Liquidity risk	The risk that the firm will not be able to meet efficiently both expected and unexpected current and future cash flow and collateral needs without affecting either daily operations or the financial condition of the firm.[24]

14 Definitions, unless otherwise indicated, are taken from the occasional papers or this article.

15 Adapted from IPCC reports (Allen et al., 2014). Note that BAU is defined at a general conceptual level here, thus the acute definition of it depends on the purposes of the studies and varies in terms of detailed assumptions.

16 Adapted from glossary of online database of European Central Bank (2020).

17 Adapted from BCBS Publications (BCBS, 2000).

18 Adapted from technical documents by NGFS (2019c).

19 Note that ESG scoring methodologies varies according to users and purposes, thus the definition here is a general conclusion based on some ESG scoring practices by institutions like AXA Investment Managers (2020).

20 Adapted from background papers commissioned by the Global Commission on Adaptation to inform its 2019 flagship report (Stadtmueller et al., 2019).

21 Adapted from the definition of "green finance" in the report by Green Finance Study Group (2016). Please note that the scope and definitions of "green" now still varies across institutions according to different purposes (See OECD publication by Inderst et al., 2012).

22 Adapted from background papers commissioned by the Global Commission on Adaptation to inform its 2019 flagship report (Stadtmueller et al., 2019).

23 Adapted from glossary of online database of European Central Bank (2020).

24 Adapted from publication of BCBS (2008).

Market risk	The risk of losses arising from movements in market prices of assets, including but not limited to equities, bonds, foreign exchanges, and commodities.[25]
Non-performing loans (NPLs)	Loans that satisfy either or both of the following criteria: (a) material exposures which are more than 90 days past due; (b) the debtor is assessed as unlikely to pay its credit obligations in full without realisation of collateral, regardless of the existence of any past-due amount or of the number of days past due.[26]
Operational risk	The risk of loss resulting from inadequate or failed internal processes, people and systems or from events, including legal risk, but excludes strategic and reputational risk.[27]
Physical risks	Economic costs and financial losses resulting from the increasing severity and frequency of extreme climate change-related weather events (such as heat waves, landslides, floods, wildfires and storms) as well as longer term progressive shifts of the climate (such as changes in precipitation, extreme weather variability, ocean acidification, and rising sea levels and average temperatures), and rises in sea levels. In addition, losses of ecosystem services (e.g., desertification, water shortage, degradation of soil quality or marine ecology), as well as environmental incidents (e.g., major chemical leakages or oil spills to air, soil and water/ocean) also fall into the category of physical risks.[28]
Representative Concentration Pathway (RCP)	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover. The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term pathway emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome.[29]
Shadow price of water	In order to include environmental indicators in economic analysis, their costs and benefits need to be expressed in monetary terms.Due to inadequate market pricing or regulation, the price paid for water often does not reflect the actual costs and benefits of water to all potential users at its source. Therefore, it is necessary to adjust the price paid by users to reflect a more accurate valuation of the resource. The resulting adjusted or estimated price is called a "shadow price".
Stress test	The evaluation of an FI's financial position under a severe but plausible scenario to assist in decision making within the FI. The term "stress testing" is also used to refer not only to the mechanics of applying specific individual tests, but also to the wider environment within which the tests are developed, evaluated and used within the decision-making process.[30]
Total economic value	The Total Econnomic Value (TEV) concept is drawn from environmental economics. A TEV framework provides a structured approach to estimating the economic value of the benefits that environmental assets provide to society.

25 Adapted from publication of BCBS (2016).

26 Adapted from glossary of online database of European Central Bank (2020).

27 Adapted from publication of BCBS (2011).

28 Partly adapted from NGFS (2019a). Note that the definitions of physical and transition risks in this work are slightly different from (i.e. broader than) the definitions provided in the NGFS first comprehensive report. In the NGFS first comprehensive report, physical and transition risks only focus on climate-related impacts, while in this report both environment and climate-related risks/impacts are taken into account.

29 Adapted from IPCC (2014) and TCFD (2017a).

30 Adapted from publications of BCBS (2009).

Transition risks

The risks relate to the process of adjustment towards a low-carbon economy. The process of reducing emissions is likely to have significant impact on all sectors of the economy affecting financial assets values.[31]

Underwriting risk

The loss on underwriting activity in the insurance or securities industry.[32] For insurance industry, is the risk that an insurance company will suffer losses because the economic situations or the occurring rate of incidents have changed contrary to the forecast made at the time when a premium rate was set.[33]

Vulnerability

The level of damage which would be expected at different levels of intensity of a hazard. For example, when a storm surge hits an area with weak building regulations and few flood mitigation measures, it is more vulnerable to loss compared to an area that has strong flood control infrastructure and strong building regulations. Vulnerability assessment may include secondary impacts such as business interruption.[34]

Water stress

Water stress measures the ratio of total water withdrawals in a catchment in a given year (the sum of domestic, industrial, and agricultural) to the total available water (the amount available to the same catchment averaged over a long period). Higher values indicate more competition among users. Water stress is one independent element of the shadow price calculation, alongside population. This paper uses the terms water stress and water scarcity interchangeably.

31 Adapted from NGFS (2019a). In its work, the NGFS has incorporated the risk associated with emerging legal cases related to climate change for governments, firms and investors, e.g. liability risks, as a subset of physical and transition risks (NGFS, 2019a). See also footnote 28.

32 Adapted from Kumar (2014).

33 Adapted from inspection manual papers published online by FSA Japan (2020).

34 Adapted from background papers commissioned by the Global Commission on Adaptation to inform its 2019 flagship report (Stadtmueller et al., 2019).

Appendix 1 Classification of environmental and climatic sources of financial risks and examples

Physical Risk	Sub-category	Examples and damages
Extreme weather events	Tropical cyclones/ typhoons	A NBER study shows that in the US, cyclone events will generate a long-term disturbance that will reduce 7.4% of GDP growth in 20 years, equivalent to off-setting 3.7 years of average development.[35] A CICERO report states, Hurricane Harvey in Texas caused $125 billion in damage into total; by sectors, outage peak of 10,000 MW of electricity capacity, oil production declined by 21% and industries had to close down for about one week, port traffic was delayed for more than a week, 107 deaths occurred and about 50,000 homes were destroyed.[36] Another study by Blackrock shows that physical exposure of properties to hurricane damage will rise by as much as 275% by 2050 due to the higher frequency and intensity of hurricanes.[37]
	Floods	According to Accenture,[38] 30% of companies surveyed attributed 5% of their lost revenue to the disruption of their supply chains. Another study by Zurich Group[39] revealed that 51% of supply chains were affected by adverse weather over the past year. 49% of businesses lost productivity from such disruption, while their costs increased by 38% and their revenue decreased by 32%. One notable example is the 2011 flood in Thailand. Thailand's automobile and electronic manufacturing sector was completely halted, making up 80% of the total economic loss in the country. Most factories stopped production for over 30 days, disrupting supply chains and reducing annual automobile production by 20%. 17.5% of the factories were completely destroyed and could not resume operations. This led to Toyota and Honda losing almost 60% of net profits in 2011 compared to the previous year.[40]
	Winter storms	The Atlantic reported that winter storm Jonas in the US caused an economic loss of $1 billion and 12,000 cancelled flights in a mere three days in 2016.[41] According to the US Meteorological Society, there is a visible trend of increasing frequency and intensity of winter storms from 1950 to present,[42] and this trend is likely to continue with the catalyst of global warming.[43] According to the MCA of China, the winter storms in 2008, made over 2 million people homeless and caused an economic loss of RMB 151.6 billion in China.[44]
	Heat waves	The American media web Vox reported that the heat wave in Europe on June-July 2019 brought Central Europe into extreme temperatures of 45 °C, causing 30,000 direct and indirect deaths and an economic loss of €13 billion.[45] The USGCRP indicated, as global warming exacerbates, heat waves occurring in the US has increased three-fold in the past 50 years.[46] Deryugina and Hsiang pointed out that more frequent hot days can reduce workers' productivity by as much as 28% and slow down national annual economic growth by 0.12%; Intuitively, a weekday above 30 °C costs an average county in the United States $20 per person.[47]

35 Hsiang S.M & Jina A.S. The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence From 6,700 Cyclones. National Bureau of Economic Research Working Paper No. 20352 (2014). Retrieved from *https://www.nber.org/papers/w20352.pdf*
36 CICERO, Climate & Environmental Risks, 2019.
37 Blackrock (2019). Getting physical: Scenario analysis for assessing climate-related risks. Retrieved from *https://www.blackrock.com/us/individual/literature/whitepaper/bii-physical-climate-risks-april-2019.pdf*
38 Bolgar, C. (2007). "Corporate resilience comes from planning, flexibility and the creative management of risk." The Wall Street Journal: A12.
39 Zurich Financial Service Group and Business Continuity Institute (2011). Supply Chain Resilience 2011. Zurich.
40 Haraguchi, M. and U. Lall (2015). "Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making." International Journal of Disaster Risk Reduction 14: 256-272.
41 The Atlantic. How Much Did Jonas Cost the Economy? Retrieved from *https://www.theatlantic.com/business/archive/2016/01/cost-jonas-storm-2016/426816/*
42 Vose R.S. et al. Monitoring and understanding changes in extremes: Extratropical Storms, Winds, and Waves. Bull. Amer. Meteor. Soc., 95, 377–386, *https://doi.org/10.1175/BAMS-D-12-00162.1*
43 NASA Earth Observatory. The Impact of Climate Change on Natural Disasters. Retrieved from *https://earthobservatory.nasa.gov/features/RisingCost/rising_cost5.php*
44 Chinese Ministry of Civil Affairs. The ministry of civil affairs reported the situation of the disaster caused by the recent freezing of cold rain, snow and disaster relief. Retrieved from *https://web.archive.org/web/20080228023927/http://www.mca.gov.cn/article/zwgk/mzyw/200802/20080200011960.shtml*
45 Vox. 113 degrees in France: why Europe is so vulnerable to extreme heat. Retrieved from *https://www.vox.com/world/2019/6/26/18744518/heat-wave-2019-europe-france-germany-spain*
46 GlobalChange.gov. Heat waves. Retrieved from *https://www.globalchange.gov/browse/indicators/us-heat-waves*
47 Deryugina T. & Hsiang S.M. Does the environment still matter? Daily temperature and income in the United States. National Bureau of Economic Research. Working Paper 20750.

Extreme weather events	Droughts	One report by UC Davis stated that California experienced persistent drought conditions from 2011 to 2017, during which $2.7 billion of value was lost solely in 2015. The drought cut 21,000 jobs, mainly in the agricultural sector.[48] The drought also resulted in a decline in local fishery output by 60-95%.[49]
	Wildfires	According to Sacremento Bees, California utility PG&E has filed bankruptcy due to settling 30,000+ claims totaling $25.5 billion, which are associated with the consecutive wildfire in 2017-2019.[50] Solely in 2018, 58,083 wildfires have occurred in the US, 8,767,492 acres burned, and resulted in an estimated economic loss of $400 billion.[51] AccuWeather estimates the total damage and economic loss caused by the Australia wildfires from September 2019 and into 2020 will be $110 billion, based on an analysis incorporating independent methods to evaluate all direct and indirect impacts of the fires based on a variety of sources.[52] A decadal comparison shows that over the last 20 years, annual burned acreage doubled compared to the 90s.[53]
	Hailstorms	One study stated that during the past five years, claims related to wind and hail damage in the US accounted for almost 40 percent of all insured losses, averaging approximately $15 billion annually. There were 6,045 major hail storms in 2017, and more than 10.7 million US properties were affected by one or more damaging hail events in 2017.[54]
Ecosystem pollution	Soil pollution and degradation	According to UNFAO, in South Asia, land degradation is costing the region an economic loss of the order no less than US$10 billion every year, equivalent to 7% of their combined agricultural gross domestic product.[55] UNDP predicts that by 2050, the combination of land degradation and climate change will reduce global crop yields by 10-50%.[56]
	Air pollution	WHO report shows that about 6 million people die prematurely due to air pollution every year, and over 90% of these premature deaths are in developing countries.[57]
	Water pollution	According to EPA, in the US, the overuse of fertilizers and pesticides has raised the cost of producing freshwater by over 40-fold (from $0.1 to over $4 per ton)[58], and algae blooms from nutrient-rich waters have generated $500 million of economic loss annually since 1987.[59] Based on an analysis by the WEF, in developing countries, municipal and industrial waste constitute the main pollutants, e.g. water pollution in India has reduced its regional GDP growth by ~33%.[60]
	Marine pollution	A recent study by Beaumont states that plastic pollution in the world's oceans would lead to a decline in marine ecosystem service delivery valued at $2.5 trillion a year.[61] Research has shown that if plastic pollution [continues at the current pace], there would be more plastic than fish in the ocean by 2050.[62] Besides, chemicals, toxins and acidification also pose serious threats to ocean creatures.

48 Howitt R, et al. Economic Analysis of the 2015 Drought for California agriculture. Center for Watershed Sciences, University of California – Davis, Davis, CA, 16 pp.
49 Sabalow R. Why California's most productive salmon hatchery is millions of fish short. The Sacremento Bees (Dec 26, 2017). Retrieved from *https://www.sacbee.com/news/california/water-and-drought/article191351274.html*
50 Kasler D. & Bollag S. Bankrupt PG&E increases offer to California wildfire victims. Here's the utility's new plan. Sacremento Bees (Nov 18, 2019). Retrieved from *https://www.sacbee.com/news/california/article237489584.html*
51 Insurance Information Institute. Facts+Statistics: Wildfires. Retrieved from *https://www.iii.org/fact-statistic/facts-statistics-wildfires*
52 AccuWeather. Retrieved from *https://www.accuweather.com/en/business/australia-wildfire-economic-damages-and-losses-to-reach-110-billion/657235*
53 CoreLogic. 2019 Wildfire Risk Report. Retrieved from *https://storymaps.arcgis.com/stories/cb987be2818a4013a66977b6b3900444*
54 Verisk (2017). Hail: The Hidden Risk - An analysis of property exposure to damaging hail in 2017. Retrieved from *https://www.verisk.com/siteassets/media/campaigns/gated/underwriting/2017-hail-the-hidden-risk.pdf*
55 UNFAO (1994). Land degradation in south Asia: Its severity, causes and effects upon the people. Retrieved from *http://www.fao.org/3/v4360e/V4360E00.htm*
56 UNDP (2019). Combating Land Degradation, Securing a Sustainable Future. Retrieved from *https://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_land_management/combatting-land-degradation---securing-a-sustainable-future.html*
57 WHO website: *https://public.wmo.int/en/media/press-release/wmo-and-who-tackle-health-impacts-of-pollution-extreme-weather-climate-change*.
58 EPA. Nutrient Pollution. Retrieved from *https://www.epa.gov/nutrientpollution/effects-economy*
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60 World Economic Forum. Water pollution is killing millions of Indians. Here's how technology and reliable data can change that. Retrieved from *https://www.weforum.org/agenda/2019/10/water-pollution-in-india-data-tech-solution/*
61 Beaumont N.J. et al. Global ecological, social and economic impacts of marine plastic. Marine Pollution Bulletin 142(2019) 189-195
62 Future Agenda. Plastic Oceans. Retrieved from *https://www.futureagenda.org/foresights/plastic-oceans/*

Ecosystem pollution	Environmental accidents	BP's deadly 2010 Gulf of Mexico oil spill has cost the company a total of USD 61.6 billion in court fees, penalties, and clean-up costs. The oil spill significantly disrupted BP's financial performance and its stock price, as news continued to spread on the extent of the disaster. From late April of 2010 through to June of that year, BP common stock lost more than half its value as the stock's trading volume surged. As traders hurried to divest themselves, the number of shares moved jumped from a few million shares per day before the spill to hundreds of millions of shares per day in the weeks that followed. In July of 2010, BP reported a record quarterly loss of $17 billion as it set aside about $32 billion to cover spill-related costs. The company also suspended dividend payments until early 2011.[63] The 1984 Bhopal gas disaster in India has directly caused over 19,000 deaths and 560,000 injuries, leaving the region's groundwater contaminated with carcinogens 1,000+ times higher than normal levels.[64]
Sea-level rise	Chronic sea-level rise or sea surges	Various studies have estimated that sea levels will rise by about 50 centimeters by 2050 under the Paris 2°C scenario, and may rise 1.5-2 meters under scenarios of higher carbon emissions. As many as 640 million people in coastal cities may be exposed to inundation risks by 2100 if no policy action is implemented.[65] Rising sea levels could cost the world over $14 trillion annually by 2100, if the 2°C target set by the Paris Agreement is missed.[66] To fight against sea level rise, the US has considered building "sea walls" to mitigate the risks, which could cost $400 billion in the next 20 years.[67]
Water scarcity	Drought or insufficient supply for increasing demand	Global risk insights show that over 41% of the global population lives in water basins that are experiencing water stress. By 2025, without policy intervention this figure will rise to 66%.[68] A Chinese study stated that the worsening water quality due to over-exploiting water resources may have caused RMB158 billion in financial loss just in 2003.[69] Water shortage also affects the energy sector, e.g. 90% Brazilians population are facing electricity shortage problems due to decrease of water flow in the Cerrado forest.[70]
Deforestation		The Balance estimated that deforestation costs $4.5 trillion each year through the loss of biodiversity and exacerbation of water and soil erosion.[71] Besides its damage to the ecosystem, it also poses a serious threat to economic activities that rely on forestry, according to a Scientific American report.[72]
Desertification		E-International Relations reported that desertification in Saharan Africa has enlarged the desert size by 250 km to the south and 6,000 km to the east and west in the last 100 years. This has caused over 6 million Sahelian residents to move away from the region, where 70% of the arid area has deteriorated and dried.[73] In China, desertification in the Gobi Desert swallows up over 3370 km^2 of land every year, forcing millions of people to move away from their homes.[74] A 2002 report estimated that desertification could result in direct economic losses of RMB 64.2 billion annually through damaging agriculture, affecting human health and disrupting transportation.[75]

63 Investopedia (2019). BP Oil Spill: *https://www.investopedia.com/terms/b/bp-oil-spill.asp*.
64 BBC News (2009). Bhopal marks 25 years since gas leak devastation. Retrieved from *http://news.bbc.co.uk/2/hi/south_asia/8392206.stm*
65 Rosane O. 300 Million People Worldwide Could Suffer Yearly Flooding by 2050. EcoWatch (Oct 30, 2019). Retrieved from *https://www.ecowatch.com/sea-level-rise-predictions-2641159739.html*
66 Phys.org. Rising sea levels could cost the world $14 trillion a year by 2100. Retrieved from *https://phys.org/news/2018-07-sea-world-trillion-year.html*
67 The Hill. Protecting US from rising sea levels will cost $400 billion over next 20 years, study finds. Retrieved from *https://thehill.com/policy/energy-environment/449617-study-protecting-us-from-rising-sea-levels-will-cost-400-billion*
68 Global Risk Insights. The economic implications of global water scarcity. Retrieved from *https://globalriskinsights.com/2016/12/economic-cost-global-water-scarcity/*
69 Jiang Y. China's water scarcity. Journal of Environmental Management 90 (2009) 3185–3196
70 Vegan Sustainability Magazine. Biodiversity and Habitat Loss from Soybean Production. Retrieved from *http://vegansustainability.com/biodiversity-and-habitat-loss/*
71 The Balance. Deforestation Facts, Causes, Effects, and What You Can Do. Retrieved from *https://www.thebalance.com/deforestations-economic-impact-4163723*
72 Scientific American. Is Harvesting Palm Oil Destroying the Rainforests? Retrieved from *https://www.scientificamerican.com/article/harvesting-palm-oil-and-rainforests/*
73 E-International Relations. United Nations Convention to Combat Desertification: Issues and Challenges. Retrieved from *https://www.e-ir.info/2014/04/30/united-nations-convention-to-combat-desertification-issues-and-challenges/*
74 New York Times. Living in China's Expanding Deserts. Retrieved from *https://www.nytimes.com/interactive/2016/10/24/world/asia/living-in-chinas-expanding-deserts.html?_r=0*
75 Qi Lu, Bo Wu. Desertification disaster assessment and its economic value accounting in China [J]. China Population Resources and Environment, 2002(02):31-35.

Transition Risks	Sub-categories	Examples
Public policy change	Energy transition policies	According to statistics from the Carbon Tax Center, some countries have imposed taxes (e.g. carbon tax in Chile, Japan and South Africa) and levies on carbon emissions or activities that are carbon intensive, and several countries/regions employed carbon trading schemes (e.g. Europe and China) to contain carbon emissions.[76]
		The IEA further predicts that carbon price could rise beyond $150/ton by 2040 under the 2°C scenario.[77]
		The French Energy Transition for Green Growth Law (or Energy Transition Law), adopted in August 2015, sets out a pioneering roadmap to mitigate climate change and diversify the energy mix. Besides including ambitious targets around reducing GHG emissions and overall energy consumption, the law also put forward a new set of regulations on carbon reporting, i.e. financial investors and institutions are required to report their financial risks associated with climate change.[78]
		There are many examples of governments from across the globe promoting renewable energy and electric vehicles. In order to "green" the auto industry, Norway (by 2025), India (by 2030), France and the UK (by 2040) have announced schedules for termination of vehicle sales with internal combustion engines.[79]
	Pollution control regulations	London just launched Ultra Low Emission Zone, which imposes a daily charge on vehicles failing to meet environmental standards. The government claimed this action will reduce NOx emissions by 45%.[80]
		In Australia, water service providers charge residents an extra 300% fee on sewage disposal in addition to daily water usage fees.[81]
		In China, a tough regulatory package was introduced to fight air and water pollution, by shutting down most coal-burning facilities in urban areas, requiring mandatory installation of desulfurization and denitration devices for coal-fired power plants, upgrading fuel quality, and increasing levies on pollutants.[82]
	Resource conservation regulations	The US has established laws through the Resource Conservation and Recovery Act (RCRA), with the ambition to control the production, usage, recycle and disposal of solid waste, especially for monitoring the "cradle-to-grave" management of hazardous waste.[83]
		In the 1990s, Europe launched a series of regulations on Extended Producer Responsibility (EPR) (i.e. Producers required to fulfil collection targets and ensure that the end-of-life electronic equipment collected are channeled for proper recycling and disposal) to minimize solid waste and promote resource efficiency.[84] Recently, EU Member States approved a set of ambitious measures to increase the recycling rate of municipal waste. They set up a timeline to achieve the progressive targets: by 2025, they aim to enhance the municipal recycling rate up to 55%, by 2030 60%, by 2035 65%.[85]
		The Singapore government has announced a regulated e-waste management system by 2021 to ensure that electrical and electronic waste (e-waste) is managed effectively and efficiently through an EPR approach.[86]
		In the US, 32 states have issued over 70 independent laws on EPR approaches; their effectiveness varies among different states and sectors.[87]

76 Carbon Tax Center. Where Carbon is Taxed. Retrieved from *https://www.carbontax.org/where-carbon-is-taxed/*
77 IndexologyBlog (2017). Carbon Pricing Is Essential for Effective Climate-Related Financial Disclosure. Retrieved from *https://www.indexologyblog.com/2017/06/29/carbon-pricing-is-essential-for-effective-climate-related-financial-disclosure/*
78 UNEP Financial Initiative. French Energy Transition Law: Global Investor Briefing. Retrieved from *https://www.unepfi.org/fileadmin/documents/PRI-FrenchEnergyTransitionLaw.pdf*
79 Berg, A. O., C. Clapp, E. Lannoo and G. Peters (2018). "Climate scenarios demystified. A climate scenario guide for investors." CICERO Report.
80 Mayor of London. The Mayor's Ultra Low Emission Zone for London. Retrieved from *https://www.london.gov.uk/what-we-do/environment/pollution-and-air-quality/mayors-ultra-low-emission-zone-london*
81 South East Water. Residential Prices and charges. Retrieved from *https://southeastwater.com.au/Residential/Pages/WaterPricesCharges.aspx*
82 Hong Y. et al. Impact of Environmental Factors on Credit Risk of Commercial Banks. ICBC.
83 EPA. Resource Conservation and Recovery Act (RCRA) Overview. Retrieved from *https://www.epa.gov/rcra/resource-conservatiobn-and-recovery-act-rcra-overview*
84 Wikipedia, Extended producer responsibility: *https://en.wikipedia.org/wiki/Extended_producer_responsibility*
85 European Commission, Circular Economy: New rules will make EU the global front-runner in waste management and recycling: *https://ec.europa.eu/commission/presscorner/detail/en/IP_18_3846*
86 National Environment Agency. Factsheet on Updates to Singapore's E-waste Management System. Retrieved from *https://www.nea.gov.sg/docs/default-source/media-files/news-releases-docs/cos- 2019/cos-2019-media-factsheet---updates-to-e-waste-management-system.pdf*
87 Nash J. & Bosso C. Extended Producer Responsibility in the United States: Full Speed Ahead? Harvard Kennedy School M-RCBG Associate Working Paper No. 10 (May 2013). Retrieved from *https://www.hks.harvard.edu/centers/mrcbg/publications/awp/awp10*

Technological changes	Clean energy technologies	According to Bloomberg NEF, an 89% cost decrease in solar plants and 40% in wind turbines since 2010 has been observed around the globe, and this rapid cost reduction will continue to for the coming decades. This leads to their predictions that wind and solar energy are expected to supply two-thirds of global electricity in 2050, while electricity generated by coal-fired plants will shrink from the current 27% to 12%.[88]
	Energy saving technologies	High-efficiency lighting, cooling and appliances could save nearly three-quarters of global electricity consumption between now and 2030 if deployed quickly, as illustrated by IEA.[89] Canadian organizations introduced a "Passive home" methodology, which is adopted by several countries. It promotes designing new buildings that use 90% less energy for heating and cooling by using super insulation and efficient heat recovery. The existing building stock can also reduce energy consumption by 20-50%, through investing in new windows, super-insulation, heat-recovery systems, efficient appliances and small-size solar PV systems.[90]
	Clean transportation	Acumen Consulting estimated that the market of electric vehicles would continue its CAGR of 25%, and reach a size of $567 billion by 2026.[91] Bloomberg also predicts that 57% of all passenger vehicle sales in 2040 will be electric, displacing a combined 13.7 million barrels per day of oil demand.[92]
	Other green technologies	Singapore has developed a technology to turn wastewater back to drinkable water by a four-stage treatment process.[93] For solid waste, companies like ABB are developing AI-driven technologies to help effectively collect, separate and recycle municipal waste.[94]
Shifting sentiment		Institutional investors are gradually realizing that "brown" industries may face significant downside risks due to their negative environmental and climate exposures. There could be a sudden market sentiment shift in favor or "green" companies and assets and against "brown" companies and assets. Such a sentiment shift could lead to a sharp fall in market valuation of brown assets, making it more difficult for them to secure financing. Consumers may increasingly favor green products in their daily consumption, even though they are more costly. Consumer intention to buy eco-friendly products depends on the reputation, brand image, and the credibility of environmental information.[95, 96]
Disruptive business model		An MIT study shows that e-commerce shopping tends to have a more controlled environmental impact, that logistics of goods are optimized, while traditional shopping involves a much more random and frequent transportation of customers.[97] IKEA claims that e-commerce has helped reduce customer transportation to and from their stores, which accounted for 14 percent of its carbon footprint, as well as more efficient handling in its warehouse in the preparation of goods for delivery and payment.[98]

88 Bloomberg NEF. New Energy Outlook 2019. Retrieved from *https://about.bnef.com/new-energy-outlook/*
89 International Energy Agency. ETP 2017 maps major transformations in energy technologies over next decades. Retrieved from *https://www.iea.org/newsroom/news/2017/june/etp-2017-maps-major-transformations-in-energy-technologies-over-next-decades.html*
90 British Columbia Sustainable Energy Association. Renewable Energy Technologies. Retrieved from *https://www.bcsea.org/learn/get-the-facts/renewable-energy-technologies*
91 Acumen Research & Consulting. Electric Vehicle Market Size, Share, Trends, Scope, Growth Opportunity and Forecast 2019-2026. Retrieved from *https://www.globenewswire.com/news-release/2019/09/06/1912241/0/en/Electric-Vehicle-Market-Size-Worth-USD-567-2-Billion-by-2026.html*
92 Bloomberg NEF. Electric Vehicle Outlook 2019. Retrieved from *https://about.bnef.com/electric-vehicle-outlook/*
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98 Ismail M. Online commerce is impacting the environment. The Asean Post (Sep 28, 2019). Retrieved from *https://theaseanpost.com/article/online-commerce-impacting-environment*

Appendix 2 List and summary of case studies compiled by the NGFS Occasional Paper on Case Studies of ERA Methodologies

Chapters	Environmental/ climate risks covered	Sector focuses	Financial risks assessed	Jurisdictions studied	Types of models	Benefits	Limitations	Authors/ Organizations
Chapter 1	Overview							NGFS
Chapter 2	Climate physical risk	Real estate	Credit risk	Europe	CAT model	Extensive coverage of hazards	Incomplete translation from climate risk into quantifiable financial risk	427 (a Moody's affiliate)
Chapter 3	Climate transition risk	Oil and Gas	Credit risk	Not specified	IAM and PD model	Clear impact transmission mechanism	Lack of systemic risk analysis (economic network effects)	Oliver Wyman
Chapter 4	Climate transition risk	Not specified	Credit/ market risks	Europe and China	IAM, PD model, pricing model	Clear impact transmission mechanism, extensive coverage of financial products	High requirement on data and expertises requirement, lack of macroeconomic impact assessment	WU & UZH
Chapter 5	Environmental transition risk	Thermal power, cement	Credit risk	China	PD model	Quantification of credit risk for environment factors	Relatively simple assumptions about risk drivers	ICBC
Chapter 6	Climate physical risk	Real estate	Credit risk	China	CAT model, PD model, LGD model	Extensive modelling of future hazards and financial impact	High data requirement, limited coverage of hazard types so far	SUN Tianyin and Ma Jun/ Tsinghua
Chapter 7	Climate transition risk	Thermal power, oil	Credit risk	China	Energy sector model/IAMs, PD model	Multiple macro, sector and micro factors (including funding costs) considered in impact assessment	High requirement on multi-sector data and expertise, incomplete macroeconomic feedback loop	Ma Jun and SUN Tianyin/ Tsinghua
Chapter 8	Multi risks	Agriculture	Credit risk	Australia	Weighted multi-factor model	Extensive usage of environmental risk indicators	Subjective weights for integrating individual risks into overall risk	Francisco Ascui and Theodor F. Cojoianu
Chapter 9	Climate Transition Risk	Power, mining and beverage	Credit risk	Global	Total Economic Value model, financial ratios	Comprehensive evaluation of location specific shadow price of water for varied sectors	Incomplete analysis on financial risks	Henrik Ohlsen and Michael Ridley
Chapter 10	ESG	Not specified	Credit risk	Italy	PD model, LGD model, rating analysis	Introduction of practical integration of ESG into rating analysis	Insufficient details in scoring ESG factors	Intesa Sanpaolo
Chapter 11	Climate transition risk	Real estate, infrastructure	Market risk	Global	Macroeconometric model, IAMs, valuation model	Combination of top-down and bottom-up approaches	High requirement on multi-sector data and expertise	Vivid Economics
Chapter 12	Climate transition risk	Power, steel	Market risk	Global	IAMs, valuation model	Clear impact transmission mechanism, extensive coverage of assets adaptation measures	High requirement on multi-sector data and expertise, lack of macro feedback loop	Nicole Röttmer/ PwC Germany
Chapter 13	Climate physical risk	Multi-sectors	Market risk (valuation)	Not specified	Macroeconometric model, CAT model, valuation model	Consideration of multiple impact channels including macroeconomic, supply chain, sectors & financial	High requirement on multi-sector data and expertise	Acclimatise and Vivid Economics

Chapter 14	Climate transition risk	Coal and related infrastructure	Market risk	South Africa	Energy sector model, financial statement projection models	Consideration of networked risk transfers via ownership and capital structure	High requirement on multi-sector data and expertise	Climate Policy Initiative
Chapter 15	Climate transition risk	Coal and related sector and infrastructure	Market risk	South Africa	Input-output model	Consideration of cascading impacts derived from a initial shock on sectors	Detailed input-output table required	AFD
Chapter 16	Climate transition risk	Multi-sectors	Market risk	China	Extended CAMP model, Carbon factor regression model	Highlighting correlation between carbon prices and stock performance	Simplified assumption on causality, lack of feedback mechanisms	CUFE
Chapter 17	Climate physical risk	Real estate and others		Global	CAT Model	Extensive coverage of physcial risk categories	Limited analysis on financial risk metrics	Carbone 4
Chapter 18	Climate transition and physical risk	Multi-sectors	Market risk	Global	Macroeconometric model, stochastic financial model	A top-down approach with coverage of multiple risk types and global applications	Intransparency of translating macro climate risk into micro level, limited consideration of indirect damage of physical riks	Ortec Finance
Chapter 19	Climate transition risk	Fossil-fuel and other carbon sensitive sectors	Credit risk and market risk	Global	Own "late and sudden scenarios" model, valuation model, PD model	Pioneered in constructing a "disorderly transition scenario"	Oversimplied assumption of "disorderly transition scenario", high data and expertises requirement	2 degrees initiative
Chapter 20	Climate physical risk	Real estate and others	Market risk and insurance liability risk	UK, North America, Asia	CAT model, valuation model	Extensive modelling of future hazards	High data requirement, limited coverage of hazard types so far, limited consideration of indirect damage of physical events	ClimateWise/ CISL
Chapter 21	Climate transition risk	Power, fuel and transport infrastructure	Market risk	US, Europe and India	Energy sector model, valuation model	Clear impact transmission mechanism	Lack of macroeconomic feedback mechanism	ClimateWise/ CISL
Chapter 22	Climate transition and physical risks	Multi-sectors	Market risk and opportunities	Global	IAMs, CAT models, Merton model, DCF model	Coverage of both transition and physical risks, inclusion of preparedness/ adaptation measures, opportunities analysis, rich data availability	No consideration of risk factors other than cost in transition model, too short time horizon included in physical risk model, unclear differentiation in conventional climate risks and risks induced by climate change	CarbonDelta (an MSCI company)
Chapter 23	Climate transition and physical risk	Not specified	Credit risk and market risk	Not specified	IAMs, Merton model, CAT model	Extensive quantitative results; coverage of both transition and physical risks	High requirement on data and expertise, limited consideration of indirect damage of physical events	AVIVA
Chapter 24	Climate physical risk	Real estate	Insurance liability risk	USA	CAT model	Extensive modelling of future hazards	High requirement on data and expertise	RMS
Chapter 25	Climate physical risk	Not specified	Insurance liability risk	USA	CAT model	Overview of methodologies for insurance sector to assess future climate risks	High requirement on data and expertise	Swiss Re

Chapter 26	ESG	Not specified	Credit risk	Global	ESG scoring, ESG integration into rating	Clear presentation of methodologies, data sources and applications	Limited inclusion of environmental indicators	MSCI
Chapter 27	ESG	Energy, building materials, chemicals, mining, automobile, logistics	Credit risk	Global	ESG scoring, ESG integration into rating	Drawn experience from credit rating approaches; extensive coverage of issuers	Limited transparency in data source and scoring methods	Moody's
Chapter 28	ESG	Not specified	Credit risk	Global	ESG scoring, ESG index construction	Clear presentation of methodologies	Relative smaller number of issuers covered	ISS
Chapter 29	Discussion of ESG rating and data	Review and discussion of ESG data and rating methods						Olaf Weber/ University of Waterloo
Chapter 30	Discussion of ESG rating and data	Review and discussion of ESG data providers, rating agencies, development and challenges of ESG data, rating methods						RepRisk
Chapter 31	Carbon accounting of portfolio	Power and others		Global	Bottom-up approach, life-cycle GHG accounting	More accurate approaches to estimating carbon emissions and carbon footprints	High requirement on data and expertise	Carbone 4
Chapter 32	Carbon accounting of portfolio	Utility and others		Global	GHG accounting, compliance assessment	Absolute & relative carbon footprint caculation	Quality of self-reported data by issuers	ISS
Chapter 33	Carbon accounting of portfolio	Not specified		Global	GHG accounting, compliance assessment	Extensive coverage of financial products and comparability of assessed results	Quality of self-reported data by issuers	EcoAct
Chapter 34	Climate transition risk	Not specified	Market risk and opportunities	Global	ESG scoring, factor pricing model	Good application potential	Limited data on country specific carbon risk beta	VfU and University of Augsburg
Chapter 35	Discussion of climate physical risk models/tools	Review and discussion of various physical risk analysis model/methodologies						I4CE
Chapter 36	Discussion of climate transition risk models/tools	Review and discussion of various transition risk analysis model/methodologies						Carbon Trust
Chapter 37	Discussion of climate scenarios	Review and discussion of various climate scenarios						CICERO

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